Gasoline, diesel fuel and jet fuel demand in South Africa

Willem H. Boshoff

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Abstract

In recent years, the price and income elasticity of fuel demand in South Africa has featured prominently in energy and competition policy proceedings and in major corporate planning projects. The paper investigates the price and income elasticity of gasoline (petrol), diesel and jet fuel demand in South Africa. Such a study is essential, given the significant structural change in fuel consumption behaviour over the 1990s and the paper builds compare the results of econometric models based on a longer sample period covering 1982Q1 to 2010Q4 and a shorter sample period covering 1998Q1 to 2010Q4. The econometric model is based on an autoregressive distributed lag (ARDL) model, reduced to a parsimonious specification using an automated reduction algorithm.

JEL classification C22 R41

Keywords gasoline petrol diesel jet fuel price elasticity income elasticity South Africa bounds test

1 Introduction

South African fuel prices have featured prominently in the news media for over a decade, with geopolitical uncertainties and a volatile exchange rate resulting in high and variable crude oil prices. These price developments have altered fuel consumption behaviour among some consumers and producers, although many producers (including farmers) note the difficulties of reducing their demand without hampering production (Fofana, Chitiga et al. 2009). On the other hand, strong economic growth, especially in the years preceding the financial crisis, has placed significant pressure on South African fuel refineries (Merven, Hughes et al. 2010). Therefore, local policymakers and the petroleum industry are keenly interested in understanding the determinants and evolution of South African fuel demand. This interest has grown significantly over the past two years, driven by the need for accurate price and income elasticity estimates as inputs in policy decisions (including fuel pipeline tariffs) and long-run planning for large infrastructure projects (see discussion below). In addition, policymakers and industry are increasingly interested in the effects of greener and more efficient fuel technologies on fuel demand. This paper studies price and income elasticity of gasoline (petrol), diesel fuel, and jet fuel demand in South Africa, with special emphasis on structural changes in demand patterns since the late 1990s.

The paper first considers recent developments related to South African fuel demand, in order to locate the rationale and specific contributions of the paper. This is followed by a review of extant South African literature, an exposition of the econometric methodology and data, and a presentation of model results and conclusions.

*Senior Lecturer, Department of Economics, Stellenbosch University. E-mail: wimpie2@sun.ac.za. Tel: +27 21 808 2387.

2 Rationale

The primary motivation for this paper is the need for accurate estimates of price and income elasticity of fuel demand in South African policy proceedings. Specifically, over the last five years, price and income elasticity has featured prominently in energy policy and competition policy. A secondary motivation for the paper is the importance of these estimates in corporate planning at petroleum companies and financial institutions. The following sub-sections outline important instances where price and income elasticity estimates have featured prominently in recent years.

2.1 *Energy policy*

The price and income elasticity of fuel demand in South Africa were the focal points in the 2009/2010 pipeline tariff determination hearings of the National Energy Regulator of South Africa (NERSA). Transnet, the state-owned transport conglomerate, owns and operates the Durban-Johannesburg pipeline (DJP). The pipeline, constructed in 1965, feeds the so-called "in-land"[1] fuel region of South Africa, which includes Gauteng, North-West, Mpumalanga, Limpopo, the Free State, as well as parts of the Northern Cape and KwaZulu-Natal. While Transnet owns the DJP, as well as other pipelines, the government regulates pipeline tariffs (Swart 2010). Specifically, since 1 November 2005, NERSA regulates petroleum pipeline tariffs.

In 2007, NERSA granted Transnet a construction license for the New Multi Product Pipeline (NMPP), which will significantly raise future supply capacity to the in-land region. Transnet aimed to fund the construction of the NMPP by applying to NERSA for higher tariffs on the DJP (National Energy Regulator of South Africa 2010). This resulted in a high-profile legal battle between Transnet and the petroleum companies using the DJP. Petroleum companies with coastal refineries, but wanting to compete in the inland market, utilize the DJP and pay the pipeline tariffs to move their fuels inland. Other petroleum companies, including Sasol, with inland refineries do not face similar costs. Given that retail fuel prices are regulated, pipeline tariff increases would imply a significant comparative disadvantage for the petroleum companies with coastal refineries. In fact, some estimates put the total "windfall" for petroleum companies with inland facilities at around R1.7 billion (Creamer 2009). Companies with coastal refineries subsequently disputed whether pipeline tariff setting should account for construction costs of new pipelines. Nevertheless, even if these costs are to be incorporated, it was the size of the tariff adjustment that proved to be particularly contentious. Specifically, in 2009, Transnet requested at 73.5% average tariff adjustment for the 2010/2011 financial year and also signalled that increases of a similar magnitude would be required for the subsequent four years (Transnet 2008). This was a sharp deviation from the 8% tariff adjustments originally projected by Transnet and the company argued that the sharp rise was due to the particularly negative economic outlook at the time – which depressed fuel demand: lower fuel quantities reduced the total tariff revenue and it was necessary to raise the tariff in order to raise overall revenue. Pipeline tariffs form part of the retail price of fuel and a 73.5% rise would have translated into a 21 cents per litre increase (Transnet 2008). Petroleum companies with coastal refineries disputed this figure on a number of grounds, including inconsistency with international pipeline tariff-setting practices. Another source of contention – of particular importance to this paper – is that petroleum companies questioned Transnet's overly pessimistic forecasts of future fuel demand: the tariff methodology employed by NERSA allows for a retrospective compensation in future tariffs based on the extent to which projected and actual fuel volumes have diverged. Petroleum companies with coastal refineries argued that Transnet's volume forecasts are driven by pessimistic economic growth and (to a lesser extent) high oil price assumptions. These companies consequently

[1] The Main Supply Agreement (MSA) of 1954, concluded among South African petroleum companies, divided the country into two main fuel supply regions: the "in-land" region supplied exclusively by Sasol and the "coastal" region supplied by the coastal refineries (Swart 2010). Although the MSA was terminated in 2003, these definitions continue to be used widely in the industry.

generated their own volume forecasts, using alternative price and income scenarios, which suggested higher rather than lower fuel demand volumes. NERSA ultimately rejected the Transnet application, although, more recently, it has approved higher tariffs (National Energy Regulator of South Africa 2010).

2.2 *Competition policy*

In 2005, the Competition Tribunal evaluated a proposed merger between Sasol Oil and Engen to form a new merged entity Uhambo. The legal proceedings included testimony by a number of competition economists working for various petroleum companies and government. An important part of the proceedings concerned the extent to which Uhambo would enjoy market power in the in-land region and the consequent likelihood of it using this power to foreclose the in-land region to competitors. The limited pipeline capacity at the time implied that petroleum companies without in-land refineries were still dependent on Uhambo refineries – and would become increasingly dependent depending on the growth rate of inland volumes (Theron 2008). Therefore, price and income elasticity estimates and forecasts featured centrally in the case: higher growth rates in the in-land volumes would create supply constraints and foreclosure risk more quickly.

Not surprisingly, forecasts of inland and coastal fuel demand growth among the different parties diverged sharply: Table 1 presented earlier contains a summary of the elasticity estimates provided by various parties. The Tribunal rejected the merger in 2006 (Competition Tribunal 2006). The Tribunal was critical of the demand estimates provided by the merging parties, but also questioned the statistical soundness of the models presented to it by intervening parties. In general, price and income elasticity remains central to the analysis of competition issues in the petroleum industry, especially until the logistical constraints due to insufficient pipeline capacity is fully addressed.

2.3 *Corporate planning*

Estimates of price and income elasticity of fuel demand are also used extensively in the petroleum industry itself, where especially long-run fuel scenarios (based on various income and price assumptions) have featured prominently in corporate planning in recent years. The need for an accurate assessment of price and income as drivers of South African fuel demand is driven by two factors. Firstly, as mentioned, the development of further pipelines from Durban to Gauteng requires significant storage infrastructure investment to house the transported fuel in Gauteng. Informal estimates, based on the author's own involvement in these projects, suggest capital values exceeding R1 billion. Similarly, refinery infrastructure investments at the coast also depend critically on estimates of expected price elasticity and income elasticity. Demand models are therefore critical inputs into investment planning processes. Secondly, there is significant demand for a re-assessment of price and income elasticity of fuel demand in light of the impact of efficiency changes and new technology on the demand for fuel. In this regard there are also South African-specific questions relating to, for example, the taxi-recapitalization programme and its effects on demand.

The above examples demonstrate the need for accurate income and price elasticity estimates in policy proceedings and corporate planning and highlight the significant uncertainty surrounding these estimates. The following section summarizes existing research on fuel demand and identifies some of the reasons for existing estimates being less useful to policymakers and corporate planners.

