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ECONOMIC INSTRUMENTS FOR ENVIRONMENTAL REGULATION IN AFRICA: AN ANALYSIS OF THE EFFICACY OF FUEL TAXATION FOR POLLUTION CONTROL IN SOUTH AFRICA

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1. Introduction

The rapid rate of urbanization, the accompanying rapid increase in human population and of vehicles and the subsequent expansion of economic activities in major towns and cities in Africa have led to increased demand for fossil fuels including gasoline and increased emissions of carbon pollutants. This increased fuel consumption poses serious threat to the environment.

Emission and pollution statistics for South Africa reflect the heavy dependence of the population on road transport. Thus road transport can be considered as one of the most serious polluters in South Africa. As indicated in Table 1, the country has a heavy dependence on passenger cars, which makes any policy aimed at reducing carbon dioxide emissions by road transport very difficult.

Table1: Emissions and pollution statistics for South Africa

Indicators	2002	2003	2004	2005	2006
Population (millions)	42.8	43.2	45.3	45.8	45.5
Urban population (% of total)	55	57.6	58.4	59.2	57.4
Passenger cars (per 1000 people)	94	94	100	94	92
CO_2 emissions per unit of GDP (kg/ppp$ GDP)	0.9	0.8	0.9	0.8	0.8
CO_2 emissions per capita (mt)	8.3	7.9	7.4	7.4	7.6

Source: World Bank (several years).

This study is divided into parts. The first part analyzes the distributional impact of fuel taxation by assessing the progressivity of fuel expenditures. The second part looks at gasoline demand models. This section assesses the fuel demand elasticities.

The present study investigates whether fuel pricing policy could be effective in lowering fuel consumption and hence serve as an instrument to achieve lower level of pollution. The rest of the paper is organized as follows. Section 2 discusses the evolution of fuel taxation in South Africa. Empirical literature on South Africa is discussed in section 3. The empirical analyses are discussed in sections 4 and 5. Section 6 discusses the empirical results of the gasoline demand model. Section 7 concludes.

2. Policy analysis of fuel tax in South Africa

Fuel taxation in South Africa dates back to June 1978 when it was introduced as General Sales Tax (GST) at 4% or 1 cent per litre (c/l) of the pump price of 26.4 c/l. Following the 1979 oil crisis, the government introduced Central Energy Fund Levy which set fuel tax at a level of 18.75 c/l in June 1979. However, the levy was progressively reduced thereafter and was down to 4.0c/l in 1985 with the following earmarked charges: 0.055 c/l for combating oil pollution, 3.725 c/l for financing synthetic fuel production and 0.22 c/l for financing crude and fuels strategic storage. However, these earmarked taxes were phased out and GST was replaced as tax on fuel as fuel levy of 30.9 c/l in 1987.

Efficiency of carbon tax depends on their impact on fostering reduction in emissions. In other words, gasoline taxes currently account for only the cost of road construction and maintenance. Therefore, additional environmental tax on the price of gasoline would charge drivers for the damage they cause to the environment and may have the beneficial effect of reducing miles driven and encouraging people to purchase more fuel-efficient vehicles (Sipes and Mendelsohn, 2001).

3. Empirical studies of fuel demand in South Africa

There are a few studies on fuel demand for South Africa. These are summarized in the Table 2.

Table 2: Estimates of the price elasticity of demand for petrol and diesel

Study reviewed	Short term price elasticity	Long term price elasticity
S.A. Cloete & E. v.d. M. Smit (1988)	-0.25	-0.37
S.D Ngumeni (1994)	-0.1 to -0.2	
Bureau for Economic Policy Analysis (BEPA) (De Wet et al (1989)	-0.31	
Bureau for Economic Research (2003)		
- Petrol	-0.21	-0.51
- Diesel	-0.18	-0.06

These studies found elasticities to be remarkably less than unity even in the long run. They conclude that the demand for petrol and diesel is both price and income inelastic.

4. Expenditure incidence analysis

Gasoline tax is levied on the consumption of gasoline by households and motor vehicle owners. Therefore, when analyzing the effects of gasoline tax on pollution the analysis of the distributional effects of the tax (measured by tax incidence) on the society is of paramount importance. That is why distributional concerns are often central to vehicle pollution policy discussions.

