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Assessing the effectiveness of South Africa's emissions-based purchase tax for private passenger vehicles: A consumer choice modelling approach

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Abstract

South Africa is an important economy in terms of global greenhouse gas emissions and it has made progressive policy steps to address its national emissions. One significant national fiscal policy is the emissions based purchase tax for private passenger vehicles, implemented in September 2010. There has, however, been little attempt to assess the effect that this key mitigation policy has had on the emissions of new passenger vehicle fleets. This study uses a discrete consumer choice model to assess the effectiveness of this tax policy in changing consumer behaviour and reducing fleet emissions. It finds that the emissions reduction achieved by the tax were negligible compared to the increases in fleet emissions associated with the growing vehicle market. It is demonstrated that the structure of the tax policy does not suit the dynamics of the South African vehicle market and the policy would require restructuring if it is to more effectively reduce fleet emissions. In addition, for the tax policy to effect significant fleet emissions reductions in the future it will require the emergence of low- and zero-carbon vehicle technologies in the lowest price brackets of the market, possibly via subsidy policies.

Keywords: emissions tax, passenger vehicles, discrete choice modelling

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1. Introduction

In terms of carbon emissions from fuel combustion, South Africa is the world's 15th largest CO_2 emitter, contributing 1.2% of global emissions (International Energy Agency (IEA), 2014a). As a signatory to the Kyoto Protocol, South Africa ambitiously pledged to reduce its emissions by 34% and 42% by 2020 and 2025, respectively, at the 2009 COP negotiations (Environmental Defense Fund, 2014). Mercure *et al*. (2014) suggested that decarbonising the electricity sector alone will typically not be enough to meet a nation's emissions reduction targets and stabilise global temperature rises below 2 °C.

South Africa's road transport sector accounted for approximately 11% of national emissions in 2012 and thus presents a key area for emissions reductions (IEAa, 2014). South Africa's public transport infrastructure is largely under-developed, with limited rail networks and a low percentage of airline traffic (IEAb, 2014). In addition, the country's major cities have continued to expand since the abolishment of apartheid's segregated residential policies (Todes, 2012). Large economic centres, such as Johannesburg, are now characterised by sprawling low-density commuter communities (Todes, 2012). As a result, there has been a growing dependence on private road transport for both passengers and freight (IEAb, 2014). One approach to reducing emissions from private passenger vehicles is to improve the uptake of low-emissions vehicle technology (Rajan, 2006). The major challenge to increasing its penetration is making the technology cost-competitive (Grubb, 2014). Addressing the cost disparity is an attractive policy for a nation like South Africa, which has a growing vehicle population and limited infrastructural flexibility to move away from private transport. A variety of push and pull policies, such as taxes and subsidies, can be pursued to bring low-emission technologies out of niche markets (Geels, 2002; Grubb, 2014). South Africa has been progressive in this regard, with the implementation of a carbon emission-based purchase tax on new passenger vehicles as early as 2010, with amendments in 2014. There has been, however, little attempt to assess the effectiveness or model the prospective outcomes of these tax schemes (Nel & Nienaber, 2012; Pillay & Buys, 2013).

This investigation aims to shed new light on the South African vehicle emissions policy by retrospectively assessing its impact on new vehicle fleet emissions through the uptake of lower-carbon technologies. A probabilistic discrete choice model of consumer response is used to predict how consumers would have behaved within a given time period had no tax been present. The policy impact is evaluated by comparing the emissions outcomes of the modelled and observed consumer behaviours. The discrete choice model used in the analysis is based on the model developed by Mercure and Lam (2015). It is built on the assumptions of consumer choice drawn from economic theory, marketing literature and consumption anthropology. These model outputs are then contextualised within an analysis of the South African vehicle market.

2. Literature review

2.1 South African policy context

As South Africa is one of the only vehicle manufacturers in Africa, the importation of used vehicles is generally prohibited (United Nations Environment Programme (UNEP), 2010), so growth in the vehicle population is primarily through the purchase of new vehicles. South Africa has followed Europe in terms of vehicle emissions standards, with newly manufactured passenger vehicles complying with Euro 2 standards since January 2008 (National Association of Automobile Manufactures of South Africa (NAAMSA), 2010a; South African Petroleum Industry Association (SAPIA), 2008). A labelling scheme was simultaneously mandated to align with the emissions standards. South Africa's car dealers were required to display stickers on new vehicles that detail their fuel efficiency and CO_2 emissions, based on a standard drive cycle analysis from 2008 (NAAMSA, 2010b; UNEP, 2010). The labels are intended to enable consumers to evaluate their purchase options based on their prospective emissions.

The *ad valorem* taxation system for the purchase of new passenger vehicles based on their CO_2 emissions was implemented on 01 September 2010. The policy sets a tax exempt threshold level of 120 g CO_2/km, while the structure of tax was linear, with each gram of CO_2 above 120g/km being taxed at R75 per gram (NAAMSA, 2010a). This scheme was revised in August 2014 to R90 per gram and again in April 2016 to R100 per gram (South African Revenue Service (SARS), 2014; SARS, 2016). Tax is paid by the consumer at the point of purchase and is then transferred to SARS by the supplier/manufacturer (independently of value added tax). This emissions tax is the only environmental-based or carbon-based tax applied at any point in the purchase, registration or use of private passenger vehicles.

2.2 Fuel price considerations

South Africa has not experienced any recent shocks to the fuel price, while abrupt changes in fuel prices and policies can encourage gradual shifts in the uptake of particular technologies (Department of Energy, 2015; Grubb, 2014; McKinsey & Company, 2007). Furthermore, it was shown that vehicle buyers typically exhibit a strong tendency to undervalue fuel economy when purchasing new vehicles (Greene, 2011). Consumers typically require a 2-4 year payback for an additional investment in fuel efficiency and do not rely on lifetime discounting when evaluating vehicle options (Greene, 2011). For this reason, consumer choice modelling can be done successfully without considering fuel prices. Mercure and Lam (2015) also demonstrated that, even if consumers consider the lifetime fuel costs of vehicles at the time of purchase (under various discount rates), this cost is significantly lower than the initial investment of a vehicle purchase. Consequently, the fleet emissions reductions achieved per 1% tax on fuel are always smaller than equivalent tax rates on the vehicle purchase price. This suggests that an emissions tax at the point of purchase is more effective when aiming to reduce emissions through the uptake of low-emissions technologies.

