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Automotive Fuel Consumption in Brazil: Applying Static and Dynamic Systems of Demand Equations

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1. Introduction

The demand of automotive fuel is an important topic in energy policy since the demand sensibility to income and price changes can give great insights for policy makers relating, for instance, to climate change, optimal taxation and national security. The study of the automotive fuels demand in Brazil is especially relevant since in the last decades its automotive fuel market has witnessed relevant changes in the consumption structure, which used to be dominated by traditional fuels, like gasoline and diesel.

In this changing context two periods can be identified. First, from 1970 to 1990, in a context of two oil crises, the consumption grew 4.5% per year, and ethanol combustible has emerged, in 1973, as a part of a government program to reduce the oil dependency. Compressed natural gas (CNG) has also been brought on as another innovation, in the end of the 1980´s, although its consumption has only begun to grow at the middle 1990´s due to the government policy of fixing a substantial price differential in favor of CNG. So far, the Brazilian automobile industry fell short to produce CNG vehicles[1]; CNG consumers still have to install a kit which allows them to convert the vehicle between CNG as well as the original engine fuel. Most of CNG consumption in Brazil is related to light-duty trucks – such as taxi cabs, especially in the states of Rio de Janeiro and Sao Paulo, where the CNG stations network is relevant.

In the second period, from 1991 to 2005, overall combustible consumption has grown at a faster rate, of 2.8% per year. Another innovation was brought in, the flex fuel vehicles which are specially designed to run on gasoline and ethanol. In 2003, the production of flex fuel cars accounted for only 2.6% of the total auto production; three years later, this number was 75%.

The essential point to grasp here is that the introduction of flex fuel (gasoline-ethanol) vehicles and the raise of CNG have enlarged the options available to consumers to choose their automotive fuel, therefore altering, in some extent, the demand for captive fuels as gasoline. In this context, and given the assumption that dem and elasticity is a useful tool to

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[1] One notable exception is Fiat, who has started to produce CNG, Gasoline and Ethanol compatible engines.

summarize the consumers behavior, this work tries to shed light on the performance of the Brazilian demand for automotive fuels.

While the price and income elasticities of automotive fuels demand (specially gasoline) around the world have been extensively studied; see Basso and Oum (2006) for recent exercises,Goodwin, Dargay and Hanly (2004) for a recent survey and Dahl and Sterner (1991) for thorough review. However, there are very few published papers on the estimation of demand elasticities for the Brazilian automotive fuels market. Alves and Bueno (2003) constitute a single work on this regard. Through a co-integration method they estimated the cross-price elasticity between gasoline and alcohol, and find alcohol as an imperfect substitute for gasoline even in the long-run. Even though relevant, this work has focused on the gasoline market therefore not shedding light on the demand for other automotive fuels in Brazil, as diesel, ethanol and CNG.

In this turn, this work goes one step further as it estimates the matrix of price and income elasticities - in relation to gasoline, ethanol, CNG and diesel. Two related estimation approaches are employed. First it uses the traditional linear approximation of the Almost Ideal Demand System (AIDS), originally developed by Deaton and Muellbauer(1980). This is a structural and static model which fulfills the desired theoretical properties of demand (homogeneity and symmetry restrictions) while also being parsimonious in terms of number of parameters to be estimated. In order to also analyze the dynamic aspect of the long run demand, this work adopts a second approach of AIDS model using cointegration techniques based on Johansen (1988) procedures. The use of this second approach is especially relevant since the variables can be non-stationary, which could change the estimates of elasticities.

The chapter is organized as follows; section two describes the evolution of automotive fuels consumption profile in Brazil since the 1970's. Section three presents the data used. The following section describes the linear approximation of the static AIDS model and presents the first results. The fifth section develops the dynamic analysis using cointegration techniques and displays the results. The sixth, and last section, presents in a nutshell the main conclusions.

2. The evolution of automotive fuel matrix in Brazil

Table 1 presents the yearly consumption evolution in tones oil equivalent (toe) in the automotive vehicles fuel matrix since 1979. Two analytical periods must be highlighted. In the first one, between 1979-1990, the total fuel consumption presented a 2.2% growth per year, while the GNP grown at a yearly medium rate of 2.05%.

In the period between 1979 and 1990, when one considers the individual performance of each series, the ethanol is highlighted as the fuel with the highest yearly growth rate, of 71.3% per year. Indeed, the consumption level rose from eight thousand tonnes of oil equivalent, in 1979, to 5.205 thousand in 1990, causing an expressive accumulated growth. This significant expansion rhythm reflects the "Programa Nacional do Álcool" (National Ethanol Program), launched in 1973, whose the second phase was named "Proálcool", started in December 1978, when the government decided to stimulate the production of ethanol vehicles. In the first analytical period, it is also remarkable the reduction in the gasoline consumption, with an accumulated fall of 28.5% between 1979 and 1990.