Tax incidence, which reflects the welfare effects of increases in gasoline taxation, can be used to measure tax burden on various categories of households. Most studies suggest that environmental taxes tend to be at least mildly regressive making such taxes a less attractive option for policy and in particular the regressivity of gasoline tax is often cited as one of the strongest arguments against increasing this tax (West, 2004).

Tax incidence can be measured as the sum over all goods of the price change for a given good times the household's consumption of that good (before the imposition of tax change) plus the change in income following the tax. Several authors used this approach to measure incidence. Among these, Metcalf (1999) used this approach to estimate the incidence of a range of environmental taxes and Poterba (1991) and West (2004) used this approach to estimate the incidence of gas tax.

The approach of measuring tax burden just stated above can use either income or expenditure to estimate incidence. The degree to which the gasoline tax burdens households within different income categories depends on the use of income approach or expenditure approach (Poterba, 1991). Poterba (1991) used expenditure approach and included households that own vehicles as well as those that do not own vehicles in his analysis. He found that low-income households spend less of their budget on gasoline than middle-income households which suggests that a gas tax is less regressive than other studies would suggest.

Many researchers (see Porteba, 1989 and 1991; Feenberg et al., 1997) believe that taxes should be compared with a household's long-term income, or permanent income rather than its annual income. Measuring the tax burden relative to permanent income provides an estimate of household's ability to bear a tax over a lifetime. Reported annual income, by contrast, could substantially underestimate the long-term ability of some households to pay a tax. For instance households with retired workers may have small annual incomes but large savings. Moreover, households with people who are early in their careers may have low current incomes but expect substantially higher income in the future (U.S Congressional Budget Office, 2002).

Poterba (1991) argued that the annual expenditure measure provides a more reliable indicator of household well-being than annual income. The income measure has a drawback in that it does not account for shortcomings in the available data on household income. Evidence suggests that income data may understate the resources available to some households, particularly at the bottom end of the income scale, where unreported income and private transfers (such as gifts from family members) may constitute a significant share of household resources (U.S Congressional Budget Office, 2002).

Some researchers believe that a household's expenditure provides a better measure of its long-term ability to pay tax than its income does. Spending reflects both expectations of higher future income (to the extent that people can borrow money) and household saving (as people draw on accumulated resources). Thus, expenditures reflect households' permanent income better than annual income does (U.S Congressional Budget Office, 2002). In addition, using expenditure data eliminates the problem of understated household resources.

The present study calculates the budget share of fuel and transport related expenditures in total household expenditures for each category of population classified by expenditure deciles.

The budget share for each expenditure decile can be calculated as follows:

$$E_{shd} = (FE/TE) \times 100 \qquad (1)$$

4.1 Measurement of incidence

4.1.1 Data and sample

The basic data source for this analysis is the year 2000 Income and Expenditure Survey, (IES). The survey has a representative sample of about 26 264 households drawn from all provinces of South Africa. It has detailed household level data on consumption patterns as well as some data on household income, and taxes.

Household income is defined as regular income plus other income, measured on an annual basis. Total expenditures are the sum of expenditures on most household activities.

We use the expenditure measure to assess the distributional impact of fuel taxation because of its advantages highlighted in the preceding section. We assign households to deciles by total expenditure. Each decile has about 2 626 households. Fuel expenditure shares within each decile are then calculated to illustrate the distribution of fuel expenditure patterns. We also calculate similar ratios for transport related expenditures.

4.1.2 Empirical analysis

In our empirical analysis we test the hypothesis that fuel tax is progressive and can therefore be used as an effective instrument for pollution control.

Table 3 shows the ratio of fuel expenditure in total household expenditure. The budget share of fuel generally increases. The lowest expenditure decile devotes 0.03% of their total expenditures to fuel. The highest decile devotes 3.39% of their total expenditures to fuel. The expenditure-based calculations suggest that the distribution of fuel expenditure is progressive, with higher income households devoting the highest budget shares to fuel. Thus, fuel taxation is not necessarily regressive.