2.3 Consumer behaviour

The purchase of a new vehicle is one of the largest single expenses that consumers are likely to make during their lives, so it is a decision that requires careful consideration of various economic and functional factors (McShane *et al.*, 2012). Marketing research, however, has shown that the demand for products goes far beyond their price and function. Douglas and Isherwood (1979) offered an especially useful insight into the anthropology of consumption in their seminal work *The World of Goods*. An explanation of how goods carry social meaning and perform a role in making visible and stabilising the categories of culture was given. For instance, the consumption of particular goods can serve as markers of social identity within a group or association to a group. Research in the fields of economics, psychology, marketing, anthropology and sociology has recognised how social influence shapes decision making, concluding that people exhibit a strong tendency to conform to the observed behaviour of others: 'visual influence' (Burnkrant & Cousineau, 1975; McShane *et al.*, 2012). It was illustrated by McShane *et al.* (2012) that this phenomenon holds for large purchases like vehicles.

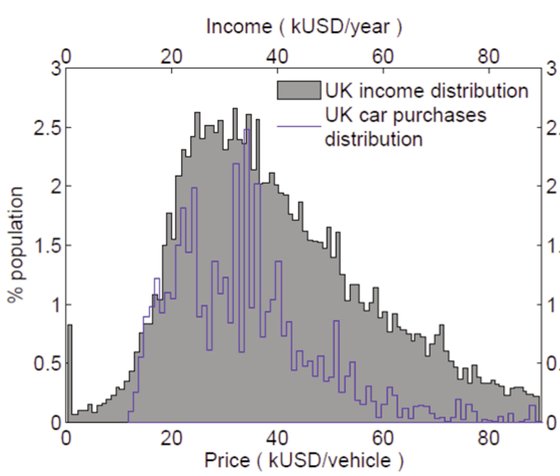

Figure 1: Comparison of the UK income distribution for 2012 and the price distribution of passenger vehicles sold in 2012 (Mercure & Lam, 2015).

It can be inferred that goods such as passenger vehicles, which are highly visible in their consumption, play an important role in displaying social identity and enforcing group characteristics. The behaviour of other members of a group act as a form of social proof or norm that people must follow to remain in the group (McShane *et al.*, 2012). This may manifest in people purchasing vehicles from a specific price subset of the vehicle market that is suitable to their social group and income level. Mercure and Lam (2015) represented this idea graphically by overlaying the lognormal income distribution of the UK population with the similarly shaped price distribution of vehicle sales for 2012 (Figure 1).

2.4 Discrete choice modelling and technology diffusion

A number of modelling procedures emerged in recognition that the consumer population is not homogeneous but rather broken up into many heterogeneous socio-economic and cultural groups, e.g., Daniel McFadden's discrete choice models to predict the choices made by individuals. These models assume a decision maker as an individual who chooses on the basis of some decision rule, among a finite and knowable set of alternatives that are each characterised by various attributes (Ben Akiva & Lerman, 1985). A discrete choice analysis that predicts a choice behaviour for the immediate or short term can serve as a very useful tool in retrospective and prospective analyses. It is understood that short-term behavioural change can manifest in longer term change as it imbeds in society. Geels (2002) described this socio-technological regime as dynamic, with the cultural, political, scientific and market forces interacting and changing over time. Altering this socio-technological regime through the introduction of various behavioural, market or institutional policies can help direct which technologies diffuse into markets (Grubb, 2014). In terms of private passenger transport, hybrid or electric vehicles could be considered as low-emission niche technologies at a very early stage of diffusion.

3. Data summary

Sales data for new private passenger vehicles was obtained from Lightstone Auto, an independent service provider to NAAMSA. The data set recorded the monthly sales figures in South African rand for each vehicle model on the market from September 2009 (included) until August 2014 (included). The dataset also matched each vehicle sale with its suggested retail price in each month. These prices were adjusted by factors of inflation provided by the World Databank (World Bank, 2015). The data set also listed the technological characteristics of each vehicle model that included engine size, fuel type, fuel consumption (l/100 km) and emissions (g CO_2 /km). This study assumes that the dataset is representative on average due to its size despite some controversy around the quoted emissions levels for some passenger vehicles.

Summing the monthly sales figures yielded five sets of annual sales data, which each run from 01 September to 31 August in the following year. These periods will be referred to as Years 1 to 5 henceforth and were chosen for their suitable alignment with the introduction of the initial and updated tax policies, implemented respectively in September 2010 and August 2014. Year 1 directly precedes the introduction of the first tax policy, which remains in effect for the following four years. Year 5 then directly precedes the implementation of the updated tax policy. An initial summary of the sales figures and market shares of the four broad categories of vehicle technology is presented in Table 1, which shows that the shares of diesel vehicles increased from 14.9% to 17.9% in the five years. Growth in hybrid shares was, however, negligible. The first 47 electric vehicles entered the market in Year 5. The growth rate slowed down and sales decreased in Year 5, while the total sales of all engine technologies increased by 43.14% from Year 1 to Year 5. This was likely due to the economic downturn in 2014, characterised by stagnant economic growth, price inflation and high interest rates (NAAMSA, 2014).

The price distribution of the South African vehicle market, illustrated in Figure 2, offers another useful perspective. This distribution of the vehicle market generally exhibits a positive skew over the period of five years, which may also be perceived to as the positive section of a lognormal distribution. Also note that only the wealthiest portion of the South African population (right-hand tail of the income distribution) is able to afford new passenger vehicles (NAAMSA, 2014). Considering this, it is conceivable that the price distribution of vehicle sales would map neatly onto the right hand tail of the South African income distribution and thus present an analogous demonstration of consumer choice to Figure 1. It is also useful to note where hybrid vehicles are placed in the price distribution despite having very small shares as an engine technology. They appear only in the upper price ranges grouped at approximately R400 000 and R800 000 and, therefore, they do not cater to consumers in the lower price ranges (where most vehicles are purchased). The distribution, in this regard, differs from the UK's where hybrids are available across most price brackets (Mercure & Lam, 2015).