3 Literature review

The literature on energy demand models distinguishes between theory-driven and empirically-driven approaches to demand modelling. Empirically-driven approaches cover a range of statistical and econometric models. Statistical models include autoregressive specifications and crude smoothing procedures and appear to outperform more sophisticated econometric and theoretical models in forecasting (Li, Rose et al. 2010). However, econometric models are useful for policy analysis and retrospective analysis. Econometric models of fuel demand boast a range of methods, including application of the recent bounds-testing approach developed by Pesaran, Shin and Smith (2001) – De Vita, Endresen and Hunt (2006) and Akinboade, Ziramba and Kumo (2008) are applications in the Southern African context. Nevertheless, even newer econometric models face challenges in dealing with structural change, a feature likely to be increasingly important in decades to come. Theoretical approaches, such as the partial adjustment model, have been applied recently to allow for changes in habits and structural breaks (Breunig and Gisz 2009). The models also seem promising, but appear to be less useful for forecasting purposes.

Academic research on fuel demand in South Africa is surprisingly scarce. However, Theron (2008) provides a useful summary of recent private-sector estimates, to which we add some additional results from the academic literature, as shown in Table 1. The price elasticity estimates for gasoline demand are generally around -0.5 and for diesel demand around -0.1. Income elasticity of gasoline demand are estimated at 0.4 (with the exception of one estimate of 1.0) while the income elasticity of diesel appears to be above 1.0.

The more recent estimates in Table 1 show very little difference from the first formal results in Cloete and Smit (1988). However, a number of factors suggest that fuel consumption behaviour has changed over the past two decades. Firstly, and most important of all, gasoline volumes grew rapidly in the 1990s but growth slowed down significantly in the 1990s; in contrast, diesel volume growth accelerated significantly since the late 1990s (see data discussion below). Secondly, electricity problems have boosted demand for alternative power sources, including diesel generators – which would affect the relationship between income and fuel volumes (see Spalding-Fecher and Matibe (2003) for an earlier summary). Thirdly, consumers become more price-sensitive over time: even price-inelastic demand will, over time, become more elastic. Modelling fuel demand over a very long period, and obtaining an average long-run relationship over this period, may not be a desirable approach. Econometrically speaking one may find an average relationship (especially if change occurs slowly), but such a relationship would bear no relation to current behaviour. Fourthly, previous research tends to rely on annual fuel data. However, in the author's experience in working with the petroleum industry, there is increased interest in, firstly, the impact of seasonal changes and, secondly, the short-run sensitivity of volumes. These features are important for planning purposes. Fifthly, current academic research focuses mostly on gasoline volumes, and there is a need for a formal assessment of diesel and jet fuel volumes in addition to gasoline. The latter has not received any attention in previous economic research, despite the significant implications for travelling resulting from inadequate jet fuel supplies, such as that experienced in August 2009 (South African Petroleum Industry Association 2010).

We therefore re-investigate South African fuel demand to study the potential impact of structural changes by using a more recent shorter sample period of a quarterly frequency.

4 Methodology

The paper employs the autoregressive distributed lag (ARDL) model proposed by Pesaran et al. (2001) to model fuel demand, coupled with an automated general-to-specific (GETS) reduction strategy. Modelling therefore starts with estimating an unrestricted ARDL model of lag order :

$$\Delta Q_t = \beta_0+\sum_{i=1}^{p}\beta_{1,i}\Delta Q_{t-i}+\sum_{i=0}^{p}\beta_{2,i}\Delta P_{t-i}+\sum_{i=0}^{p}\beta_{3,i}\Delta Y_{t-i}+\alpha_1 Q_{t-1}+\alpha_2 P_{t-1}+\alpha_3 Y_{t-1}+\gamma' Z_t+\varepsilon_t \quad (1)$$

where, in period t, Q_t is log fuel sales, P_t is log fuel price, Y_t is log income, Z_t is a vector of dummy variables dealing with data outliers, and $\{\varepsilon\}$ are assumed a serially uncorrelated series.

The ARDL model is a single-equation approach to modelling short- and long-run relationships among variables (Pesaran, Shin et al. 1996; Pesaran 1997). Endogeneity problems traditionally lead econometricians to favour a multivariate systems approach over single-equation approaches when studying long-run relationships. However, estimation and inference from the single-equation ARDL model is still valid provided a sufficient lag structure is employed. The technique has therefore gained significant popularity, also in demand modelling.

A fundamental assumption accompanying the use of an ARDL model is that of a *unique* long-run relationship among , and and the ARDL model offers a way of testing whether a unique long-run relationship can be found, as discussed below. Furthermore, the ARDL model can be applied regardless of the order of integration of the variables – avoiding the pre-testing problem faced by conventional cointegration tests.

After developing a general ARDL specification, we inspect whether the model is congruent with both data and theory: we investigate whether the signs of different parameter estimates are consistent with the predictions from theory (for example, overall negative sign for price elasticity and positive sign for income elasticity) and then run a batch of misspecification and diagnostic tests on the residuals $\hat{\varepsilon}_t$ (including tests for normality, heteroscedasticity, remaining autocorrelation and the Ramsey RESET test for specification error). If these tests are passed, the model is labelled the general unrestricted model (GUM).

The GUM is not a parsimonious model and may contain, for example, irrelevant lagged variables that may contaminate the long-run parameter estimates and lead to a less robust model. Consequently, we employ an automated GETS search algorithm to reduce the GUM to a specific model (Campos, Ericsson et al. 2005). The algorithm chooses a number of starting points and, for each path, employs a step-wise reduction strategy to omit statistically insignificant variables provided information loss is limited (information loss is measured by change in the maximized log-likelihood value). The results of the multiple paths are then unified in a single model, on which the same step-wise reduction procedure is repeated until the model arrives at a single parsimonious model – known as the specific model (Hendry and Krolzig 2001).

The specific model allows us, firstly, to test for the existence of a unique long-run relationship and, secondly, to derive long-run elasticity estimates. Pesaran, Shin and Smith (2001) show that $\alpha_1 = \alpha_2 = \alpha_3 = 0$ a test for the existence of a long-run relationship involves testing the hypothesis that against two-sided alternatives. These authors then suggests a bounds test approach, according to which the F-statistic is compared to *two* critical bounds, an upper value associated with the condition where all of P, Q and Y are $I(1)$, i.e. contain unit roots, and a lower value where all of P, Q and Y are $I(0)$, i.e. are stationary. Values falling below the lower boundary indicate the absence of a systematic relationship, while values exceeding the upper boundary confirm such a relationship. Where the test statistic falls between the two critical values, it is necessary to test for unit roots in the individual series. If the series are all integrated, the upper bound is the critical value. Where all series are found stationary, the lower bound is the critical value. For a combination of stationary and non-stationary variables the test is inconclusive if the test statistic falls between the critical bounds. The latter is not common and the bounds test approach therefore avoids (or, at least, significantly reduces) the need for pre-testing the series for unit roots.

Pesaran et al. (2001) report asymptotic critical values for the bounds test. However, Turner (2006) shows that finite-sample critical values are necessary in practice, as asymptotic critical values can be biased even for relatively large samples of 300 observations. Therefore, using an approach similar to that employed by Pesaran et al., Narayan (2005) generates critical values for sample sizes of 30 to 80. This paper compares results for the Pesaran et al and Narayan critical values, given the relatively small number of observations.

Once the existence of a long-run relationship is established, it is straightforward to calculate estimates for the long-run price and income elasticity of fuel demand:

$$\hat{\theta}_{price} = \frac{\hat{\alpha}_2}{\hat{\alpha}_1}$$

$$\hat{\theta}_{income} = \frac{\hat{\alpha}_3}{\hat{\alpha}_1}$$

The parameter estimate $\hat{\alpha}_1$ is the so-called speed of adjustment parameter, if all series are non-stationary: it shows the speed at which the ΔQ_t will respond to any long-run disequilibria. For example, if the speed of adjustment parameter is small the long run plays a less important role in the quarter-to-quarter behaviour of fuel consumption and short-run factors may be more important.

5 Data description

5.1 *Variables and data sources*

The first step in economic modelling is the identification of the parameters of interest and the collection of data on variables that will enable estimates of these parameters. In general, the demand for any good depends on various factors, including its own price, income, and prices of substitutes and complements. The literature has also emphasized the importance of accounting for a plethora of additional demand-shift factors, including preferences, technology and institutional change. While all these variables would provide a rich model of fuel demand, the empirical estimation of such a function is challenging. Specifically, accounting for changes in the underlying tastes and preferences of consumers as well as for changes in the institutional environment is a difficult task. This paper improves on current research by considering a shorter quarterly dataset that may be less exposed to structural breaks, while continuing to focus on price and income forces due to data constraints.

