Forecasting of petroleum consumption in Brazil using the intensity of energy technique

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The purpose of this paper is to forecast petroleum consumption in Brazil for the year 2000 based upon logistic models, learning models, and translog models using the technique of intensity of energy use. The models employ a time series of 30 years for projection. An investigation of the evolution of petroleum consumption profile was made based upon three characteristic effects: structural, content and scale effects. Evaluation of forecasting models presented good results, with the translog model showing the best performance in terms of accuracy. The learning and translog models indicated that GDP is the main determinant for petroleum consumption evolution in the future, defining a range of 64 000 and 109 000 thousand of tonnes of oil equivalent on two defined GDP growth scenarios.

Keywords: Petroleum consumption; Forecasting methods; Brazil

The relation between the evolution of petroleum consumption and economic activity in Brazil is used as a forecasting technique. We can define at an aggregate level the intensity of energy use (IE) as the ratio between the amount of energy consumed and the overall level of economic activity (GDP or GNP). This relationship can be used to measure different types of ratios in terms of time, or of spatial trends, of the energy system.

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This approach is a conceptually attractive long-term forecasting technique for energy and minerals, because it relates consumption in physical terms (ie tonnes of oil equivalent) to some basic determinants, such as gross domestic product (GDP) and/or population. By using several conversion coefficients or equivalents it is possible to evaluate the different forms of energy consumption (coal, petroleum, natural gas, electricity) on a standard basis.

In recent years, research has been directed to finding new methods for long-term energy demand forecasting. The intensity of energy use employed in this study is simple in terms of economic structure. This is deliberate, because when we are dealing with long-range forecasting of petroleum consumption, dynamics of demand and its major determinants, GDP and technology, may be more important than prices and their substitutes to explain across-time patterns of petroleum consumption. The tendency to formulate complex models richer in economic structure in order to simulate future consumptions is moderated to some degree by the need to build dynamics into such models and to estimate the states of at least some economic determinants.

In this work the ratio of apparent petroleum consumption to GDP, defined as IPE (intensity of petroleum usage) will be employed in three different ways. First, as a logistic model emphasizing the across-time changes in consumption, in contrast to short-run models which emphasize price theory. Second, as a simple learning model since across-time consumption reflects in part improvements in energy. Third, as a translog model expanded to include economic variables other than per capita GDP, eg own price, substitute price and technical change.

These models are tested for Brazil's petroleum consumption in the year 2000, based upon a historical

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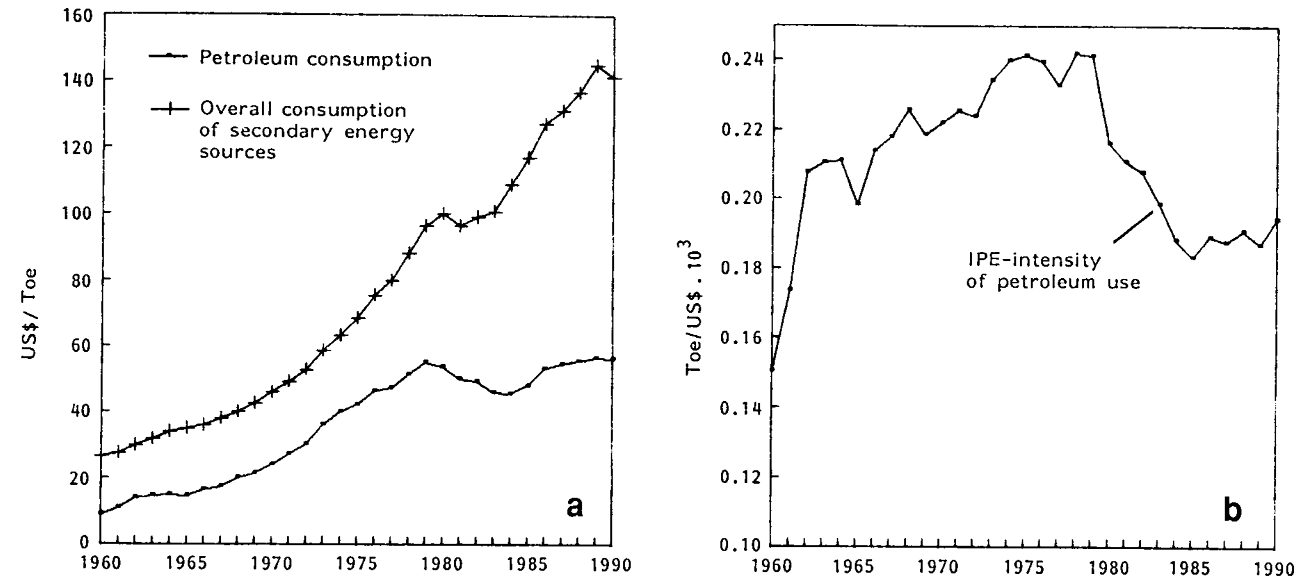

Figure 1. Petroleum consumption and intensity of petroleum use (IPE).

series of 1960–90. Most models are initially estimated on a restricted data set to permit their evaluation and further comparison by *ex post* forecast accuracy; then they are reestimated for their use for forecasting. Although these techniques were used for petroleum consumption in Brazil, their basic principles and conceptual framework are general enough for other regions and energy products.