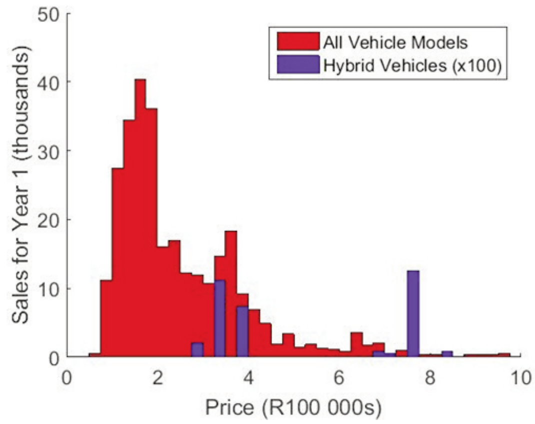

Figure 2: Price distribution of the passenger vehicle sales for Year 1 with hybrid sales highlighted in blue.

It is also useful to illustrate the relationships between price, engine size and emissions for the South African vehicle market. It is assumed that vehicles with a larger engine size are typically more luxurious and expensive (Mercure & Lam, 2015). This property holds true for the South African data set as shown by the strong positive relationship between engine size and the logarithm of price in the first panel of Figure 3. The second panel then confirms the mechanical relationship where larger engines, which produce more power, require greater volumes of fuel and thus produce higher levels of emissions per kilometre travelled. These two relationships can be exploited to produce a positive relationship between emissions and the logarithm of price in the third panel of Figure 3. This relationship can be understood in terms of the other two relationships as consumers are not paying for emissions directly but rather through paying for engine size. The market structure presented for Year 1 is representative of all five years of analysis.

Table 1: Summary of sales and market shares of four engine technologies for each sample year.

Energy type			***% Market share***		
	Year 1	*Year 2*	*Year 3*	*Year 4*	*Year 5*
Petrol	84.91	85.50	85.14	83.06	81.87
Diesel	14.97	14.34	14.68	16.82	17.98
Hybrid	012	0.16	0.18	0.12	0.14
Electric	0.00	0.00	0.00	0.00	0.00
Total sales	304 407	374 388	431 294	454 020	433 275
Growth (%)		23.92	15.12	4.96	-4.41

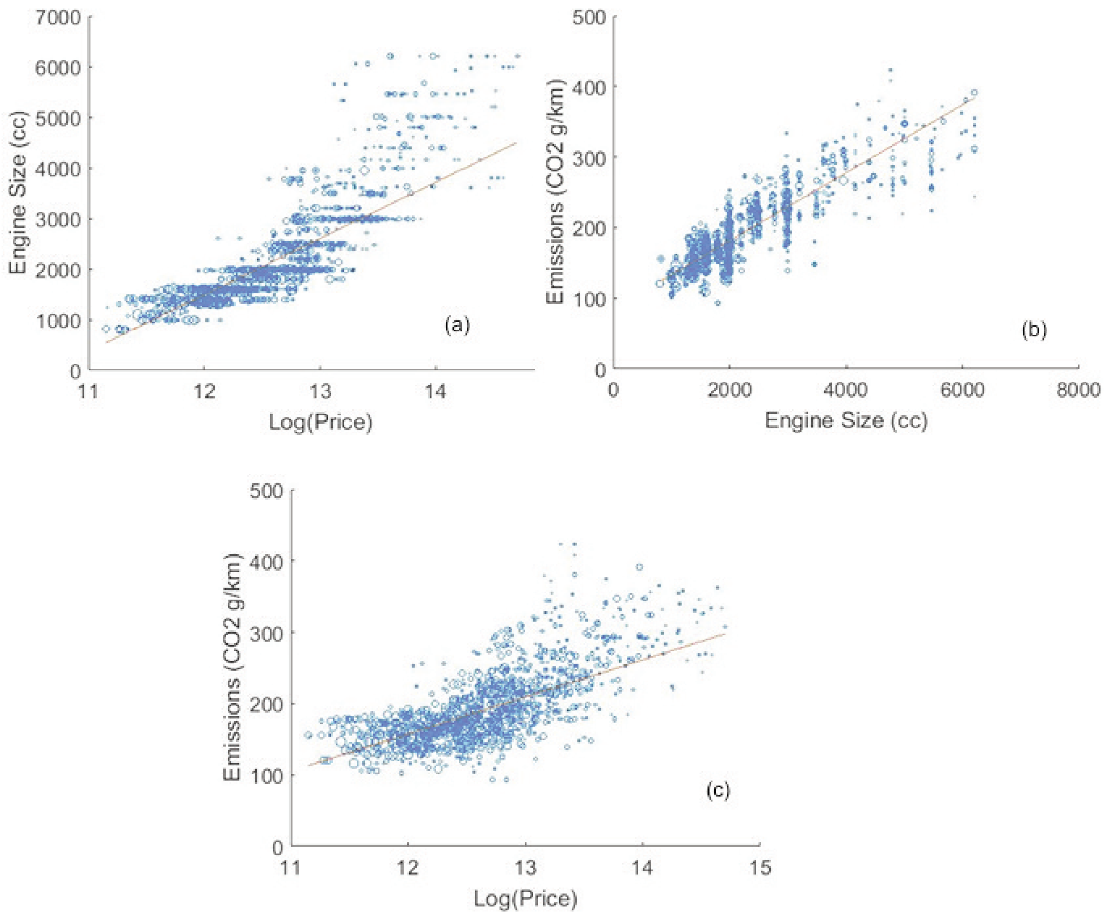

Figure 3: Population weighted univariate regression plot of the Year 1 vehicle sales depicting (a) engine size vs price, (b) emissions vs engine size, and (c) emissions vs price.