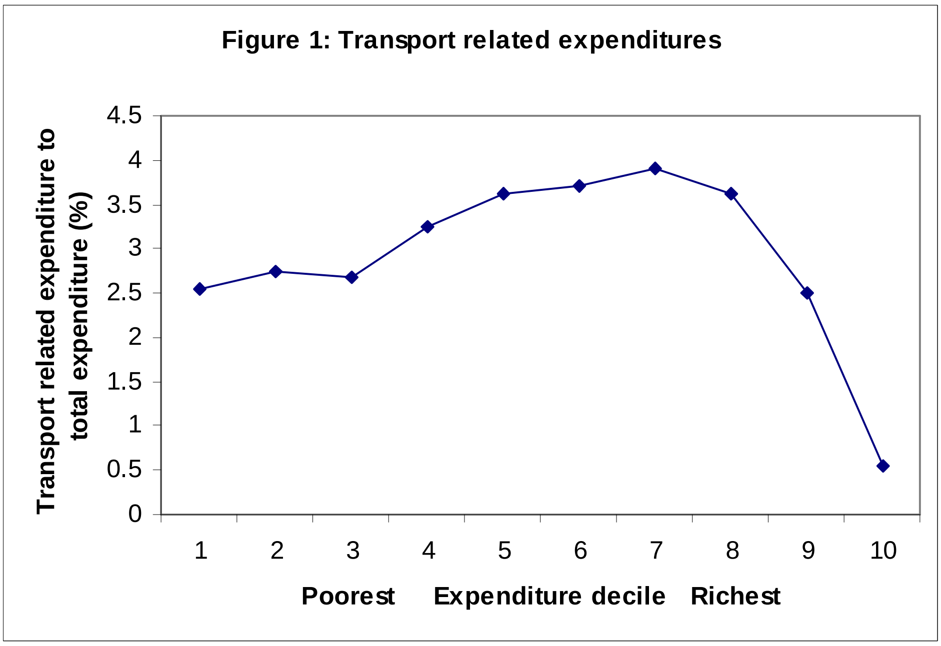
Table 3: Fuel expenditure/Total expenditure, by expenditure decile, 2000

Expenditure Deciles	Fuel exp/Total expenditure (%)
1	0.03
2	0.03
3	0.05
4	0.11
5	0.27
6	0.50
7	0.74
8	1.30
9	2.74
10	3.39

Source: Authors' tabulations using 2000 Income and Expenditure Survey.

Households also make use of fuel indirectly in other transport related activities. This is done through the use of public and hired transport. The total transport- related expenditure was computed by adding household expenditures on bus travel, train, rented vehicles and furniture removal and transportation of goods. These expenditures are reported in the survey. Figure 1 shows the proportion of expenditures devoted to transport related activities in total household spending. The first decile devotes 2.55% of total expenditures to transport. The share of such expenditures in total expenditure increases with income until the seventh decile.

Figure (1) plots an Engel curve of the share of transport related expenditures in total household expenditure. The curve is hump-shaped, indicating that the middle income households spend more on fuel that is not used for the household's own transport purposes. This result indicates that transport related services are a necessity for middle income households. A similar observation was made by Santos and Catchesides (2005).



Source: Income and Expenditure Survey, 2000.

Table 4 shows the proportion of expenditures devoted to fuel and transport related activities. The share of fuel and transport-related expenditures in total expenditure generally increases with income. The lowest decile devotes 2.58% of total expenditures to fuel. The highest decile devotes 3.94% of their expenditures to fuel and transport related activities. The budget shares show progressivity of expenditures with the ninth decile devoting 5.24% of their budgets to fuel and transport-related expenditures.

Table 4: Fuel and transport related expenditures/Total expenditure, by Expenditure Decile, 2000

Expenditure deciles	Transport expenditures/Total expenditure (%)
1	2.58
2	2.77
3	2.73
4	3.36
5	3.89
6	4.22
7	4.65
8	4.93
9	5.24
10	3.94

Source: Authors' tabulations using 2000 Income and Expenditure Survey.

