Is Global Gasoline Demand Still as Responsive to Price?[1]

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Abstract

The popular perception among the lay community seems to be that gasoline consumption does not respond to price. However, numerous econometric studies have been done on gasoline demand elasticities and at least thirteen studies have been devoted to surveying this work. (See Dahl (2006).) All of these surveys conclude that gasoline consumption does respond to price, and most of them come to a quantitative conclusion about the values for the price elasticity. The majority conclude that the short-run price elasticity (annual) is between -0.2 and -0.3, and the long-run elasticity is between -0.6 and -0.9.

However, over time gasoline expenditures have become a smaller percent of consumer budgets and vehicles have become more durable. These changes might have implications for both short- and long-run responsiveness to price. We have found five recent econometric studies for transport fuel demand on three countries that have data beyond 2000. Of these recent studies only Hughes et al. (2006) tested whether recent price and income elasticities are statistically similar to an earlier period for the U.S. They used monthly data and found a smaller price response recently compared to the 1970s.

We build upon Hughes et al. and other studies by examining whether gasoline demand elasticities are stable using an Autoregressive Distributed Lag model (ARDL) for the U.S., 13 other OECD countries, and 9 other non-OECD countries representing the majority of current and potential future key consumers. Our results support those of Hughes et al. and find the U.S. price responsiveness is lower now than in the 1970's. Surprisingly, however, we find that price elasticities have been stable for the majority of other countries in our investigation. We also find gasoline tends to have inelastic short- and long-run price elasticities that are smaller in absolute value than income elasticities for most countries.

Keywords: Gasoline Demand, ARD, General to Specific, Elasticities

JEL Classficiation Codes: C13, Q41

[1] Opinions or points of view expressed in this paper are those of the authors and do not necessarily represent the official position or policy of the Colorado School of Mines, Saudi Aramco, or the Kingdom of Saudi Arabia.

Introduction

Oil products for transport are major inputs for many essential products, leading to almost continuous and growing consumption as shown by the top line in Figure 1. The last dip in consumption was 1982 when both high prices and a global recession coincided. Knowing how oil consumption and product use will evolve is important for oil producers, refineries, and product consumers. For example, the International Energy Agency (IEA) in its various *World Energy Outlooks* from 2004-2008 rather consistently estimated that the oil and gas sector will need to invest trillions of US dollars in the next 2-3 decades for exploration, development, and refining. For producers and refiners to make such investments, an understanding of future oil consumption growth is essential. In addition, consumers of oil products are equally interested in these markets as they will have to make long run capital decisions for oil product use. Last but not least the increasing global concern over carbon emissions make an understanding of future oil product consumption of interest to governments who will be implementing policies to reduce our global carbon footprint.

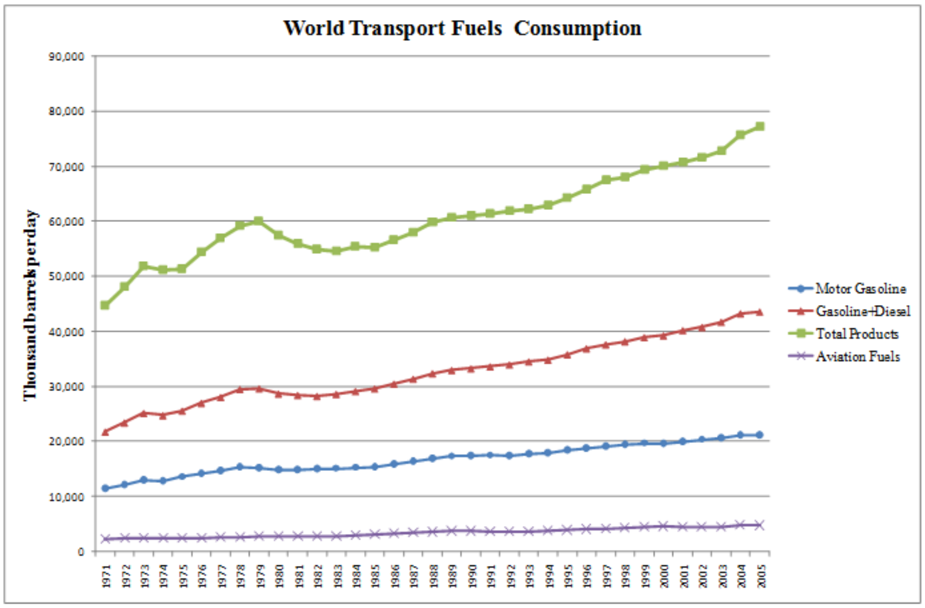

Figure 1: World Transport Fuel Consumption
Source: IEA (n.d.b)

Increasing income, wealth, and globalization are dramatically increasing the mobility demand for people, which should increase the demand for gasoline and other transport fuels. For example, the consumption of gasoline in the transport sector in China increased from 1971-2004 by 9 fold (from 95,560 barrels per day to 918,540 barrels per day). Such growth in gasoline as well as other transport fuel use is reflected in the dominant and growing share of gasoline, diesel/gasoil, and jet fuel in the product mix shown in Figure 1. US EIA (2008) suggests that this trend towards increasing transport fuels from oil is likely to continue as shown in Figure 2.

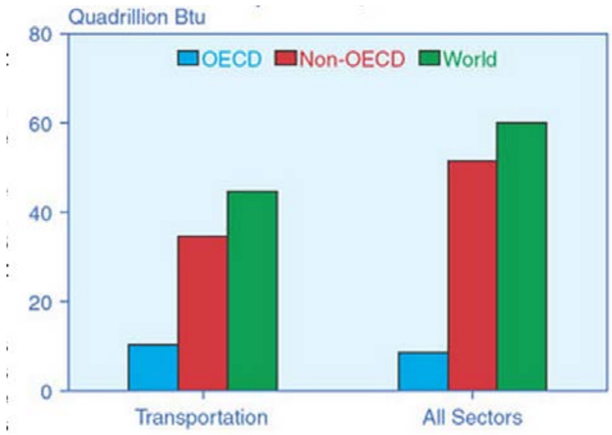

Figure 2: Forecasted Change in World Liquids Consumption for Transportation and Other Sectors from 2005 to 2030

Source: US EIA (2008)

Gasoline has remained an important share of total world oil product consumption and inched up over the sample above from about 25% to 27% of total oil product. Given its continuing importance and the availability of data, numerous researchers have econometrically estimated demands for gasoline using a variety of models and econometric techniques. However few have the length or breadth of coverage of our work. Our paper examines the demand for gasoline in road transportation on data from 1970-2005 for 23 countries representing the majority of current and potential future key consumers. Jointly, these countries consume 14.5 million barrels per day (bbl/d) of gasoline (84% of the world's consumption).

We apply an Autoregressive Distributed Lag model (ARDL), which nests seven alternative specifications that span most of the models encountered in the literature (Charemza and Deadman (1997). This model allows us to more extensively test most of the models encountered in the gasoline demand literature including the error correction model (ECM). Although stationarity/cointegration testing in now standard practice, most of the older studies and even some of the more recent do not do such tests. As we will carefully test all data for all countries, our results may indicate which earlier estimates are candidates for spurious regression.

There is some evidence that gasoline may be less price elastic than it once was. Hughes et al. (2006) tested whether recent price and income elasticities are statistically similar to an earlier period. Our study builds on their study by testing for parameter stability for all 23 countries. and allowing the data to pick any breaks for each country.

In some studies, the price of oil rather than the price of gasoline has been used. We fear that oil prices may introduce errors in variables as changing taxes and refinery margins as well as subsidies mean oil prices may not be a good representation of what buyers are actually paying at the pump. In addition to price and income, which are standard variables that most studies tend to use, we also consider substitution between gasoline and diesel fuel as well as investigating the effect of available structural variables including urbanization rate, female labor force participation rate, and industrial GDP. Although these variables have seen occasional use as noted below in the literature review, we are aware of no study that has systematically tested all these structural variables on a global scale. In the current world of massive structural change and rising fuel prices, previous estimates without current data and structural variables may provide misleading estimates of gasoline demand.

The breath of countries (23), diversity of countries (OECD, OPEC and other developing countries) and the length (as long as 1970 to 2005) of our data sample allows us to test and answer the question whether gasoline demand is still as responsive to price or not at the individual country level. Our extensive data collection gives us more precise, current, and consistent data. It contains a set of pump prices for each fuel rather than the price of oil. It not only covers the current price run up, it also overlaps data for most existing studies. It includes new structural variables that have only been used in a handful of studies. We believe that this data set affords us a unique opportunity to not only find more reliable and updated estimates of gasoline demand in the studied countries but to build upon and improve the existing models in the literature.

We apply the general to specific modelling (GTS) modeling on the most general ARDL model to date. This model allows us to systematically test across seven model types that span the existing literature. This flexible approach and comprehensive data set allows us to answer important questions about size, stability and timing of demand response for each of the 23 countries.

Literature Review

We have found 173 studies that included estimates of gasoline demand elasticities covering more than 50 countries. Dahl (2006) summarized thirteen surveys on gasoline demand elasticity as shown in Table 1. She found the majority focused on OECD countries and only included data up to 2000.[2] The gasoline short-run summary annual price elasticity most often ranges from -0.2 to -0.3, while the long run summary annual price elasticities vary somewhat more with most ranging between -0.6 and -0.9. Fewer surveys report income elasticities. Their short run summary income elasticities range between 0.3 and 0.5 and their long-run summary elasticities vary more widely with some elastic and others inelastic.

Table 1: Summary Elasticity Statistics of Existing Surveys on Gasoline

	Number of studies	Coverage years	P_{SR}	P_{LR}	Y_{SR}	Y_{LR}
Taylor (1977)	7	70-76	(-0.1, -0.5)	(-0.25, -1)		
Bohi (1981)	11	74-78	-0.20	-0.70		Near 1
Kouris (1983) country CSTS	7	75-83	(-0.1, -0.2)			
Kouris (1983) US TS	7	72-83	(-0.2, -0.4)	-0.70		
Bohi and Zimmerman (1984)	10	79-82	-0.20	Inelastic	0.40	Elastic
Dahl (1986)	69	69-84	-0.29	-1.02	0.47	1.38
Dahl and Strener (1991a, 1991b)	~100	66-88	-0.26	-0.86	0.48	1.21

[2] These elasticities do not represent the range for all studies but are representative elasticities.