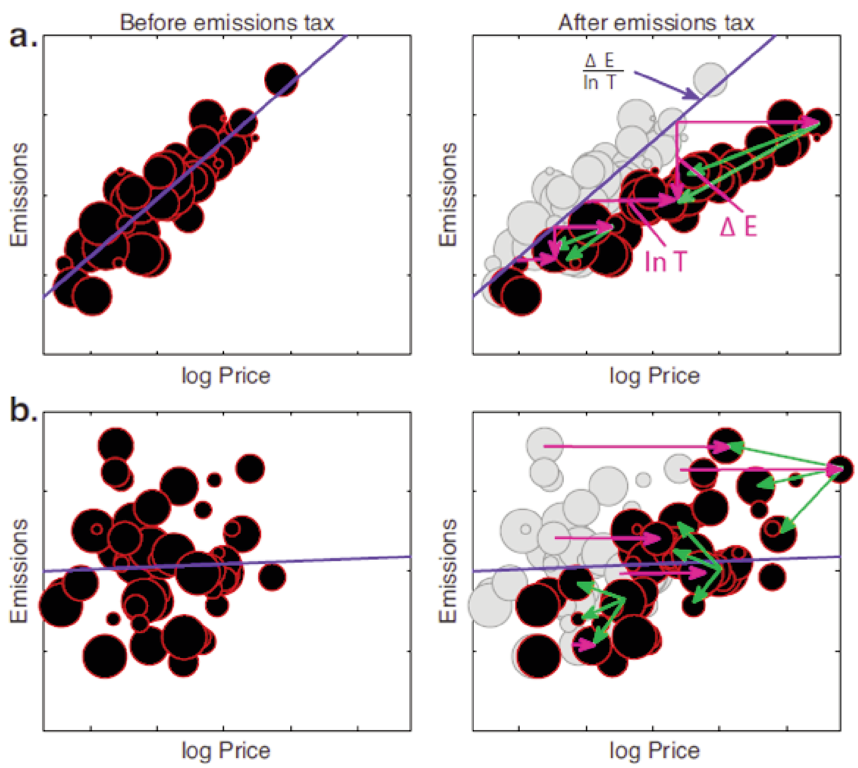

Figure 4: A schematic representation of emissions based fiscal policy effectiveness for (a) strong and (b) weak correlations before (left-hand side) and after (right-hand side) emissions tax (Mercure & Lam, 2015).

4. Model and methodology

The effectiveness of a purchase tax in achieving reductions in vehicle fleet emissions relates to its ability to encourage consumers to substitute towards lower emissions vehicles. Mercure and Lam (2015) have shown that a policy's ability to do this is dependent on the market structure and in particular the relationship between emissions and price. Returning to the work of McShane *et al.* (2012), the suggestion is that individual consumers seek to remain within a socially set price bracket when purchasing a new passenger vehicle. In the event of changes in vehicle prices, due to a tax or subsidy, some vehicle models may move out of a given individual's price bracket while others will move into it. Consumers are, however, assumed to not consider the fuel price when making a decision, as suggested in the literature (Greene, 2011).

Consider the two hypothetical vehicle markets presented in Figure 4. Each bubble represents a vehicle model with its size representing the number of sales of that model. After applying an emissions tax each bubble shifts rightward to a new position in the emissions price plane, as indicated by the pink arrows. The top pair (a) shows that the market was well structured with exponentially more expensive vehicles having proportionally greater emissions levels on average. Each consumer, after applying the tax, typically found vehicles of lower emissions levels that fell within their stationary price bracket. The effectiveness of the policy is, therefore, well defined in this situation. The bottom (b), however, shows the market was less structured when comparing price with emissions. Emissions levels of the vehicle models entering a given consumers price bracket after the tax were, as a result, uncertain and, consequently, the effectiveness of a tax policy. Mercure and Lam (2015) demonstrated that insights into the potential policy effectiveness of emissions-based purchase taxes can be drawn from the slope and correlation of the relationship between prices and emissions.

A more detailed analysis of the policy induced changes can be conducted using a model of distributed choice dynamics. The model presented here was used to analyse passenger vehicle markets in six world regions (Mercure & Lam, 2015). It is still assumed that, in the presence of a tax, consumers will remain within their socially determined price bracket and compensate for the price increase by selecting a vehicle model of a lower price. The emissions and price region (*E, lnp*) in which consumers search the market, can be defined by the probability distribution in log scale: $f(lnP_i - P_i)$, where is the price of vehicle model *i* that is considered by consumers before the tax takes effect, is the price of the alternative vehicle model *i* considered after the tax takes effect, although this value does not include the tax. T_j is the tax rate multiplier as a proportion of vehicle price for vehicle model *j* calculated from its emissions level E_j, and σ is the consumers' tolerance to price variation.

The model follows McShane *et al.* (2012) by assuming that the probability of a consumer substituting from vehicle model *i* to *j* under the tax is proportional to the relative popularity of model *j*. This popularity is measured by its number of sales (N_j) over all other sales ($\sum_k N_k$). Combining this with the probability distribution previously defined yields the probability of substituting for *i* to *j* gives Equation 1.

$$P_{i\to j} = \frac{N_j f(lnP_i - lnP_j + lnT_j)}{\sum_k N_k f(lnP_i - lnP_k + lnT_k)} \quad (1)$$

N_i is then the number of sales of model *i* for a given time period. Once the tax takes effect a number of these prospective consumers will consider other vehicle models, including model *j*. Applying Equation (1) to N_i, the number of consumers changing their choice from *i* to *j* is given by Equation 2.

$$\Delta N_{i\to j} = N_i N_j \frac{f(lnP_i - lnP_j + lnT_j)}{\sum_k N_k f(lnP_i - lnP_k + lnT_k)} \quad (2)$$

There is also a non-zero probability that consumers of model *j* will change to model *i* after the tax, resulting in the net changes between models *i* and *j* expressed in terms of Equation 3.

$$\Delta N_{ij} = \Delta N_{i\to j} - \Delta N_{j\to i} \quad (3)$$

These net changes in vehicle model choices are then multiplied by the vehicle emissions levels and summed over all models to give the total change in emissions ΔE as in Equation 4. Dividing this by the total number of vehicles N_{tot}, as in Equation 5, produces a value for the average change in emissions $\overline{\Delta E}$ in Equation 6.