	CNG	*Diesel*	*Gasoline*	*Ethanol*	*TOTAL*
1979	0	10.902	10.397	8	22.491
1980	0	11.401	8.788	219	21.611
1981	0	11.280	8.413	709	21.014
1982	0	11.515	8.014	853	21.460
1983	0	11.025	6.847	1.504	20.549
1984	0	11.486	6.140	2.332	21.070
1985	0	11.846	6.043	3.103	22.124
1986	0	13.948	6.808	4.280	26.340
1987	0	14.689	5.931	4.546	26.306
1988	3	14.981	5.809	4.974	26.817
1989	2	15.868	6.527	5.641	28.905
1990	2	15.983	7.436	5.205	29.276
Average yearly annual growth (1979-1990)*	-13,9%	3,2%	-2,8%	71,3%	2,2%
Accumulated growth rate (1979-1990)	-36,1%	46,6%	-28,5%	63725,0%	30,2%
1991	2	16.587	8.059	5.225	30.751
1992	0	16.882	8.023	4.784	30.878
1993	22	17.325	8.436	4.931	32.012
1994	40	18.106	9.235	4.974	34.025
1995	43	19.280	11.057	5.069	37.250
1996	32	20.165	12.946	4.987	40.295
1997	41	21.422	14.156	4.233	42.530
1998	116	22.453	14.772	3.933	44.124
1999	140	22.704	13.770	3.594	43.412
2000	275	23.410	13.261	2.774	42.766
2001	503	24.071	12.995	2.170	42.946
2002	862	25.086	12.426	2.214	44.459
2003	1.169	24.252	13.115	1.919	44.329
2004	1.390	25.939	13.560	2.466	47.334
2005	1.711	25.804	13.595	2.885	48.073
Average yearly annual growth (1991-2005)	58,2%	3,0%	3,5%	-3,9%	3,0%
Accumulated growth rate (1991-2005)	97171%	56%	69%	-45%	56%

* The annual growth rate of CNG was based on the period 1988/1990

Source: own elaboration based on data from MME (2005)

Table 1. Annual Fuel Consumption of Automotive Vehicles (10^3 toe): 1979-2005

In the second analytical period, between 1991-2005, the total automotive fuel consumption presented a pace higher than the period before, having reached the expansion rate of 3% per year, while the GNP grown at 2.4% per year. In this period, the negative point is the ethanol, with yearly fall of 3.9% per year. On the other hand, gasoline presented a growth rate of 3.5% per year, which reinforces the negative (substitution) relationship between the dynamics of consumption of gasoline and ethanol. impressive remarkable aspect of this period was the CNG fuel expansion, with yearly growth rate of 58%, having increased from 2 thousands toe in 1991 to 1.171 thousands toe in 2005 (see Table 1).

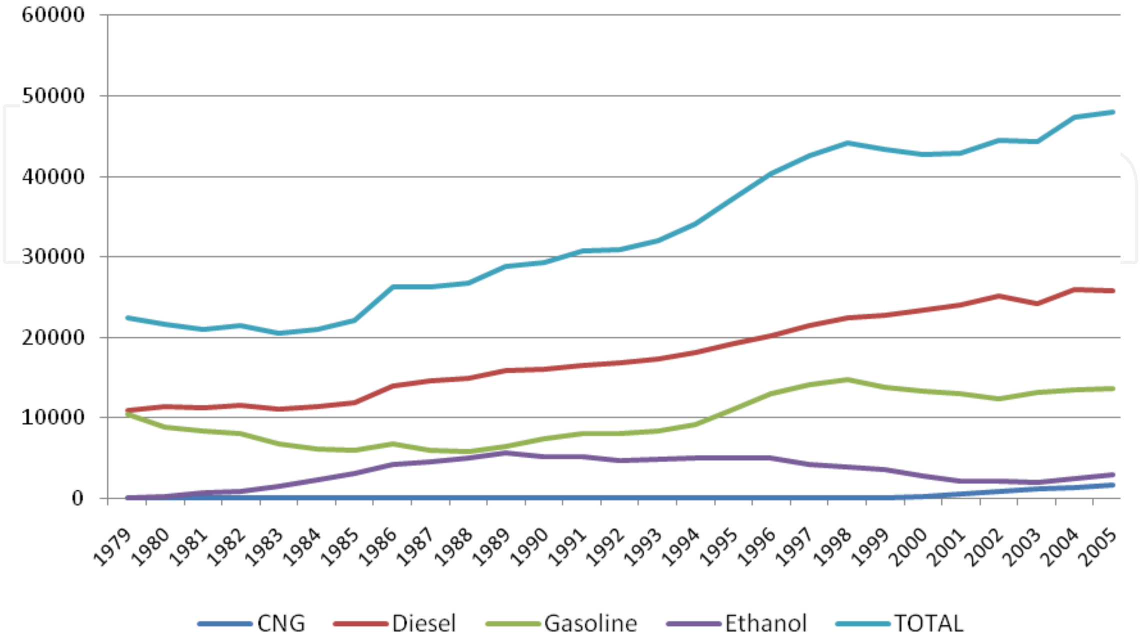

Fig. 1. Evolution of Fuel Consumption of Automotive Vehicles (10^3 toe): 1979-2005

Regarding diesel fuel, it is worth emphasizing its almost constant expansion rate; while in the first period, between 1979 and 1990, the growth was of 3.2% per year, in the period after 1991 the growth rate was of yearly 3.0%.

Considering the same analytical periods, but focusing on the consumption share of each fuel and not on their individual series performance, it is possible to identify aspects that are as relevant.

Diesel performs as the main automotive fuel used in two periods. Between 1979 and 1990 its average share was of 53.7%; in the following period, from 1991 to 2005, the average share was of 53.4%. The diesel share in the vehicle fuel matrix has thus kept almost constant in the last three decades. Some possible explanations for this picture is the high dependency of the road transport modal, and the fact that 100% of the production and sales of buses and trucks – which are the most used in long distance transport, use diesel engines. It is worth noting that ever since 1979 there have not been effective replacements of diesel in the consumption structure, in spite of the relevant imports pressures of the fuel to Brazil.

As expected, gasoline evolves as the second fuel with the highest relative share in the vehicle fuel matrix in the two periods; with average share of 31% in the first period and 29.4%, in the second. It is important to mention, however, that in spite of the fact that this average share has kept steady in the periods considered, there were distinct movements in the demand behavior of gasoline in the two periods. While between 1979-1990 the gasoline share fell from 46.2% in 1979 to 25.4% in 1990; in the second analytical period, the share rose from 26.2% to 28.3% in 2005.