The expenditure-based measure of fuel tax incidence shows that fuel taxes are progressive. This point confirms Poterba's (1991) result that using an expenditure-based measure (as a proxy for lifetime income) will result in less regressivity. When all forms of fuel use are taken into account fuel expenditures are progressive[2].

5. Gasoline demand models

5.1 Data description and choice of variables

It is commonly agreed that the level of income and prices are crucial determinants of the consumption of motor gasoline (Storchmann 2005). The data used are for the time period 1970- 2006. Fuel consumption is proxied by final household expenditure on petroleum products measured in millions of rands at constant 2000 prices. The income variable is real gross domestic product at market prices in millions of rands measured at constant 2000 prices. The data for fuel consumption and real income were obtained from the South African Reserve Bank. Petrol price data were obtained from the South African Energy Statistics and the South African Petroleum Industry Association. The fuel prices

[2] We would like to point out that our study has limitations in the sense that it does not address efficiency. The study however, does set the stage for further investigations into the relationship between the fuel tax instrument and the quality of the environment.

were converted to real 2000 values using the domestic consumer price index. The consumer price index used is for the total consumer prices for metropolitan areas (with base year 2000) seasonally adjusted. The consumer price index data were obtained from the South African Reserve Bank.

5.2 Methodology

According to consumer theory approaches by Lancaster (1966) and Muth (1966), the demand for fuel is a derived demand. It is not fuel itself, which gives benefits to the consumer but the end product, mobility produced by the consumer with the help of such inputs as cars, fuel and time. It therefore has two components of adjustment: vehicle utilization and the composition of the vehicle stock (Sterner et al. 1992). They also noted that the adjustment process could take a number of years given the long-lived nature of motor vehicles. Thus, such factors as fuel price, income and number of vehicles affect the demand for fuel.

We use co-integration and error correction modeling to analyze fuel demand in South Africa. We specify our fuel demand model as a function of real fuel price and real income[3], as is shown in equation (2).

$$G = f(P, Y) \qquad (2)$$

For models of gasoline demand and miles traveled log linear specifications are the most commonly used (Dahl, 1986). Accordingly, our study uses a log linear model of fuel demand. Equation (2), which represents the long run model, can be expressed as

$$\ln G_t = \alpha_0 + \alpha_1 \ln P_t + \alpha_2 \ln Y_t + \varepsilon_t \qquad (3)$$

Where ln is the natural logarithm; G is real household spending on petroleum products, α is a constant; P stands for real petrol price inclusive of the fuel levy; and Y is real gross domestic product at market prices; ε is the random error term. This specification has been found to be easy to interpret and is not data intensive (Sterner et al., 1992).

[3] We do not consider the indirect effects of fuel taxation.

According to economic theory an increase in fuel prices is expected to reduce petrol consumption and an increase in real income is expected to increase petrol consumption. Thus, the coefficients α_1 and α_2 are expected to be negative and positive respectively. The estimated coefficients give the price (α_1) and income (α_2) elasticities.

5.2.1 Stationarity and co-integration

a) Testing for stationarity and co-integration

Most previous gasoline demand studies did not recognize the non-stationary nature of time series data. Recent studies have expressed concern over this methodological issue (Graham and Glaister 2002). This has led to the use of co-integration techniques, which seek to model the non-stationary nature of time series data explicitly. The use of this method is employed as a means of distinguishing the short-run from the long-run petrol demand characteristics, and for calculating the speed of adjustment towards the long-run values.

The first step in co-integration analysis involves checking for stationarity in all the variables. This was done using the augmented Dickey Fuller and Phillips-Perron unit root tests. The results are reported in Table 5. The null hypothesis of non-stationary cannot be rejected in levels for all the variables. The null hypothesis can be rejected in first differences. Thus, the series are integrated of order one, I(1).

