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Greening the vehicle fleet, how does South Africa's tax reforms affect new car sales

Mfundo Nkosi, Johane Dikgang, Dambala Kutela Gelo¹ and Alain Pholo²

Abstract

An increasing number of countries around the world have linked taxes with passenger vehicle carbon dioxide (CO₂) emission rates. Policymakers use vehicle and fuel taxes to target and reduce transportation greenhouse gas emissions. In 2010, the South African government joined this group, linking taxes to passenger-vehicle CO₂-emission rates by introducing the vehicle CO₂ tax, to reduce the carbon output of the new vehicle fleet by incentivising the purchase of more fuel-efficient vehicles. However, there is little evidence of the relative efficacy of this measure in South Africa. Based on new-vehicle sales data from 2010 to 2012, single-group interrupted time-series analysis (ITSA) reveals that CO₂ taxes reduced average carbon emissions only marginally. This prompted the vehicle-CO₂ tax reforms of 2013. Based on subsequent new-vehicle sales data, from 2013 to 2018, we find that the reforms have led to significant CO₂ reductions. Overall, CO₂ taxes moved consumer preference to low-emission vehicles (i.e., vehicles in the band producing less than 120g/km), and discouraged the purchase of bigger, heavier and more powerful vehicles. They also had a great effect on average emissions; by 2018, average carbon emissions had declined by 21% compared to 2010, to 151g/km. Moreover, there is some evidence that the tax has affected the mix of new vehicles that vehicle manufacturers sell in the South African market, as the volume of low carbon intensity new vehicles increased significantly, to 31% of total sales in 2018 compared to 13% in 2010.

Keywords: CO₂, emissions, taxes, vehicles.

JEL Codes: H31, L62, Q41, Q54, R48.

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1. Introduction

The increase in temperatures globally is attributed to rising atmospheric concentrations of greenhouse gases (GHGs). Among GHGs, CO₂ is the main factor in global warming; and the direct use of fossil fuels, as well as indirect energy consumption linked to fossil-fuel combustion, all contribute to CO₂ emissions (Lin, 2009). Liquid fuels are key in the transportation sector. Different fuels emit different amounts of CO₂ in relation to the energy they produce during the combustion process. Motorised vehicles – especially passenger cars and light and medium commercial vehicles, due to the large numbers produced – account for a significant portion of the emissions coming from the transportation sector.

To reduce CO₂ emissions from passenger vehicles, an increasing number of countries (in both developed and developing economies) have introduced policies and measures for new vehicles. Often, the amount of CO₂ emitted from a vehicle is a linear function of the amount of fuel it uses. David and Montag (2014) argue that since CO₂ emissions generate social external costs, through their effect on climate change, that are not captured by the price mechanism, a tax on CO₂ is indicated. An ideal tax would alter consumer prices so that they match the marginal social external costs.

Policies and measures commonly used around the world to curb car emissions may be divided into two categories: ‘command and control’ regulations, and market-based incentives. Historically, many European countries subsidised or taxed new vehicle purchases or ownership, depending on vehicle characteristics correlated with CO₂ emissions. For example, Germany taxed vehicle ownership largely according to engine size. However, since the mid-2000s many of these countries have reformed their tax regimes to link taxes directly to vehicle CO₂ emission levels. For example, France currently taxes and subsidises vehicle purchases, and the amount changes discretely according to vehicle emission rate. Germany and Sweden, on the other hand, impose annual registration taxes (i.e., circulation fees) that increase linearly with carbon emissions rates (Klier and Linn, 2015). In the UK, a vehicle’s circulation tax is a step function of the emission level (Cerruti, Alberini and Linn, 2018).

There has been an evolution in the approaches to research design used in the literature to measure consumer response to vehicle taxes; some are descriptive, and some use econometric modelling techniques. Rogen et al. (2011) and Kok (2015) use an ex-post analysis method that is largely descriptive. Benvenutti et al. (2019) use system dynamics, which is ex-ante and involves

simulations and machine learning. Ciccone (2014; 2018) uses the Difference in Differences (DID) approach. Estimating a price coefficient and simulating its effect on vehicle tax in a vehicle demand model based on some assumptions made about consumer responsiveness, is a commonly used approach (see Adamou et al., 2012; Brockwell, 2013; D'Haultfoeuille et al., 2014; D'Haultfoeuille et al., 2016; Grigolon et al., 2018; Li et al., 2014; Rivers and Schaufele, 2015). This study uses a single-group analysis method called interrupted time series analysis (ITSA), as it is deemed more suitable for the South African dataset. The interrupted time-series analysis (ITSA) for single-group comparisons is used to estimate the effect of an intervention of this nature. ITSA differs from most other intervention study designs in that it involves a before-and-after comparison within a single population, rather than a comparison with a control group. Lopez Bernal et al. (2018) argue that this has the advantage that selection bias and confounding due to between-group differences are limited.

In 2010, South Africa joined a growing number of countries by adopting its own fiscal measures in the form of a CO₂ emissions tax, with the aim of nudging buyers towards purchasing less polluting new passenger vehicles. The tax is largely based on engine size and is levied based on the amount of CO₂ emitted per vehicle, increasing for every g/km emitted over 120g/km of CO₂. This study assesses the effectiveness of this policy and the effect of the subsequent tax reforms on the sales of new vehicles, especially high-polluting vehicles. We compare the South African tax reforms to others in the world regarding their effectiveness in reducing emissions rates. Thus, our study focus is on the use and efficacy of fiscal instruments, which entails setting CO₂ emissions targets, with punitive measures taken against vehicle manufactures and consumers who fail to comply. This research assesses the effectiveness of South Africa's legislative efforts to reduce carbon emissions from passenger vehicles, by ascertaining the short-run impacts of the CO₂-differentiated tax on three main control variables, as well as controlling for autocorrelated disturbances. The main outcome variables are:

1. The average CO₂ emissions resulting from sales of new passenger vehicles.
2. The average shift from high- to low-emitting vehicles, which invariably means from bigger to smaller engines.
3. The shift from petrol to diesel cars.