Table 2 reports the data sources used in the econometric analysis. Note that the South African Petroleum Industry Association (SAPIA) only provides volume data until 2008. This followed competition concerns relating to the exchange of volume data among petroleum companies (see, for example, Das Nair and Mncube (2009)). Data for the last two years were obtained from an independent expert, who has collated information from various companies for other purposes. The technique used to construct the data follows the usual methodology employed by SAPIA and is directly comparable.

As far as prices are concerned, we use the real retail price of gasoline and diesel fuel and the real oil price in South African currency (rand) for jet fuel (we do not have actual jet fuel prices available). For income, we use real disposable income for gasoline and real gross domestic product (GDP) for diesel fuel and jet fuel. The difference is motivated from previous South African research, which find a better fit for disposable income than GDP in gasoline demand functions (Theron 2008). Before proceeding to the formal modelling, we present a brief descriptive analysis of the fuel consumption data in order to highlight structural breaks.

5.2 *Structural breaks*

This study is motivated by the need to reassess price and income elasticity on the basis of a more recent and quarterly dataset that is less prone to structural breaks than longer and annual data employed by previous researchers. Figure 1 reports gasoline and diesel fuel volumes for the period 1982 to 2010.

Figure 1 suggests a structural break around 1998 in gasoline volumes: before 1998 a strong time trend is visible, but none after 1998. At around the same time, diesel fuel volumes appear to accelerate strongly relative to the previous sideways movement. In Figure 2, jet fuel volumes behave similarly (although we only have data available from 1994 onwards): volumes experience strong growth up to around 1998 but subdued growth subsequently. These structural changes motivate demand models for gasoline and diesel fuel based on both the entire sample period from 1982Q1-2010Q4 and a shorter sample period of 1998Q1-2010Q4. Jet fuel is modelled only for 1998Q1-2009Q3 due to data constraints. The longer sample period provides a standard against which to assess earlier estimates, while the shorter recent sample period provides an indication of how elasticity estimates may have changed in recent years. Of course, the graphical impressions of structural change are merely indicative and in the discussion of the model results we employ formal breakpoint tests to highlight structural change.

5.3 *Graphical relationships*

Figures 3, 4 and 5 graph gasoline, diesel and jet fuel volumes relative to the real price of each fuel. While the relationship between price and gasoline volumes may be clear for the first two decades, the bivariate relationship becomes quite murky from 2000 onwards. The same holds for diesel and jet fuel. In general, however, the data suggests a negative relationship, which is consistent with previous findings.

The relationship between fuel volumes and income is seen graphically in Figure 6, which shows clearly the positive long-run relationship between the various fuel types and real disposable income (a similar graph is obtained when using real GDP).

6 Results

This section presents the regression results for the different ARDL demand models. The ARDL results depend critically on the choice of lag structure. We use the Akaike and Schwarz information criteria to select optimal starting lag lengths. These metrics suggest a lag order of four for the gasoline and jet fuel models, twelve for the diesel model based on the longer sample period and seven for the diesel model over the shorter sample period. The specific models that emerge from the GETS reduction process usually contain only lags of a first or second order, which suggests that the starting lag lengths are not restrictive.

As argued, our approach involves, firstly, generating a GUM and, secondly, a specific model. Here we only present the specific model results. In each case, the GUM passed all data misspecification tests and was found congruent with theory. The results are available upon request. The regression results is then followed by misspecification tests, graphs related to parameter stability, then the bounds test results and finally a table reporting the long-run estimates of price and income elasticity.

6.1 *Gasoline*

The GUM for gasoline demand for the shorter and longer sample period is first used to detect structural change. Structural change is assessed using Chow (1960) tests for parameter constancy (see, for example, Hendry and Nielsen (2007: 195-197)). The break-point Chow test aims to test whether the model specification fitted on a sample period ending at is able to predict all of the remaining data points, for every feasible . Figure 7 reports the graphical results for the gasoline GUM:

While the figure evaluates the test statistic at a 10% critical value, the p-values for the period 1996 to 1998 are between 4.85% to 8.8%. These suggest significant structural change in this period, confirming the need for a separate model based on a shorter sample period.

Table 4 present the gasoline demand models for both the longer and shorter sample periods. A range of misspecification tests, reported in Table 5, confirm the adequacy of both models at a 5% significance level. However, as expected, the model based on the longer sample period fails the RESET, which likely picks up the impact of a structural break on the functional form of the regression.

It is possible to further investigate the stability of the two gasoline demand models using recursive estimation: this method estimates the same model on smaller sub-sample periods to assess the stability of the parameter estimates. Figure 3 reports recursive parameter estimates for price and income elasticity for the model based on the longer sample period.

Figure 8 suggests significant instability in both parameters during the mid-1980s and stability afterwards. Figure 9 replicates the exercise for the gasoline model based on the more recent shorter sample period and confirms that this model produces more robust parameter estimates. Therefore, even if results are similar for the two models, we are less certain about the results for the longer sample period. Put differently, one should be careful of using a single demand model spanning a long sample period, as is the practice in previous South African fuel demand research.

If one is willing to accept both specific models, one may proceed to the bounds test. Table 6 shows the results, confirming a significant long-run relationship for both sample periods.

Given confirmation of a long-run relationship, Table 7 reports estimates for the parameters in the long-run relationship. The suggested long-run price elasticity estimate from both models are around -0.55, while the long-run income elasticity is estimated at around 0.8 (see Table 7). Following Akinboade et al. (2008) we estimate standard errors using Bardsen (1989).

Although our price elasticity estimates for gasoline demand correspond with those obtained by Akinboade et al. (2008), it is not clear whether the result indicates unchanged consumer behaviour or whether the correspondence is due to chance because of parameter instability. We also find significantly higher income elasticity in both our sample periods, which suggests that consumption of gasoline is actually much more sensitive to the consumer's financial position. While some previous studies also find high income elasticity, none of these studies look closely at the problem of structural change and the problem of relying on a long sample period.

Finally, the speed-of-adjustment parameter for both demand models is around 0.2 (see Table 4), which implies that it takes about five quarters for a long-run disequilibrium to be corrected. This speed is quite different from the speed suggested by previous annual data models of about five years (Akinboade, Ziramba et al. 2008). Such a protracted response is not intuitive, as is evident from simply comparing quarterly fuel consumption and price. We therefore argue that our gasoline demand estimates offer an improvement over current research.

6.2 *Diesel fuel*

We follow a similar approach to estimate the demand function for diesel fuel in South Africa, developing a model based on both the longer and shorter sample period. As with the gasoline, this approach is confirmed by Chow (1960) breakpoint tests, reported in Figure 6.

The break in diesel demand appears to be more pronounced than that for gasoline demand. In fact, even after including dummy variables to account for extreme outliers, we do not succeed in identifying a unique long-run relationship for the 1982Q1-2010Q4 sample period. As argued earlier, the ARDL only allows for a single long-run relationship: finding none may yet imply that there are two relationships – perhaps due to structural change. In fact, we find a significant long-run relationship for the 1998Q1-2010Q4 period; the GUM for this period is congruent with data and theory, showing signs consistent with theory and passing all misspecification tests.

Despite the unsatisfactory results for the longer-sample GUM we also report the specific model derived from this GUM. As noted, the longer-period GUM's problems carry over into its specific model, which includes no long-run component. We therefore focus mostly on the 1998Q1-2010Q4 specific model:

Table 9 confirms the adequacy of the specific model for 1998Q1-2010Q4 and highlights some of the problems of the longer period specific model (notice, for example, the p-value for the RESET test, which is an indicator of structural change). The problems are likely the result of the significant change in behaviour of diesel fuel consumption during the mid 1990s – a period included in the longer sample period (refer back to Figure 1).

Figure 11 reports recursive estimation results for the specific model based on the shorter sample period. The figure suggests that the estimates are fairly stable. Although confidence intervals in 2000 and 2001 are wide, these are the result of the very short subsample periods over which the first recursive estimates are derived and the graph shows subsequent estimates to be very stable.

Only the model based on the more recent sample period passes the bounds test, as shown in Table 10, suggesting a significant long-run relationship between diesel fuel price, income and diesel fuel consumption over this period.

Table 11 reports the long-run elasticity estimates suggested by the shorter sample period. Demand elasticities for the shorter period specific model is estimated at around -0.2 for price and 1.5 for income. These results are consistent with previous diesel fuel demand estimates for South Africa of about -0.1 for price and 1.4 for income (refer to Table 1).

Although research on diesel fuel demand in South Africa is not ubiquitous our diesel fuel results appear to be consistent with previous findings. Specifically, the results highlight the significant role of economic growth in driving demand for diesel fuel in South Africa, much stronger than for gasoline. Furthermore, even if one takes the diesel model over the longer period to be merely indicative, a case can be made that economic growth remains the most important driver of diesel fuel consumption.