Goodwin (1992)	12		-0.27	(-0.71, -0.84)		
Dahl (1995)	14	89-93	-0.20	-0.60		< 1.0
Espey (1996) US	41	69-90		-0.65		0.91
Espey (1998)	95	66-97	-0.16	-0.81	0.32	0.90
Graham and Glaister (2002)	113	66-00	(-0.2, -0.3)	(-0.6, -0.8)	(0.3, 0.5)	(0.5, 1.50)
Hanly, Dargay, Goodwin (2002)	69	72-00	-0.25	< -0.6	0.40	> 1.0

Sources: Dahl (2006).

Notes: Coverage indicates the years of the study not the data coverage.

Although most of these surveys come to some summary elasticities, they note that there is considerable elasticity variation across countries, and different studies even get different elasticities for the same country. These differences might result from different models and time periods. We hope that by testing across model types and testing for stability, we will estimate the most accurate elasticities possible.

Out of the 27 estimates on multiple countries, only two studies (Dunkerley and Hoch (1987) and Gately and Streifel (1997)) have data with our breath of coverage. Only one (Dunkerley and Hoch (1987)) has as much diversity with a mix of developing, OECD and OPEC countries. However, both have questionable price variables. The former uses nominal instead of real gasoline prices and the later uses oil instead of gasoline prices, which we suspect may bias their estimates. Neither of these broad studies has data beyond 1993 and so they do not include the recent global economic growth, structural change, and run up in fuel prices. Indeed, we have found only five econometric studies for transport fuel demand on three countries that have data beyond 2000 as noted in Table 2.

Table 2: Summary of New Studies (Data beyond 2000)

Study name	**Years of coverage**	**Country**
De Vita, Endresen, and Hunt (2005)	(1980-2002)	Namibia
Iooty, Queiroz, and Roppa. (2007)	(1970-2005)	Brazil
De Vita, Endresen, Hunt (2006)	(1980-2002)	Namibia
Wadud, Graham, Noland (2006)	(1984-2003)	USA
Small, Van Dender (2007)	(1966-2001)	USA
Hughes, Knittel, Sperling (2006)	(1975-80 and 2001-06)	USA
Polemis (2006)	(1978-2003)	Greece

Source: Authors

There is some evidence that gasoline may be less price elastic than it once was. Of these recent studies only Hughes et al. (2006) tested whether recent price and income elasticities are statistically similar to an earlier period. However, their study focused on gasoline in only one country, the US. Also, they used monthly data without accounting for seasonality and without including any lags; hence their estimates may represent only a short run effect. Finally, their stability testing was made with a prior selection of the time period breaks rather than allowing the data to indicate if and when a break occurs. Our study improves on Hughes et al. (2006) by testing for parameter stability for all 23 countries. We use annual data and dynamic models to uncover the short and long-run effects, and we allow the data to tell us if and when statistical breaks occur. This stability of elasticities is of interest as the petroleum market may have experienced structural shifts in the last four decades. Fortunately, our data not only includes this recent data but overlaps data for most of the older studies allowing us to evaluate previous work.

In the literature, the majority of gasoline demand studies include variables for gasoline price (P_G) and some measure of income without considering substitution across gasoline and diesel. In fact, we found only a few studies on aggregate gasoline consumption that tested diesel substitution for gasoline by including the price of diesel (P_D) in the regression. Iooty et al. (2007) found a positive cross-price elasticity on diesel fuel in one specification and a negative cross-price elasticity in another on Brazilian annual data through 2005. Unfortunately, they do not report any significance levels for their coefficients. Miklius et al. (1986) finds a significant cross-price elasticity for diesel fuel on cross- section time-series data for seven Asian countries through 1981. Polemis (2006) finds a significant cross-price elasticity for diesel fuel on Greek annual data through (2003). Salehi-Isfahani (1996) finds an insignificant cross-price elasticity on the price of number 2 fuel oil (a proxy for the price of diesel fuel) on annual Iranian data through 1993. Uri (1982) finds a positive and significant (at the 10% level) cross-price elasticity of diesel fuel on annual U.S. data through 1978. Wohlgemoth (1997) finds a positive cross-price elasticity of diesel fuel on Mexican data through 1993 but, unfortunately, does not report any significance level. Although these results are mixed, they prompt us to do more systematic and comprehensive work to test for the diesel cross price elasticity on all countries in our sample.

We also consider three additional economic and structural variables. Wohlgemuth (1997) argues that not only income (i.e. GDP) but also GDP structure is important in determining road transport fuels demand. Rao and Parikh (1996) checked this hypothesis for India on data through 1994, but found that the coefficient on industrial GDP was not significant. We provide further evidence on this structural issue by testing whether adding industrial share of GDP affects gasoline consumption for any of our selected countries.

As people move from rural to urban areas or as females enter the labor force their gasoline demand patterns may change. Two studies included the rural urban transition by including the percent of population in urban areas as a variable. Dewees et al. (1975) found a significant negative coefficient on urbanization for Canadian cross-section time-series provincial data through 1974. Aznar and Castrillo (1988) estimated for Spain on data through 1982 and found a coefficient on urbanization to be significantly negative. Only Porter and Rao (1996) considered a female labor force participation rate variable when estimating gasoline for the US, and they found it to be positively significant. We also include these additional variables for our selected countries. Although these variables are hypothesized occasionally to be determinants of gasoline demand, no study has systematically tested all these additional variables on a global scale. We also expect these variables to be more influential in developing countries experiencing rapid structural change.

Since most of the variables encountered in such demand work are non-stationary, the problem of spurious regression is a real possibility that only eight studies have addressed for gasoline (Bentzen (1994), Eltony and Al-Mutairi (1995), Samimi (1995), Ramanathan (1999), Alves and Bueno (2003), Cheung and Thomson (2004), Dahl and Kurtubi (2001) and Polemis (2006)). Moreover, all eight restrict their estimation to one specific model, the ECM, rather than testing for the best model. We follow their lead and test for stationarity of all variables and for cointegration for all equations.

In the transportation literature only two studies Franzen (1994) and Gately and Streifel (1997) have systematically estimated multiple specifications. Only 27 studies focus on groups of countries where the rest are individual estimates. Out of these 27 studies only two studies Franzen (1994) and Gately and Streifel (1997) have systematically estimated multiple specifications. However, Franzen limited his estimation to only four model specifications (lagged endogenous, polynomial distributed lag, inverted-V, and error correction model (ECM)); he neither tested across models nor did he come to a final conclusion about which model performs best; he focused only on gasoline in the OECD countries with data up to 1985. Finally, in Franzen's models there was no consideration of coefficient structural stability over his sample, nor did he include variables measuring structural change in rapidly developing counties such as industrial GDP. Similarly, Gately and Streifel limited their estimation to three basic specifications (a static model, a Koyck lag, and a model including one lag on exogenous variables. Although, Gately and Streifel (1997) do estimate and pick preferred models in 37 developing countries for seven products, none of their specifications include more than one lag on any variable. Although they do test for an asymmetric price response, they do not otherwise test for parameter stability.

In our paper, we will build on Franzen (1994) and Gately and Streifel (1997) by using time series for multiple countries with multiple models. However, we test across more specifications, using an "Autoregressive Distributed Lag Model" or ARDL. This general ARDL model will include the six variables and their lags along with lagged endogenous variables as summarized in equation 1 in the next section. Charemza and Deadman (1997) illustrated how the ARDL nests most model specifications found in the econometric energy demand literature. Thus it allows us to test which of them performs better for each country.

The ARDL model proposed in our study provides a more flexible and general model specification than all previous studies. It is consistent with economic theory but with minimum restrictions. With longer time series, instead of preselecting a model specification, we are able to use the data to pick a preferred model. In estimating this model, we follow the methodology of Davidson *et al.* (1978) known as general-to-specific (GTS) which reduces the number of lags and variables by testing for fit and/or significance of variables, or the Schwartz Information Criteria (SIC) grid. We systematically test and find the best model using the general-to-specific modeling technique and reduce the number of variables and lags using sequential t-tests as justified in Hamilton (1995) and Pesaran and Shin (1998). Moreover, we test parameter stability over the sample period using CUSUM and Chow tests to identifiy any possible structural breaks.

In the literature, a general ARDL model has not been applied to the transportation sector, but Fatai et al. (2003) compared and tested it against several econometric approaches including the ECM for electricity in New Zealand. They found the ARDL model to have more precise estimates and better forecasting performance than the ECM. Bentzen and Engsted (2001) also applied an ARDL model to estimate Danish household demand for energy with good results.

DATA AND METHODOLOGY

An econometrics approach, using a single-equation multivariate regression for each country and each product is used in this study. The models are country-specific so this process will result in unique models, for gasoline demand in each of the 23 countries studied for data from 1970-2005 unless otherwise indicated. The principal statistical tool used in this estimation is the software package E-views. The ARDL model used in this study with all variable measured in logs is:

$$Q_t = \beta_0 + \sum_{i=0}^{n} \beta_{Gi} \mathrm{P}_{\mathrm{G}\,t-i} + \sum_{j=0}^{m} \beta_{Dj} \mathrm{P}_{\mathrm{D}\,t-j} + \sum_{k=0}^{p} \beta_{Yk} Y_{t-k} + \sum_{s=0}^{r} \beta_{Us} U_{\mathrm{t}-s} + \sum_{v=0}^{w} \beta_{Iv} I_{\mathrm{t}-v} + \sum_{x=0}^{z} \beta_{Fx} F_{\mathrm{t}-x} + \sum_{l=1}^{q} \beta_{\lambda l} Q_{t-l} + \varepsilon_{\mathrm{t}} \qquad (1)$$

The definition and sources for the variables in equation (1) are as follows:

Q is gasoline consumption in road transportation measured in tons of oil-equivalent per capita (TOE/capita) from IEA (n.d.b). The population data were gathered from World Bank (n.d.a).

Y is real GDP per capita measured in 2000 local currency from World Bank (n.d.b). We expect this variable to be positively related to *Q*.