The role played by the ethanol is worth to mention. The average share has kept almost steady in the analyzed periods: 10.8% between 1979-1990 and 9.8% between 1991- 2005. However, there had been different trends during this period. In the first period the share rose significantly, going from 0% in 1979 to 17.8% in 1990, as a consequence of the programs focused on the ethanol diffusion. In the second period, there was a fall from 17%, in 1991, to

6.0% in 2005. Finally, it is important to stress the CNG role, of little relevance, having reached the average share of 0.9% between 1991 and 2005.

In the analysis of the performance of all these fuel consumptions a relevant aspect to be highlighted is the demand sensibility to price and income variations, which is captured by the price- and income elasticities, respectively. Detecting a high or reduced sensibility of demand to price and income parameters can give interesting insights to the policy planning about what is the goal of the vehicle fuel matrix in Brazil.

3. The data

Time-series data for the consumption of automotive fuels in Brazil are not in abundant supply. The Brazillian Ministry of Mines and Energy (MME) has historically collected annual data for prices and consumption of automotive fuels since 1970 (see MME(2006)). More recently, (June, 2001), the National Petroleum Agency (ANP) has also taken this role and started to collect monthly data on price and consumption of fuels[2]. This work has used the annual data collected by MME, since it is better suited to identify the long term consumption profile. A companion paper uses the monthly data for a shorter period of time to implement a similar exercise to also analyze the elasticity, and is available upon request to the authors. Table 2 shows the main descriptive statistics of the main series used in this analysis, namely, the natural log of the prices and the consumption-share of diesel, gasoline, CNG and ethanol drawn from “Balanço Energético Anual"(MME, 2006).

Variable	N	Mean	SD	Min	Max
Year	36	1988	-	1970	2005
Natural log of the price – Gasoline[1]	33	4.551	0.387	3.17	5.142
Natural log of the price – Ethanol[1]	27	4.714	0.264	4.235	5.204
Natural log of the price - CNG[1]	29	3.165	0.339	2.329	3.877
Natural log of the price - Diesel[1]	33	3.883	0.392	2.854	4.758
Expenditure-share Gasoline[2]	33	49.065	14.489	31.529	77.234
Expenditure-share Ethanol[2]	27	16.095	9.705	0.043	31.807
Expenditure-share CNG[2]	18	0.212	0.308	0	0.943
Expenditure-share Diesel[2]	33	37.651	7.462	22.766	51.594

Source: own elaboration based on data from MME(2005). [1]prices are in 2005 US$/boe (US$ per barrel of equivalent oil); [2]Expenditure share of each fuel means the expenditure (price x quantity) with this fuel in terms of total expenditure with the four fuels.

Table 2. Summary Statistics of Main Variables of Interest

4. The static approach: measuring elasticities through a Linear Approximation of an Almost Ideal Demand System (LA-AIDS)

The elasticities of energy consumption in automotive segment in Brazil, in the 1970-2005 period, are initially estimated through a linear approximation of the Almost Ideal Demand System (hereby called LA-AIDS).

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[2] Actually, ANP collects monthly data on price of CNG, diesel gas, and ethanol. Regarding consumption, it gives monthly data on gasoline, ethanol and diesel (including that for industrial use), but not on CNG.

The traditional LA-AIDS model, developed by Deaton and Muellbauer(1980), departs from a specific cost function and gives the share equations in a n-good system as:

$$w_i = \alpha_i + \sum_{j=i}^{n} \gamma_{ij} \ln p_j + \beta_i \ln\left(\frac{X}{p}\right) \tag{1}$$

where w_i is the budget-share associated with the ith good, α_i is the constant coefficient in the *i*th share equation, γ_{ij} is the slope coefficient associated with the *j*th good in the *i*th share equation, total expenditure X is given by $X = \sum_{i=1}^{n} p_i q_i$ in which q_i is the quantity demanded for the ith good, p_j is the price on the *j*th good and *P* is a linear price index defined as $\sum_{i=1}^{n} w_i \ln p_i$.

The conditions required to make the model consistent with the theory of demand are:

$$\text{Adding-up: } \sum_{i=1}^{n} \alpha_i = 1, \sum_{i=1}^{n} \gamma_{ji} = \sum_{i=1}^{n} \beta_i = 0 \tag{2}$$

$$\text{Homogeneity: } \sum_{j=1}^{n} \gamma_{ji} = 0 \tag{3}$$

$$\text{Symmetry: } \gamma_{ij} = \gamma_{ji} \tag{4}$$

The conditions (2) and (3) are linear restrictions which may be tested by standard techniques, whereas condition (4) is imposed by the model and so is not testable. Once these restrictions are observed, system (1) characterizes a demand function system of which the sum equals total expenditure, is homogeneous of 0 degree in prices and expenditure, and satisfies the Slutsky symmetry propriety. Relative price variations affect demand through the parameters γ_{ij} - a percentual variation of the j*th* good affects the expenditure share of i*th* good, holding real expenditure X/P constant – and variations on real expenditure affect demand through parameters β_i.