The next section presents a brief analysis of some patterns of petroleum consumption in Brazil during the past 30 years, as a framework for facilitating the application of the forecasting models. This is followed by a general review of different concepts, modelling and forecasting of the ratio energy/GDP. Finally, the last section is devoted to the evaluation of the models.

Petroleum consumption in Brazil

The extended period of 1960–90, used as a background for statistical projections, was fundamental to the Brazilian petroleum market and industry build up (Figure 1). The fast industrialization of the economy until 1980 was the main reason for consumption growth. This process of easy and rapid economic progress during the post-war period was called 'petroprosperity' because of the central role played by petroleum consumption in shaping the economic dynamics.[1] Technologies which prevailed in that period used that source of energy intensively. For example, roads provided the basis for the new transport system of that period, thus playing a central role in the economic unification between the main regions of the country. On the other hand, the main driving consumer force was centred on the car. At the same time, the heavy industry shift made intensive use of petroleum products and hydroelectricity.

The increase of petroleum consumption in the Brazilian market was covered exclusively by imports of crude petroleum. The national petroleum company Petrobrás, which took care of production, refining and transport, became self-sufficient in its refining capacity, but relied heavily on crude imports. During the 1960–80 period imports increased almost nine times, covering nearly all demand fluctuations (Table 1). In this sense, Brazil is a special case in the group of large- and medium-sized Third World countries. Most of these countries in Latin America are export oriented or at most self-sufficient in their petroleum supply. In Brazil, however, the formation of one of the largest petroleum markets in the Third World (55 million tonnes oil equivalent/year) was predominantly covered by imports, as was the case in Western Europe and Japan. This singular situation occurred in a country of continental dimensions, but which initially has not indicated a high level of petroleum production, despite some recent favourable geological reservoirs in off shore areas.

Its great volume of petroleum imports critically penalized the Brazilian economy in the two petroleum shocks of 1973 and 1979. After the last shock, consumption stabilized and internal production developed by Petrobrás in the off shore basins, increased dramatically (see Table 1), showing a

Table 1. Economics of petroleum in Brazil (thousand tonnes of oil equivalent).

	1960	1967	1973	1979	1985	1990
Petroleum consumption (*Cpetro*)[a]	8.892	17.378	36.126	55.006	48.106	56.539
Overall consumption of secondary energy sources (C_t)	26.735	38.126	58.627	96.464	117.039	141.297
Petroleum imports	5.638	10.474	35.165	50.049	27.422	28.882
Petroleum production[c]	4.049	7.318	8.493	8.262	27.493	31.905
GDP[b]	59243	79802	154206	227749	263004	290941
$Cpetro/C_t$	0.33	0.46	0.62	0.57	0.41	0.40

[a] Apparent petroleum consumption in thousand of toe. [b] GDP expressed in thousand of US$ constant 1989 values. [c] Conversion factors $1m^3 = 0.864$ tonnes (1989).

Sources: Petroleum: Ministerio da Infra-Estrutura, *Balanço Energético Nacional (BEN)*, Brasília, DF, several issues; GDP; *Relatório Banco Central* (several issues); *Conjuntura Economica-FGV* (several issues).

remarkable capacity for productive transformation of the Brazilian economy.

To elucidate some of this important transformation in petroleum consumption patterns, we have made a more detailed analysis of three characteristic effects. These effects are analytical instruments which throw light on the structural changes in patterns of energy consumption and economic growth. These instruments only allow structural change perception without covering the main determinants of the overall process. These effects are not deterministic; rather they reflect the influence of numerous economic changes in the petroleum consumption profile.

For a better understanding of consumption trends and of the intensity of petroleum use (IPE), it is necessary to establish analytical tools for distinguishing the principal structural changes in the relationship between energy and economics during the last decades in Brazil. The petroleum consumption in year t can be considered a product of three ratios, represented as follow:[2]

$$Cpetro = Cpetro/C \,.\, C/GDP \,.\, GDP \qquad (1)$$

where:

- *Cpetro* = apparent petroleum consumption
- *C* = overall consumption of secondary energy sources
- *GDP* = the total output of the economy produced during the year t, represented by the gross domestic product

The impacts of petroleum consumption produced by the economic growth can be evaluated by using increments in the following way:

$$\Delta Cpetro = \Delta(Cpetro/Ct) + \Delta(Ct/GDP) + \Delta(GDP) + \epsilon \qquad (2)$$

where

$\Delta(Cpetro/Ct)$ = structural effect
$\Delta(Ct/GDP)$ = content effect
$\Delta(GDP)$ = scale effect
ϵ = residues

or by using the formulation of intensity of petroleum use:

$$\Delta(IPE) = \Delta(Cpetro/GDP) = \Delta(Cpetro/Ct) + \Delta(Ct/GDP) + \epsilon \qquad (3)$$

Equation (3) shows that the intensity of petroleum use (IPE) as a function of GDP, depends directly on fluctuations of petroleum contributions in the energy matrix (structural effect) and the intensity of energy GDP (content effect). The analysis of past trends consumption suggests the use of Equation (2), because it accommodates the three effects that are important for petroleum consumption evaluation.