South Africa provides an excellent opportunity to examine the effects of vehicle taxes because the tax reforms were significant and frequent. A growing number of policymakers are adopting vehicle taxes because of their cost-effectiveness, administrative simplicity, and incentives for new technology. Moreover, there is a move towards adopting broader CO₂-based taxes. Although there is a growing literature on the efficacy of the broad-based taxes used in countries such as France, Germany, Sweden, the UK and Norway in reducing average CO₂ emission rates of new passenger vehicles, there is little evidence of their impact in developing countries.

Moreover, emerging economies account for most the world's population, and a significant (if not the largest) portion of new-vehicle sales; hence, effective CO₂ vehicle taxes in such economies could result in significant reductions in emissions. There is little empirical evidence of whether South Africa's tax – which is charged at the time of purchase – is a linear function of the CO₂ emissions rate, or if it changes with the emissions rate in discrete amounts. Our investigation sheds light on whether South African consumers are responding to what is an up-front purchase tax, and if these responses are proportional to upward adjustments in tax rates. Moreover, the environmental effects of introducing a CO₂-differentiated tax on CO₂-emissions intensity in South Africa are unclear. This study therefore asks the following research questions:

- (a) To what extent has consumer preference moved away from high-emitting to low-emitting vehicles?
- (b) To what extent has this policy influenced the average CO₂ emission amount in South Africa, in relation to the recommended EU level of 120g/km of CO₂?

The answers to these questions will provide policymakers with insight into the effectiveness of emission policies and inform future policy recommendations.

Given the characteristics of emerging economies when compared to developed countries, it is imperative that studies are conducted to ascertain whether these policies are applicable and effective in their context. Emerging economies present a different perspective from which different conclusions can be reached. According to Hafner et al. (2017) studies in developed countries suggests that environmental concerns play an important role in vehicle choice. Money, reliability, costs and practical considerations were found as some of the factors that influenced the choice of vehicle choice by consumers. Some other factors which featured more prominently are image of the brand or model and identity. The biggest factor at play at the point of purchase is pitting personal values or ideals with monetary costs and practicality.

Kahan et al. (2011) assert that various psychological variables influence most types of environmental behaviours; examples are specific beliefs, attitudes, norms and motives. In the study of environmental ideology as a determinant of consumer choice, according to Kahan et al. (2017) it has been found that the US has strong environmental movements differentiated into 'greens' and 'browns', where the 'greens' are citizens who prioritise environmental issues, foster a certain psychological behaviour, and need to belong and share a common goal of protecting property and making greener transportation choices than the average consumer, thus voluntarily living a more restrained lifestyle. According to Vosper and Mercure (2016), the purchase of a vehicle is one of the largest single expenses a consumer is likely to make in his or her lifetime; the pressures that emanate from the associated psychology, marketing, anthropology and sociology to result in decision-making surpass the price and function of the vehicle and play a huge role in displaying social identity and enforcing a 'belonging' characteristic.

This study differs from most studies in the literature, in various ways. Firstly, it was carried out in a developing country. Secondly, the data generation process in developing countries such as South Africa is different compared to those in developed countries. Thirdly, developing countries such as South Africa do not have strong environmental lobbyists or 'greens'; therefore, it was interesting to find out whether the motives for buying cars in South Africa as inferred from the ITSA regression results differ significantly from the findings in the existing literature. This is another factor that drives differences in data generation between developed and developing countries.

This is one of the few studies in the literature (see Kok, 2015) that examines relatively longer-term (eight years) effects ex-post the introduction of the policy; a modest but significant contribution, as most studies examine only short-term (i.e., first year) effects. The case of South Africa is of interest because it is the first country in the African continent to implement such a policy. Most studies have been conducted in Europe and North America; this study gives a glimpse into whether these policies are also relevant (and work) in developing countries.

The rest of the research is divided into five sections. Section Two is a discussion of regulations governing emissions and South African background, while Section Three presents the empirical approach. Section Four is an overview of the data and variables and in Section Five, the empirical findings are discussed. In the last section (Section Six), a summary is presented.

2. Regulations governing vehicle emissions South African background

The latest data (from 2019) show that new-vehicle sales in South Africa rose to a 13-year high of 442 123 cars in 2006, after a record low of 186 005 cars sold in 1994 (NAAMSA, 2019). As the largest new-vehicle market in Africa, making up 37% of total sales, and the 18th-biggest market in the world (Posada, 2018), South Africa – like elsewhere in the world – views increased car sales as a major cause for concern, as they mean that carbon emissions from cars are also on the rise. According to Posada (2018), South African manufacturers sold more than 412 000 new vehicles in 2015 and exported more than 333 000 units in the same year. The size of the South African motor industry in comparison with the world suggest that the contribution of South Africa to global warming through vehicle CO₂ emission by passenger vehicles is sizeable (Posada, 2018).

There is room to align the use of command-and-control measures, such as emission standards, with market-based instruments, such as fiscal tools, to achieve emission reduction targets – especially as new-vehicle purchases are on the rise globally. Considering the increase in car sales and preference for SUVs, it is uncertain that the various carbon emission targets will be reached. Vehicle taxation is key to making progress towards building less- polluting cars, which is a determinant of emission levels. Although taxes have commonly been adopted, they do differ between countries.