6.3 *Jet fuel*

Jet fuel consumption data is more limited than gasoline or diesel fuel data and are only available from 1994Q1. We estimate jet fuel demand for 1998Q1-2009Q3 to retain comparability with the other models. We find the GUM to be congruent with data and theory and subsequently derive the specific model using the GETS automated procedure. The regression results for the specific model are reported in Table 12 and show a very simple specification, which includes only the lagged dependent variable in addition to the long-run variables.

The specific model appears to pass all of the diagnostic tests as shown in Table 13:

The recursive results suggest that the model produces extremely stable parameter estimates for long-run price and income elasticity, as shown in Figure 8.

Given the stability of the specific model, we perform the bounds test and finds evidence of a statistically significant long-run relationship at a 5% critical level, as shown in Table 14:

Similar to the diesel fuel demand, the specific model suggests that jet fuel demand has a fairly low long-run price elasticity of around -0.1 and an income elasticity of about 0.9, as shown in Table 15:

In general, the jet fuel demand function suggests that economic growth, rather than oil prices, is determinative for jet fuel sales in South Africa. In addition, the specific ARDL model indicates a very high speed-of-adjustment parameter (-0.68, see Table 12), which suggests that any long-run disequilibrium is corrected within less than two quarters. The long run relationship, therefore, plays a significant role in quarter-to-quarter consumption changes in South African jet fuel demand.

7 Conclusions

The results from the demand models for gasoline, diesel fuel and jet fuel presented in this paper can be summarized as follows. Firstly, the results for the gasoline models are consistent with earlier estimates. To be sure, this research finds higher *point* estimates for long-run price and income elasticity: we find price elasticity estimates of -0.59 for the shorter sample period compared to -0.44 for the longer period; for income elasticity we find 0.82 compared to 0.67. However, once standard error bands are taken into account, we do not find statistical evidence of a significant mean difference. In addition, we also find a higher speed-of-adjustment point estimate (-0.3 compared to -0.2), but there are no statistically significant differences. However, what is interesting is that the speed-of-adjustment estimate for both the longer and shorter periods is significantly faster than suggested by other research: -0.2 suggests 5 quarters for long-run equilibrium to be restored, which contrasts with findings of around two years based on annual data (see Akinboade et al. (2008)). These results shed led on the impact of price and income volatility on gasoline volumes. Gasoline demand is slowly becoming more sensitive to price and income changes, but much of the volatility in gasoline fuel sales are due to volatility in underlying price and income rather than greater sensitivity to these drivers.

Secondly, the results suggest important new findings for diesel demand. We do not find evidence of a unique long-run relationship between diesel volumes, price and income over the longer sample period. This does not indicate that such a relationship do not exist, as there may have been structural changes to this relationship. This is confirmed by the significant long-run relationship uncovered over the shorter sample period. The long-run price elasticity suggested by this relationship is -0.21 compared to around -0.1 suggested in previous (and not publicly available) research (refer back to Table 1). Standard error confidence intervals do not suggest significant differences. However, we do find statistically significant higher income elasticity for diesel demand. This is not surprising, given the strong relationship between diesel demand and economic growth in recent years. For the first time, speed-of-adjustment estimates are obtained for diesel: the -0.48 estimate suggests that disequilibria are corrected within two quarters, which is much quicker than for petroleum. In fact, the rapid equilibrium-adjustment estimates for gasoline and diesel fuel suggest that long-run equilibrium adjustment is an important factor in the short-run behaviour of gasoline and diesel fuel demand – lending credence to the focus on long-run estimates in this paper.

Thirdly, the paper presents the first price and income elasticity estimates for jet fuel demand. Long-run price elasticity is estimated at -0.1 and income elasticity at 1.0 for the period 1998Q4-2009Q3. Speed-of-adjustment is very fast: less than 1 quarter.

In general, the demand models presented in this paper shed new light on emerging fuel demand patterns in South Africa. There are slow increases to be seen in price and income elasticity of gasoline demand, while our models suggest much higher income elasticity for diesel demand. Furthermore, adjustment to long-run disequilibrium occurs much quicker than previous research suggests. The paper also estimates jet fuel price and income elasticity, showing that income elasticity is much higher than price elasticity.

References

[1] Akinboade, O. A., E. Ziramba, et al. (2008). "The demand for gasoline in South Africa: an empirical analysis using co-integration techniques." Energy Economics **30**: 3222-3229.

[2] Bardsen, G. (1989). "Estimation of long-run coefficients in error-correction models." Oxford Bulletin of Economics and Statistics **51**(3): 345-350.

[3] Breunig, R. V. and C. Gisz (2009). "An exploration of Australian petrol demand: unobservable habits, irreversibility and some updated estimates." The Economic Record **85**(268): 73-91.

[4] Bureau for Economic Research (2003). The feasibility of a fuel tax levy in the Western Cape. Cape Town, Western Cape Provincial Treasury.

[5] Campos, J., N. R. Ericsson, et al., Eds. (2005). Readings on General-to-Specific Modeling. Cheltenham, Edward Elgar.

[6] Chow, G. C. (1960). "Tests of equality between sets of coefficients in two linear regressions." Econometrica **28**: 591-605.

[7] Cloete, S. A. and E. v. d. M. Smit (1988). "Policy implications of the price elasticity of demand for petrol in South Africa." South African Journal of Science **84**: 227-229.

[8] Competition Tribunal (2006). Decision in the large merger between Sasol Ltd, Engen Ltd, Petronas International Corporation and Sasol Oil (Pty) Ltd and Engen Ltd. Case No 101/LM/Dec04.

[9] Creamer, T. (2009). Nersa spectacularly rejects Transnet's call for 74% pipeline-tariff hike. Engineering News. [Online] Available: http://www.engineeringnews.co.za/article/nersain-spectacular-rejection-of-transnets-call-for-74-pipeline-tariff-hike-2009-05-04, Creamer Media.

[10] Das Nair, R. and L. Mncube (2009). The role of information exchange in facilitating collusion - insights from selected cases. Third Annual Competition Commission, Competition Tribunal and Mandela Institute Conference on Competition Law, Economics and Policy in South Africa. University of the Witwatersrand, Johannesburg.

[11] De Vita, G., K. Endresen, et al. (2006). "An empirical analysis of energy demand in Namibia." Energy Policy **34**: 3447-3463.

[12] Fofana, I., M. Chitiga, et al. (2009). "Oil prices and the South African economy: a macro-meso-micro analysis." Energy Policy **37**(12): 5509-5518.

[13] Hendry, D. F. and H.-M. Krolzig (2001). Automatic econometric model selection. London, Timberlake Consultants Ltd.

[14] Hendry, D. F. and B. Nielsen (2007). Econometric Modeling: A Likelihood Approach. Oxford, Princeton University Press.

[15] Li, Z., J. M. Rose, et al. (2010). "Forecasting automobile petrol demand in Australia: an evaluation of empirical models." Transportation Research Part A **44**: 16-38.

[16] Merven, B., A. Hughes, et al. (2010). "An analysis of energy consumption for a selection of countries in the Southern African Development Community." Journal of Energy in Southern Africa **21**(1): 11-24.

[17] Narayan, P. K. (2005). "The saving and investment nexus for China: evidence from cointegration tests." Applied Economics **37**: 1970-1990.

[18] National Energy Regulator of South Africa (2010). Transnet Limited's tariff application for: a 51.3% allowable revenue increase for its petroleum pipelines system for 2010/11. IDMS No. 45374. Pretoria.

[19] Pesaran, M. H. (1997). "The role of economic theory in modelling the long run." The Economic Journal **107**(Jan): 78-191.

[20] Pesaran, M. H., Y. Shin, et al. (1996). Testing for the existence of a long run relationship. DAE Working Paper No. 9622. Cambridge, Department of Applied Economics, University of Cambridge.

[21] Pesaran, M. H., Y. Shin, et al. (2001). "Bounds Testing Approaches to the Analysis of Level Relationships." Journal of Applied Econometrics **16**: 289-326.

[22] South African Petroleum Industry Association (2010). 2009 Annual Report. Cape Town, Nova Communications.

[23] Spalding-Fecher, R. and D. K. Matibe (2003). "Electricity and externalities in South Africa." Energy Policy **31**(8): 721-734.

[24] Swart, C. J. (2010). The South African liquid fuels market: yesterday, today and tomorrow. University of Stellenbosch Business School. Bellville, Stellenbosch University. **Master of Business Administration:** 92.

[25] Theron, N. (2008). "The Sasol/Engen (Uhambo) merger - foreclosure and white fuel demand growth rates." South African Journal of Economic and Management Sciences **11**(3): 264-278.

[26] Transnet (2008). Application for the setting of Transnet Pipelines' petroleum pipeline tariffs and the approval of its storage tariff for the year 2009/10. Johannesburg.

[27] Turner, P. (2006). "Response surfaces for an F-test for cointegration." Applied Economics Letters **2006**(13).