Based on these especifications, a LA-AIDS model of the Brazilian automotive fuel demand of four categories of fuel (gas, ethanol, CNG and diesel) can then be written as:

$$w_{it} = \alpha_i + \sum_j \gamma_{ij} \ln p_{jt} + \beta_i \ln\left(\frac{X_t}{P_t}\right) + \mu_{it} \tag{5}$$

where:

w_{it} = consumption share of fuel *i* in period *t*, defining $w_{GAS}, w_{ETH}, w_{CNG}, w_{DIE}$;

p_{it} =price of the ith good in period *t*, defining $p_{GAS}, p_{ETH}, p_{CNG}, p_{DIE}$;

X_t = total expenditure in all fuels in period *t;*

P_t = geometric price index in period t; and

μ_{it} = error term

From the estimation of system (5), Marshallian[3] price (ε_{ij}) and expenditure (η_{ij}) elasticities can be calculated as:

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[3] Marshallian elasticities (also refereed as uncompensated elasticities) are derived from the Marshallian demand equation and are specifically obtained from maximizing utility subject to the budget constraint.

$$\varepsilon_{ij} = \frac{\lambda_{ij}}{w_i} - \beta_i \left(\frac{w_j}{w_i} \right) \tag{6}$$

$$\varepsilon_{ii} = -1 + \frac{\lambda_{ij}}{w_i} - \beta_i \tag{7}$$

$$\eta_i = \frac{\beta_i}{w_i} + 1 \tag{8}$$

Since the expenditure shares, w_i, add up to 1, the variance-covariance matrix is singular, and so the estimation requires omitting one of the share equations; after the estimation of the remaining share equations, the parameters of the omitted equation are obtained via the adding up restrictions. The technique in LA-AIDS model estimation is Zellner's Generalised Least Square method for seemingly unrelated regression (SUR).

4.1 Parameter estimates

	Coef.	Std. Err.	z	P>z	95% Conf. Interval	
qDemand1						
$\ln P_{GAS}$	-0.013	0.058	-0.230	0.821	-0.127	0.100
$\ln P_{ETH}$	0.161	0.051	3.130	0.002	0.060	0.262
$\ln P_{CNG}$	-0.005	0.002	-3.170	0.002	-0.008	-0.002
$\ln P_{DIE}$	-0.143	0.022	-6.470	0.000	-0.187	-0.100
$\ln X / P$	-0.201	0.065	-3.090	0.002	-0.328	-0.073
cons	4.714	1.369	3.440	0.001	2.031	7.397
qDemand2						
$\ln P_{GAS}$	0.161	0.051	3.130	0.002	0.060	0.262
$\ln P_{ETH}$	-0.019	0.050	-0.380	0.704	-0.117	0.079
$\ln P_{CNG}$	-0.002	0.001	-1.640	0.101	-0.004	0.000
$\ln P_{DIE}$	-0.141	0.011	-12.480	0.000	-0.163	-0.119
$\ln X / P$	0.133	0.063	2.130	0.033	0.011	0.256
cons	-2.684	1.323	-2.030	0.042	-5.277	-0.091
qDemand3						
$\ln P_{GAS}$	-0.005	0.002	-3.170	0.002	-0.008	-0.002
$\ln P_{ETH}$	-0.002	0.001	-1.640	0.101	-0.004	0.000
$\ln P_{CNG}$	0.001	0.001	0.870	0.382	-0.001	0.002
$\ln P_{DIE}$	0.006	0.001	4.150	0.000	0.003	0.009
$\ln X / P$	0.005	0.001	3.620	0.000	0.002	0.007
cons	-0.096	0.027	-3.570	0.000	-0.148	-0.043

Source: own elaboration

Table 3. The Restricted SUR Estimation of the Demand System Equation Using Static LA-AIDS Model

Table 3 presents the seemingly unrelated regression (SUR) estimation results of the LA-AIDS model – as defined in (5) – with homogeneity and symmetry restrictions imposed.

Tables 4 and 5 present price and income elasticities calculated at the mean values of the budget shares ($\overline{w_i}$). All own-price elasticities ($\varepsilon_{11}, \varepsilon_{22}, \varepsilon_{33}$) are negative and inelastic. Concerning the cross price elasticities, some inconsistencies are depicted since $\varepsilon_{13}, \varepsilon_{31}, \varepsilon_{14}, \varepsilon_{41}, \varepsilon_{23}, \varepsilon_{32}, \varepsilon_{24}$ and ε_{42} are negative, thus indicating, for instance, a surprisingly complementarity between gasoline and CNG and between gasoline and diesel.

		Gasoline (P_1)	Ethanol (P_2)	CNG(P_3)	Diesel(P_4)
ε_{1j}	Gasoline	-0.826	0.395	-0.009	-0.138
ε_{2j}	Ethanol	0.595	-1.263	-0.012	-1.186
ε_{3j}	CNG	-3.180	-1.815	-0.753	1.881
ε_{4j}	Diesel	-0.462	-0.400	0.015	-0.324

Table 4. The Marshallian Uncompensated Price Elasticities of the Demand System Equation using Static LA-AIDS Model

η_1	**Gasoline**	0.591
η_2	**Ethanol**	2.013
η_3	**CNG**	4.983
η_4	**Diesel**	1.166

Source: own elaboration

Table 5. The Expenditures Elasticities of the Demand System Equation using Static LA-AIDS Model

Before trying to explore these surprising outcomes, it is necessary to check if they satisfy the economic properties defined in restrictions (2) and (3). The Wald test presents a test statistic of $\chi^2(6) = 13.71$, above the critical value at the 5 per cent level of significance, 12.59), therefore indicating a strongly rejection of symmetry and homogeneity restrictions. Furthermore, the residual analysis of the model showed being non White Noise with serial correlation (see Table 6).

qDemand1	Portmanteau (Q) statistics	48.6008
	Prob > chi2(14)	0.000
qDemand2	Portmanteau (Q) statistics	58.296
	Prob > chi2(14)	0.000
qDemand3	Portmanteau (Q) statistics	47.0503
	Prob > chi2(14)	0.000

Source: own elaboration

Table 6. Portmanteau Test for White Noise

5. The dynamic approach: estimating a cointegrated LA-AIDS model

The economic inconsistency of the results presented above clearly underscores the necessity to consider in more depth the dynamic aspect of consumer choice. The point is that the rejection of homogeneity and symmetry restrictions is probably a consequence of dynamic mis-especification of the model The. In order to overcome this aspect and to better explain the consumer behavior in the long run, this work employs now a dynamic approach with non-stationarity and cointegration of the time-series.