Taxes as fiscal instruments have been implemented widely, in different forms and variants. They are broadly pitched at the purchase, ownership and usage of vehicles, such as sales tax at vehicle purchase, feebates and tax incentive schemes, annual licence-renewal fees, once-off excise taxes, and (on fuel) carbon taxes, which are determined by various factors including the CO₂ content of the fuel (see Ciccone, 2018; Konishi and Zhao, 2016). These taxes are key, as they increase the cost of ownership and should therefore influence consumer preferences to some degree. Other strategies include the decarbonisation of vehicles, the improvement of fuel standards, and the improvement of public transportation and infrastructure to reduce demand for private vehicles (see Cerruti et al, 2018; Ciccone, 2018; ICCT, 2019; Yan and Eskeland, 2018).

There are other exogenous factors that contribute to the magnitude of the success of fiscal policy interventions, from both the supply and the demand side; such as competition between vehicle manufacturers (supply-side effect), rate of economic growth, fuel prices, and people's attitudes and motives (demand-side effects) (Hugh and Richard, 2011). Emerging economies such as China, India, Brazil and South Africa have adopted similar policies to deal with this externality, such as

once-off excise taxes (He and Bandivadekar, 2011). However, there is a growing body of literature supporting the use of carbon and fuel taxes rather than a once-off excise tax, as the former are deemed to be far-reaching and more effective (see Cerruti et al., 2018; Ciccone, 2018; Jacobsen, 2013). A contrary view argues that CO₂-differentiated tax is more effective primarily in cases in which consumer willingness to pay for a car is not affected by expected future costs of fuel (price inelasticity) (see Yan and Eskeland, 2018; Grigolon et al., 2018; Allcott et al., 2014).

This paper focuses only on the CO₂ emissions tax for passenger vehicles which was introduced in 2010. The South African passenger vehicle market is still trailing behind in efficiency and greening of the fleet when compared to the European market. The European market has advanced faster than South Africa in most of the technical attributes which explains why Europe is emitting 15% less CO₂ in the passenger vehicle space. The decline in average vehicle emissions continue to be observed in the South African market and yet the rate seems to have flattened out in the European market. All the other technical attributes in the South African market seems to resemble the patterns observed in the European market. South Africa still has a long road ahead to be able to catch up with Europe and attain the emission targets recommended by the UN. This tax is based on the vehicle emissions levels and any level above the recommended 120g CO₂/km. According to National Treasury (2010) every new passenger car sold is charged, \$5.03³ for every g/km over 120 g/km of CO₂. This was later revised to \$6.04 per g/km in 2013, \$6.71 in 2016 and \$7.38 in April 2018. On the 1st of March 2011, vehicles used for transport of goods including double cabs were added as a new category. These were to be charged \$6.71 for every g/km over 175 g/km which was later revised to \$8.39 in 2013 and \$9.40 in 2016 and \$10.07 in 2018.

South Africa introduced the CO₂ emission reform policy with the view of nudging consumers towards greener vehicles. For the policy to be effective there should be a positive response from both the supply and demand side. There are technical attributes that the vehicle manufacturers can adjust to allow their fleets to emit less CO₂. There is a correlation between the average CO₂ emissions and technical attributes like the vehicle engine displacement, engine power, weight and lastly the type of fuel the vehicle uses. Suppliers also to capture the full consumer spectrum need to offer a variety of vehicles which will appease both the consumers and the policy makers. This is captured in the segmentation of the passenger vehicle market into variants of models which vary in power, size, weight, performance and shapes.

³ US\$1 = South African Rand R14.90 at the time the thesis was written.

Table 1 below presents a correlation matrix which brings into perspective on how the addition of a carbon dioxide emission tax in South Africa is constraining to the consumer and how the different components of vehicles are interdependent.

Table 1: Pearson correlation matrix between CO₂ emissions and other vehicle technical parameters

	CO ₂ Emissions	GVM	HP	KW	Engine Size
CO ₂ Emissions	1.0000				
GVM	0.5894	1.0000			
HP	0.1505	0.0746	1.0000		
KW	-0.0805	-0.2413	0.2626	1.0000	
Engine Size	0.4908	0.5088	0.1260	-0.2676	1.0000

The table above shows the relationship between CO₂ emissions and four vehicle technical factors namely the gross vehicle mass (GVM), the power variables horsepower (HP) and Kilowattage (kW) and engine displacement. The table shows a positive relationship between CO₂ emissions with the (GVM), (HP), the engine size and a negative relationship with the (KW). This suggests that manufacturers should target these vehicle attributes to balance the constraining effect of the policy and the utility function of the consumers, invariably with the engine sizes getting smaller the power must increase hence the inverse relationship between average CO₂ emissions and the power (i.e., kW).

3. Empirical Approach

This study uses a similar approach to Ciccone (2018) but differs in terms of empirical method. It uses a single-variable analysis method by employing the use of an interrupted time series analysis (ITSA) as opposed to a DID approach as there is no clear distinction between the control and treatment groups. ITSA has been widely used in clinical and other health-related literature (see Gasparrini and Bernal, 2015; Bernal et al., 2017; Caswell, 2017), community interventions (Biglan et al., 2000), public policy and regulatory actions (Linden, 2015), the effect of microeconomic conditions such as financial recession on the suicide rate (Bernal et al., 2013) and as a quasi-experimental alternative to randomised controlled trials (Caswell, 2017). Gasparrini (2018) argued that ITSA has several advantages, including control for time-invariant factors by design and

econometrically, it is possible to control for time-varying confounders, even though strict assumptions must be employed in the assessment of the causal hypothesis.