$$\Delta E = \sum_{ij} E_j \Delta N_{ij} \quad (4)$$

$$N_{tot} = \sum_i N_i \quad (5)$$

$$\overline{\Delta E} = \frac{\Delta E}{N_{tot}} \quad (6)$$

The total amount of tax paid lnT is calculated similarly by multiplying the model specific tax rates (approximately $= lnT_j$) to the number of model sales adjusted with changes and summing over all models, as shown in Equation 7. This expression is divided by the total vehicle sales to give the approximate average tax rate $\overline{lnT}$ as in Equation 8.

$$lnT = \sum_{ij} (\Delta N_{ij} + N_i) lnT_j \quad (7)$$

$$\overline{lnT} = \frac{lnT}{N_{tot}} \quad (8)$$

The ratio $\overline{\Delta E}$ / $\overline{lnT}$ yields the average emissions change per unit tax (tax of 100%). This is interpreted as the indicator of efficiency for a fiscal policy. The uncertainty range for $\overline{\Delta E}$ (and consequently for $\overline{\Delta E}$ / $\overline{lnT}$ as well) is calculated from the variation in individual choices and is represented as $\delta\overline{\Delta E}$, giving Equation 9, where $\langle\ \rangle$ represents a population weighted average.

$$\delta\overline{\Delta E} = \sqrt{\langle \Delta E^2 \rangle - \langle \Delta E \rangle^2} \tag{9}$$

The same formulae can be produced for variables such as engine size and price. Furthermore, the model is equally applicable for subsidy policy in the form of a negative tax. The model can be applied in the same way as a subsidy to account for an income effect where consumers are believed to have more income, due to economic growth, and thus search the market for higher priced vehicles. The model, when applied to a given sample from a given time period, estimates how that sample would have behaved in the same period under the imputed stimulus (tax, subsidy or income change).

This analysis uses the model in its current form to conduct a retrospective evaluation of the tax policy that was implemented in September 2010 by estimating the consumer choice changes induced by the tax and calculating the resulting changes in fleet emissions for each year that the tax was in effect. The model estimates how consumers would have behaved in each period had no tax been implemented by adjusting the vehicles' prices in each year to include their individual emissions taxes and then modelling the tax policy in reverse (an equal negative tax). These changes in consumer choice are used to calculate a change in total fleet emissions for each period which is, subsequently compared against total fleet emissions growth and tax revenue accrued. The 2010 tax policy is also compared to the expected emissions reductions modelled under larger taxes.

The tax rate is calculated using the legislated fee of R75 per g CO_2/km of emissions above 120 g CO_2/km. Consumers' tolerance to price variation <> is chosen to be 10%, as suggested in Mercure and Lam (2015). The discrete choice model is coded and run in MATLAB with the data sets being stored in Microsoft Excel.

5. Results of analysis

5.1 Tax effects

The four sample periods where the same emissions tax was in effect (Years 2, 3, 4 and 5) are firstly considered. The average fleet emissions (g CO_2/km) for each year is summarised in Table 2.

The total fleet emissions for each year can be modelled under a 'no tax' simulation and compared to the actual fleet emissions where the tax was present. Subtracting these values gives an estimate of the total emissions reduced as a result of the tax. Multiplying these emissions reductions by the expected distance travelled over a vehicle's lifetime (166 300 km for South Africa) yields the lifetime quantity of CO_2 reduced for the fleet in tons (Merven *et al.*, 2012). Dividing the total fleet emissions reduced by the number of vehicles sold gives the average fleet emissions reduced. As explained in Section 4, dividing the average fleet emissions reduction by the average tax rate offers a measure of the effectiveness of the tax policy. The applied tax rates are also used to calculate the total tax revenue accrued for each period of the policy. The modelled outputs for these figures are summarised in Table 3, which shows that the tax policy reduced fleet emissions below what they would have been. Over four years the tax policy prevented the future emission of approximately 76 431 tons of CO_2 for the fleets' active lives and accrued more than R5.19 billion in consumer taxes. The positive emission reductions achieved by the tax and the declining average fleet emissions shown in Table 2 substantiated the influence of tax.

Table 3 also shows that the emissions reduction achieved by the tax declined over time. The average tax rate also decreased over the period, although more slowly, and thus the policy effectiveness also decreased. Table 4 shows that the total fleet emissions increased rapidly, except for the last period where vehicle sales declined. The growth in total fleet emissions was much larger than the reductions effected by the tax. In Year 2 the emissions reduction achieved by the tax accounted for only 1.8% of the annual growth in emissions and 0.3% of the total fleet emissions. The reduction in fleet emissions associated with the reduced sales in Year 5 was 70 times greater than the reductions effected by the tax. This was caused by the negligible contribution of the tax policy that was, in turn, overshadowed by the growth in vehicle sales.

The results show that that the tax policy implemented in 2010 was not able to curtail the growth in fleet emissions. An average tax rate of 1.47% was, however, small, considering South Africa's value-added tax of 14% and that one quarter of the fuel price comprises taxes. As such, it would be useful to explore whether other tax regimes would offer larger or more effective emission reductions. The modelled policies were structured in the same way as the implemented policy by varying the tax fee per g CO_2/km above the same threshold of

Table 2: Summary of the average fleet emissions for the five sample years.

Period	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*
Average fleet emissions without tax (g CO_2/km)	173.94	168.02	162.81	157.66	154.61

Table 3: Summary of the estimated policy impacts for the four years of implementation.

Parameter	*Year 2*	*Year 3*	*Year 4*	*Year 5*
Fleet emissions reduction (g CO_2/km)	185 000	133 000	78 000	62 00
Fleet lifetime CO_2 reduced (tons)	30 845	22 122	13 053	10 410
Reduction in average fleet emissions (g CO_2/km)	0.50	0.31	0.18	0.15
Effectiveness (average g CO_2/km reductions per 1% tax)	0.34 (±0.45)	0.24 (±0.44)	0.15 (±0.62)	0.15 (±0.58)
Average tax rate (%)	1.47	1.29	1.13	0.97

Table 4: Summary of the total fleet emissions, the fleet emissions growth and the emissions reductions from the tax policy for the five sample years.