This second approach here applied follows the idea that there may exist a long run equilibrium cointegrating demand system which can be identified and estimated for it would provide a basis to test the effects of price and income on the demand for automotive fuels. The short run adjustments towards the long run equilibrium are also considered. The process of correction may not be completed in one period – probably because of consumer habits, imperfect information and adjustment costs – and so the short run responses to price and income changes guide to the long run effects towards the equilibrium. In this turn, the restrictions of symmetry and homogeneity may not be accepted in the short run, but can be satisfied in the long run, that is why it is important to consider the long run equilibrium. This work then incorporates this dynamic aspect of consumer choice following the cointegration theory for it is possible to meet the requirements of identification/estimation of: long run preference parameters; separation of short run from long run effects; and LA-AIDS system.

In order to describe the dynamic model of LA-AIDs, the system in (5) can be rewritten as a vector error correction model (VECM) as follows:

$$\Delta Y_t = \mu D_t + \Gamma_1 \Delta Y_{t-1} + ... + \Gamma_{q-1} \Delta Y_{t-q+1} + \Pi Y_{t-1} + e_t \tag{9}$$

where Y_t = ($w_{GAS}, w_{ETH}, w_{CNG}, w_{DIE}, \ln P_{GAS}, \ln P_{ETH}, \ln P_{CNG}, \ln P_{DIE}, \ln(X / P))'$ - in other words, a 8 x 1 column vector of budget shares (9 less one variables, which is arbitrarily deleted in order to overcome the singularity of the system), prices and real expenditure - D_t is a vector of deterministic variables (intercept, trends…); μ is the matrix of parameters associated with D_t , Γ_i are 8 x 8 matrices of short run parameters (i=1,….,q-1), where q is the number of lags; Π is a 8 x 8 matrix of long run LA-AIDS parameters; and e_t is the vector of disturbances following identical and independent normal distributions with zero mean and $E(e_t e_t^{'}) = \sum . \; x_t$

Once the series in Y_t are integrated of order one, the balance between left and right hand side of model (13) will be achieved only if the series are cointegrated. The number of cointegrating vectors is defined by the rank of the matrix Π ; if rank (Π) =r, then Π can be written as a product of (8 x r) matrices α and β , as follows $\Pi = \alpha\beta'$. Matrix β has the long run parameters, such that $\beta' Y_{t-1}$ represents the *r* long run steady-state equilibriums. Matrix α is called the loading matrix, and their parameters represent the speed of adjustment to disequilibrium after a shock in the long run relationships. The matrices α and β are not unique, and thus there are many possible α and β matrices containing the cointegrating relations (or linear transformations of them). In those cases, cointegrating relations with economic content cannot be extracted purely form observed time series (Krätzig and Lütkepohl 2004).Therefore, the economic interpretation of the cointegrating vectors as structural long run relationships requires the imposition of at least r^2 restrictions (r of which are related to normalization conditions) on cointegrating space. In this work, in order for the cointegrating vectors to correspond to consumer demands based on a LA-AIDS model, symmetry and homogeneity restrictions were imposed.

It is worth emphasizing how the error correction model (9) depicts the consumption behavior. When consumers reach their long run optimizing allocation of expenditure across products they define a baseline plan. This baseline expenditure pattern can be modified for two reasons. First, through new information (on prices and real income) available since previous period, and whose impact in the baseline budget-shares is captured through the terms $\Gamma_j s = (1,...,q-1)$, the short term parameters and second, through the natural changes of budget shares in the current period, even without new information of last period. This is captured by the term ($\alpha\beta' Y_{t-1}$); which is the error correction term and where α denotes the speed of adjustment towards the long run equilibrium ($\beta' Y_{t-1}$).

5.1 Parameter estimates

Before the estimation of VECM model it is common practice to test for stationarity and orders of integrations in time series data. This is done here through the Augmented Dickey Fuller test (see Table 7). Results indicate that it is not possible to reject the hypothesis that all variables are I(1) using 1% and 5% levels of significance

Variable	**Lags**	**Model[a]**	**t-statistic**
w_{GAS}	1	τ	-1.623
Δw_{GAS}	0	τ	-3.325***
w_{ETH}	7	τ_μ	-2.804
Δw_{ETH}	3	τ	-2.039**
w_{CNG}	9	τ	5.996
Δw_{CNG}	0	τ	-3.508***
$\ln P_{GAS}$	8	τ_τ	-2.712
$\Delta \ln P_{GAS}$	0	τ	-6.972***
$\ln P_{ETH}$	1	τ	-2.183
$\Delta \ln P_{ETH}$	0	τ	-8.151***
$\ln P_{CNG}$	10	τ_τ	-3.292
$\Delta \ln P_{CNG}$	0	τ	-5.407***
$\ln P_{DIE}$	0	τ_τ	-3.322
$\Delta \ln P_{DIE}$	0	τ	-6.273***
$\ln X / P$	0	τ	2.522
$\Delta \ln X / P$	0	τ	-4.026***

a: Model τ indicates that Dickey Fuller does not contain any deterministic component; τ_μ indicates that only a constant is considered; and τ_τ indicates the inclusion of an intercept and a trend
***(**) Denotes the rejection of the null hypothesis at the 1%(5%) level of significance

Source: own elaboration

Table 7. Unit roots tests

Once identified the non stationarity of the variables, a VECM is specified with eight variables (w_{DIE} is excluded to avoid singular matrix). This model becomes operational once defined the lag order (q), the deterministic component to be considered, and the cointegration rank(r). Due to the almost heavily parameterized nature of the system and the modest sample size (t=33), the decision was taken to obtain the most parsimonious system as possible.The estimation was then carried out with just one lag (q=1)[4]. Relating to the cointegration rank, it is normally assumed that among (2n+1) variables (n budget shares, n prices and real expenditure) there are n-1 cointegrating vectors. In this work, with 9 variables, it is thus expected to have 3 cointegrating equations. Table 8 presents the Johansen trace statistic, which confirms the presence of three cointegrating relationships[5].