1960–73: diffusion of petroleum consumption

Brazil's growth of GDP, industrial production and trade was very high until the oil shock of 1973–74. In these years, the share of petroleum consumption in the energy matrix reached a maximum of 60% against 32% in 1960 (Table 2). During this period, two distinct phases can be identified: 1960–67 and 1967–73. Although the two phases showed identical growth rates, a close look at Equation (2) reveals a distinct rationality (Table 1).

Table 2. Average annual percentage growth of the main determinants of petroleum consumption.[a]

	$Cpetro/C_t$	C_t/GDP	*Cpetro*	*GDP*	*IPE*	C_t
1960–67	5.54	0.10	11.07	5.20	5.51	5.23
1967–73	4.06	−2.88	12.33	11.14	1.06	7.93
1973–79	−2.62	0.97	5.10	6.90	−1.64	7.89
1979–85	−3.93	1.91	0.13	2.28	−2.16	4.18
1985–90	−1.22	1.99	1.44	0.77	0.73	2.76

[a] *Cpetro* = apparent petroleum consumption; C_t = overall consumption of secondary energy sources; *IPE* = *Cpetro/GDP*.

Sources: *Balanço Energético Nacional* (several issues); GDP: *Relatório Banco Central* (several issues); *Conjuntura Economica-FGV* (several issues).

$$\Delta\ Cpetro = \Delta\ Cpetro/Ct + \Delta\ Ct/GDP + \Delta\ GDP + \epsilon$$

$$(1960\text{–}67)\ 11.07 = 5.54 + 0.10 + 5.20 + 0.23$$

$$(1967\text{–}73)\ 12.33 = 4.06 - 2.88 + 11.14 + 0.21$$

An intense growth in petroleum consumption marked the first phase (1960–67). The main causes can be attributed to the fast penetration of petroleum in the national energy matrix consumption (structural effect) and also to Brazil's economic expansion. The IPE grew considerably, at an annual rate of 5.5% in this period, which can be put down to a positive structural effect.

The next phase 1967–73 showed distinct effects functioning, despite similar consumption trends. The performance of the Brazilian economy from the mid-1960s until the mid-1970s was impressive, with GDP growing at an average annual rate of about 11.5%. These years are frequently referred to as the period of the Brazilian miracle, which created favourable conditions for an increase in consumption and in the penetration of petroleum in the energy consumption matrix. Petroleum consumption did not increase substantially, because there was a reduction in the content effect (−2.88%). The justifications for these variations have been evaluated elsewhere. A significant change of the macroeconomic setting in the second half of 1960s, which included an important expansion of imports coefficient, contributed to internal economic disruptions in energy consumption.[3]

1973–90: substitution of petroleum products

Although this period was very heterogeneous, it exhibits a constant reduction in relative shares of petroleum in the energy matrix. Based on this, three characteristic phases can be distinguished. The first covers the two petroleum shocks with a steady growth of petroleum consumption at an annual rate of 5.1%, as shown below:

$$\Delta\ Cpetro = \Delta\ Cpetro/Ct + \Delta\ Ct/GDP + \Delta\ GDP + \epsilon$$

$$(1973\text{–}79)\ 5.10 = -2.62 + 0.97 + 6.90 - 0.15$$

The main reason for this continuous increase was the maintenance of economic expansion, with high rates of growth even when compared with other periods. After the first shock, a noticeable share reduction of petroleum in the energy matrix (structural effect), was followed by an increase in the content effect (0.97%). This elevation of IE (intensity of energy use) was induced by changes in productive structure, generated by programmes of imports substitution such as II PND (national programme of development). Consequently, IPE dropped −1.64% as a result of the structural effect mentioned previously (Table 2).

The second oil price shock determined the next phase (1979–85), associated with the upheaval of international conditions, creating disruptions in the country's balance of payments. Internal energy policy responded with severe changes to this situation, implementing corrections in the energy matrix to reduce oil imports products. Petroleum consumption stabilized in this period, as we can see below:

$$\Delta\ Cpetro = \Delta\ Cpetro/Ct + \Delta\ Ct/GDP + \Delta\ GDP + \epsilon$$

$$(1979\text{–}85)\ 0.13 = -3.93 + 1.91 + 2.28 + 0.13$$

The consumption of non-oil fuels was largely encouraged, as indicated by the negative structural effect. At this stage, the structural effect resulted from a substitution between energy products, while in the previous period that effect indicated changes in the productive structure of the economy with impacts on the energy matrix. The oil substitution in the 1979–85 period was based upon the following framework: fuel petroleum substitution in the industrial sector by electricity, steam coal and charcoal.[4] In the transport sector gasoline was displaced by sugarcane ethanol.