P_G and P_D are the prices of gasoline and diesel fuel in real local currency from IEA (n.d.a) supplemented with data from GTZ (n.d.) and OPEC (n.d.). We expect these prices to be negatively and positively related, respectively, to gasoline consumption.

I is industrial share of GDP from World Bank (n.d.b) We are not sure a priori of the expected sign of its coefficient.

U is urbanization and *F* is female labor force participation rates from World Bank (n.d.a). Urbanization rate is hypothesized to be negative for gasoline as we expect demand for this fuel decreases when people cluster in cities. The effect of female labor force participation rate depends on the driving habits of the females before and after entering the labor force. For example, if female driving was limited before being employed but the commute to work increases mileage driven, the coefficient would be positive. Alternatively, if most females commute using mass transit fueled by diesel fuel, the coefficient may be insignificant. One can even imagine a scenario in which females did a significant amount of driving before entering the labor force that falls with increased time pressures after they enter the labor force. Alternatively if the increase in driving is not commensurate with the increase in income, the coefficient on participation rate would also likely be negative.

GDP Deflator from World Bank (n.d.b) was used to convert all monetary variables from nominal to real:

Our 23 countries were chosen based on size and data availability. They jointly consumed about 84% of world gasoline consumption in 2005. Country abbreviations are given in parenthesis after their name. As shown, the US dominates global gasoline road consumption by a large margin. China is the largest consumer amongst the developing countries. Japan is also a large consumer and has only recently been superseded by China.

Out of the 23 countries included in this study, 14 belong to the Organization of Economic Cooperation and Development (OECD), 4 countries belong to the Organization of Oil Producing and Exporting Countries (OPEC), and the last 5 countries do not belong to either organization and will be referred to as OTHER. The abbreviations used for countries are in accordance with the International Organization for Standardization (ISO) which uses a three-letter code system. Table 3 summarizes the countries included in each group, along with their abbreviations for this study.

The sample period is 1970-2005 for most OECD countries, 1980-2004 for most OPEC countries, and an array of time spans for countries in the OTHER group. Table 3 contains the exact sample years for each country.

Table 3: Gasoline Consumption for the Studied Countries in 2005.

	COUNTRY	Gasoline Consumption (Kilo-Tons/year)	Percentage of world %	Sample	
Other	Brazil (BRA)	13,103	1.50%	1986	2004
	China (CHN)	46,097	5.28%	1994	2005
	India (IND)	8,648	0.99%	1971	2005
	Russia (RUS)	26,260	3.01%	1990	2003
	Thailand (THA)	5,275	0.60%	1971	2005
OPEC	Indonesia (IDN)	12,942	1.48%	1971	2005
	Iran (IRN)	17,854	2.05%	1980	2005
	Saudi Arabia (SAU)	12,753	1.46%	1980	2005
	Venezuela (VEN)	10,652	1.22%	1971	2005
OECD	Australia (AUS)	14,520	1.66%	1970	2005
	Belgium (BEL)	1,762	0.20%	1970	2005
	Canada (CAN)	29,751	3.41%	1970	2005
	France (FRA)	10,479	1.20%	1970	2005
	Germany (DEU)	22,946	2.63%	1971	2005
	Italy (ITA)	13,453	1.54%	1970	2005
	Japan (JAP)	44,391	5.09%	1970	2005
	Korea (PRK)	6,969	0.80%	1980	2005
	Mexico MEX)	27,683	3.17%	1978	2005
	Netherlands (NLD)	4,097	0.47%	1970	2005
	Spain (ESP)	7,260	0.83%	1970	2005
	Turkey (TUR)	2,644	0.30%	1978	2005
	United Kingdom (GBR)	18,731	2.15%	1970	2005
	United States (USA)	370,362	42.46%	1970	2005
	Total	***728,632***	***83.50%***		
	World	***872,257***			

Source: IEA (n.d.b)

* One barrel of oil per day (bbl/d) = 50 tons of oil equivalent per year (Ton/Year) assuming a 33 API gravity. Country abbreviations are given in parenthesis after their name.

Methodology and Procedure

In this section, we will indicate the methodology and procedures implemented to arrive at optimal models for road transport gasoline demand for each country. The three main steps are stationarity tests and order of integration assessment, Engle-Granger cointegration tests, and error diagnostic analysis and model selection.

1. Stationarity Tests and Order of Integration Assessment

Assessing the order of integration for all the variables is an important step before the variables are regressed on each other. If we regress two non-stationary (i.e. I(1) or higher) variables on each other and find that the error is I(0) then we conclude that these variables are cointegrated or move together in the long-run. Conversely, if the error term is found to be I(1), research may find a high correlation between these variables that does not represent a real causal relationship. This phenomenon is formally known as spurious regression. Phillips (1986) provides the theoretical justification for spurious regression when he shows that OLS estimates for the $\beta's$ are not consistent and the standard *t*-statistics testing for significance diverge when variables in the regression are not cointegrated. Therefore, the statistical inferences for a regression on non-cointegrated variables are invalid. He also shows that the Durbin Watson statistic goes to zero in the limit and the correlation between adjacent regression errors goes to one, suggesting a high degree of serial correlation in a spurious regression.

We use the ADF test to assess the order of integration of our variables and conclude that they all have a unit root without a deterministic trend or drift, except for gasoline consumption per capita for Spain, which is found to be I. So cointegration is a possibility for most countries that will be explored in the next section.

2. Engel-Granger Cointegration Tests

Engel and Granger (EG) proposed a cointegration residual based test to confirm if the I(1) variables in question are cointegrated or not. This test has been the most often applied in the literature as it provides an easy way to confirm the existence of a cointegrating relationship in a single equation. The EG test is performed by running the regression on levels on the following gasoline equation:

$$Q_t = \beta_0 + \beta_1 P_{Gt} + \beta_2 P_{Dt} + \beta_3 Y_t + \beta_4 U_t + \beta_5 I_t + \beta_6 F_t + \varepsilon_t \qquad (2)$$

We run this regression, and test if the residuals are stationary (I(0)); the null hypothesis that the residuals are not stationary implies that the variables are not cointegrated. If the null is rejected, then our variables are cointegrated. Using the Engle-Granger residual based test we confirmed that a cointegrating relationship exists in all countries at the 1% level as shown in in Table 4 (no cointegration was tested for Spain).[3]

Table **4**: Co-integration Test Statistics for Gasoline ARDL Model

Country	*Errors Order of Integration (ADF)*	*ADF Test Statistics* *P-value*	*Remarks*

[3] Other cointegration tests exist such as Johansen's, which is a system approach that is capable of finding if more than one cointegration relationship exists. It is mostly used to investigate the causality direction among variables that is not a concern in our study.

Australia	I(0)	0.0003	Co-integration established
Belgium	I(0)	0.0339	Co-integration established
Brazil	I(0)	0.0012	Co-integration established
Canada	I(0)	0.0122	Co-integration established
China	I(0)	0.0002	Co-integration established
France	I(0)	0.0131	Co-integration established
Germany	I(0)	0.0038	Co-integration established
India	I(0)	0.0002	Co-integration established
Indonesia	I(0)	0.0079	Co-integration established
Iran	I(0)	0.0007	Co-integration established
Italy	I(0)	0.0007	Co-integration established
Japan	I(0)	0.0000	Co-integration established
Korea	I(0)	0.0029	Co-integration established
Mexico	I(0)	0.0007	Co-integration established
Netherlands	I(0)	0.0536	Co-integration established
Russia	I(0)	0.0042	Co-integration established
Saudi Arabia	I(0)	0.0000	Co-integration established
Spain	I(0)	0.0011	Co-integration established
Thailand	I(0)	0.0022	Co-integration established
Turkey	I(0)	0.0058	Co-integration established
USA	I(0)	0.0084	Co-integration established
UK	I(0)	0.0000	Co-integration established
Venezuela	I(0)	0.0001	Co-integration established

Note: P-values are reported by E-views

3. Error Diagnostic Analysis and Model Selection

Now that we have assessed the order of integration for our variables and have established cointegrating relationships, we move to the modeling. We start with the ARDL specification to estimate gasoline demand and include lags of each of the seven variables (price of gasoline, price of diesel, gross domestic product, female labor force participation, urbanization rate, industrial gross domestic product, and lagged endogenous variable). As is common with annual data we begin with two lags of each right hand side (rhs) variable along with contemporaneous values (e.g Narayan and Smyth (2005)).

There are two standard way to choose the variables and lags in this model, the Schwartz Information Criteria (SIC) with a grid search and the sequential *t* test. We begin with (SIC) using a grid search, based on the residual sum of squares adjusted for degrees of freedom shown in the following equation:

$$SIC = \log\left(\frac{RSS}{n}\right) + \log\frac{(k+1)}{n}$$

Where, n is sample size, k is number of parameters, and RSS is the summed squared residuals from the regression. Other selection criteria exist such as adjusted coefficient of determination ($\bar{R}^2$), and Akaike's Information Criterion (AIC) but SIC was preferred because it is the most powerful (Kennedy 2004).

All possible models within a country are estimated and the one with the lowest SIC is chosen. This selection process is easy to apply and provides a systematic way of searching for all possible combinations.[4] However, the disadvantage of this process is that chosen models may have serially correlated errors which invalidate the *t* statistics and statistical inference on individual elasticities.

The second and more traditional methodology is the sequential t test. Once we have a final specification, we test for the model's stability using the CUSUM test. From this test and the graph provided by E-views, we identify if any structural break is present. Then we reconfirm with a Chow test for five break points centered around the break year indicated by CUSUM. If the structural break is confirmed, we estimate the regression using a dummy variable that allows us to distinguish between the period prior and after the break point. The use of the dummy variables allows us to distinguish the source of the break (i.e. price, income or structural variables).

EMPIRICAL RESULTS

1. Schwartz Grid Search Approach

The Schwartz Criteria (SIC) using a grid search methodology investigates all possible models within a country using different combinations of variable lags in search of the model with the best fit. The SIC's method results are presented in Table 5. In these tables the first column shows the lowest SIC value obtained from the grid search along with price and income elasticities, and lagged endogenous variable coefficients. Furthermore, the last two columns indicate whether this optimal model's estimated errors are serially correlated (so we cannot rely on statistical inference) and whether the coefficients have correct relative magnitudes and signs.