Table 1: Estimates of price and income elasticity of South African fuel demand

Authors	Sample period	Price elasticity	Income elasticity
Cloete and Smit (1988)	1970-1983	-0.24 (gasoline, short-term) -0.37 (gasoline, long-term)	0.43 (gasoline)
Bureau for Economic Research (2003)	n.a.-2003	-0.21 (gasoline, short-term) -0.51 (gasoline, long-term) -0.18 (diesel, short-term) -0.06 (diesel, long-term)	n.a.
Akinboade et al (2008)	1978-2005	-0.47 (gasoline, long-term)	0.36 (gasoline, long-term)
Theron (2008) summary of BER model	1984-2004	-0.19 (gasoline, short-term) -0.62 (gasoline, long-term) -0.1 (diesel, long-term)	0.1 (gasoline, short-term) 1.0 (gasoline, long-term) 1.36 (diesel, long-term)
Theron (2008) summary of Econometrix model	n.a.	-0.24 (gasoline) -0.14 (diesel)	0.38 (gasoline) 1.47 (diesel)

Table 2: Variables and data sources

Variable	Source	Description
Gasoline sales	South African Petroleum Industry Association (SAPIA) (up to 2008), industry sources	Petrol sales in millions of litre, 1982Q1-2010Q4
Diesel fuel sales	SAPIA (up to 2008), industry sources	Diesel sales in millions of litre, 1982Q1-2010Q4
Jet fuel sales	SAPIA (up to 2008), industry sources	Jet fuel sales in millions of litre, 1994Q1-2009Q3
Gasoline price	SAPIA	Retail coastal pump price of 95 octane petrol in Rand, 1982Q1-2010Q4
Diesel price	SAPIA	Retail coastal pump price of 0.05% sulphur diesel in Rand, 1982Q1-2010Q4
Oil price	South African Reserve Bank (SARB)	Quarterly Brent crude oil (spot) in US dollars (data series KBP5344M), 1980Q3-2010Q4
General price level	SARB	Private consumption deflator, base year 2005, 1982Q1-2010Q4, calculated from nominal and real private consumption expenditure (data series KBP6007D and KBP6007L)
Income	SARB	Household disposable income in millions of Rand, base year 2005 (data series KBP6246L), 1982Q1-2010Q4 Real gross domestic product in millions of Rand, base year 2005 (data series KBP6006D), 1982Q1-2010Q4
Rand dollar exchange rate	SARB	Rand dollar exchange rate (data series KBP5339M), 1982Q1-2010Q4

Table 4: Specific models for gasoline demand (dependent variable)

1982Q1-2010Q4		**1998Q1-2010Q4**	
Regressor	**Coefficient (Standard error)**	**Regressor**	**Coefficient (Standard error)**
	-0.29 (0.07)		
	0.14 (0.06)		
	-0.23 (0.02)		-0.22 (0.04)
	0.21 (0.06)		0.52 (0.24)
	-0.19 (0.04)		-0.30 (0.11)
	-0.11 (0.02)		-0.13 (0.03)
	0.16 (0.03)		0.20 (0.06)
	0.74		0.84

Table 5: Misspecification tests for gasoline demand models

	1982Q1-2010Q4	**1998Q1-2010Q4**
Test name	**Test statistic (probability)**	**Test statistic (probability)**
AR (1-4) test	1.69 (0.14)	1.56 (0.21)
ARCH (1-4) test	0.96 (0.43)	0.82 (0.52)
Normality test	1.16 (0.56)	0.67 (0.72)
Heteroscedasticity test	0.71 (0.79)	0.79 (0.67)
Ramsey RESET	1.96 (0.15)	1.16 (0.33)

Table 6: Bounds test results for gasoline demand models

Sample period	**F-statistic**	**10% critical bounds**	
		Lower bound ( )	**Upper bound ( )**
1982Q1-2010Q4	11.25**	3.17 (asymptotic)	4.14 (asymptotic)
1998Q1-2010Q4	5.00** #	3.17 (asymptotic)	4.14 (asymptotic)
		3.33 (finite)	4.31 (finite)

** Reject at 5% asymptotic significance level # Reject at 10% finite-sample significance level

Table 7: Long-run elasticities of gasoline demand

Sample period	**Price elasticity (standard error)**	**Income elasticity (standard error)**
1982Q1-2010Q4	-0.44 (0.04)	0.67 (0.04)
1998Q1-2010Q4	-0.59 (0.13)	0.82 (0.16)

Table 8: Specific models for diesel fuel demand (dependent variable)

1983Q2-2010Q4		1998Q1-2010Q4	
Regressor	**Coefficient (Standard error)**	**Regressor**	**Coefficient (Standard error)**
	-0.66 (0.07)		-0.40 (0.09)
	-0.31 (0.05)		
			0.09 (0.06)
	-0.09 (0.04)		
	0.11 (0.04)		
	-0.13 (0.04)		-0.26 (0.04)
	-0.17 (0.03)		
	-0.08 (0.03)		
			0.21 (0.03)
	3.26 (0.32)		5.61 (0.79)
			-2.99 (0.75)
			3.10 (0.60)
	1.36 (0.29)		
			-1.35 (0.51)
	1.35 (0.34)		
	-1.16 (0.35)		
			-0.48 (0.11)
			-0.10 (0.03)
			0.75 (0.16)
	0.90		0.93

Table 9: Misspecification tests for diesel fuel demand specific models

	1983Q2-2010Q4	1998Q1-2010Q4
Test name	**Test statistic (probability)**	**Test statistic (probability)**
AR (1-4) test	1.46 (0.21)	0.97 (0.44)
ARCH (1-4) test	1.17 (0.33)	0.47 (0.76)
Normality test	3.61 (0.16)	3.27 (0.20)
Heteroscedasticity test	1.14 (0.32)	0.58 (0.91)
Ramsey RESET	2.72 (0.07)	0.04 (0.96)

Table 10: Bounds test results for diesel fuel demand models

Sample period	**F-statistic**	**10% critical bounds**	
		Lower bound ( )	**Upper bound ( )**
1983Q2-2010Q4	0.88	3.17 (asymptotic)	4.14 (asymptotic)
1998Q1-2010Q4	9.17** [#]	3.17 (asymptotic)	4.14 (asymptotic)
		3.33 (finite)	4.31 (finite)

Table 11: Long-run elasticities of diesel fuel demand

Sample period	Price elasticity (standard error)	Income elasticity (standard error)
1998Q1-2010Q4	-0.21 (0.08)	1.56 (0.11)

Table 12: Specific models for jet fuel demand (dependent variable)

Regressor	Coefficient (Standard error)
	0.11 (0.03)
	-0.68 (0.08)
	-0.08 (0.01)
	0.68 (0.08)
	0.67

Table 13: Misspecification tests for jet fuel demand specific models

Test name	Test statistic (probability)
AR (1-4) test	2.44 (0.07)
ARCH (1-4) test	0.36 (0.84)
Normality test	1.82 (0.40)
Heteroscedasticity test	0.94 (0.51)
Ramsey RESET	0.69 (0.50)

Table 14: Bounds test results for jet fuel demand models

Sample period	F-statistic	10% critical bounds	
		Lower bound ( )	**Upper bound ( )**
1998Q1-2009Q3	35.03**	3.17 (asymptotic) 3.33 (finite-sample)	4.14 (asymptotic) 4.31 (finite-sample)

** Reject null hypothesis at 5% significance level

Table 15: Long-run elasticities of jet fuel demand

Sample period	Price elasticity (standard error)	Income elasticity (standard error)
1998Q1-2009Q3	-0.11 (0.01)	0.99 (0.03)

Figure 1: Gasoline and diesel fuel sales in South Africa (millions of litre), 1982Q1-2010Q4