A marked rise in the intensity of energy use (IE) resulted from import substitution and from a great emphasis on an export-oriented policy to achieve larger positive surpluses in the trade balance. Despite its poor performance (less than historical average values), GDP had a positive role in the increase of energy consumption. As a result of conflicting forces, the IPE continued to decrease, because the petroleum consumption growth had been less than GDP.

The more recent stage of 1985–90 shows an extension, or even a progression, of the economic crisis. However, petroleum consumption did begin to increase. This evolution can be described as follows:

$$\Delta\ Cpetro = \Delta\ Cpetro/Ct + \Delta\ Ct/GDP + \Delta\ GDP + \epsilon$$

$$(1985\text{–}90)\ 1.44 = -1.22 + 1.99 + 0.77 + 0.10$$

An expected growth of consumption, even modest, was associated with low international and domestic petroleum prices. Nevertheless, the structure effect was still negative, but at a lower level, as observed above. On the other hand, the content effects were increasing with high rates, indicating a trend in the Brazilian economy which began after the first oil price shock and increased during the 1980s.

During this period, GDP showed insignificant progress, because of the huge reduction of its growth rates in 1990. Consequently, as a result of this process IPE started a remarkable growth of 0.73% per year.

Forecasting intensity models

Several authors have used the intensity of energy ratio to forecast the evolution of energy.[5] The approach used in this study is similar to those proposed by one of the authors for mineral commodities.[6] The procedure for forecasting petroleum consumption in the 1960–90 period is very straightforward and can be accomplished through the following steps:

- Fitting a GDP or GDP per capita function. In this study, this was done by projecting a simple exponential trend model for both variables.
- Estimation and fitting of IPE by different models: logistic, learning, and translog.
- Evaluation of forecasting method by average absolute error (AAE).
- Petroleum consumption forecasts to the year 2000 were made simply by multiplying IPE by forecast GDP, and by using different assumptions for GDP, petroleum prices, and substitutes prices.

In the present work we are more restricted to long-range macroeconomic trends and to long time series. Consequently, the use of GDP tends to favour the IPE as a forecasting tool because we are not individually examining the various sectors of the economy in terms of the overall energy consumption of each energy product.

The logistic trend models and simple learning models associate petroleum consumption with economic output, while translog models are expanded to include other economic variables in addition to per capita GDP or GDP eg own price, substitute price, and technical change.

The ratio of consumption (D_t) to a measure of national income (Y_t), such as GNP or GDP, was defined as intensity of use for mineral commodities.[7] The concept can be easily extended to the case of petroleum with minor modifications. Malenbaum showed that intensity of use plotted against per capita income, y, exhibits a skewed bell-shaped pattern for highly industrialized economies, where the graph of y against IU or IPE is of lognormal type shape.[8]

A fundamental criticism is that the simple intensity model does not describe the use of an energy product by a domestic economy in a comprehensive sense because it ignores the energy embodied in imported and exported products, technical change and relative prices of substitutes.

Attempting to preserve the robustness of the lognormal-type pattern, Harris and Jeon showed that representing the intensity pattern by a lognormal model implies an income demand model in which income elasticity of demand varies with income level.[9] This demonstration is based upon the equivalence of lognormal and translog models as summarized in Appendix 1, which gives the following model:

$$IPE_t = T(y, P, Ps, \tau; \Omega) \tag{4}$$

where

P = own price
Ps = substitute price
τ = technical change
Ω = coefficients of expanded translog model

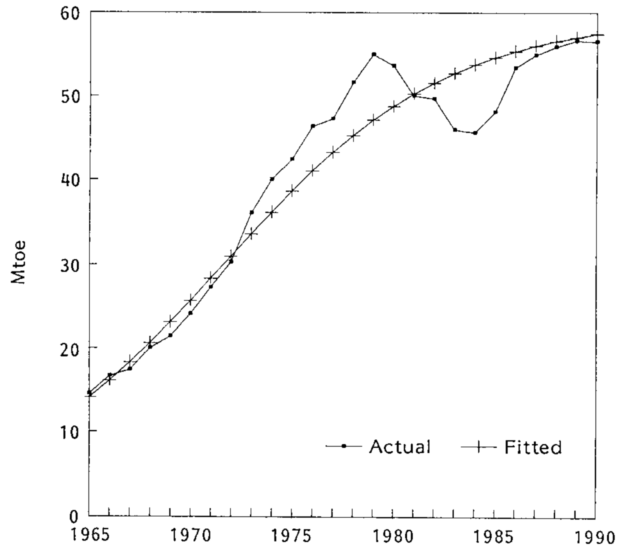

Figure 2. Actual and estimated consumption logistic model.

Simple time trend projection of IPE

Trend projection is based upon the premise that the petroleum demand over time presents a general regularity of growth or decline that will persist in the future. Trend analysis and projection requires a history of economic activity sufficient to clearly describe patterns of long-term growth or decline in time series. Then, based upon a number of strong assumptions, a mathematical trend model is fitted and extrapolated to some future time horizon.