Although the SIC grid search is easy to apply and provides a systematic methodology, unfortunately it produced unacceptable results that either conflicted with economic theory (e.g. negative income elasticities, positive price elasticities, or long run elasticities less than short run elasticities in absolute value violating the Le Chatelier Principle) or with statistical theory. As a matter of fact, out of the 23 countries, 19 gasoline equations had serial correlation and no statistical inference could be performed.

4 The grid search program for E-views was modified from Dagher (2008).

Table 7: Gasoline Results using the Schwartz Information Criteria Grid Search

Country	SIC	P	P(-1)	P(-2)	P(LR)	Y	Y(-1)	Y(-2)	Y(LR)	Q(-1)	Q(-2)	Q(-3)	SIC*	Economic**
Australia	-11.622	0.63	0.28	-0.21	0.25	-0.37	-0.41	-0.31	-0.39	-0.71	-0.26	-0.82	No	No
Belgium	-4.580	-0.73	0.67	0.16	0.87	-1.27			-10.80	0.48	0.40		No	No
Brazil	-5.127	-1.56			-2.49	3.13	-10.53		-11.82	0.37			No	No
Canada	-15.053	2.41	4.91	-4.94	0.69	-3.10	-0.45	-8.98	-3.65	-0.07	-2.36		No	No
China	-7.273	0.00			0.00	2.50			2.13	-0.18			Yes	No
France	-10.527	0.49			0.54	0.76	0.72	-2.34	-0.95	0.09			Yes	No
Germany	-5.937	-0.05	0.11	-0.06	0.00	1.38	-1.51		-0.31	0.47	0.11		No	No
India	-6.699	-0.16	0.30	-0.22	-0.09	0.34	-0.87		-0.70	0.39	-0.75	0.61	Yes	No
Indonesia	-3.946	-0.36	-0.22	-0.17	1.33	0.87	0.47	-0.48	-1.49	0.95	0.62		Yes	No
Iran	-4.843	-0.17	-0.15	0.08	-0.25	1.16			1.19	0.32	-0.30		No	Yes
Italy	-7.205	0.18	-0.61		-3.04	-0.15	0.97	-0.82	0.05	0.26	0.89	-0.29	No	No
Japan	-7.613	0.46	-0.26	-0.59	-0.23	-1.54	2.56	-1.33	-0.18	-0.33	-0.41		No	No
Korea	-6.483	-0.23	0.05	0.18	0.00	0.81	-1.26	0.86	0.70	0.46	-0.24	0.20	No	No
Mexico	-8.504	-0.51	0.19	-0.33	-0.89	0.89	-0.18	-0.16	0.76	0.85	-0.77	0.18	No	No
Netherland	-7.549	0.44	0.33	1.56	-18.94	-3.52	3.31	-3.36	29.14	-0.48	1.60		No	No
Russia	-4.603	0.21			0.25	-0.78			-0.91	0.15			No	No
Saudi	-4.828	-0.38	-0.25	-0.15	-0.30	-0.96	0.25	2.25	0.60	-0.34	-0.47	-0.75	No	No
Spain	-4.961	-0.78	-1.00	0.88	3.54	0.36	-0.35	-0.75	2.95	0.13	0.76	0.36	No	Yes
Thailand	-4.159	-0.09	-0.32	0.12	-0.51	0.54			0.93	0.18	-0.26	0.50	No	Yes
Turkey	-2.376	-0.23			0.86	2.26			-8.34	0.41	0.35	0.51	No	No
USA	-7.179	-0.61			2.62	0.09	-0.53	0.62	-0.77	1.32	-0.84	0.75	No	No
UK	-6.906	0.16	1.17	0.64	1.36	0.08	-0.90		-0.57	-0.45			No	No
Venezuela	-7.767	-0.23	-0.13	-0.14	1.69	0.51	0.72	-1.81	1.97	-0.93	0.11	2.11	No	Yes

Source: Authors

* Could we rely on statistical inference because of serial correlation (SC)?

** Is the model adhering to the Chatelier Principle and sign conventions?

Finally, the SIC grid search may be a good tool for forecasting but our interest in this study is to obtain individual elasticity estimates for the studied countries. So we proceed to the sequential *t*-test in the next section.

2. Sequential *t*-test Approach

Given the unexpectedly poor results for the SIC grid search methodology, we next turn to the sequential *t* test. Our favored models using the sequential *t*-test for gasoline (G_t) road demand in the 23 countries are presented in Table 8 below. All variables, except dummies, are measured in logs.

Table 8: Sequential t-test Approach Final Models

Australia:

$$G_t = 0.31 - 0.04\, P_{G_t} + 0.10\, Y_t + 0.57\, G_{t-1} + 0.27 G^*_{t-2} + \varepsilon_t$$

(0.015) (0.033) (0.170) (0.144)

R^2 = 0.987418 SIC= -4.878865 Sample=(1970-2005)

Belgium:

$$G_t = -7.30 + 6.95 * D80{,}05 - 0.39\, P_{G_t} + 0.57\, Y_t - 0.89\, Y_t * D80{,}05$$

(0.036) (0.103) (0.119) (0.131)

$$+0.46\, G_{t-1} + 0.29\, G_{t-2} * D80{,}05 + \varepsilon_t$$

(0.069) (0.075)

R^2 = 0.981626 SIC= -4.317373 Sample=(1970-2005)

Brazil:

$$G_t = -9.39 - 0.01\, P_{G_t} + 0.93\, Y_t - 0.40\, I_t + 0.28\, G_{t-1} + \varepsilon_t$$

(0.003) (0.253) (0.115) (0.057)

R^2 = 0.960530 SIC= -2.404447 Sample=(1986-2004)

Canada:

$$G_t = -5.49 - 0.09\, P_{G_t} + 0.39\, Y^*_t + 0.51\, G_{t-1} + \varepsilon_t$$

(0.054) (0.175) (0.148)

R^2 = 0.979198 SIC= -5.277962 Sample=(1970-1979)

$$G_t = -1.49 - 0.19\, P_{G_t} + 0.09\, Y_t + 0.87\, G_{t-1} + \varepsilon_t$$

(0.039) (0.033) (0.045)

R^2 = 0.949725 SIC= -5.101364 Sample=(1980-2005)

China:

$$G_t = -2.00 - 0.12\, P_{G_t} + 0.26\, Y_t - 6.14\, U_t + 0.02\, G^*_{t-1} - 0.21\, G^*_{t-2} + \varepsilon_t (0.032)$$

(0.306) (0.823) (0.097) (0.107)

R^2 = 0.990353 SIC=-4.424119 Sample=(1994-2005)

Continue (Table 8):

France:

$$G_t = -6.89 + 7.25 * D85{,}05 - 0.31\, P_{G_t} + 0.22\, P_{G_t} * D85{,}05 + 0.60\ Y_t$$

(1.944) (0.073) (0.098) (0.195)

$$-0.76\ Y_t * D85{,}05 + 0.25\, G^*_{t-1} + 1.13\, G_{t-1} * D85{,}05 + 0.27\, G^*_{t-2}$$

(0.223) (0.203) (0.297) (0.165)

$$-0.72\, G_{t-2} * D85{,}05 + \varepsilon_t$$

(0.296)

R^2 = 0.993773 SIC= -4.659605 Sample=(1970-2005)

Germany:

$$G_t = -1.79 - 0.30\, P_{G_t} + 0.18\ Y^*_t + 0.90\, G_{t-1} + \varepsilon_t$$

(0.084) (0.116) (0.084)

R^2 = 0.969527 SIC= -4.823612 Sample=(1987-2005)

India:

$$G_t = -8.25 - 0.12\, P_{G_t} + 0.66\ Y_t + 0.92\, G_{t-1} - 0.35\, G_{t-2} + \varepsilon_t$$

(0.041) (0.158) (0.193) (0.136)

R^2 = 0.994637 SIC= -3.497299 Sample=(1973-2005)

Indonesia:

$$G_t = -4.75 - 0.11\, P_{G_t} + 0.29\, Y_t + 0.76\, G_{t-1} + \varepsilon_t$$

(0.024) (0.057) (0.057)

R^2 = 0.996213 SIC= -3.773979 Sample=(1972-2005)

Iran:

$$G_t = -7.09 - 0.09\, P_{G_t} + 0.52\, Y_t + 0.80\, G_{t-1} + \varepsilon_t$$

(0.041) (0.238) (0.114)

R^2 = 0.959706 SIC= -2.073275 Sample= (1980-2005)

Italy:

$$G_t = 52.79 - 0.28\, P_{G_t} + 0.07\, P_{D_t} - 12.63\, U_t + 0.95\, G_{t-1} + \varepsilon_t$$

(0.032) (0.024) (0.672) (0.024)

R^2 = 0.993082 SIC= -4.991388 Sample=(1978-2005)

Continue (Table 8):

Japan:

$$G_t = -2.62 - 0.06\, P_{G_t} + 0.15\, Y_t + 0.83\, G_{t-1} + \varepsilon_t$$

(0.023) (0.066) (0.043)

R^2 = 0.996680 SIC= -5.911780 Sample=(1983-2005)

Korea:

$$G_t = -3.48 - 0.23\, P_{G_t} + 0.49\, Y_t - 1.63\, F_t + 1.09\, I_t$$

(0.052) (0.065) (0.472) (0.382)

$$+0.97\, G_{t-1} - 0.17\, G_{t-2} + \varepsilon_t$$

(0.076) (0.062)

R^2 = 0.998052 SIC= -2.650006 Sample=(1980-2005)

Mexico:

$$G_t = -4.01 - 0.28\, P_{G_t} + 0.33\, Y_t + 0.71\, G_{t-1} + \varepsilon_t$$

(0.046) (0.109) (0.069)

R^2 = 0.948346 SIC= -3.860490 Sample=(1978-2005)

Netherlands:

$$G_t = -2.55 - 0.42\, P_{G_t} + 0.14\, P_{D_t} + 0.08\, Y_t + 0.73\, G_{t-1} + \varepsilon_t$$

(0.076) (0.029) (0.031) (0.049)

R^2 = 0.927251 SIC= -4.855866 Sample=(1978-2005)

Russia:

$$G_t = -9.30 + 0.21\, Y_t + 0.08\, G_{t-1} + \varepsilon_t$$

(0.034) (0.092)