Table 5: Tests for stationarity of the variables

	Augmented Dickey- Fuller		Philips- Perron	
Variable	Levels	First differences	Levels	First differences
lnG	-1.65(0)	-5.21(0)***	-1.99(3)	-5.21(3)***
lnY	-1.61(1)	-3.56(1)**	-1.54(3)	-3.92(3)**
lnP	-1.79(0)	-6.04(0)***	-1.81(3)	-6.04(3)***

Note: ADF is the augmented Dickey-Fuller test and PP is the Phillips-Perron test. ***, and ** denote rejection of unit root null hypothesis at the 1%, and 5% and level, respectively. The numbers in the parentheses represent the number of lags used in each test. For all cases trend and intercept were included.

The second step involves estimating two regressions. The first is the co-integrating relationship shown in equation (3). The residual ε_t is also interpreted as the co-integrating linear relation. The results of the co-integrating regression are given in Table 6. The sign of real income is positive, while that of fuel price is negative as is expected. The CRDW test simply examines the DW of this regression to see if it is significantly greater than zero. The second regression is the ADF test (to obtain the t-statistics of ρ) of the following form:

$$\Delta \hat{\varepsilon}_t = \hat{\rho}\varepsilon_{t-1} + \sum_{t=1}^{4} \delta_i \Delta\varepsilon_{t-1} \qquad (4)$$

The results of the co-integration test are given in Table 6.

Table 6: Results of co-integrating regressions

Dependent variable: lnG	
Regressor	Parameter estimate
Constant	-11.93 (-14.0)
ln Y	1.64 (25.4)
ln P	-0.54 (-8.3)
Adjusted R^2	0.95
CRDW	0.43**
t-statistic of residual in ADF, i.e equation 4.	-3.15*

**,* significant at 5% and 10% level of significance, respectively. The figures in the parentheses show t-statistics. The critical values were obtained from Engle and Granger (1987), Table III, p. 270.

6. Results of model estimation

6.1 The error correction model

While petrol consumption, gross domestic product and petrol prices may be cointegrated in the long-run, in the short-run there may be disequilibrium. The error correction model (ECM) captures the short-run adjustment towards the long-run equilibrium. This model examines the short-run characteristics of petrol demand.

The ECM model combines both short run dynamic changes represented by changes in the variables and the long run adjustment process captured by the coefficient δ_3 in equation

(5). The ECM implied by our long-run cointegrating relationship can be presented as follows:

$$\Delta lnG_t = \delta_0 + \delta_1 \Delta lnP_t + \delta_2 \Delta lnY_t + \delta_3 EC_{t-1} + u_t \qquad (5)$$

Where Δ indicates change in variable over time, δ_0 is a constant; δ_1 and δ_2 are the short-run price and income elasticities; EC is the error correction term which is a residual from the long-run cointegrating relationship, is defined as (y_{t-1}- βx_{t-1}) and the other variables are defined as before. The ECM structure suggests that short-run movements in petrol consumption (ΔG) are related to short-run changes in national income (ΔY) and real petrol prices (ΔP). The cointegrating vector coefficient δ_3 is expected to be negative and statistically significant in order to correct deviations from the long-term trend (Samini, 1995:334). The residuals from the error-correction model feed into the Engle-Yoo third step. The third step is necessary in order to adjust the cointegrating parameter estimates. This adjustment eliminates the bias from the nonstationarity of the series in levels.

The variables in the ECM are *I*(0) and therefore, the t-statistics can be used to determine the significance of the estimates. Based on equation (5), the short-run income and price elasticities are 0.68 and -0.31 respectively. The estimation results of the error correction model are reported in Table 7.

Table 7: An error correction model of petrol consumption

Dependent variable: ΔlnCons		
Regressor	Parameter estimate	t-statistic
EC_{t-1}	-0.18	-2.09**
Δln Y	0.68	2.16**
Δln P	-0.31	-5.79***
Adjusted R^2	0.50	
DW	1.41	
Diagnostic tests	Statistic	p-value
Jarque-Bera test	0.61	0.74
Breusch-Godfrey LM test	1.73	0.19
ARCH LM test	0.82	0.45
White's test	0.57	0.75

***, ** Significance at 1 percent and 5 percent level, respectively.

The final ECM model passes a battery of diagnostic tests, which are reported in Table 7. The Jarque-Bera statistic confirms the normality of the residuals. The Breusch-Godfrey's LM test rejects the presence of serial correlation. The ARCH test rejects first and second orders hetero-scedasticity in the disturbance terms. White's test also rejects the presence of hetero-scedasticity in the residuals.