Maximum rank	Trace statistic	5% critical value
0	174.74	124.24
1	103.83	94.15
2	70.08	68.52
3	44.24*	47.21
4	22.15	29.68
5	8.34	15.41
6	0.44	3.76
7		

Source: own elaboration

Table 8. Results from Johansen Cointegration Rank Test

As mentioned previously, the economic interpretation of the cointegrating vectors as structural long run relationships requires the imposition of at least r^2 restrictions. In this work, it should be at least 9 restrictions. Therefore, besides the three normalization restrictions, it was also imposed three homogeneity and three symmetry constraints in order to be consistent with economic theory. Table 9 reports the estimated α and β matrices with the standard errors of the parameters[6].

The diagnosis statistics of the results are clearly satisfactory. The jointly hypothesis testing of the symmetry and homogeneity restrictions points out their empirical support; the likelihood ratio statistic of over-identifying constraints was 10.18, which is under the

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[4] This is a reasonable premise since relatively low order vector auto regressive models generally suffice in cointegration analysis. Concerning the deterministic term, the model was specified with the constant terms restricted to cointegration space.

[5] Due to the small sample used, it could be argued that this result is not valid. It was used then the Juselius (1999) approach, in which the significance of the adjustment coefficients of 3rd cointegrating vector is tested. According to this proposal, if all α_{i3} are non-significant, the cointegration rank should be reduced to 2. In the present case, all of the estimated adjustment coefficients for the third cointegration vector were significant, indicating that the model does have exactly the same number of cointegrating vectors and equations estimated (see Table 9 for loading coefficients from VECM estimation).

[6] A first check on the model statistical adequacy is made through some misspecification tests, like Doornik and Hansen normality test and Breusch-Godfrey autocorrelation test. The results approve the one lag specification; the test statistic of normality test was 18.86, with p-value of 0.275 , while the Breusch-Godfrey test statistic was 11.20, p-value of 0.190.

critical value of at the 5 per cent level of significance ($\chi^2(6)=12.59$). Overall, considering both the residual analysis and the hypothesis test of symmetry and homogeneity restrictions, it seems reasonable to indicate that dynamic model is more appropriate than the static model to describe the expenditure allocation process of Brazilian demand of automotive fuels

Tables 10 and 11 finally present the elasticities calculated. Before discussing the elasticities estimated, it must be emphasized that they are functions of price and expenditure shares and therefore vary over the data set. Following Balcombe and Davis(1996), the elasticities are here calculated at the last point in the data set, and not at the mean values, due to the fact that elasticities are themselves non-stationary random variables, given the nonstationarity of the data used (see Table 7).

	w_{GAS}	w_{ETH}	w_{CNG}	$\ln P_{GAS}$	$\ln P_{ETH}$	$\ln P_{CNG}$	$\ln P_{DIE}$	$\ln X/P$	**Constant**
$\hat{\beta}'_1$	1	0	0	1.237	-1.061	-0.034	-0.142	-0.749	15.354
				(0.125)	(0.099)	(0.006)	(0.037)	(0.134)	(2.819)
$\hat{\beta}'_2$	0	1	0	-1.061	0.680	0.039	0.342	0.724	-15.489
				(0.099)	(0.082)	(0.004)	(0.022)	(0.110)	(2.320)
$\hat{\beta}'_3$	0	0	1	-0.034	0.039	-0.001	-0.004	0.010	-0.198
				(0.006)	(0.004)	(0.002)	(0.005)	(0.005)	(0.097)
		α coefficients				t-values for α			
Δw_{GAS}		0.216	0.325	0.814		0.187	0.196	1.126	
Δw_{ETH}		-0.501	-0.567	-2.928		0.131	0.137	0.791	
Δw_{CNG}		-0.002	-0.002	0.000		0.007	0.008	0.044	
$\Delta \ln P_{GAS}$		0.982	0.950	13.233		1.498	1.566	9.018	
$\Delta \ln P_{ETH}$		1.790	1.887	8.792		1.812	1.895	10.909	
$\Delta \ln P_{CNG}$		1.535	1.498	7.137		2.270	2.374	13.666	
$\Delta \ln P_{DIE}$		0.674	0.520	9.757		1.465	1.532	8.819	
$\Delta \ln X/P$		-1.040	-1.087	-4.611		0.380	0.397	2.287	

* Standard error under parenthesis

Source: own elaboration

Table 9. Estimated β^* and α matrices under long run structural identification

As already shown the model has been approved by statistical tests, but if this is to be presented as a reasonable picture of Brazilian automotive fuels consumption, the implied behavioral measures must be in conformity to the theory of demand. From this point of view the results are also satisfactory.As required the own-price elasticities has negative signs. Ethanol and gasoline are, by far, the most sensitive fuels with quite elastic reactions to their own price changes. Focusing on the cross price elasticities, the positive signs for ($\varepsilon_{12}, \varepsilon_{21}$) and ($\varepsilon_{13}, \varepsilon_{31}$) indicates a substitution relation between gasoline and ethanol, and between gasoline and CNG. This can, a priori, indicates that the flex fuel technology (gasoline and ethanol) and the CNG conversion technology have preserved the substitutability among the fuels. These results are then consistent with microeconomic predicitions sincethese technologies tend to reinforce the substitution relation between the referred fuels as it allows the individual consumer to consider two fuels options in the same utility function, in which he will choose the cheaper option, holding fixed the energetic equivalence ratio of substitution between them.