R^2 = 0.555883 SIC= -3.379347 Sample=(1993-2005)

Saudi Arabia:

$$G_t = -7.97 - 0.08\, P_{G_t} + 0.52\, Y_t + 0.64\, F_t + 0.59\, G_{t-1} + \varepsilon_t$$

(0.031) (0.151) (0.189) (0.087)

R^2 =0.863660 SIC= -3.161057 Sample=(1980-2005)

Continue (Table 8):

Spain (not cointegrated):

$$G_t = -8.48 + 13.13 * D92{,}05 - 0.16\, P_{G_t} - 1.49\, P_{G_t} * D92{,}05 + 1.01\, P_{D_t}$$

(2.789) (0.071) (0.614) (0.417)

$$+0.62\, Y_t^* - 1.03\, Y_t * D92{,}05 + 0.36\, G_{t-1} + 0.92\, G_{t-2} * D92{,}05 + \varepsilon_t$$

(0.265) (0.318) (0.159) (0.217)

R^2 = 0.983351 SIC= -3.749341 Sample=(1970-2005)

Thailand:

$$G_t = -0.30 - 0.19\, P_{G_t} + 0.22\, Y_t + 0.75\, G_{t-1} + \varepsilon_t$$

(0.025) (0.049) (0.044)

R^2 =0.994498 SIC= -3.435677 Sample=(1972-2005)

Turkey:

$$G_t = -7.23 - 0.32\, P_{G_t} + 0.28\, Y_t + 0.76\, G_{t-1} + \varepsilon_t$$

(0.073) (0.134) (0.079)

R^2 =0.889398 SIC= -1.867767 Sample=(1978-2005)

USA:

$$G_t = -3.10 - 0.17\, P_{G_t} + 0.11 P_{G_t} * D89{,}05 + 0.14\, Y_t + 0.68\, G_{t-1} + \varepsilon_t$$

(0.025) (0.019) (0.036) (0.073)

R^2 =0.905560 SIC= -5.204750 Sample= (1970-1981 and 1989-2005)

UK:

$$G_t = -2.86 - 0.13\, P_{G_t} + 0.18\, Y_t + 0.26\, I_t + 0.87\, G_{t-1} + \varepsilon_t$$

(0.017) (0.058) (0.060) (0.031)

R^2 =0.974847 SIC= -4.542577 Sample=(1971-2005)

Venezuela:

$$G_t = -3.34 - 0.05\, P_{G_t} + 0.21\, Y_t + 0.82\, G_{t-1} + \varepsilon_t$$

(0.009) (0.036) (0.033)

R^2 =0.910778 SIC= -3.810222 Sample=(1972-2005)

Source: Authors

Note: Numbers in parenthesis are standard errors. G= Road gasoline consumption per capita, P_G = Real price of gasoline, P_D = Real price of diesel, Y = Real GDP per capita, U = Urbanization rate, I = Industrial GDP share, L = Female labor force participation rate. Dummy variables are zero outside the interval stated in the regression and one within. For example D89,05 in the US regression means that D=1 from 1989 to 2005 and 0 otherwise.

Statistically the equations for gasoline are excellent, as they are for the most part cointegrated and explain more than 90% of the variation in the majority of the studied countries. Second, the final model specification was dominated by the popular lagged endogenous specification that has own price, income and a lagged endogenous variable. Third, the structural variables were disappointing for us as they were significant in only seven countries. Industrial GDP in gasoline estimation was significant and as hypothesized positive for the UK but significantly negative for Brazil. Also, the urbanization rate variable, as hypothesized, was significantly negative for gasoline estimation in China and Italy. Moreover, the female labor force participation rate variable was significantly positive for Saudi Arabia, Turkey, and Italy but negative for South Korea and the UK.

Fourth, out of the 23 countries we surprisingly found that only 6 countries experienced structural breaks (Belgium, Canada, France, Turkey, and the US). However, these breaks were not only during the price shock periods as hypothesized but occurred at different points of time. For example, only Belgium, Canada, and the US had break points after a price shock (1980, 1979, and 1981). France and Turkey break point (1985 and 1995) may be related to other non-price structural changes within these countries such technological changes and economic recession (CUSUM graphs are shown in Appendix A). The cause of the structural break was found by testing the significance of a dummy variable included with each variable to pinpoint the specific variable that causes this break. We found that only the US had a structural break because of only the price shock, which can be attributed to the fact that gasoline expenditures of the total GDP dropped from 4.5% in 1980 to 2.2% in 1985. For Belgium, Canada, France and Turkey, price shock and GDP shifts were both contributing factors to the structural break behavior. In these countries GDP shifts could be explained by knowing that vehicles became more efficient during this period and because of the stock saturation effect in most of these countries. Fifth, substitution from gasoline to diesel was confirmed in seven mostly developed countries (Australia, Indonesia, Italy, Netherlands, Spain, Turkey, and the UK).

As we are interested more in the country's individual own price and income elasticities, we compute both short and long run price and income elasticities for gasoline in Table 9 respectively, which contain elasticities along with the model specification. The final model specification is abbreviated in the third column. As we showed in equation (1) the ARDL model includes at the most seven variables in the following presentation ARDL (price of gasoline, price of diesel, GDP per capita, urbanization rate, female labor force participation rate, industrial GDP, and lagged endogenous variable). For example, an ARDL (1,0,1,0,0,0,2) shows that we have price of gasoline, GDP per capita, and two lags of the endogenous variable as our explanatory variables. Moreover, we have calculated the 95% confidence interval for gasoline price and income elasticities estimates as shown in Table10. These confidence intervals give us a better indication of the relative preciseness of our estimate and allow for a better comparison with previous literature estimates.

Table 9: Gasoline Model Results.

Country	Type	ARDL	Adj RSQ	Pg-SR	Pg-LR	Y-SR	Y-LR	Q(-1)	Q(-2)	Sample
Australia	Paramt	(1,0,1,0,0,0,2)	0.986	-0.043	-0.258	0.098	0.588	0.566	0.268	1970-2005
	Stand. Error			0.015	-	0.034	-	0.170	0.144	
Belgium	Paramt	(1,0,1,0,0,0,1)	0.973	-0.391	-1.523	-0.318	-1.240	0.460	0.283	1980-2005
	Stand. Error			0.036	-	0.120	-	0.070	0.075	
	Paramt	(1,0,1,0,0,0,2)	0.991	-0.392	-0.726	0.570	1.056	0.460		1970-1979
	Stand. Error			0.036	0.457	0.103	0.457	0.070		
Brazil	Paramt	(1,0,1,0,0,1,1)	0.949	-0.015	-0.021	0.935	1.296	0.279		1986-2004
	Stand. Error			0.003	0.018	0.253	0.018	0.057		
Canada	Paramt	(1,0,1,0,0,0,1)	0.943	-0.119	-0.929	0.095	0.746	0.872		1980-2005
	Stand. Error			0.040	0.275	0.033	0.275	0.045		
	Paramt	(1,0,1,0,0,0,1)	0.969	-0.093	-0.192	0.390	0.800	0.513		1970-1979
	Stand. Error			0.054	0.097	0.175	0.097	0.148		
China	Paramt	(1,0,1,1,0,0,2)	0.982	-0.116	-0.098	2.652	2.243	0.024	-0.207	1994-2005
	Stand. Error			0.032	-	0.306	-	0.097	0.107	
France	Paramt	(1,0,1,0,0,0,2)	0.977	-0.311	-0.651	0.600	1.257	0.254	0.269	1970-1984
	Stand. Error			0.073	-	0.195	-	0.203	0.165	
	Paramt	(1,0,1,0,0,0,2)	0.994	-0.090	-0.281	-0.160	-0.500	1.130	-0.450	1985-2005
	Stand. Error			0.098	-	0.223	-	0.297	0.296	
Germany	Paramt	(1,0,1,0,0,0,1)	0.963	-0.296	-3.095	0.182	1.907	0.904		1987-2005
	Stand. Error			0.084	1.126	0.116	1.126	0.084		
India	Paramt	(1,0,1,0,0,0,2)	0.994	-0.123	-0.286	0.663	1.542	0.917	-0.347	1973-2005
	Stand. Error			0.041	-	0.158	-	0.193	0.136	
Indonesia	Paramt	(1,0,1,0,0,0,1)	0.996	-0.108	-0.455	0.287	1.211	0.763		1972-2005
	Stand. Error			0.024	0.383	0.057	0.383	0.057		
Iran	Paramt	(1,0,1,0,0,0,1)	0.954	-0.095	-0.477	0.523	2.622	0.801		1980-2005
	Stand. Error			0.041	0.414	0.239	0.414	0.114		
Italy	Paramt	(1,1,0,1,0,0,1)	0.992	-0.276	-5.560	-	-	0.950		1978-2005
	Stand. Error			0.032	2.376	-	-	0.024		
Japan	Paramt	(1,0,1,0,0,0,1)	0.996	-0.063	-0.375	0.149	0.880	0.831		1983-2005
	Stand. Error			0.023	0.220	0.066	0.220	0.044		
Korea	Paramt	(1,0,1,0,1,1,2)	0.997	-0.232	-1.142	0.491	2.418	0.966	-0.169	1980-2005
	Stand. Error			0.052	-	0.065	-	0.076	0.063	
Mexico	Paramt	(1,0,1,0,0,0,1)	0.942	-0.277	-0.969	0.330	1.154	0.714		1978-2005
	Stand. Error			0.046	0.639	0.109	0.639	0.070		
Netherland	Paramt	(1,1,1,0,0,0,1)	0.915	-0.421	-1.592	0.084	0.316	0.735		1978-2005
	Stand. Error			0.076	0.718	0.031	0.718	0.050		
Russia	Paramt	(1,0,0,0,0,0,1)	0.713	-	-	0.215	0.235	0.083		1993-2005
	Stand. Error			-	-	0.034	0.215	0.093		
Saudi	Paramt	(1,0,1,0,1,0,1)	0.838	-0.080	-0.198	0.520	1.279	0.594		1980-2005
	Stand. Error			0.031	0.644	0.151	0.644	0.087		
Thailand	Paramt	(1,0,1,0,0,0,1)	0.994	-0.189	-0.742	0.223	0.879	0.746		1972-2005
	Stand. Error			0.025	0.258	0.049	0.258	0.044		
Turkey	Paramt	(1,0,1,0,0,0,1)	0.876	-0.325	-1.356	0.278	1.160	0.760		1978-2005
	Stand. Error			0.073	1.001	0.134	1.001	0.080		
USA	Paramt	(1,0,1,0,0,0,1)	0.909	-0.058	-0.182	0.142	0.444	0.680		1989-2005
	Stand. Error			0.020	0.042	0.036	0.042	0.073		
	Paramt	(1,0,1,0,0,0,1)	0.843	-0.170	-0.531	0.140	0.438	0.680		1970-1981
	Stand. Error			0.025	0.082	0.036	0.082	0.073		
UK	Paramt	(1,0,1,0,0,1,1)	0.971	-0.133	-1.049	0.179	1.416	0.873		1971-2005
	Stand. Error			0.018	0.629	0.058	0.629	0.031		
Venezuela	Paramt	(1,0,1,0,0,0,1)	0.902	-0.046	-0.263	0.209	1.201	0.826		1972-2005
	Stand. Error			0.010	0.180	0.036	0.180	0.034		

Note: ARDL (1,1,1,1,1,1,1) represent price of gasoline, price of diesel, GDP per capita, urbanization rate, industrial GDP share, female labor force participation rate, and lagged endogenous variable, respectively, where a zero means that the variable is not included in the model.