Forecasting by trend projection requires the simultaneous identification of the preferred trend model and of the database for the estimation of model parameters. The selection of a model and data by visual inspection of fit and sum of squares of residuals is difficult when two or more models both fit the data reasonably well.[10] Accordingly, they suggest the comparison of slope and intercept characteristics computed from time-series data with those known models. A computed program can easily select the time series trend model.[11]

The program generates a logistic model (Figure 2) based upon the slope characteristic of a five-period moving average of the IPE data for 1965–90 period:

$$d_t = \frac{15.40668}{0.26+0.84^t} \quad t = 1.26$$

Learning model

Learning models are important management tools and have been used to assist in planning, budgeting and goal setting, and economic analysis.[12] A learning model describes the empirical relations between output and input quantities, where improvement of learning is present.

There are two motivations for using learning models in forecasting mineral consumption that can be extended to petroleum consumption. The first is that energy consumption must reflect to some degree the energy savings created by technical changes in energy utilization, and these changes are evidence of a type of learning.

The second motivation does not derive from learning and improved application of a given technology at all, but from the nature of time-series data and their use in long-range forecasting. Simply stated, this approach forecasts integral series as an indirect means of forecasting the derivatives rather than forecasting the time.

A simple learning model based upon projection of integral series was defined in the following way:

$$\tilde{W}_t = \frac{\tilde{D}_t}{\tilde{Y}_t} = L(\tilde{Y}_t) \qquad (5)$$

where

$\tilde{D}_t$ = cumulative petroleum consumption
$\tilde{Y}_t$ = cumulative per capita income
$L(\ )$ = a learning function

Once parameters of the learning model $L(\ )$ for $\tilde{W}_t$ have been estimated, the model can be transformed to describe annual consumption, D_t (see Appendix 2). Figure 3a shows a plot of $\tilde{W}_t$ against $\tilde{Y}_t$. Regression analysis and several transformations indicated in Appendix 2 produced the following linear consumption equation:

$$D_t = 19.8519 Y_t .\ \tilde{Y}_t^{0.2029}$$

Figure 3b also shows the fit of consumption derived from the learning model to the actual petroleum consumption data. Consumption is forecast for a future year by substituting the variables (GDP per capita projected and cumulative) in this equation. The unavailability of data limits us to simple forms, but there are other possible extensions of learning models which could be used to forecast petroleum consumption and energy products.[13]

Translog model

Given that the lognormal is an acceptable model for the relation of IPE to per capita GDP, a translog

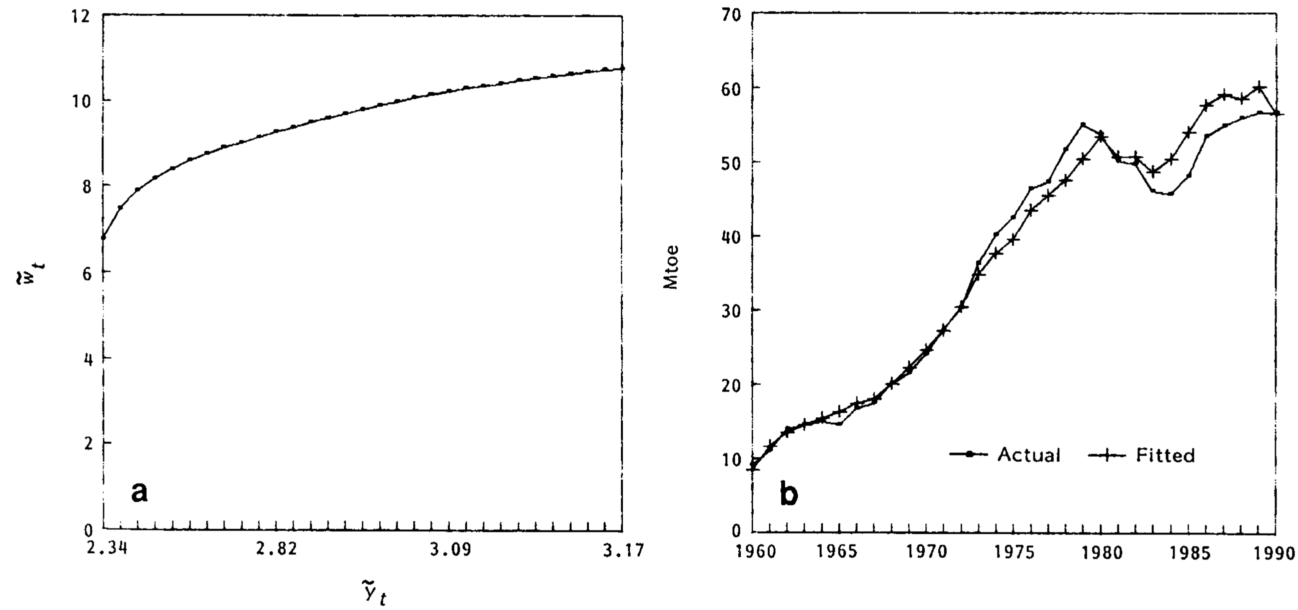

Figure 3. Simple learning model.

model can be drawn from Equation (4). Neither of these models or combinations could be applied directly to Brazilian petroleum consumption because measures of technical change or productivity were not available for the time period of analysis. To compensate for these problems, time was used as a proxy for technical change.