6.2 Results of the lagged endogenous model

Table 8 gives the estimation results of the lagged endogenous model ($\ln G_t = \alpha_0 + \alpha_1 \ln P_t + \alpha_2 \ln Y_t + \alpha_3 \ln G_{t-1} + \varepsilon_t$). The price and income coefficients have the expected signs and are statistically significant.

Table 8: Elasticity estimates[4] from the lagged endogenous model

Elasticities		
	Short-run	Long-run i.e $\alpha_1/(1-\alpha_3)$ and $\alpha_2/(1-\alpha_3)$
Price	-0.23	-0.72
Income	0.52	1.63

Table 9: Elasticity estimates from co-integration and error correction models

Elasticity	Short-run	Long-run
Price	-0.31	-0.75
Income	0.68	1.66

The application of more than one model is crucial in order to ascertain the robustness of the results. The lagged endogenous model is only used as a robustness check. The two models give generally similar short-run and long-run elasticity estimates. On the basis of co-integration and error correction models our long-run price elasticity of petrol demand is approximately -0.75 and the short-run (impact) elasticity is approximately -0.31. This finding shows that a change in petroleum price will have a larger impact on petrol consumption in the long run than in the short-run as is expected.

Our results suggest that the long-run income elasticity of petrol consumption is around 1.66, whereas the short-run (impact) income elasticity is around 0.68. This finding shows that a change in income will have a larger impact on petrol consumption in the long run than in the short-run. The high-income elasticity suggests that petrol consumption will continue to grow as the economy grows, while the significant price elasticities suggest that tax policies to reduce consumption could be successful. The absolute value of the long-run income elasticity is more than twice as much as that of the price elasticity. This indicates that fuel prices must rise faster than the rate of income growth if petrol consumption is to be stabilized.

[4] If we use bounds testing approach our elasticity estimates are similar. The respective price elasticities are -0.33 and –0.75 while the income elasticities are 0.71 and 1.43. This Table is only included as a robustness check.

According to our study petrol consumption is price-inelastic but income-elastic in the long-run. Our results for price elasticity are similar to those found by earlier studies on South Africa. Studies by Cloete and Smit (1988) and the Bureau for Economic research (2003) found the short-run price elasticity for petrol to lie between –0.21 and –0.25, while the long-run price elasticity lied between -0.37 and –0.51. However, our short-run and long-run elasticities are higher than those of earlier studies.

7. Conclusions

This study, based on the analysis of household survey data concludes that fuel tax is not regressive. The analysis of indirect fuel use shows that middle income groups spend more on fuel than other income groups. Such an analysis shows some progressivity of fuel tax as the budget share of indirect fuel increases until the seventh decile. Our results suggest that a fuel tax would not necessarily impose excess burden on the poorest households as has been argued in the literature. When all forms of fuel use are taken into account fuel expenditures are in effect progressive. This suggests that fuel tax would be an effective and desirable instrument for pollution control.

Gasoline demand estimation shows that a statistically significant negative relationship exists between petrol consumption and petrol price. The price elasticities are -0.31 and -0.75 in the short-run and long run respectively. The short-run and long-run income elasticities are 0.68 and 1.66 respectively. These findings confirm earlier empirical studies on gasoline demand, which have shown that gasoline demand is generally price inelastic but income elastic in the long-run. Long-run elasticities are larger than short-run elasticities as is expected. This is because demand becomes more elastic with time as consumers find substitutes for petrol. Our study provides estimates of elasticities that are in the range of previous studies in developing countries.

The high income elasticity suggests that we can expect fuel consumption to continue growing, while the significant price elasticities suggest that tax policies to reduce fuel consumption could be successful.

We must mention that our conclusions are to be viewed with the knowledge that our analysis does not consider the indirect effects of fuel taxation. Reducing carbon emissions requires much more than just taxing fuel. Other sectors contributing to gas emissions like industry or agriculture need to be included in any environmental policy aimed at reducing such emissions.

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