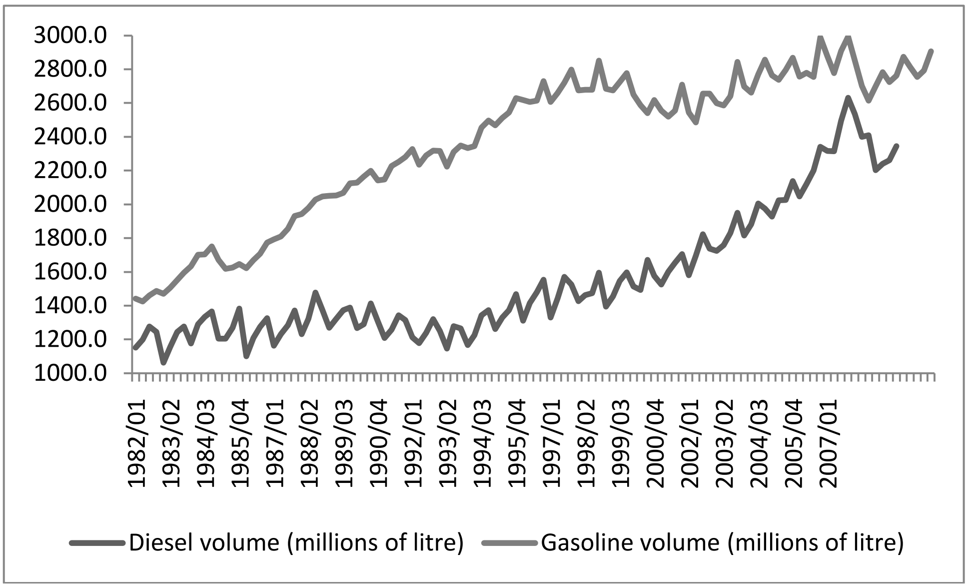

Figure 2: Jet fuel sales in South Africa (millions of litre), 1994Q1-2009Q3

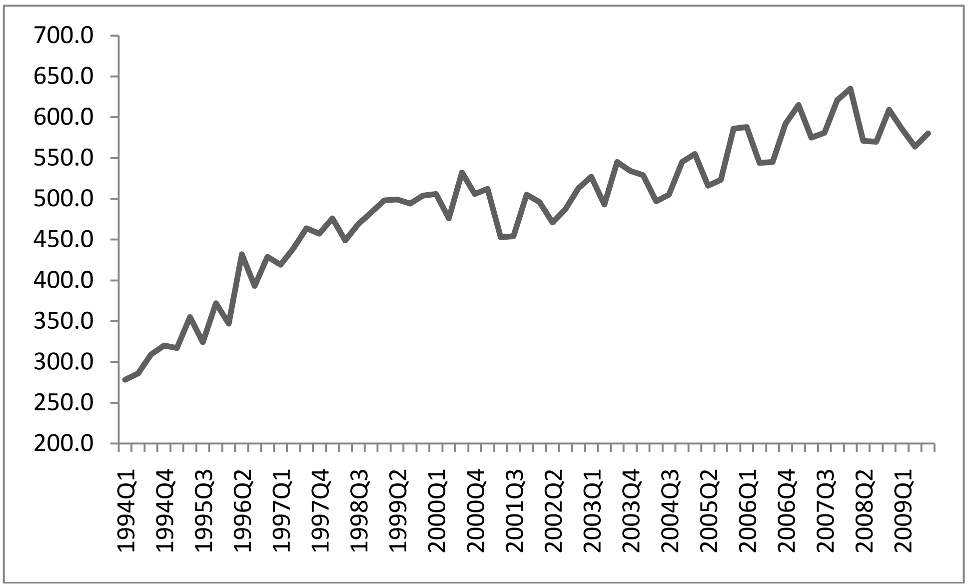

Figure 3: Gasoline sales in South Africa and the real price of gasoline (95 octane, coast) (deflated using the consumption expenditure deflator)

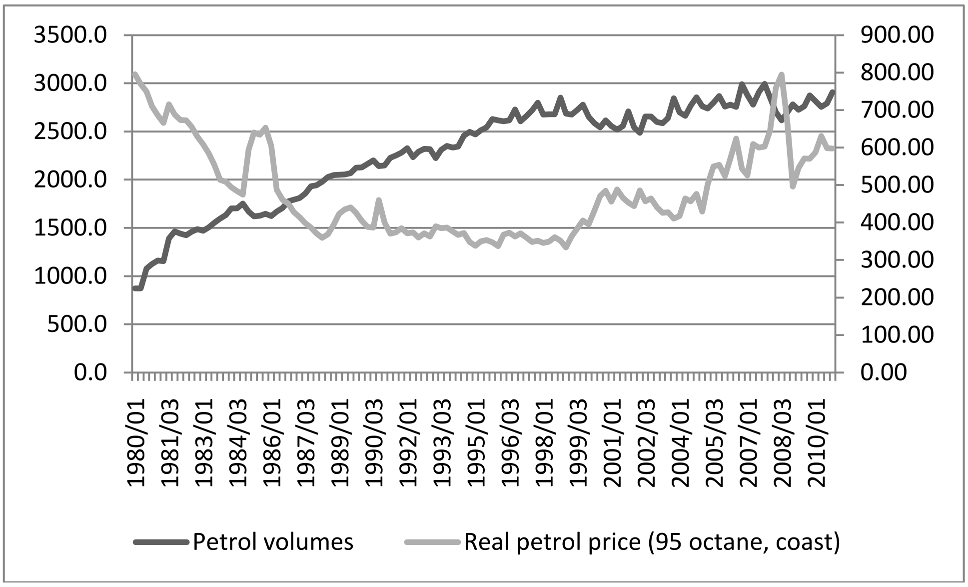

Figure 4: Diesel sales in South Africa and the real price of diesel (0.005% sulphur) (deflated using the consumption expenditure deflator)

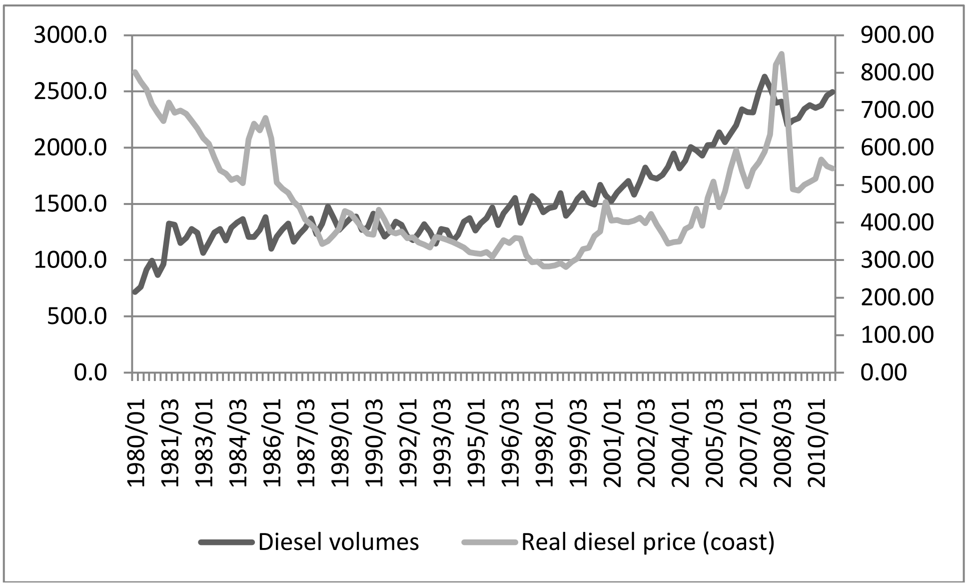

Figure 5: Jet fuel sales in South Africa and the real price of jet fuel (Brent crude in Rand) (deflated using the consumption expenditure deflator)

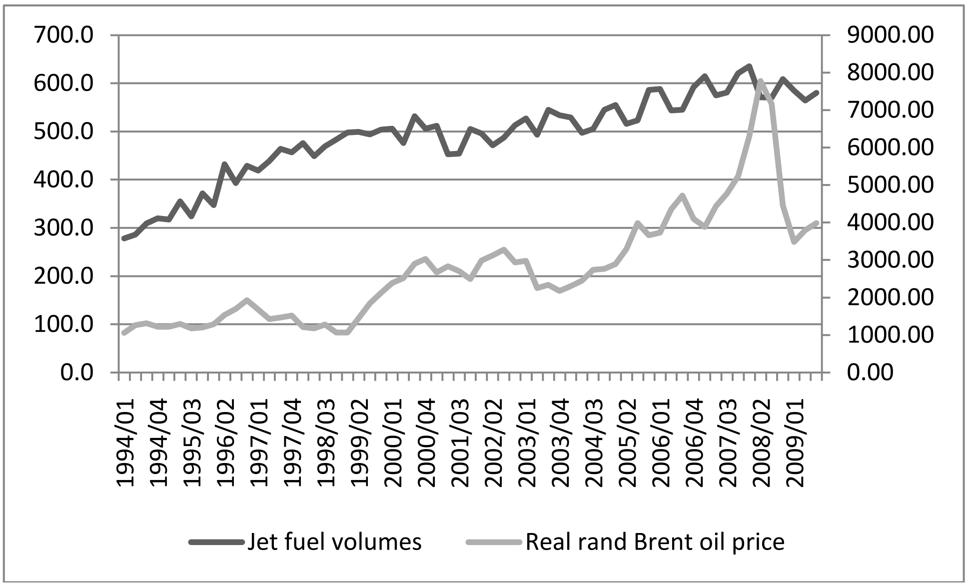

Figure 6: Gasoline, diesel and jet fuel sales in South Africa and real disposable income