A constructed substitute price (Pw_t) was developed using the principal substitute petroleum energy sources – industrial electricity, coal, steam coal, and ethanol – based upon weighted percentages of consumption in the energy matrix. In this model we are restricted to the 1973–90 period due to availability of time series prices. The selection of relevant cross-products by stepwise regression was made through the statistical package SAS generating the following translog model:[14]

$$D_t = 0.1966 y_t^{1.0787 - 0.0066 \ln(P_t) - 0.013 \ln(Ps_t) \tau_t^{0.0582 \ln(Ps_t) - 0.1028 \ln(\tau_t)}}$$

where

D_t = petroleum consumption tonnes of petroleum equivalent
y_t = GDP (billion 1989 US$)
P_t = petroleum price (US$/tonnes oil equivalent 1987 constant price)
Ps_t = weighting substitutes petroleum price (US$/ tonne oil equivalent – 1987 constant price)
τ_t = time as a proxy for technical change

Figure 4 shows the fit of the translog consumption model for the base period 1973–90.

Evaluation of forecasting models

One of the most significant aspects in the evaluation of forecasting methods relates to the efficacy of the model to reproduce, at satisfactory levels, the real conditions of petroleum consumption in the energy system. Obviously, the integral representation of the process is an ideal reference. This restriction leads to the use of validation methods based upon screening tests to verify the degree of accuracy.

Evaluation of the accuracy of the forecasting method is based on *ex post* performance on a test

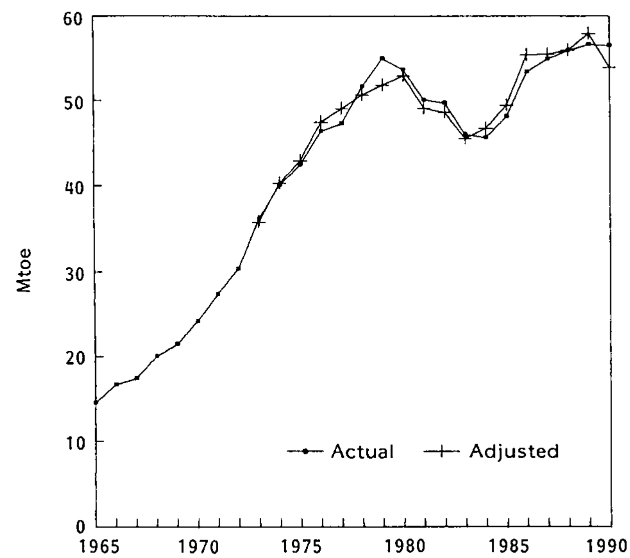

Figure 4. Actual and estimated consumption translog model.

Table 3. Average absolute errors (AAE) of estimated models for petroleum consumption in Brazil.

Model	Observed period	AAE	*Ex post* period	AAE
Logistic	1965–90	0.07	1985–90	0.04
Learning	1960–90	0.05	1985–90	0.05
Translog	1973–90	0.02	1985–90	0.02

period (1985–90) by average absolute error (AAE). For this purpose the last few years were deliberately withheld in the estimation of the models. Then, the entire data set was reestimated and these models were used to forecast petroleum consumption in the year 2000. Table 3 shows the accuracy of results for the different models, and the forecasts of petroleum consumption were summarized in Table 4. GDP estimates for the year 2000 are based upon IPEA projections of two scenarios of 2.0% and 5.8% annual average rates of growth; these give the low and high forecast respectively.[15]

Projection of translog models depends on price forecasting. However, reliable price forecasts are particularly elusive in the real world. Because of the difficulty of price forecasting, prices are usually treated as sensitivity variables. In this paper, two projections of price trends were used. The first alternative was developed under the assumption that the prices of petroleum and their substitute energy sources will remain constant at their average values for the 1990 period defined in Table 3 as translog(1). The second projection was based upon the assumption that the price level will experience the high values of the 1980–85 period defined as translog(2).

The logistic model presented a good fit for the last four years (1987–90), and became less inaccurate in the periods of low consumption (1983–84) and when the consumption reached a peak in 1978–80. These results reflect the functioning of a logistic curve which increases slowly during its youth, then experiences a period of very rapid growth, after which the rate of growth decreases, eventually levelling off, but never showing an absolute decrease.

The projections based upon the logistic model indicated a consumption of 59.152 thousand tonnes of oil equivalent (Table 3), which represents a low growth rate of 5% in a 10 year period. The logistic model anticipated the petroleum consumption saturation due to energy shock, and demonstrated a low sensitivity for a possible surge in consumption. Due to an irregular behaviour pattern, this model tends to generate a consumption saturation in the Brazilian case similar to mature economies. The results could be more auspicious by forecasting the global energy consumption, with low fluctuation level due to substitutions between energy sources.

The simple learning model represents the recent recovery of petroleum consumption very well. The possibility of incorporating successive petroleum shocks and scenarios of GDP growth is one of the great advantages of that kind of model. Accordingly, the learning system is a good model for irregular petroleum consumption pattern and for the representation of the initial stages of early Brazilian industrialization.