Linden (2015) argued that it also offers a quasi-experimental design with a potentially high degree of internal validity if multiple observations on an outcome variable of interest both pre- and post-intervention can be obtained. The strengths of ITSA over and above allowing the population to act as its own control group are, it controls for autocorrelated disturbances, it is sensitive to modelling choices for impact and trend, it helps with diffuse effects on long lags and lastly its ecological design is based mostly on aggregated data and has issues with measurements changes and concurrent events. Using all the strengths of ITSA the study will attempt to shed light into the impact of the impact of CO₂ emissions tax in South Africa. This approach is very helpful when dealing with causality in time-series data and is particularly helpful in cases where control groups are unavailable, as is the case with the South African carbon emissions tax. The policy was introduced in South Africa for all passenger cars at industry level. For this study, the impact of CO₂-differentiated tax was carried out on the three main outcome variables: average CO₂-emissions overtime, migration from high-emitting to low-emitting vehicles, and migration from petrol to diesel vehicles. This study assessed the magnitude of the effect of the adoption of the tax policy in 2010 on these three variables, as well as the impact of subsequent tax reforms carried out in 2013. Since there is only one group in this study, the standard ITSA model can be expressed as follows:

$$Y_t = \beta_0 + \beta_1 \text{Intervention}_t + \beta_2 \text{Post}_t + \beta_3 \text{Intervention}_t \text{Post}_t + \mu_t \quad (1)$$

where Y_t refers to average outcome variable measured from 1994 to 2018, β_0 is the starting level of the outcome variable, β_1 is the gradient of the outcome variable up to the intervention, and Intervention_t is the intervention period. β_2 refers to a change in the level of the outcome variable immediately after the intervention (short-term), Post_t is the dummy indicator representing the intervention, taking on the value 0 for period before intervention and 1 for the period after the intervention, and β_3 is the difference between pre- and post-intervention slopes of the outcome variable. $\text{Intervention}_t \text{Post}_t$ is the interaction term and μ_t refers to the random error term and assumed to follow an AR (1) process.

4. Data

4.1.Data Description

Our data source is a large time-series dataset compiled by Lightstone⁴, and sourced from the National Association of Automobile Manufacturers of South Africa (NAAMSA). There are five primary vehicle attributes: market, manufacturer, make, type and model. The secondary attributes include body shape, application, source, suggested retail price range, suggested retail price, engine size range, engine size, kilowatts, horsepower, fuel type, drive type, gear type, gross vehicle mass, emissions control and economic (ECE) consumption and ECE emissions.

Extracted attributes include average CO₂ emission for the vehicles sold in that year, the average engine sizes of all the vehicles sold in that year, the proportion of diesel vehicles sold in that year, the proportion of the engine sizes categorised into five bands, see Table 2 below. The average kilowattage of the vehicles sold that month, the average horsepower of the vehicles sold that year, the average gross vehicle mass in kilograms of all vehicles sold that year, and the average suggested retail price are all shown, see Table 2 below.

Table 2: Migration of consumers from bigger to smaller engines vehicles engine categorization

Variable name	Engine size band in cc's	Category	CO ₂ Emission band
less_120	Less than 120cc	Small sized engines	Low
bt121_140	Between 121cc to 140 cc		
bt141_180	Between 141cc to 180 cc	Medium sized engine	Medium
bt180_250	Between 181cc to 250 cc	Big sized engines	High
greater_250	Greater than 250cc		

⁴ This is South Africa's leading provider of statistical information for the automotive industry. This data is administered by Lightstone Auto which provides data-driven insights, online market intelligence and new vehicle sales data to the South African motor industry.

We could estimate the total CO₂ emission tax from the data. The total tax revenue can be calculated from the data using the following method. Table 3 below is used for illustrative purposes, an example of how the ECE emissions tax for each vehicle sold may be calculated.

Table 3: Example of CO₂ tax calculation

Manufacturer	BMW GROUP
Make	BMW
Type	BMW 1-Series
Body Shape	Hatch (5 door)
Suggested Retail Price	\$17 458
Engine Size	1.6
Fuel Type	Petrol
Drive Type	4x2
Gear Type	Manual
ECE Emissions	180

Table 3 above shows the variables that can be extracted from the master file to calculate how much CO₂ tax will be levied on that vehicle at point of sale. The following steps must be followed.

1. Apply this formula: for every passenger car, the vehicle tax will be \$6.71 for every g/km of CO₂ above 120g/km
2. 180 – 120 gives 60g/km (from Table 3 above)
3. 60 g/km * \$6.71 = \$402.60, which will be added to the retail price as CO₂ emissions tax
4. Aggregate the data for each vehicle sold per required period to make up the dollar figure for expected revenue.

Other information (such as monthly petrol and diesel prices) was obtained from the Department of Energy (DOE). Data for the Gross Domestic Product was obtained from the World Bank.

4.2.Descriptive Statistics

The Table 4 below shows descriptive statistics of the passenger vehicles mined from the 57 manufacturers between 1994 and 2018. In all the preceding regressions, the dependent variable was either one of the main control variables or one of the technical parameters averaged over the sampled period. The control variables are used to ascertain the efficacy of the vehicle emission tax

at reducing the level of CO₂ emissions, while the technical parameters are viewed to ascertain the response to the reform from the supply side. Some of the data (such as average petrol and diesel prices) were only available from 2007.

Table 4: Descriptive statistics of all the attributes in the data analysis file

	Sample	Mean	Std Dev	Min	Max
Av CO ₂ emissions	108	163.19	10.376	149.44	188.06
Av engine size	300	1.92	0.10	1.68	2.20
Prop Diesel	300	0.182	0.100	0.00	0.90
Engine > 120ccm	300	0.06	0.06	0.00	0.31
Engine bt121_140ccm	300	0.140	0.033	0.06	0.25
Engine bt141_180ccm	300	0.300	0.060	0.18	0.49
Engine bt181_250ccm	300	0.308	0.046	0.19	0.44
Engine < 250ccm	300	0.196	0.044	0.100	0.330
Av kW	300	91.380	23.912	21.48	146.77
Av horsepower	300	124.323	32.490	29.23	199.53
Av gross vehicle mass	300	1849.98	96.127	1011.99	2192.45
Av retail price \$	25	17573	7928	1700	29191
Av petrol price	12	0.75	0.19	0.44	1.02
Av diesel price	12	0.68	0.17	0.40	0.95
SA growth rate	25	2.76	1.69	-1.54	5.60
Vehicle sales volumes	25	298216	84531	176721	442123

The average CO₂ emissions have a mean of 163g/km CO₂, with a standard deviation of 10g/km over the 300 sample months. Other technical parameters such as engine size, kilowatts and horsepower have a mean of 1.92 litres⁵, 91 kW and 124 horsepower respectively. The mean growth rate of the country over the study period was 2.8%, with a minimum of -1.54% and a maximum of 5.6%, which is also positively correlated with the cycles of vehicle sales in the data, such that the highest volume of sales was recorded in the year with the highest growth rate, which was 2006. All the petrol, diesel and suggested retail prices are Rand denominated.