Note: Henceforth Spain has been removed because it was found earlier that no cointegrating relationship exists.

Table 10: Gasoline Demand Elasticity Confidence Interval Estimates.

	Sample	P-SR	P-LR	Y-SR	Y-LR
Australia	**1970-2005**	(-0.073, -0.013)	-	(0.031, 0.164)	-
Belgium	**1980-2005**	(-0.302, -0.480)	-		
	1970-1979	(-0.322, -0.073)	(-1.620, 0.169)	(0.368, 0.772)	(0.161, 1.950)
Brazil	**1986-2004**	(-0.022, -0.009)	(-1.675, 1.632)	(0.440, 1.430)	(-0.358, 2.949)
Canada	**1980-2005**	(-0.197, -0.041)	(1.468, -0.389)	(0.030, 0.161)	(0.206, 1.285)
	1970-1979	(-0.199, 0.013)	(-0.382, -0.002)	(0.047, 0.733)	(0.610, 0.990)
China	**1994-2005**	(-0.179,-0.053)	-	(2.051, 3.252)	-
France	**1985-2005**	(-0.282, 0.102)	-	(-0.596, 0.276)	-
	1970-1984	(-0.454, -0.167)	-	(0.218, 0.982)	-
Germany	**1987-2005**	(-0.461, -0.131)	(-11.18, 4.992)	(-0.045, 0.409)	(-6.180, 9.993)
India	**1973-2005**	(-0.203, -0.043)	-	(0.353, 0.972)	-
Indonesia	**1972-2005**	(-0.154, -0.061)	(1.205, 0.296)	(0.175, 0.399)	(0.461, 1.962)
Iran	**1980-2005**	(-0.175, -0.015)	(-1.288, 0.335)	(0.055, 0.990)	(1.811, 3.434)
Italy	**1978-2005**	(-0.338, -0.214)	(-10.21, -0.903)	-	-
Japan	**1983-2005**	(-0.109, -0.018)	(-0.807, 0.057)	(0.019, 0.279)	(0.448, 1.312)
Korea	**1980-2005**	(-0.334, -0.130)	-	(0.368, 0.618)	-
Mexico	**1978-2005**	(-0.368, -0.186)	(-2.222, 0.284)	(0.116, 0.543)	(-0.099, 2.407)
Netherland	**1978-2005**	(-0.570, -0.272)	(-3.000, -0.185)	(0.023, 0.145)	(-1.092, 1.724)
Russia	**1993-2005**	-	-	(0.148, 0.282)	(-0.186, 0.656)
Saudi	**1980-2005**	(-0.141, -0.019)	(-1.460, 1.064)	(0.224, 0.815)	(0.017, 2.542)
Thailand	**1972-2005**	(-0.238, -0.139)	(1.248, -0.237)	(0.128, 0.319)	(0.374, 1.384)
Turkey	**1978-2005**	(-0.469, -0.181)	(-3.319, 0.606)	(0.015, 0.540)	(-0.803, 3.122)
USA	**1989-2005**	(-0.097, -0.020)	(-0.256, -0.100)	(0.069, 0.211)	(0.278, 0.697)
	1970-1981	(-0.220, -0.120)	(-0.691, -0.371)	(0.069, 0.211)	(0.278, 0.697)
UK	**1971-2005**	(-0.167, -0.098)	(-2.282, 0.185)	(0.065, 0.293)	(0.182, 2.649)
Venezuela	**1972-2005**	(-0.064, -0.027)	(-0.616, 0.090)	(0.138, 0.279)	(0.848, 1.554)

Note: (-) no estimate is available. Standard errors for long run elasticities were calculated using the delta method as described by Greene (2000). Confidence intervals are calculated using estimates from Table 10 and based on the formula: The 95% confidence interval $= \beta \pm (\text{t value} * \text{Standard error})$.

As shown in Table 10, the results for gasoline demand are statistically very reasonable and we further analyze and compare these results in the following sections.

3.1 Short-run Price Elasticity

Short-run price elasticity for all countries were significantly negative as expected. Overall, the short-run price elasticity ranged from -0.42 to -0.02 with a median of -0.13 as shown in Figure5 compared to -0.30 to -0.20 in the survey summaries (Dahl, 2006) .

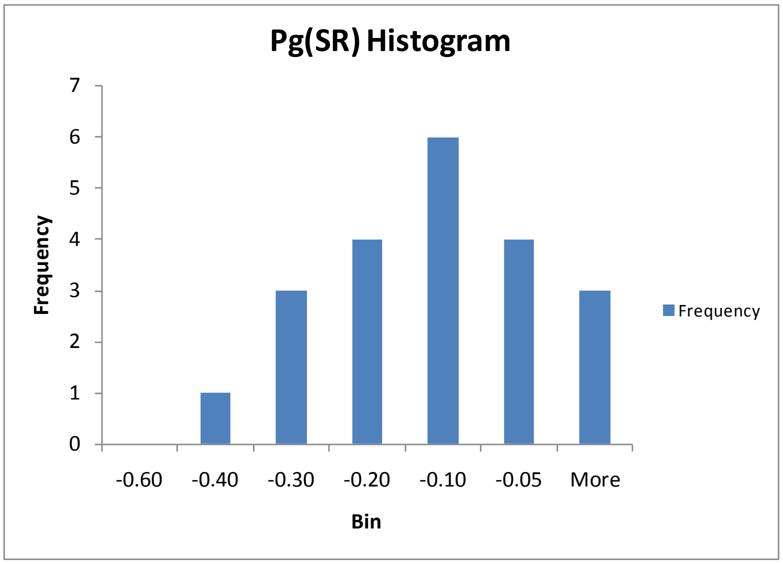

Figure 5: Gasoline Short-run Price Elasticity Histogram

Note: The number indicated below the bar is the category center.

We noticed that six European countries (Belgium, France, Germany, Italy, Netherlands, and Turkey) had comparable rather elastic short-run price elasticities around -0.30. The majority of these countries have very well developed mass transportation sectors that are possible substitute for passenger cars in an environment of high gasoline prices.

Furthermore, we noticed that countries with the highest income per capita (Australia, Canada, USA, Japan, and UK) had very inelastic short-run price elasticities around -0.08, which indicates that consumer's reaction to gasoline price increase is very limited in the short-run. The first three of these countries have lower population densities and less well developed public transit for surface travel. Oil exporting countries (Saudi, Iran, and Venezuela) have short-run price elasticities similar to that of rich countries although their income is not comparable but this is explained by the relatively low level of gasoline prices, short-run elasticities were around -0.08. Countries with real annual incomes per capita lower than $2,500 at the midpoint of the sample (China, India, Indonesia, and Thailand) had similar short-run price elasticities around -0.11. Although slightly more elastic on average, only for Thailand did the short run price elasticity 95% confidence interval not contain -0.08.

As a final point on the short-run price elasticity, countries with a structural break (Canada, France, Spain, Turkey, and USA) had an elasticity that is relatively more inelastic (i.e. less negative) in the recent period compare to the 70's and early 80's. This shows that consumer reactions for these countries during the 70's and 80's were more responsive to price changes in the short-run, while during later periods the response was more limited. We believe that this is because gasoline expenditures are a smaller percentage of consumer's budget now compared to earlier periods as income has been growing faster than gasoline expenditures in the last three decades. Also, vehicles last longer so a smaller percentage is replaced each year compared to earlier periods.

3.2 Long-run Price Elasticity

The long-run price elasticity for all reported countries was significantly negative and ranged from -1.60 to -0.02 with a median of -0.65 as shown in Figure 6 (Germany and Italy were excluded as outliers with elasticities of -5.60 and -3.09, respectively,[5] where the rest of the countries were less elastic than -1.50), compared -0.90 to -0.60 in the survey summaries (Dahl, 2006).

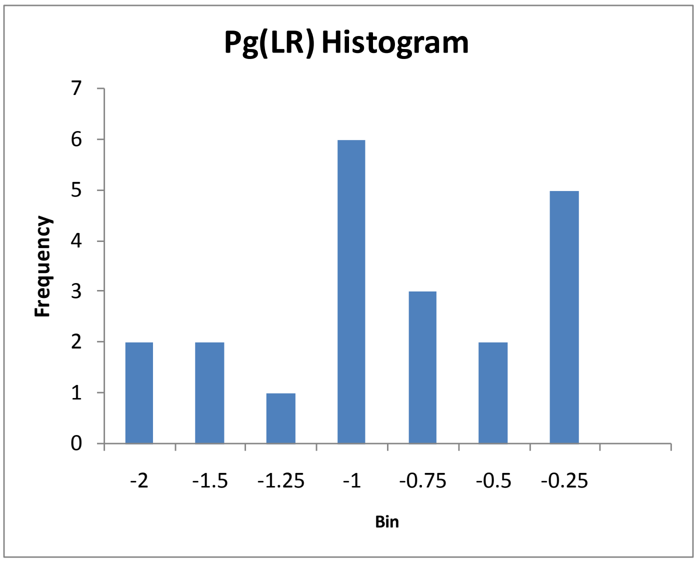

Figure 6: Gasoline Long-run Price Elasticity Histogram

Note: The number indicated below the bar is the category center.