The translog model presented the best fit for the *ex post* period and the entire data set. This model includes the major determinants of across-time petroleum consumption: petroleum price, price induced energy sources substitution, level of economic activity and technical changes. The regression results of the translog model appear satisfactory. The goodness of fit for the equation is very satisfactory, having a value of $R^2 = 0.95$. The Durbin–Watson test indicated a low level of autocorrelation between the variables. As in the two former models, the GDP plays a key role in shaping petroleum consumption in the study period as indicated by coefficient (1.0787). This is reflected by small price elasticity of consumption P_t and Ps_t and technical change τ_t.

The learning model indicated a moderate level of growth of petroleum intensities (IPE) in all proposed scenarios (Table 4). This shows that the evolution of petroleum intensities projected by the learning model for the year 2000 is similar to 1985–90 period. By contrast, the translog model denoted a decline in IPE, which demonstrated the substantial impacts in the future evolution of petroleum consumption when price and technical change are incorporated. Discrepancies in projected figures between learning and translog(1) models can be attributed to technical change in the reduction of future consumption values. In both GDP scenarios, these discrepancies are more significant than the differences generated by petroleum price and their substitutes in the translog(1) and translog(2) models. Technical change explains almost two-thirds of induced variations in the high growth scenario and 57% in the low growth scenario. Yet, the faster the growth is in the economic scenario, the faster the technical change projected by the model.

A comparison of projected values indicated that the impacts of the petroleum price estimated in the translog model were relatively small when compared with GDP variations or even technical progress at the evolution of future consumption. Consequently, if the petroleum price remains at the 1990s' relatively low levels, we will probably obtain a reduction in

Table 4. Brazilian petroleum demand forecasts to the year 2000 by different models (thousand tonnes of oil equivalent).[a]

Model	Low (GDP = 2.0%)	IPE average annual rate (%) (1990–2000)	High (GDP = 5.8%)	IPE average annual rate (%) 1990–2000	Time trend projection
Logistic	–	–	–	–	59.192
Learning	74.913	0.38	109.586	0.53	na
Translog(1)	68.773	−0.47	95.944	−0.79	na
Translog(2)	64.298	−1.1	89.469	−1.49	na

[a] Scenarios for GDP: Institute de Pesquisa Econômica Aplicada (1991). Scenarios for prices: translog(1) – petroleum price = US$15.8 toe, and substitute energy sources = US$42.7/toe (constant price 1987); translog(2) – petroleum price = US$36.1/toe, and substitute energy sources = US$51.2/toe (constant prices 1987)

Source: *Balanço Energético Nacional* (several issues) for price.

IPE. In another sense, even with duplicated price reaching the levels of the early 1980s, the consumption would fall only 4.4 millions of tonnes of oil equivalent in this pessimistic scenario.

Conclusions

The purpose of this study was to analyse the evolution of the intensity of petroleum use (IPE) and petroleum consumption in Brazil in the last 30 years, and to forecast petroleum consumption for the year 2000, using a combination of quantitative methods and economics for long-range projection, emphasizing the IPE technique.

Examination of entire consumption time series indicated that a decrease in petroleum in the energy matrix started in 1973. Consequently, it seems that petroleum will retain the same relative position in the energy matrix or even start a slight recovery. The historical series reveals a constant increase of IE since 1973. In our opinion, this process will probably be exhausted in the near future because it lacks real economic feasibility.

The learning and translog models showed that the GDP is the main explanatory variable in the evolution of petroleum consumption. They exhibited similar results within the range of 64 and 109 millions of tonnes of oil equivalent. A secondary role in the framework of petroleum consumption was developed by technical change followed by petroleum prices and their substitutes, which became more important with the reduction in the level of consumption and IPE. Evaluation of absolute average errors (AAE) indicates that the translog model showed the highest accuracy. This model describes petroleum consumption satisfactorily by involving not only economic activity, but also petroleum prices, substitutes and technical change.

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Appendix 1

Translog intensity model

Examination of the definition of intensity of energy usage as an economic model leads by analogy to a simple income demand model:

$$d_t = A.y\alpha_t$$

where

d_t = per capita energy consumption
y_t = per capita income
A and α = parameters

Recalling that the concept of IPE and a generalized equivalent of the lognormal function:

$$IPE_t = \frac{K}{\sigma\sqrt{2\pi}}\exp\left(-\frac{1}{2}\left(\frac{\ln y-\mu}{\sigma}\right)^2\right)$$

where K, σ and μ are lognormal curve parameters and A, β_0, and β_1 translog parameters, and where

$$\ln A = \ln K - \ln\sqrt{2\pi} - \mu^2/2\sigma^2$$
$$\beta_0 = \mu/2\sigma^2$$
$$\beta_1 = -1/2\sigma^2$$