⁵ 1 cubic centimetre (cc) = 1 litre

5. Empirical findings

5.1. Empirical approach and identification

This study assesses the impact of CO₂-differentiated tax through three main control variables. These variables are interconnected and interrelated; changes in consumer behaviour could ultimately manifest in an aggregate reduction in CO₂ emissions. After the introduction of emissions tax, high-emitting vehicles cost on average 4% more than they did before (Posada, 2018), and this is a strong signal to consumers to be critical in their choice of purchase, discouraging convenience over affordability.

The first control variable is average CO₂ emissions. This is due to consumers involuntarily changing their preference from high-emitting cars to low-emitting cars because of the high price tag brought about by the emissions tax. The proportion of low-emitting to high-emitting cars pre- and post-policy intervention is the second control variable. It is hoped that in the long run this will lead to a reduction in aggregate average CO₂ emitted. Migration of vehicle preference from petrol to diesel cars is the third control variable, as diesel vehicles are known to emit less CO₂ than petrol-fuelled vehicles. The trend analysis in the next section will discuss the three main outcome variables in detail, in as far as vehicle characteristics changed over the period of the implementation of the vehicle emissions tax. The overall findings of this study will be presented in this section. The results and discussions below will be broken down in terms of the three main control variables.

Expanding the standard ITSA regression model (as specified in equation 1) to assess the impact of South African emissions-tax and its subsequent revisions takes the following form:

$$Y_t = \beta_0 + \beta_1 T_t + \beta_2 X_t + \beta_3 X_t T_t + \beta_4 Z_t + \beta_5 Z_t T_t + \beta_6 Z_t X_t + \mu_t \quad (2)$$

where: Y_t is the outcome variable, β_0 is the intercept at the beginning of the study, β_1 is the slope prior to the intervention in 2010, β_2 is the change in level of whatever dimension is measured for the control variable in the period from 2010 to 2013, and β_3 is the difference between the pre-intervention slope and the 2010 to 2013 slope. β_4 is the slope prior to the intervention in 2013, β_5 is the change in the level of whatever dimension is measured of the control variable after 2013, and β_6 is the difference between the 2010 to 2013 slope and the 2013 to 2018 slope. T_t = time since the start of the study (1994 to 2018), X_t is a dummy variable representing the 2010 intervention (0 represents pre-intervention and 1 represents post-intervention), $X_t T_t$ is an interaction term, Z_t is a dummy variable representing the 2013 intervention (0 represents pre-intervention and 1 represents

post-intervention), and Z_tX_t is another interaction term. According to Herrington and Velicer (2015), a time-series analysis can be represented as a generalised least-squares problem:

$$\mathbf{b} = (\mathbf{X}'\mathbf{T}'\mathbf{TX})^{-1}\mathbf{X}'\mathbf{T}'\mathbf{TZ} = (\mathbf{X}*\mathbf{X})^{-1}\mathbf{X}*Y \quad (3)$$

where \mathbf{b} is a vector and contains all the parameters of interest, X is the design matrix, the vector of observed data is represented by Z , and the dependency in the data is removed from the data by T , which is a lower triangulation matrix. The four parameters typically of importance in the \mathbf{b} vector for a time-series analysis are the level of the series, the slope of the series, the change in the level, and the change in the slope. The pattern of change over time is represented by the slope parameters, which are a set of the unique parameters of a longitudinal design. One advantage of employing a longitudinal design is that it allows for investigation of patterns over time. There is therefore no dependency on the data if the transformation matrix $T=I$, the identity matrix and the parameter estimates are provided by the standardised general linear model.

Therefore, the estimation equation will take the following form:

$$AvCO_{2t} = \beta_0 + \beta_1_t + \beta_2_{x2010_t} + \beta_3_{x_t2010_t} + \beta_4_{x2013_t} + \beta_5_{x_t2013} + \mu_t \quad (4)$$

When the regression is run using ITSA, default names are used to represent the different variables in the model. Table 5 below is a cross-reference to the default names for the variables that appear in the regression output in Table 6 and 7 below.

Table 5: Variable description

Variable	Description
t	Time since start of study
x(trperiod)	Dummy variable representing the intervention periods (preintervention is 0, otherwise 1)
x_t(trperiod)	Interaction of _x and _t

5.2 Empirical Results

5.2.1 Average CO₂ emissions

The main variable is average CO₂, annotated as AvCO₂. This variable is used to measure the average CO₂ from the aggregated CO₂ emissions of the passenger vehicles sold per month. Even though the dataset is from 1994 to 2018, the regression was only run from 2010 to 2018, as in the years prior to 2010 there is a lot of missing CO₂ emissions data, as it was not compulsory for manufacturers to stipulate it. As noted by Vosper and Mercure (2016), only in 2008 were South

African car dealers obliged to adopt a labelling scheme such that new vehicles were required to display stickers of fuel efficiency and CO₂ emissions based on the standard drive-cycle analysis.. The other variables are the migration from bigger- to smaller-engines vehicles – ascertained by breaking the dataset into the five engine-size bands: less than 1.20cc, between 1.21 and 1.40cc, 1.41 to 1.80cc, 1.81 to 2.50cc and greater than 2.50cc – running individual regressions, and graphing consumer behaviour. The last control variable is the share of diesel vehicles, for which the proportion of diesel-powered vehicles and the last two control variables are regressed and graphed throughout the study period, i.e., 1994 to 2018.