Also relevant are the estimated sizes of $\varepsilon_{11}, \varepsilon_{21}, \varepsilon_{31}$ and ε_{41} being - 3.84, 8.09, 0.54 and 0.27; these numbers show that when gasoline price increases by 1 per cent, for example, consumers reduce the gasoline consumption by 3.84%, while compensating for the ethanol (8.09%) CNG (0.54%) and diesel (0.27%). This can so be regarded as evidence of a high substitutability, first, between gasoline and ethanol and, second, between gasoline and CNG. Concerning the superiority of the substitutability level of gasoline/ ethanol in relation to the level of gasoline/CNG, what can be argued is that the choice between the gasoline and ethanol seems to be more attractive for the consumers, since they don't have to pay any extra cost besides the cost related of the vehicle acquisition. In this regard, this trend will be certainly reinforced as long as the production of original flex fuel vehicles increases. On the other hand, the choice between CNG and gasoline is more restricted since the consumer has to face two distinct costs, the cost of buying a vehicle and the cost of installing the conversion kit of CNG.

		Gasoline (P1)	Ethanol (P2)	CNG(P3)	Diesel(P4)
ε_{1j}	Gasoline	-3.848	1.503	0.007	0.258
ε_{2j}	Ethanol	8.097	-3.583	-0.044	-3.881
ε_{3j}	CNG	0.540	-0.620	-0.780	1.374
ε_{4j}	Diesel	0.269	-0.668	0.269	-0.627

Source: own elaboration

Table 10. Marshallian Uncompensated Price Elasticities of the Demand System Equation using Dynamic LA-AIDS Model

η_1	**Gasoline**	1.188
η_2	**Ethanol**	0.077
η_3	**CNG**	-0.523
η_4	**Diesel**	1.014

Source: own elaboration

Table 11. Expenditures Elasticities of the Demand System Equation using Dynamic LA-AIDS Model

With respect to the depicted substitutability between gasoline and diesel, some comments have to be made. The result seems reasonable only because the model uses aggregated data. On the other hand, from a microeconomic perspective this result does not make sense, since these fuels do not represent real substitution options. First, because of the absence of a technology, which could allow this substitution and second, because diesel and gasoline are used by different profiles of automobiles; those devoted to long distance freight transport or land carriage typically use diesel, since it is cheaper than gasoline. In this sense, it is worth stressing that the model neglects the control for the fact that choice possibilities are different among different kinds of automobiles. This lack of control can also justify other inconsistent result here produced, the negative cross price elasticities of ($\varepsilon_{23}, \varepsilon_{32}, \varepsilon_{24}, \varepsilon_{42}$), which could evidence a surprisingly complementarity between ethanol and diesel, and between ethanol and natural gasoline.

As regards the expenditure elasticities, Table 11 shows that gasoline, ethanol and diesel are normal goods, and with the exception of ethanol, they are expenditure elastic. An interesting result concerns the CNG. Its elasticity is negative and is thus estimated to be an inferior good.

This result is possibly related to the motivation and income profile of current CNG consumers. The Brazilian production of new cars originally designed to run on CNG is almost irrelevant. The great majority of CNG consumers install the conversion kit expecting substantial fuel expenditure savings, in particular for those that drive long distance on a regular basis, as light duty passenger vehicles (essentially taxi drivers. In this sense, the CNG consumption profile in Brazil is not devoted to the large scale public transport system, as in Bangladesh, Pakistain or India. It is then important to note that the investment on conversion kit to CNG act as a fixed cost that only consumers who really want to save expenditure are inclined to pay. Hence, CNG consumers are definitely motivated by the cost saving purposes, especially due to the government policy of fixing relative prices favoring the fuel as a way to promote the expansion of natural gas consumption in the country[7]. The Brazilian demand of CNG is then still related to small scale transport, for which income is a great restriction.

What seems clear is that the choice of CNG fuel is thus driven mainly by the price aspect and less by the non pecuniary factors, as its energetic efficiency. Hence, it is reasonable to outline that as income increases the saving purposes tend to be less relevant and even if there are more consumers who are able to pay the fixed cost of the conversion kit, there would also be an increasing number of consumers – at least among those not interested in commercial purposes as taxi drivers are – who could begin to consider the low efficiency of the fuel[8] as reasonable criteria of choice, and so CNG could be less preferred.

This result is reinforced by the signals estimated of real expenditure ($\ln(X/P)$) parameters of - β_1, β_2 and β_3 in model (13). Once the symmetry and homogeneity restrictions are valid, as it is the case, demand theory predicts that positive $\beta^{'}s$ means "luxury good", and a negative sign means "necessary good" (Deaton and Muellbauer 1980) (Deaton and Muellbauer 1980). The real expenditure parameter of CNG share equation (β_3) is negative, while β_1 and β_2 have positive signs (see Table 9). CNG is so estimated as a "necessary good", and gasoline and ethanol are considered "luxury goods", in the sense that as the consumer gets more income he demands proportionally more gasoline and ethanol, and less CNG.