Given

$$IPE_t = \frac{\dfrac{D_t}{pop_t}}{\dfrac{Y_t}{pop_t}} = \frac{d_t}{y_t} = \frac{D_t}{Y_t}$$

or

$$d_t = IPE_t.y_t$$

where d, y_t are per capita petroleum consumption and per capita GDP respectively and pop_t population. Therefore,

$$d_t = Ay^{\beta_0+1+\beta_1\ln y_t} \Leftrightarrow IPE_t = Ay^{\beta_0+\beta_1\ln y_t}$$

Finally,

$$D_t = d_t.pop_t = IPE_t.Y_t$$

Thus, the income elasticity of per capita demand is $\beta_0 + 1 + \beta_1.\ln y_t$, and the income elasticity of intensity of petroleum energy(IPE) is $\beta_0 + \beta_1.\ln y_t$. The value of this demonstration lies in the fact that it is a formal linkage of IPE and demand. Designating the translog IPE model by $T(y;\beta)$, where $\beta' = [A,\beta_1,\beta_2]$, the derived demand theory suggests that a more complete description of IPE would include own price P, substitute price Ps and technical change τ:

$$IPE_t = T(y,P,Ps,\tau;\Omega)$$

where Ω is a vector of coefficients of the expanded translog model. Usually, stepwise regression analysis eliminates many of the cross-product variables to give a simplified model. The estimation in our case resulted in the classical power model as a special case.

$$\begin{aligned}\ln D_t = {} & 1.6268 + 1.0787\ln(y_t) \\ & - 0.0066\ln(y_t)\ln(P_t) \\ & - 0.0131\ln(y_t)\ln(Ps_t) \\ & + 0.0582\ln(\tau_t)\ln(Ps_t) \\ & - 0.1028\ln(\tau_t)^2\end{aligned}$$

Table 5 gives the model statistics.

Table 5. Model statistics (R^2 = 0.956).

Variable	Parameter estimate	Standard error	*T*-statistics
intercept	−1.6268	2.7196	−0.598
$\ln(y_t)$	1.0787	0.2267	4.758
$\ln(y_t)\ln(P_t)$	−0.0066	0.0019	−3.436
$\ln(y_t)\ln(Ps_t)$	−0.0131	0.0065	−2.002
$\ln(\tau_t)\ln(Ps_t)$	0.0582	0.0156	3.732
$\ln(\tau_t)^2$	−0.1028	0.0158	−6.516

Appendix 2

Demand estimation by a learning system

The improvement of system performance that is repetitive and predictable is considered to be the result of learning. Defining $\tilde{W}_t$ as a learning measure:

$$\tilde{W}_t = \frac{\tilde{D}_t}{\tilde{Y}_t} = L(\tilde{Y}_t)$$

The most widely known and used learning model is a simple power relationship of $\tilde{W}_t$ to $\tilde{Y}_t$:

$$\tilde{W}_t = A\tilde{W}_t^b$$

where

$$b = \ln(\theta)/\ln(2)$$

and

θ = learning rate
$1 - \theta$ = rate of progress
$\theta = 2^b$

Then, algebraically,

$$\tilde{D}_t = \tilde{W}_t * \tilde{Y}_t = L(\tilde{Y}_t)$$
$$\tilde{D}_t = L(\tilde{Y}_t) * \tilde{Y}_t$$

Interestingly, $\tilde{D}_t/\tilde{Y}_t$ could also be interpreted as cumulative intensity, $I\tilde{E}P$, since $IEP = D_t/Y_t$. With such a definition, we can write the following as an alternative expression:

$$I\tilde{E}P_t = L(\tilde{Y}_t)$$

Returning to the original specification of learning measure, $\tilde{W}_t$, it is clear that cumulative demand is:

$$\tilde{D}_t = L(\tilde{Y}_t) * \tilde{Y}_t$$

Consequently:

$$D_t = \frac{d\tilde{D}_t}{dt} = L'(\tilde{Y}_t)\frac{d\tilde{Y}_t}{dt}\tilde{Y}_t + L(\tilde{Y}_t)\frac{d\tilde{Y}_t}{dt}$$

Thus, an annual demand function can be drawn:

$$D_t = [L'(\tilde{Y}_t)\tilde{Y}_t + L(\tilde{Y}_t)]\ \frac{d\tilde{Y}_t}{dt}$$

$$= [L'(\tilde{Y}_t)\tilde{Y}_t + L(\tilde{Y}_t)]Y_t$$

A learning pattern can easily be obtained by selecting the linear form of data ($\tilde{W}_t$ and $\tilde{Y}_t$). This learning model is of a simple linear form, not the standard log-linear model. By arranging all of the terms it is possible to estimate a demand function. The consumption model can be obtained by regression analysis applied in the learning relation (Figure 3):

$$\ln\tilde{W}_t = 0.7883 + 0.2229\ln\tilde{Y}_t$$
$$(R^2 = 0.992)$$

where

$\tilde{W}_t$ = cumulative consumption/cumulative per capita GDP
$\tilde{Y}_t$ = cumulative per capita GDP

Alternatively, $\tilde{W}_t = 2.1997.\tilde{Y}_t^{0.209}$; as pointed out previously the model can describe the annual consumption D_t,

$$D_t = 19.8519Y_t.\tilde{Y}_t^{0.2029}$$