Below are the regression results, in which all the control variables are presented over the analysis period, showing the effect both in direction and magnitude of the two treatment periods, namely September 2010 and 2013. Typically, if a tax is successful, average CO₂ emissions should decline over time towards the recommended target. The policy question to answer would be how much of the observed change in the control variables can be attributed to the emissions tax itself. Table 6 below shows the three main variables: change in average emissions, migration of consumers from big-engines vehicles to relatively smaller engines, and potential migration from petrol to diesel vehicles.

Table 6: Estimating of the effects of the South African vehicle emissions tax using ITSA regression

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variables	Av CO2	Engine size < 1.20cc	Engine size _bt1.21-1.40cc	Engine size_bt 1.41-1.80cc	Engine size_bt 1.81-2.50cc	Engine size > 2.50cc	Prop Diesel
t	-0.963*** (0.109)	0.0002 *** (0.000)	-0.000 (0.000)	-0.0009 *** (0.000)	0.0004*** (0.000)	-0.0003*** (0.000)	0.001*** (0.000)
x2010	-0.040 (0.666)	0.0006 (0.005)	0.0314 * (0.0129)	0.052 *** (0.0098)	-0.065 *** (0.016)	-0.018** (0.009)	-0.038*** (0.007)
x_t2010	0.540*** (0.116)	-0.0006 ** (0.000)	-0.0006 (0.000)	0.0013 *** (0.000)	-0.0001 (0.000)	-0.001*** (0.000)	-0.0003 (0.000)
x2013	-1.314 (1.041)	-0.0005 (0.006)	0.0281 ** (0.010)	0.017 * (0.001)	-0.036 * (0.014)	-0.010 (0.011)	0.012 (0.016)
x_t2013	0.207 *** (0.038)	0.002 *** (0.000)	-0.0007 (0.000)	-0.002 *** (0.0004)	-0.0002 (0.000)	0.0002 (0.000)	-0.000 (0.0005)
cons	186.9*** (0.589)	0.006 (0.003)	0.142 *** (0.006)	0.400 *** (0.008)	0.277 *** (0.007)	0.177*** (0.008)	0.014* (0.010)

Post Intervention Linear Trend: 2010

Treated: $_b [t] + _b [x_t2010]$

Treated	-0.424 *** (0.035)	-0.0008 *** (0.000)	-0.0006 (0.0005)	0.005 (0.000)	0.0003 (0.000)	-0.0008*** (0.000)	0.0009*** (0.0004)
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Post Intervention Linear Trend: 2013

Treated: $_b [t] + _b [x_t2010] + _b [x_t2013]$

Treated	-0.216 *** (0.015)	0.003 *** (0.000)	-0.0014 *** (0.0002)	-0.001*** (0.000)	0.0001 (0.0002)	-0.0006 *** (0.0002)	0.0008*** (0.0003)
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Observations 108 300 300 300 300 300 300

Newey-West standard errors in parentheses denoting ***1%, **5%, and *10% significance

As shown in the regression Table 6 above, the starting level of the average CO₂-emissions intensity was estimated at 186.9g/km of CO₂ in 2010. As this was already much higher than the 120g/km target, it warranted a policy intervention. The CO₂-emissions intensity appeared to decrease significantly every year prior to 2010, by 0.96 g/km of CO₂ on average. In the first year of the

intervention (2010), there was no significant impact to the average CO₂ emissions intensity. However, the period that followed saw a marginal significant increase in the annual trend of CO₂-emissions intensity (relative to the pre-intervention trend) of 0.5g/km CO₂ emissions per year. In a way, the intervention seemed not to be yielding the desired outcome, and a more aggressive policy was required – hence the revision of the tax rate in 2013.

In the second year of intervention (2013), there was no increase in average CO₂-emissions intensity of CO₂, followed by a significant increase in the annual trend of CO₂-emissions intensity (relative to the pre-intervention trend) of 0.2 g/km of CO₂ emissions per year. From the linear combinations of estimators (lincom) estimate produced by specifying post-intervention linear trend, we also see that after the intervention was introduced in 2010, the average CO₂-emissions intensity decreased annually at a rate of 0.4g/km of CO₂. In the 2013 revision, average CO₂-emissions intensity decreased annually at a rate of 0.2g/km of CO₂, a decline in average CO₂ – was evident, however in response to the research question, one would question the efficacy of this CO₂ differentiated tax policy.

To ensure that we fit a model that accounts for the correct autocorrelation structure, we test for autocorrelation using the Breush Goedfrey method. The output table from the autocorrelation test shows that autocorrelation is not present (up to twelve lags tested). Thus, our initial model specifying lag (1) should correctly account for this autocorrelation.

5.2.2 Proportion of Low vs High CO₂ emitting vehicles

Furthering on the assumption that the reduction of the CO₂ intensity is driven from two levels, namely the migration of consumer vehicle demand from high emitting to low emitting vehicles and secondly, the increase in the share of diesel-powered vehicles. Table 6 above shows the starting proportions of the 5 engine categories. It is very clear from the results that the proportion of the small sized engines i.e., less than 1.20 was the smallest even less than 1% of the total passenger vehicle market share and the bulk of the vehicles were in the middle band i.e. 40%. The proportions for the 3 smallest engine categories was increasing post the 2010 and significantly so on the categories between 1.21 and 1.40cc and between 1.41 and 1.80cc and the inverse was observed for the remaining bigger engines, i.e., categories greater than 1.81cc.