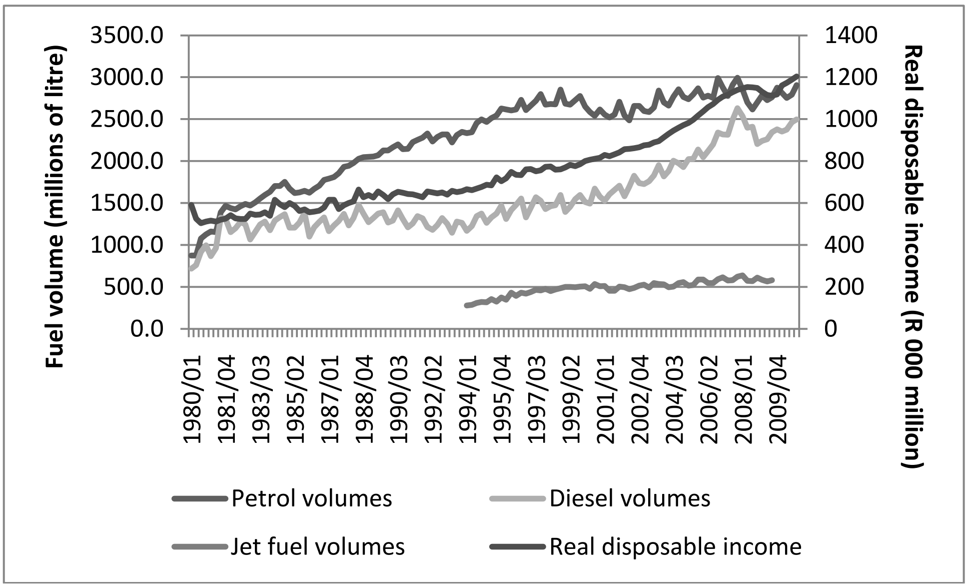

Figure 7: Recursive Chow tests for parameter non-constancy in gasoline GUM

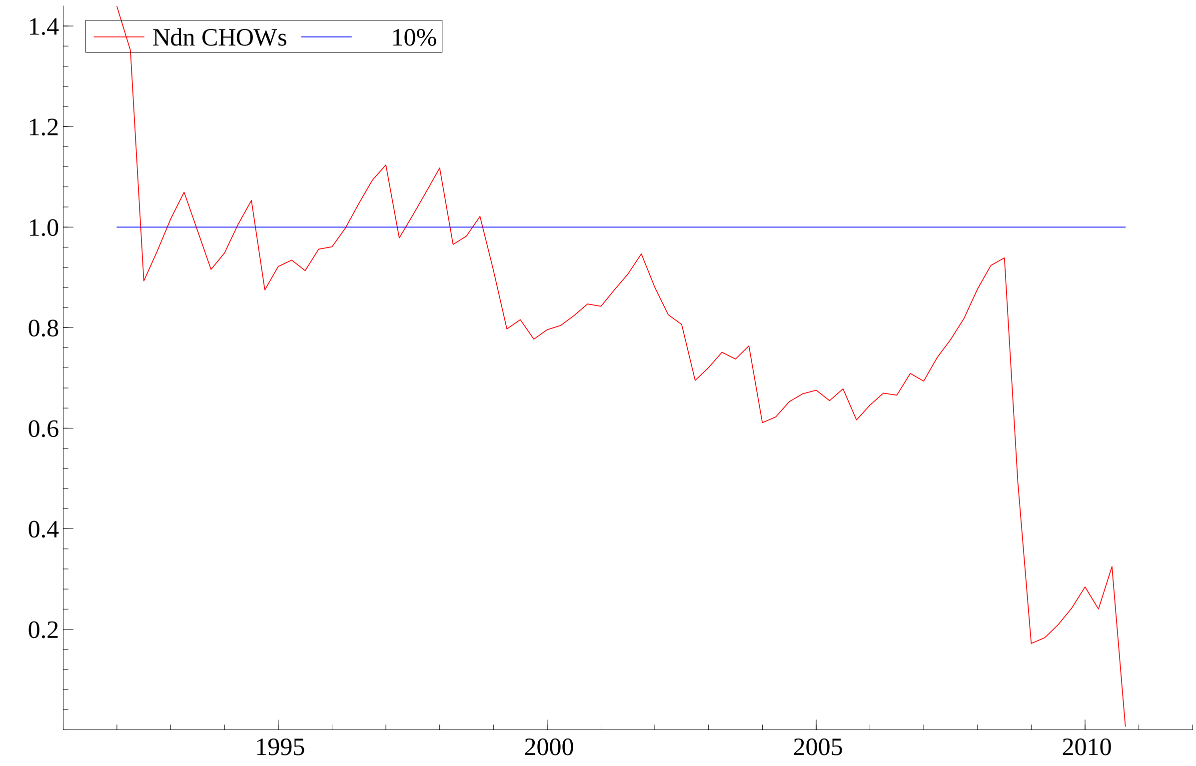

Figure 8: Recursive estimates for long-run price and income elasticity parameters in gasoline demand models (1982Q1-2010Q4) (initial sample size 40 data points)

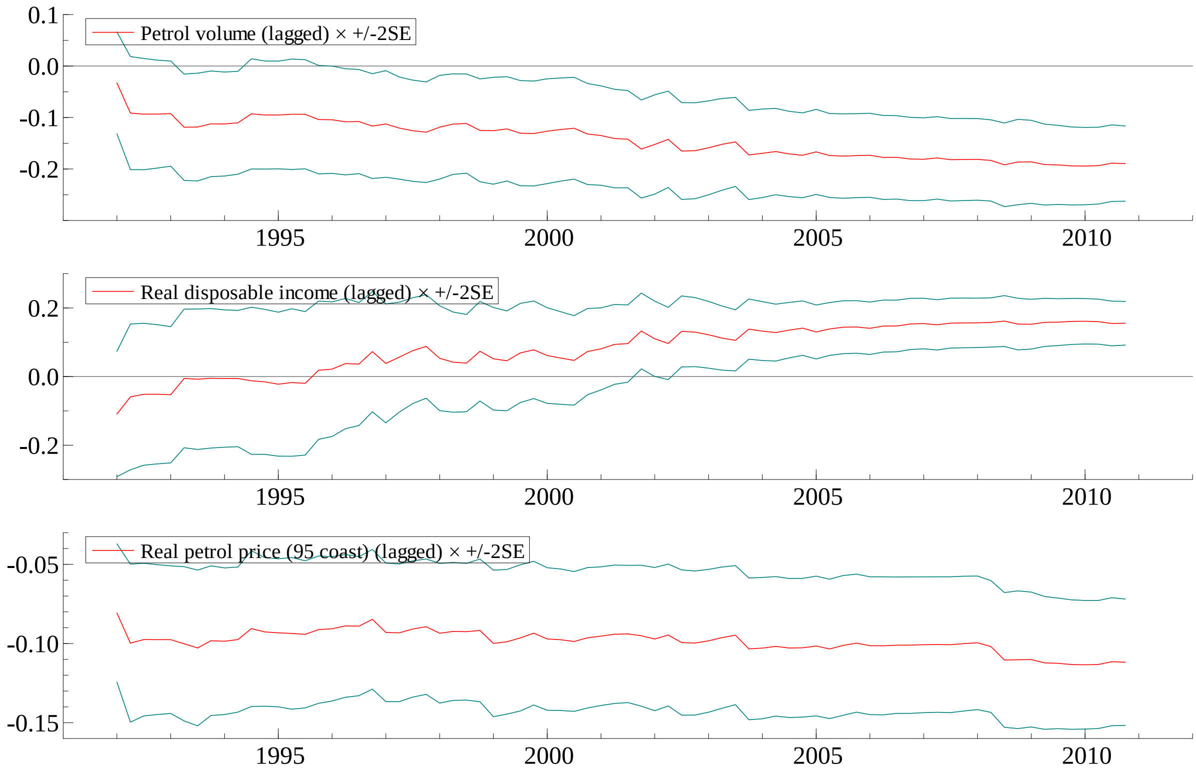

Figure 9: Recursive estimates for long-run income elasticity parameter in gasoline demand models (1998Q1-2010Q4) (initial sample size 40 data points)