All the European countries along with Korea had long-run price elasticities greater in absolute value than -1.00. This demonstrates that in the event of persistently high gasoline prices, the long-run consumption in these countries will decrease by a larger percent than the price increase. This might be attributed to the availability of mass transportation and other substitutes such as diesel cars in these countries allowing consumers to adjust considerably more in the long-run.[6] Also, we noticed that low income, high population countries (Thailand, Indonesia, India, and China) have a long-run elasticity that is relatively more inelastic (less than -0.70). This suggests that a limited number of substitutes are available for consumers to adjust. One obvious reason is lack of the mass transportation sophistication level compared to the European countries.

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[5] These high elasticities result from coefficients on the lagged endogenous variable close to 1.

[6] Mass transportation and the stock of diesel powered cars were not included as explanatory variables due to data limitations.

Moreover, oil producing countries (Saudi Arabia, Iran, and Venezuela) had long-run price elasticities relatively less elastic at -0.20, -0.48, -0.27, respectively. This demonstrates that consumers in these countries in the long-run adjust consumption by on average about 35% to a 100% price increase. This shows that we see lower adjustment in countries that have relatively lower fuel prices. A final observation, countries with a large geographical mass such as the USA, Australia, and Canada had long-run elasticity of -0.18 in recent period, -0.26 and -0.93 respectively.

3.3 Short-run Income Elasticity

The short-run income elasticity for all countries was significantly positive, except for Spain and Belgium (both had a structural break and income elasticity is positive for the period prior to the break point). The negative income elasticity in the later period may reflect the shift from gasoline to diesel fuel. The short-run income elasticity ranged from 0.08 to 0.93 with a median of 0.25 as shown in Figure , compared to 0.3 to 0.5 in survey summaries (Dahl, 2006).

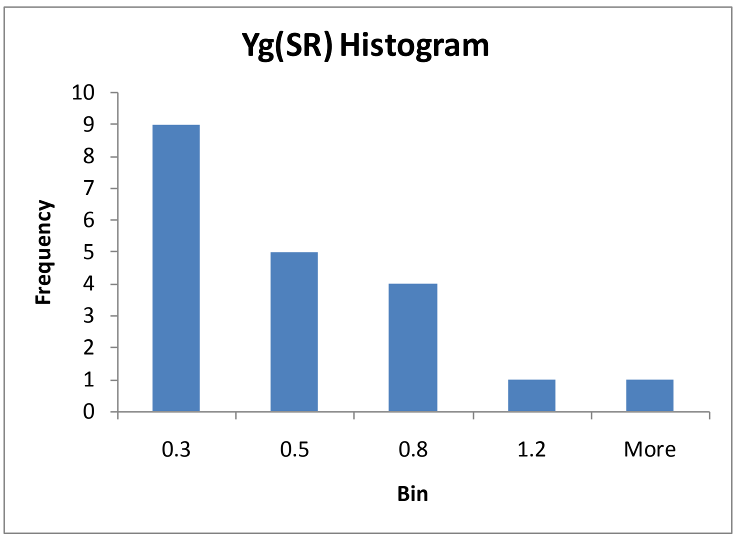


Figure 7: Gasoline Short-run Income Elasticity Histogram

Note: The number indicated below the bar is the category center.

Most of the countries had short-run income elasticity below 0.60 except countries with high population and low annual income per capita such as China, India and Brazil where elasticity was 2.60, 0.70 and 0.94 respectively. The high income countries with large geographical mass (USA, Canada, and Australia) had similar elasticities around 0.13 suggesting that short-run income increases, will not boost gasoline consumption significantly as the required driving is already taking place. Finally, countries with low gasoline price (Saudi Arabia and Iran) have elasticities around 0.50.

3.4 Long-run Income Elasticity

The long-run income elasticity for all countries was significantly positive, except for Belgium. Again we believe its negative income elasticity reflects a strong shift out of gasoline and into diesel fuel during the 1980’s. The bulk of the long-run income elasticities ranged from 0.23 to 2.62 with a median of 1.20 as shown in Figure , compared to greater than 1.0 in survey summaries (Dahl, 2006).

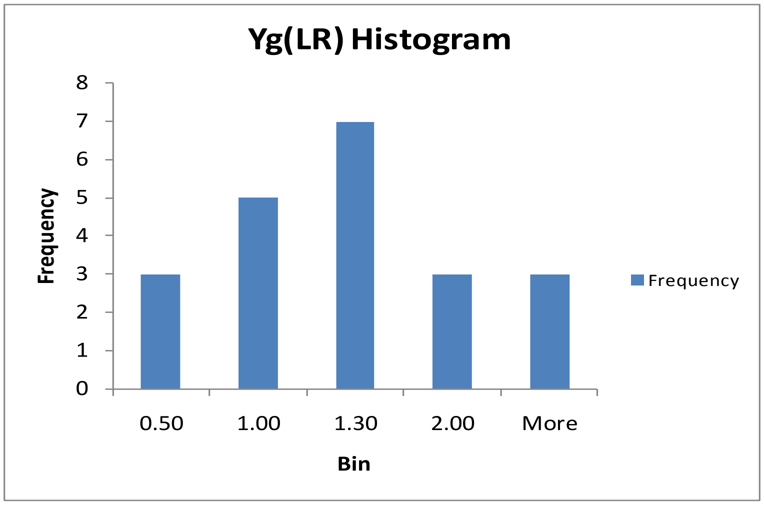


Figure 8: Gasoline Long-run Income Elasticity Histogram

Note: The number indicated below the bar is the category center.

Many of the countries (i.e. China and India) with long-run elasticity more than 1.00 have relatively low cars ownership per capita compare to the US with an elasticity of 0.33). This shows that as a nation's income increases, consumers in the long-run will react by increasing the stock of vehicles leading to a gasoline consumption increase. Consumers will increase their vehicle stock holdings at different rates depending on the number of vehicles per capita at any point of time as well as any policy restrictions on new car ownership. For example, countries such as China and India with a very low number of vehicles (6.76 and 5.95 vehicles per 1000 people, respectively) will react considerably more to income increases compared to countries with a high level of vehicle holdings such as the US (473.5 vehicles per 1000 people). However, high population densities and traffic congestion may cause some governments to restrict car ownership in big cities. In 2013, China had vehicle ownership restrictions in Beijing, Shanghai, and Gangzhou with other congested cities also considering restrictions (Feng and Li (2013)).

The majority of the countries experience most of the adjustment during the first 10 years. Also, the adjustment in the developed countries with more saturation in vehicle stock is relatively slower than the less developed.

5. Comparing Results with the Literature

In this section, we compare the individual results for each country with results from the literature in Table 11. The literature studies cited in the Tables are the most closely comparable to our models using lagged endogenous and with the most over lapping data. Overall, we find that our individual estimates for the developed countries tend to be more inelastic in the short-run and the long-run compared to older results. However, the individual estimates for the developing countries show a different behavior where price elasticity is generally more inelastic while income elasticity is more elastic now compared to older results. These results for the developing countries give more decisive conclusions compare to Dahl (1993) where she had no final conclusion and claimed that estimates are sensitive to model type. Her conclusion goes in line with our initial proposal of carefully and systematically modeling each country using the ARDL approach to achieve reliable estimates. A possible intuitive explanation for the developing country's inelastic price response is the fact that only the rich are driving so a price increase will not affect them very much.

Table 11: Gasoline Results Comparison with Major Studies in the Literature.

Country	Study		P_{SR}	P_{LR}	Y_{SR}	Y_{LR}
Australia	This study		-0.043	-0.258	0.098	0.588
	Franzén (1995)	1960-1986	-0.050	-0.180	0.180	0.710
Belgium	This study		-0.391[a]	-1.595[a]	-0.318[a]	-1.299[a]
	Franzén (1995)	1960-1986	-0.360	-0.710	0.630	1.250
Brazil	This study		-0.015	-0.021	0.935	1.296
	Rogat & Sterner (1998)	1960-1994	-0.230	-0.980	0.200	0.900
Canada	This study		-0.119[a]	-0.929[a]	0.095[a]	0.746[a]
	Franzén (1995)	1960-1986	-0.250	-1.070	0.120	0.530
China	This study		-0.116	-0.098	2.652	2.243
	Gately & Streifel (1997)	1971-1993	–	–	–	0.840
France	This study		-0.311	-0.651	0.600	1.257
	Franzén (1995)	1960-1986	-0.360	-0.070	0.640	1.230
Germany	This study		-0.296	-3.095	0.182	1.907
	Franzén (1995)	1960-1986	-0.050	-0.570	0.040	0.480
	Dargay (1988)	1960-1985	-0.290	-0.730	0.490	1.230
India	This study		-0.123	-0.286	0.663	1.542
	McRae (1994)	1973-1987	-0.321	–	1.384	–
	Ramanathan (1999)	1972-1994	-0.209	-0.319	1.178	2.682
Indonesia	This study		-0.108	-0.455	0.287	1.211
	McRae (1994)	1973-1987	-0.197	–	1.691	–
	Dahl & Kurtobi (2001)	1970-1995	-0.194	-0.815	0.310	1.303
	Gately & Streifel (1997)	1971-1993	–	–	–	1.010
	Chakravorty, Fesharaki & Zhou (2000)	1972-1992	-0.203	-1.440	0.121	0.858
Iran	This study		-0.095	-0.477	0.523	2.622
	Chakravorty, Fesharaki & Zhou (2000)	1972-1992	-0.022	-0.057	(?)	(?)
	Kianian (1983)	1956-1978	-0.020	-0.730	0.220	0.880
	Salahi-Isfahani (1996)	1965-1993	-0.120	-0.340	0.530	1.510
Italy	This study		-0.276	-5.560	NA	NA
	Franzén (1995)	1960-1986	-0.370	-1.150	0.400	1.250
Japan	This study		-0.063	-0.375	0.149	0.880