The trend post trend past 2010 compared to the trend before 2010 shows that lowest band category was decreasing significantly, and this was opposite to the intended consequence of the policy. The middle band showed an increasing trend which is in line with what was observed in the European countries implementation of similar policies. The 2013 reform of the vehicle tax seemed to have initiated the desired policy effects directionally, as the proportion of the smallest sized vehicles especially sizes between 1.21cc and 140cc increased significantly whilst the categories between 1.81 and 2.50cc seemed to have decreased significantly. The trend observed post the 2013 reform is in line with the policy outcome expectations where the proportion of the lowest engines significantly increased whilst those of the biggest engines significantly decreased.

Table 6 above further shows, focusing on engine sizes smaller than 1.20cc, for example, that the starting proportion of this category of engine size in 1994 was estimated at 0.6% of the total market share; it appeared to be increasing by 0.02 % annually prior to the 2010 policy intervention.

In 2010 the impact was not immediately apparent, as the proportion of vehicles with engine sizes smaller than 1.20cc did not change significantly, instead started to decrease by as much as 0.06% annually in the period between 2010-2013 and the reform in 2013 the effect was not significant to this category at the time of legislation. It however, seemed to begin yielding the answer required, as the proportion of vehicles in this category started increasing by a magnitude of 0.2% annually leading to 2018. When these results are contrasted with the lincom estimates the proportion of vehicles decreased by 0.08% after the 2010 policy implementation; but the intended policy outcome of increasing the proportion of low emitting vehicles was realised in 2013, when the trend started increasing, by 0.3% in the period post 2013. The policy only began to be effective in this category of engine size after the second treatment period.

5.2.3 The share of diesel-powered vehicles

Table 6 above shows that the starting proportion of diesel-fuelled cars was 1.4% of total market share. In 2010, the proportion of diesel-powered passenger vehicles declined by 3.8%; and the trend after 2010 was negative compared to the period before the emission tax implementation, meaning that diesel-vehicle sales were growing at a much slower pace than before the intervention. The 2013 revision of the rate seemed to yield the desired results, as the proportion of diesel vehicles rose by 1.2%; but the trend thereafter remained almost flat.

5.3 Secondary Variables

The Table 7 below shows how the technical parameters were prior to the intervention, and how the level and the trend was affected by both the 2010 and the 2013 interruption periods. The power variables would generally be expected to increase as both the weight and the engine size parameters decrease.

Table 7: Estimating the South African CO₂ tax on the secondary technical parameters

	(1)	(2)	(3)	(4)
	Average HP	Average kW	Average Gross vehicle mass	Average Engine size
Variables				
t	0.526 *** (0.036)	0.387*** (0.0267)	0.877*** (0.097)	0.001*** (0.000)
x2010	-23.46 *** (3.706)	-17.28*** (2.723)	12.594 (14.769)	-0.087*** (0.016)
x_t2010	-0.334 * (0.187)	-0.247* (0.138)	-0.120 (0.922)	-0.003*** (0.001)
x2013	-1.331 (4.664)	-0.982 (3.434)	-17.921 (23.103)	-0.016 (0.024)
x_t2013	-0.304 * (0.186)	-0.226 * (0.137)	-2.158** (1.035)	-0.001 (0.000)
cons	61.406*** (4.837)	45.048 *** (3.543)	1731.01*** (14.474)	1.84*** (0.006)
Post Intervention Linear Trend: 2010				
Treated: $_b [t] + _b [x_t2010]$				
Treated	0.189 (0.183)	0.141 (0.135)	0.997 (0.916)	-0.002* (0.001)
Post Intervention Linear Trend: 2013				
Treated: $_b [t] + _b [x_t2010] + [_b [x_t2013]$				
Treated	-0.116*** (0.0234)	-0.085*** (0.017)	-1.161** (0.481)	-0.003*** (0.000)
Observations	300	300	300	300

Newey-West standard errors are in parentheses. ***1%, **5%, and *10% significance

The three secondary variables namely HP, kW and Average engine size all seemed to have reduced significantly when the 2010 emissions tax was implemented. The average gross vehicle mass is the only variable in this category where an opposite effect was observed. The starting variables were 61.406 horsepower, 45.048kW and 1.84cc whilst it was 1731.01kg for the GVM. All the four variables were increasing significantly pre- the 2010 intervention. Post the 2010 intervention a significant decreasing trend was observed for all the four variables which was an indication that the supply market was responding to the policy signal.

In the 2013 reform however, all the four variables were not significantly affected. Engine size, for instance, started at an average of 184cc in 1994. Prior to the intervention, engine sizes were growing by 0.001cc annually. In the first interruption of 2010, engine sizes seemed to have decreased by 0.087cc, and the rate of engine-size growth post 2010 was negative when compared to the trend prior to 2010 which was a reversal of a pre-policy trend. Engine sizes were decreasing at a rate of 0.003cc per year. This was the expected trend for the reform, as smaller engines are correlated with lower emissions.

In the 2013 intervention, engine sizes continued to be negatively affected; the average engine size in 2013 was 0.061kg lighter than the average engine size of 2010. The trend of engine growth preceding the 2013 reform remained negative – which highlights that for emissions to be lowered, there is not only one variable at play, but a combination of technical parameters. The post-intervention linear trend for engine size is negative in both interaction periods, meaning that average engine size did decrease relatively after the reform. These results must be contrasted with the Pearson correlation matrix shown in Table 1 above.

6. Conclusions

This study analyses how CO₂ differentiation in South Africa affected the attributes of new passenger vehicles. CO₂-differentiated tax is levied on a vehicle according to how much CO₂ in g/km that vehicle is specified to emit. This carbon emissions tax is largely based on engine size and amount of CO₂ in g/km emitted per vehicle. In South Africa, every g/km over 120g/km of CO₂ is taxed. On 1 March 2011, vehicles used for the transport of goods, including double cabs, were added as a new category. The differentiated CO₂ emissions rates were adjusted in 2013.