Overall, even though the estimations from cointegrated LA-AIDS are statistically (and economically) better interpreted than those from the static model, it is necessary to put forward that they still have to be cautiously evaluated. First, due to the limited span of

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[7] This pricing policy was stated by the government in order to diffuse the natural gas consumption in Brazil when the natural gas imports from Bolivia begun.

[8] At least in the way the CNG is currently used by engines not originally designed to run on it

observations over time, resulting in only 33 points in time for each variable[9]. For instance, the absence of longer data series makes difficult a bootstrapping analysis to estimate standard errors of the elasticities. Second, because the model uses aggregated data and not micro level records for households; and even with aggregated data it does not consider vehicle characteristics factors – as fleet composition by fuel, which could be a significant parameter in explaining the expenditure allocation process.

6. Conclusions

This work aimed at estimating the price and income elasticities of automotive fuels demand in Brazil. The analysis of the expenditure allocation process among the gasoline, ethanol CNG and diesel was carried out through the estimation of a linear approximation of an AIDS model. This model is very convenient due to its ability to fulfill much of the desired theoretical properties of demand, being at the same time parsimonious regarding the number of parameters. Furthermore, the equations to be estimated derived from LA-AIDS are linear in parameter which allows the use of econometric methods widely available in terms of testing and estimating procedures. Two estimation methods were tried: a static and a dynamic (cointegrated). Specification tests seem to support the use of the dynamic model.

Based on the favorable diagnostic on the second set of estimations it is important to point out some of their relevant results.

First, it is worth to remark the high substitutability between gasoline and ethanol, and also the fact that this substitution relation is larger than the one observed between gasoline and CNG. Some comments concerning this result are thus in order. This finding seems to confirm the rationale that flexible technologies tend to reinforce the substitution relation between the fuels. This is particularly true for the gasoline and ethanol because the consumers don’t have to pay an extra cost besides those related with the vehicle buying to access the possibility of choosing between the refereed fuels. On the other hand, the option between CNG and gasoline is more restricted since the consumers have to pay not only for a vehicle but also to install the conversion kit of CNG. There is then a transaction cost which is not irrelevant. This difference in favor of the substitubility between gasoline and ethanol seem to increase as the production of original flex fuel vehicles increase.

Second, the estimations here produced suggest that gasoline, ethanol and diesel are normal goods, and except for ethanol, they are expenditure elastic. An interesting result concerns the CNG which is estimated as an inferior good. A possible explanation for this outcome could be the motivation and income profile of current CNG consumers. These consumers are mainly interested in saving purposes, since CNG is favored by a specific government policy of price differential with liquid fuels. For this reason, the choice of CNG fuel is driven mainly by the price aspect and less by the non pecuniary factors, as its low energetic efficiency. As income increases, the saving purposes tend to be less relevant and even though there are more consumers who are able to pay the cost to install the CNG kit, there would also be an increasing number of consumers who would consider the low efficiency performance of the fuel as a reasonable choice criteria, and so CNG could be less preferred.

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[9] By the time this work was reviewed the Brazillian Ministry of Mines and Energy has launched the Balanco Energetico Nacional from 2009 which contains annual data on fuel price and consumption until 2008. Therefore, even if the work has considered this last annual data collection it would have resulted in only three more annual observations for each variable. That being the case, it is reasonable to assume that the results here produced would not present significant changes if the data was extended.

Overall this work tried to improve the understanding of the consumer's behavior and their possibilities and criteria to choose automotive fuel in Brazil. Two important policy implications can be derived from this analysis. First, there are implications on tax revenues from gasoline sales. Based on the result of a high substitutability between ethanol and gasoline and considering that the production of flex fuel vehicles has been augmenting in an expressive rate since its launching in 2003, the future gasoline consumption is likely to be more dependent on ethanol prices. For this reason, the tax revenue from gasoline can be affected by the supply of ethanol which as an agricultural commodity has intrinsic seasonalities and can be subject to potential supply disruptions. Considering that the share of tax on final price of gasoline is quite relevant in most state governments in Brazil, governments may have to redesign their fiscal policy regarding this fuel in order to smooth its tax revenue. Second, there are implications on the government strategy to promote the use of natural gas. Considering that the pace of GNC expansion has presented an impressive level (see Table 1) and assuming the fact here assessed that the fuel is an inferior good, the government may have to readequate its fuel pricing policy in order to direct the consumption of natural gas to other worthier uses than for small scale transportation.

A possible extension to this work is to examine some specific states from Brazil, for which is possible to use monthly data (at least from 2001 ownwards), to explicitly consider the taxes charged on the fuels (which assume different levels among the states), and to include further controls through aggregated data on stock of vehicles by fuel (which is available only at the states level). Through this measures it will be possible improve the estimation of the parameters of interest.

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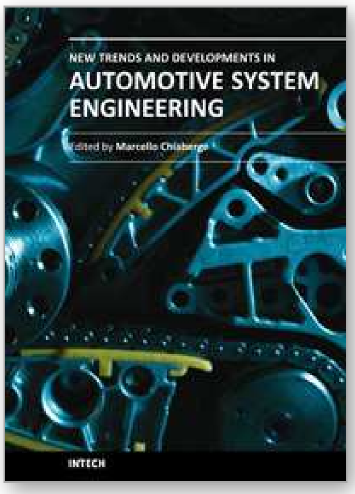

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In the last few years the automobile design process is required to become more responsible and responsibly related to environmental needs. Basing the automotive design not only on the appearance, the visual appearance of the vehicle needs to be thought together and deeply integrated with the â€œpowerâ€ developed by the engine. The purpose of this book is to try to present the new technologies development scenario, and not to give any indication about the direction that should be given to the research in this complex and multi-disciplinary challenging field.

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