Parameter	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*
Total fleet emissions (kg CO_2/km)	51 919	62 146	69 324	70 473	66 060
Fleet emissions growth (kg CO_2/km)	.	10 412	7 178	1 149	-4 413
Tax induced fleet emissions reduction (kg CO_2/km)	.	185	133	78	62

Table 5: Summary of the predicted fleet emissions reductions achieved in Year 2 for three different tax fees.

Tax fee value (R/g CO_2/km > 120g/km)	*Average tax rate (%)*	*Tax induced fleet emissions reduction (kg CO_2/km)*	*Percentage of annual emissions growth (%)*	*Percentage of total emissions (%)*
R75	1.47	185	1.7	0.3
R275	5.25	845	8.1	1.4
R500	9.22	1 599	15.3	2.6

120 g CO_2/km, for the sake of comparability. These policy options were presented for Year 2 only, as similar interpretations could be drawn for each period. Figure 5 shows Year 2 model outputs of policy eff-ectiveness for twenty variations of the tax fee.

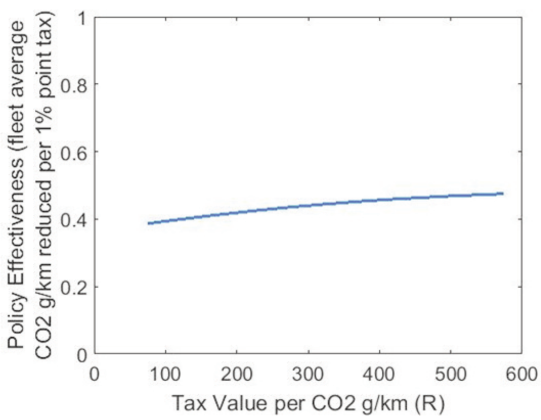

Figure 5: Plot of the policy effectiveness for a range of possible tax values.

Figure 5 shows that the policy effectiveness of the varying tax fees was comparable at approximately 0.45 g CO_2/km average emissions reduction per 1% tax. Having established that the various tax fees have comparable levels of effectiveness, their estimated fleet emissions reduction against the growth in fleet emissions for Year 2 was evaluated. The estimated emissions reduction results of the actual tax fee (R75) and two alternative fees are presented in Table 5. The table shows that even for policies producing fairly large average tax rates, nearing 10%, the emissions reduction achieved counteracted 15.36% of the emissions growth for Year 2. Curbing emissions growth with the current tax structure, even under large fees, appears to be unlikely in a vehicle market that is growing rapidly. If the market were not growing, however, it would still require an average tax rate of nearly 10% to reduce total new fleet emissions by 2.6%. This implied that if the tax intended to reduce emissions, its structure did not suit the structure and/or dynamics of the South African vehicle market.

5.2 Market dynamics

The structure of the vehicle market can be explored by examining the price and emissions distribution of the vehicle sales for each period. These are presented in the histograms in Figures 6 and 7 respectively. Figure 6 shows that the general form of the price distribution gave a positive skew for each sample year. As with Figure 2, the distributions in Figure 6 can be imagined to map onto the right hand tail of the South African income distribution. The changes in shape can be associated with changes in the income distribution. In periods of economic growth the income distribution shifted rightwards, causing an income effect where individuals have more money to spend. For South Africa, the rightward shift of the income distribution enables a larger