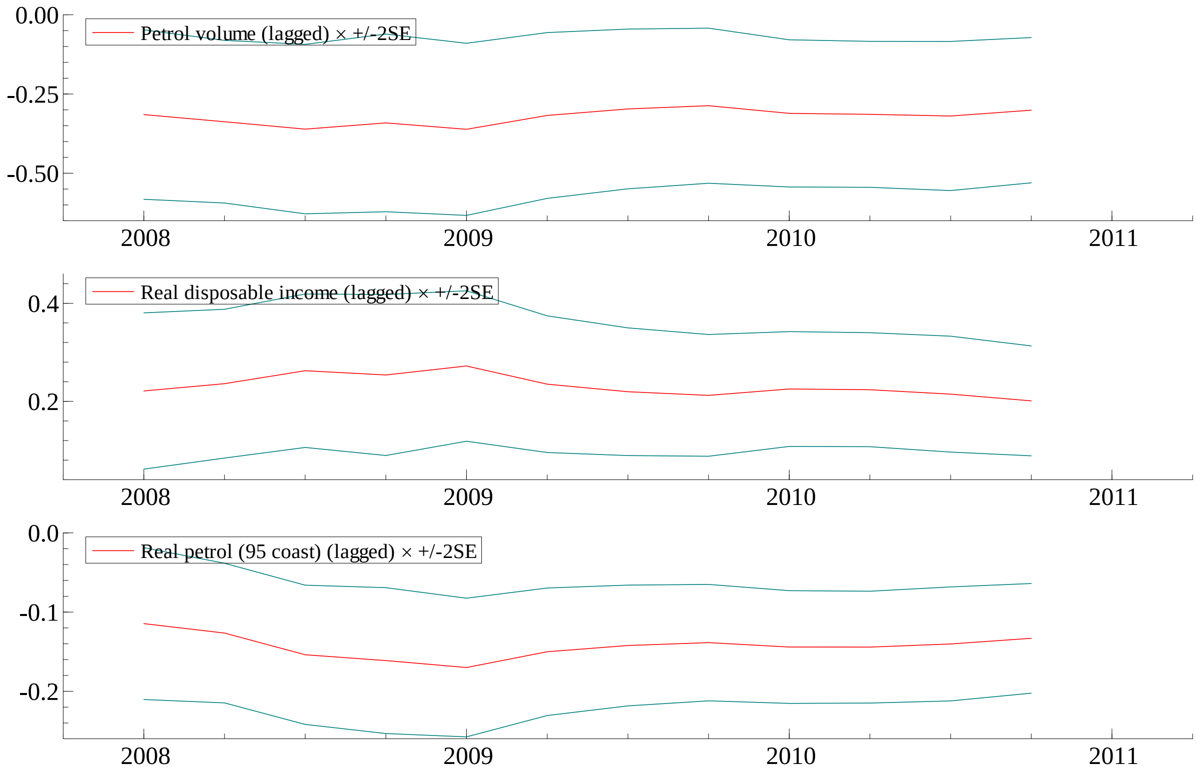

Figure 10: Recursive Chow tests for parameter non-constancy in diesel model

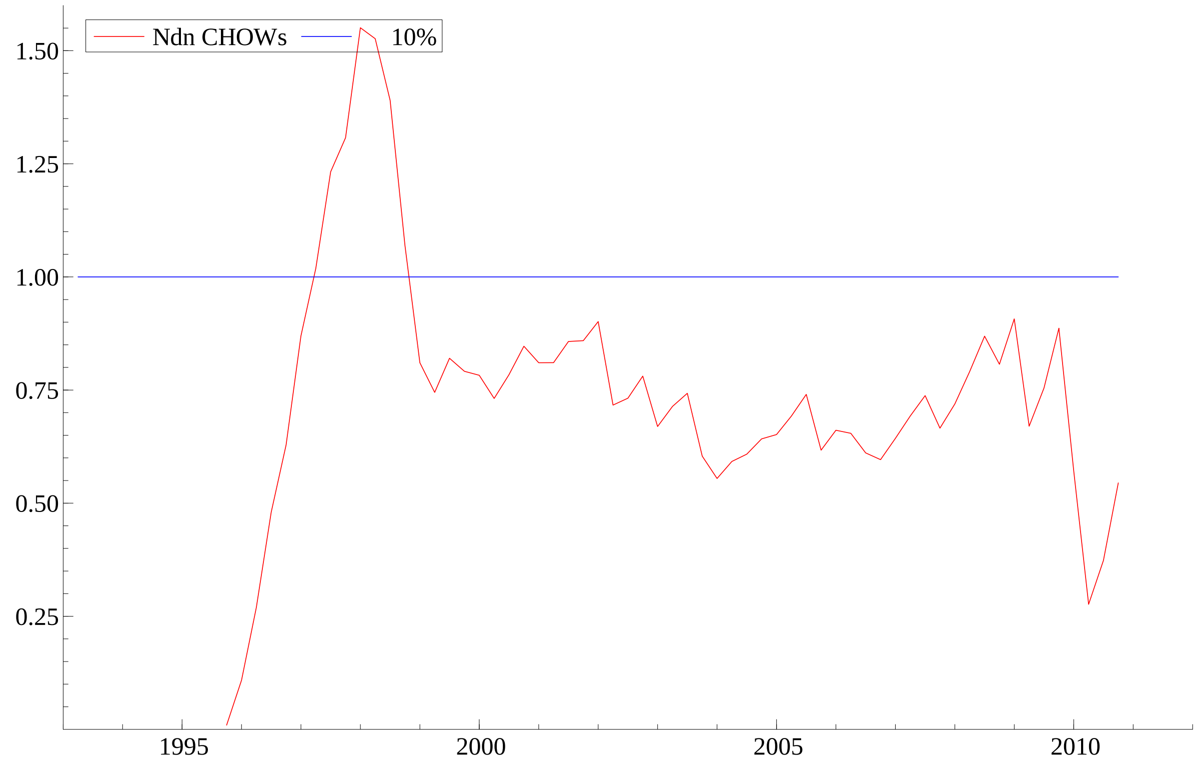

Figure 11: Recursive estimates for long-run income elasticity parameter in diesel fuel demand model (1998Q1-2010Q4) (initial sample size 40 data points)

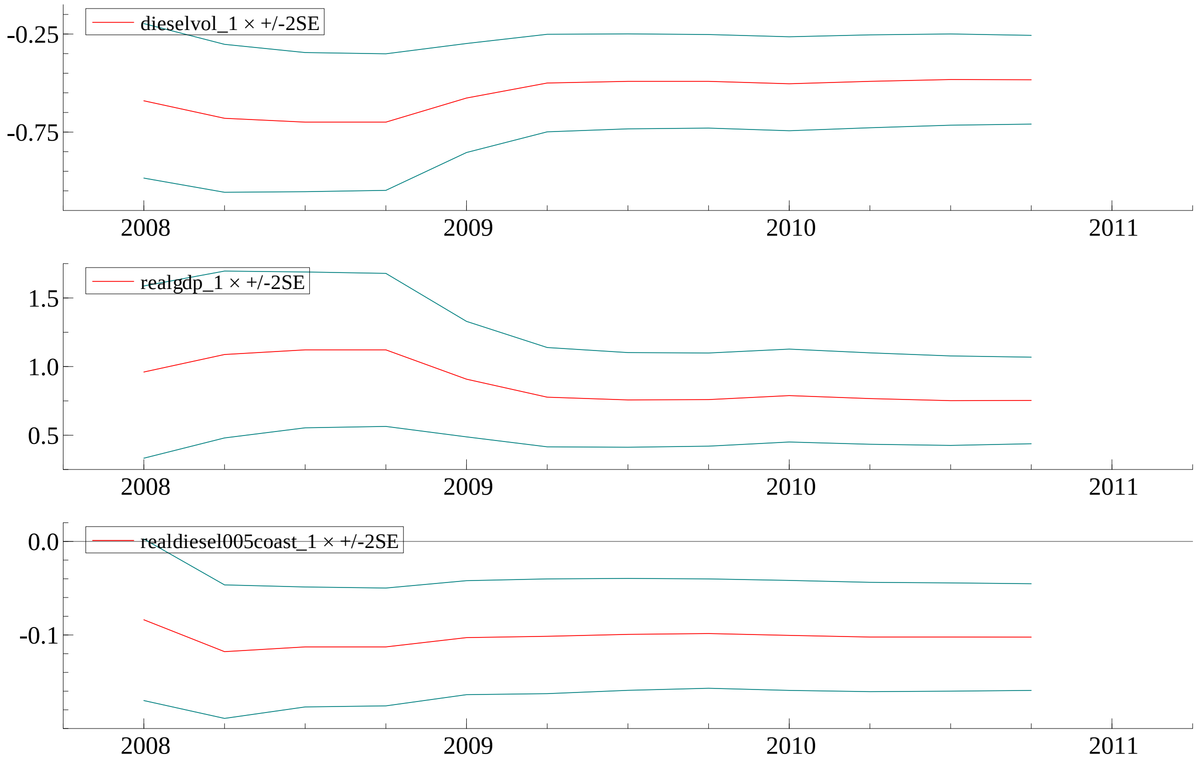

Figure 12: Recursive estimates for long-run income elasticity parameter in jet fuel demand models (1998Q1-2009Q3) (initial sample size 10 data points)