This research examines the effectiveness of the CO₂-emissions tax, using three main control variables: aggregated CO₂-emissions intensity in g/km, the migration of consumer preference from

high- to low-emitting vehicles, and the shift towards diesel-powered cars and the proportions thereof. The rationale for the tax is to nudge consumers into purchasing low-emitting vehicles, encouraging movement towards a greener economy. There is huge potential to improve consumer decision-making on the issue of purchasing environmentally friendly vehicles. The focus of our analysis is on new passenger cars, as they represent an overwhelming majority of the cars on South African roads. Using data from NAAMSA, the paper assesses to what extent consumer preferences have shifted away from high-emitting to lower-emitting vehicles, and to what extent these have influenced the average amount of CO₂ emissions in South Africa in relation to the recommended EU standard of 120g/km of CO₂, in both the short and the long run.

The analysis shows that there has been a shift in consumer choices regarding passenger vehicles in South Africa. The shift has been predominantly to smaller-engine, petrol-fuelled cars. A general shift towards lower-emitting vehicles was observed. The shift to diesel cars has been slower than was experienced in European countries. There has been growth in the total number of sales of new passenger vehicles year on year, in tandem with the fluctuations of GDP per capita.

South Africa has seen a 31g/km decrease in expected CO₂ emissions in the eight years since this tax has been introduced, of which 19% may be attributed to the CO₂ vehicle tax. The decrease can also be attributed to technology efficiency gains from the supply side among other factors, including other exogenous factors such as fuel technology. From the demand side, the CO₂-emissions decrease can be attributed to a shift in consumer buying patterns, towards smaller engines and lower-emitting vehicles. In South Africa, the CO₂ emissions tax was effective in bringing down average weighted CO₂ emissions from an average of 161g/km in 2014 to 151g/km in 2018. The 2013 tax rate adjustments seem to have sent the right signal to consumers and accelerated progress towards the desired trajectory. But the reduction in average CO₂ emissions seems to be decreasing in magnitude year on year, and the regulators must come up with alternative methods to nudge the consumers further – to the desired 120g/km, and towards the 2025 vision of reducing carbon emissions by 42%.

The study also ascertained the degree to which other attributes such as engine size, weight and power output of new vehicles changed in the period after the intervention. The findings of this study are consistent with findings from Germany, the UK, the USA, France, Finland, Sweden, the Netherlands and Denmark (see Cerruti et al., 2018; Alberini and Bareit, 2016; Klier and Linn, 2015; Stitzing, 2016; Kok, 2015; Mabit, 2014). Overall, aggregate CO₂ emissions in g/km went

down. Even though the adoption of diesel-powered vehicles is not as high as in other regions such as Europe, the main control variable assumes that the underlying factors are similar.

The magnitude of the aggregate reduction in CO₂ emissions in South Africa is lower than in most of the European countries. By 2010, Norway and Ireland's average CO₂ figures were already in the region of 140g/km, which is lower than the South African level in 2018 (see Adamou et al., 2012; Cerruti et al., 2018; D'Haultfoeuille et al., 2014; Konishi and Zhao, 2016; Klier and Linn, 2015; Alberini and Bareit, 2016; Yan and Eskeland, 2018). A lack of incentive for OEMs to innovate and invest in research and development in South Africa has added to the slower decline in vehicle carbon emissions, as consumers are generally left with a pool of not-so-efficient vehicle to choose from. Vosper and Mercure (2016) assert that for the vehicle carbon-emissions tax to have significant effect, the policy will have to evolve drastically, enabling the emergence and increased market absorption of low- and zero-carbon vehicle technologies, possibly in the lowest price brackets of the market; and this can be unlocked through subsidy policies. There seem to be no incentives from government for manufacturers to sell cars with cleaner engines. Such cars end up being expensive, disadvantaging the manufacturers, who are competing in the open market. Future policy implementations should consider how behaviour can be influenced on both the supplier and the consumer side.

When the policy was first mooted, the idea was to make vehicle CO₂ tax transparent to the consumers, over and above the retail price of a vehicle. It was anticipated that this extra vehicle tax 'price tag' visibility would naturally nudge consumers towards alternatives with similar performance but lower CO₂ tax, inadvertently lowering overall vehicle CO₂ emissions. However, the implementation did not prescribe a method for how this visibility might be presented; neither did it provide an oversight function. These were left to the car dealerships to decide. Out of eight dealerships visited in Gauteng, only one made the CO₂ tax visible to the consumers – the rest just built it into the retail price. This kind of behaviour by the dealerships is counterintuitive, as it does not aid in influencing consumer behaviour or in making consumers emissions sensitive.

The lack of mechanisms and oversight regarding making the tax visible to consumers has left consumers to their brand loyalty, the constraining effect on real income of the legislation, and the perceived performance of both brand and vehicle, which is a factor that works to the dealerships' advantage. Policymakers should prescribe how they envisage this transparency should be

presented to the consumer; further, there should be an oversight function that ensures that this practice is followed and standardised countrywide.

Another factor which might have contributed to the slower decline in CO₂ emissions is the fact that fuel pricing in South Africa is government regulated. This phenomenon does not allow the fuel refineries to compete against each other in improving fuel technology, which is another factor that could assist in the reduction of vehicle CO₂ emissions. Some of the latest and most efficient European-produced engines cannot be used in South Africa, as there is no fuel available that is compatible with them. This is a consideration for future implementations or amendments to the policy, as it would accelerate the reduction of CO₂ emissions.

Our study is subject to some limitations, firstly, given that some of the dummy variables are just 3 lags apart, the results are likely to suffer from multicollinearity and secondly, post 2013 had series of tax rates, representing that period with just a dummy variable does not give a good representation of the evolution of the tax rates.

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