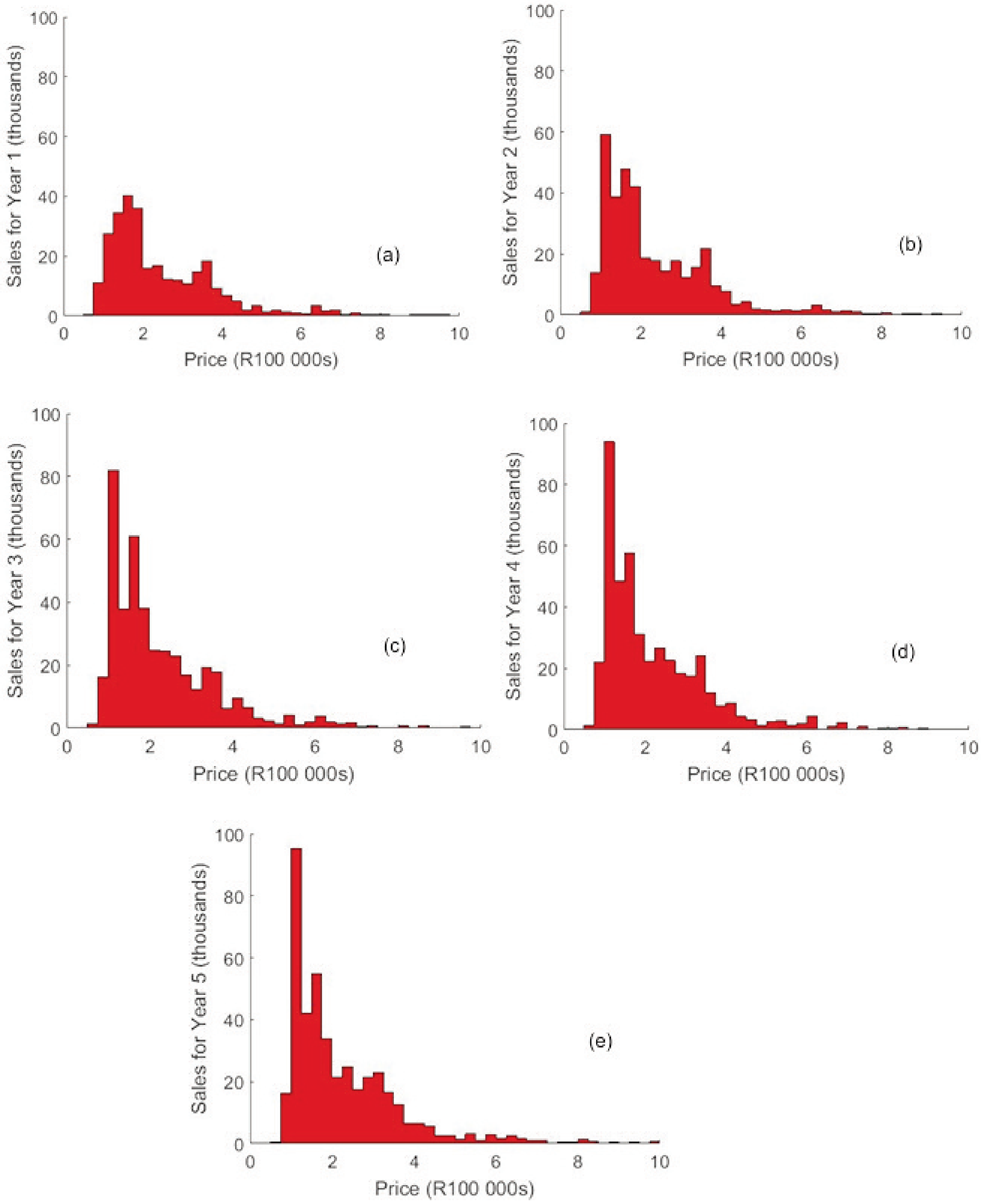

Figure 6: Histograms of the price distribution of vehicle sales for each of the five sample years, including those in (a) Year 1, (b) Year 2, (c) Year 3, (d) Year 4 and (e) Year 5.

upper section of the income distribution to access the vehicle market. These new entrants were concentrated in the lower price ranges with some consumers moving up the price ranges and reinforcing the low distribution. Thus, the income effect in the South African vehicle market is characterised not only by consumers seeking more expensive vehicles but also by a large growth in vehicle sales particularly in the lower price ranges of the market.

The histograms in Figure 7 depict the emissions distribution of the vehicle sales in each sample year, which appear similar to the price distributions due to the positive relationship between emissions and price. However, the additional small leftward tails can be explained by the few low emissions models available in the upper price ranges. Over time the distributions appear to maintain their general form, while increasing in size and shifting leftwards, with the peak moving from 160 g CO_2/km in Year 1 to 130 g CO_2/km in Year 5.

This leftward movement of the market's emissions distribution helps explain the falling average fleet emissions seen in Table 2 as well as why the tax policy would have become less effective with a larger

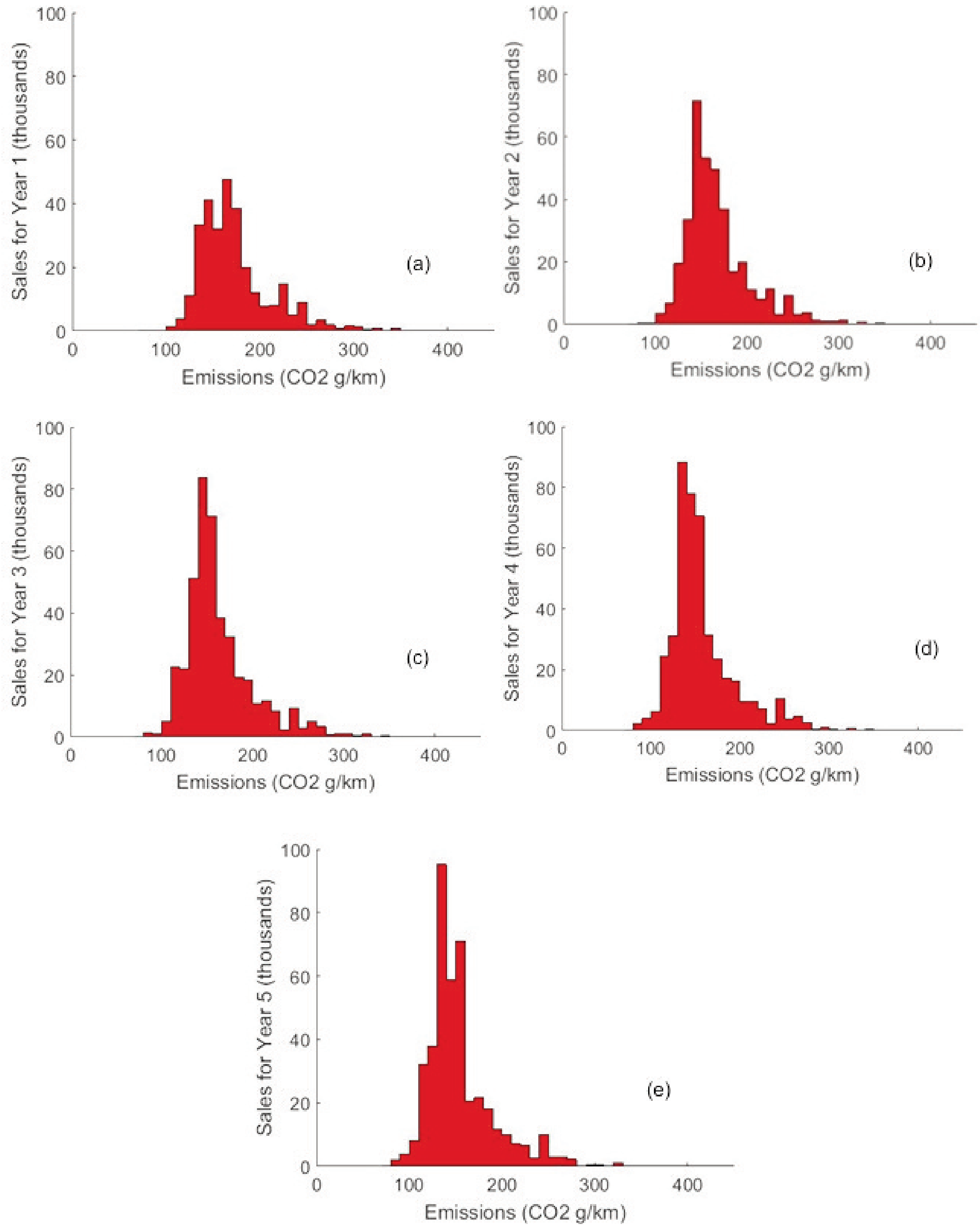

Figure 7: Histograms of the emissions distribution of vehicle sales for each of the five sample years, including those in (a) Year 1, (b) Year 2, (c) Year 3, (d) Year 4 and (e) Year 5.

portion of the market unaffected by tax. The market share of vehicles emitting below the taxable level of 120 g CO_2/km has grown from 1.75% in Year 1 to 10.68% in Year 5.

These changes in the distributions may be attributed to a growing vehicle market as a product of an income effect, where new entrants are predominantly buying low-emission vehicles. There may also be a technological force in effect as a function of improvement of fuel efficiencies for new vehicle models or variations of prior models entering the market. More than 25% of vehicle sales in each sample year were of vehicle models that were not available in the previous year. Changes in technological relationships can be explored by examining the outputs of the unweighted regression analyses of vehicle sales for each sample year presented in Table 6.

Table 6 shows that the relationship between engine size and price was fairly consistent, with the slope and intercept terms both varying only slightly between periods. This is because larger engines remained consistently more highly priced. In the relationship between engine size and emissions,

Table 6: Summary of regression outputs from the non-weighted regression plots between price, engine size and emissions for all five sample years.

	X: Log (price), Y: Engine size			*X: Engine size, Y: Emissions*			*X: Log (price), Y: Emissions*		
	Slope	*Intercept*	*R^2*	*Slope*	*Intercept*	*R^2*	*Slope*	*Intercept*	*R^2*
Year 1	1450.45	-16089.83	0.71	0.043	97.16	0.73	62.14	-591.40	0.51
Year 2	1399.06	-15480.08	0.72	0.042	94.80	0.72	58.04	-547.57	0.52
Year 3	1432.64	-15874.84	0.70	0.041	91.45	0.70	57.14	-539.21	0.47
Year 4	1412.49	-15617.40	0.71	0.041	88.30	0.69	56.87	-539.49	0.48
Year 5	1346.73	-14853.04	0.71	0.040	85.72	0.64	50.09	-460.34	0.39

however, both the slope coefficient and the intercept term were slowly decreasing. This can be visualised as the flattening off and downward shift of the regression line.

This transformation can be interpreted as the introduction of more low emitting models across the engine sizes and particularly in the larger engine sizes, in respect with technical improvements in fuel efficiency. This demonstrates that there is, in fact, a technological force in the market, despite the difficultly in quantifying it. Based on incremental improvements in model variations observed in the data, the impact of this force on changes in fleet emissions was much smaller than the income effect.

6. Discussion and conclusions

The results of the discrete choice model and market structure analysis provide a useful platform from which to retrospectively evaluate the emissions tax policy introduced in September 2010. It is useful to consider the structure and value of the emission tax in terms of its effect on both: emissions and the consumer population. For a developing economy such as South Africa's it is important that policies do not limit the mobility of the populace. With a relatively limited public transport infrastructure the vehicle market must not be made more exclusive. The current structure, which includes an emissions threshold for the tax, does thus present a safeguard against excluding new entrants. However, it was demonstrated that the fleet emissions reductions achieved by the tax were negligible compared to the growth in fleet emissions resulting from the increased sales. Despite modelling much larger tax fees, the policy was unable to curtail the emissions growth driven by sales increases. Even assuming a zero growth of sales an average tax rate of near 10% reduced total fleet emissions by only approximately 2.6%. It is clear that the tax policy in its current form is unable to reduce or even stabilise fleet emissions.

The structure and dynamics of the South African vehicle market can help to explain why the tax has been so ineffective in reducing fleet emissions. As only the upper section of the South African income distribution is able to access the vehicle market, the largest portion of the consumers are located in the lowest price brackets and consequently the lower emissions brackets. As the tax-free emissions threshold is set very close to the peak of the emissions distribution of sales, a large portion of the market only incurs very little or no tax on their vehicle purchase and thus are not incentivised to greatly change their consumer behaviour. Furthermore, due to the manner in which economic growth and the accompanying income effect manifest in the South African vehicle market, these lower price brackets are likely to continue to grow and increase fleet emissions. Understanding this dynamic confirms to policy makers that in order for this form of tax policy to effect fleet emissions reductions there needs to be low- and zero-carbon options available in the lowest price brackets for the majority of consumers. The tax-free emissions threshold would also need to be reduced accordingly, so as to incentivise changes in consumer behaviour at the lower price brackets. Alternatively, the linear tax approach could be rethought altogether and a tax could be calculated based on an emissions level as well as vehicle price. However, further modelling would be required before proposing a detailed alternative tax structure.

While a technological force was observed to be active within the South African vehicle market, the rate of technological improvement in fuel efficiency appears to be expectedly gradual. The pace of technological improvement is unlikely to result in the emergence of low- or zero-carbon technologies, such as hybrids and electric vehicles, in the lower price brackets in the short term. Therefore it would be advisable for policy makers intent on effecting emissions reductions from emissions taxes on private passenger vehicles to explore policies that aim to simultaneously stimulate the supply of low- and zero-emissions vehicles in the lowest price ranges. This could involve actively implementing aspects of the Electric Vehicle Road Map (2013) which emerged as a product of South Africa's Industrial Policy Action Plan. The Road Map seeks to develop a local electric vehicle industry through the application of emerging technology and incentives for manufacturers. It also considers subsidies for electric vehicles to make them cost competitive. Inferences from this investigation are that these subsidies should place the vehicles in the lowest price brackets of the market if the passenger vehicle fleet were to be significantly decarbonised. This may require substantial investment and funding.

The tax policy in its current form was successful in accruing over R5.19 billion in tax revenue over its four years of implementation. Increases in the tax fee will assist in maintaining this revenue stream. This tax revenue could be used to finance the objective of subsidising zero-emissions vehicles and their supporting infrastructure, provided that the aim of the fiscal policy is to reduce fleet emissions from new passenger vehicles. It is important that this should not give windfall profits to selected vehicle manufacturers.

This investigation showed that, as a stand-alone instrument, the emissions-based purchase tax for private passenger vehicles was unable to curtail emissions within the South African vehicle market and simply served as a revenue source for the National Treasury. Combining the tax policy with a suitable subsidy scheme may, however, encourage the diffusion of low- and zero-emission technologies into the market and ultimately decarbonise the private passenger vehicle fleet.

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