	Franzén (1995)	1960-1986	-0.150	-0.760	0.150	0.770
South Korea	This study		-0.232	-1.142	0.491	2.418
	McRae (1994)	1973-1987	-0.496	−	(?)	−
Mexico	This study		-0.277	-0.969	0.330	1.154
	Gately & Streifel (1997)	1971-1993	−	-0.290	−	2.700
	Berndt & Botero (1985)	1960-1979	-0.170	-0.330	0.730	1.350
	Rogat & Sterner (1998)	1960-1994	-0.120	-1.710	0.080	1.140
Netherlands	This study		-0.421	-1.592	0.084	0.316
	Franzén (1995)	1960-1986	-0.570	-2.290	0.140	0.570
Russia	This study				0.215	0.235
Saudi Arabia	This study		-0.080	-0.198	0.520	1.279
	Al-Sahlawi (1988)	1970-1985	-0.080	-0.670	0.110	0.920
	Almak`i (1987)	1967-1983	-0.118	-0.810	0.078	0.530
	Chakravorty, Fesharaki & Zhou (2000)	1972-1992	-0.077	-0.517	0.098	0.658
	Al-Faris (1993)	1973-1980	-0.080	-0.300	0.020	0.070
Spain	This study		-1.650[a]	5.893[a]	-0.410[a]	1.464[a]
	Franzén (1995)	1960-1986	-0.140	-0.300	0.960	2.080
Thailand	This study		-0.189	-0.742	0.223	0.879
	McRae (1994)	1973-1987	-0.337	−	0.819	−
	Gately & Streifel (1997)	1971-1993	−	-1.000	−	(?)
	Birol & Guerer (1993)	1970-1990	-0.290	−	0.440	−
Turkey	This study		-0.325	-1.356	0.278	1.160
	Franzén (1995)	1960-1986	-0.310	-0.610	0.650	1.290
USA	This study		-0.058[a]	-0.182[a]	0.142[a]	0.444[a]
	Franzén (1995)	1960-1986	-0.180	-1.000	0.180	1.000
	Hughes, Knittel & Sperling (2006)	2001-2006	-0.040	−	0.500	−
UK	This study		-0.133	-1.049	0.179	1.416
	Franzén (1995)	1960-1986	-0.110	-0.450	0.360	1.470
Venezuela	This study		-0.046	-0.263	0.209	1.201
	Gately & Streifel (1997)	1971-1993	−	−	−	5.58
	Chakravorty, Fesharaki & Zhou (2000)	1972-1992	-0.03	-0.063	0.056	0.118

Note:2. (?): Insignificant. −: Not estimated.

CONCLUSION AND POLICY IMPLICATIONS

This paper has applied the ARDL general-to-specific modeling technique for 23 countries to estimate gasoline and diesel demand in the road transport sector using data from 1970-2005. We believe that our estimates are more reliable than earlier work for a number of reasons: we systematically tested across models while considering the stationarity and spurious regression issues; we considered model stability; we considered cross price substitution between gasoline and diesel and we included a number of rather important economic and demographic variables. The final model specification was dominated by the lagged endogenous specification, and hence, estimates in the literature using such model specification may be producing trustworthy estimates whereas vehicle stock models were extremely disappointing and should be used with caution unless quality stock data are available.

We found that all countries ARDL results were bounded by a cointegrating relationship (except for Spain), and hence we avoided having a spurious regression in our estimates. Moreover, and in contrast to our earlier hypotheses, our models in general tend to be stable. Only six countries experienced statistical structural breaks at different points of time and not only during price shocks. We found that the US was the only country that experienced a structural break because of only price shock. This indicates structural breaks could be attributed to other factors such as GDP shifts (Belgium, France, and Spain). Moreover, cross price substitution was established in seven mostly developed countries. We found that the absolute value of the ratio of gasoline to diesel price elasticities ranges between two and four, demonstrating that substitution between diesel to gasoline requires larger diesel price shifts (Italy, Netherlands, and Spain).

The structural variables that we include were not as important as we expected and were significant in only seven countries. We found that industrial GDP and urbanization rates had the expected positive and negative signs, respectively, while female labor force participation rate variable had conflicting signs. The stock model, given our results is a questionable specification. Also, we found that in general the speed of adjustment toward equilibrium is slower for gasoline compared to diesel for most of the countries, and the adjustment in the developed countries is relatively slower than the less developed.

Demand elasticities are typically two to three times more elastic in the long-run than in the short-run. Income elasticities are typically much larger than the absolute values for price elasticities except for long-run where they are more similar in absolute value. These results have important policy implications. Fuel tax policy has been used extensively in many countries to control fuel consumption and generate revenues for governments. This study shows that tax policies with an objective of energy conservation will not be as effective as previously believed in the short-run. Furthermore, rapid income growth suggests very high price increases will be needed to choke off further consumption increases.

In general, our elasticity estimates vary widely across countries confirming the earlier findings in the literature. Most short-run price elasticities range from -0.42 to -0.02 (median is -0.13) and most long-run price elasticities range from -1.60 to -0.02 (median is -0.65), while the most short-run income elasticities range from 0.08 to 0.93 (median is 0.25) and long-run income elasticities range from 0.23 to 2.62 (median is 1.20). Thus, fuel taxes to manage consumption must be designed with each individual country in mind.

In some cases, a structural break was found, and the more recent demand estimates are less demand elastic such as in the USA. In such cases, market players may expect larger demand response than will actually happen, and it is important to use estimates on the most up-to-date data possible. Finally, given the relatively high ratio of long- to short-run price elasticity in most of the countries, key producers are encouraged to maintain stand-by capacity to have better control of prices and obtain extra revenues in the short-run during times of high prices. However, this stand-by capacity should ensure that these high prices are not sustained for a long period leading to a significant oil demand decrease in the long-run.

Future work could apply panel data analysis to uncover any possible geographical or s effects between similar countries. The cointegration/error correction approach using the vector error correction model could be applied to reveal if more than one cointegrating relationship exists. Finally we could include data points for more recent years as they become available to incorporate the significant price increase that have taken place during these last two years.

APPENDIX A: RAW DATA GRAPHS

Here we present a graph of the raw data used in our ARDL model. The variables are abbreviated as follows:

GRPC = gasoline consumption per capita

DRPC = diesel consumption per capita

PGAS = real price of gasoline in local currency

INDGDP = industrial GDP share

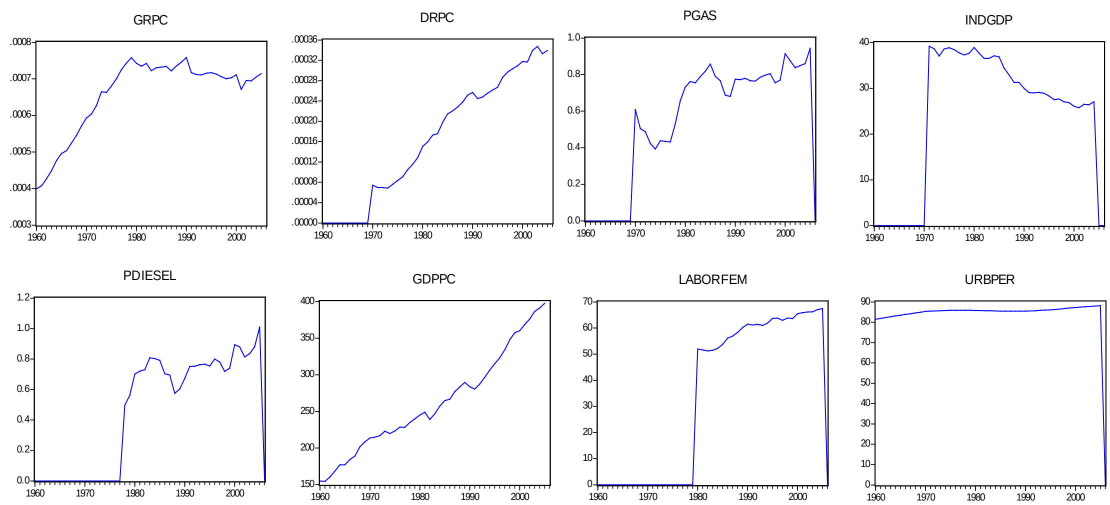
PDIESEL = real price of diesel in local currency

GDPPC = real GDP per capita in local currency

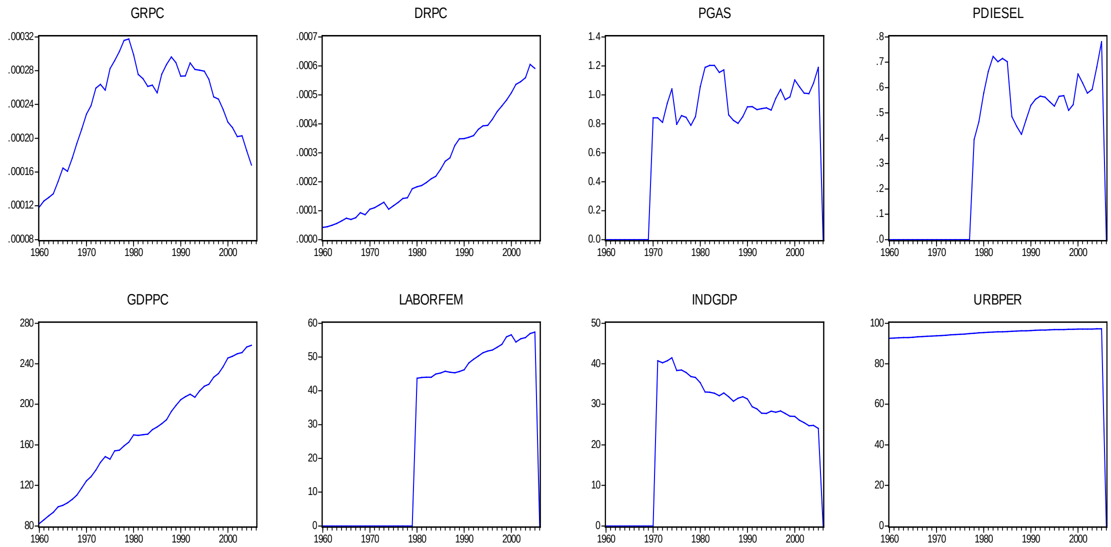
LABORFEM = female labor force participation rate

URBPER = urbanization rate

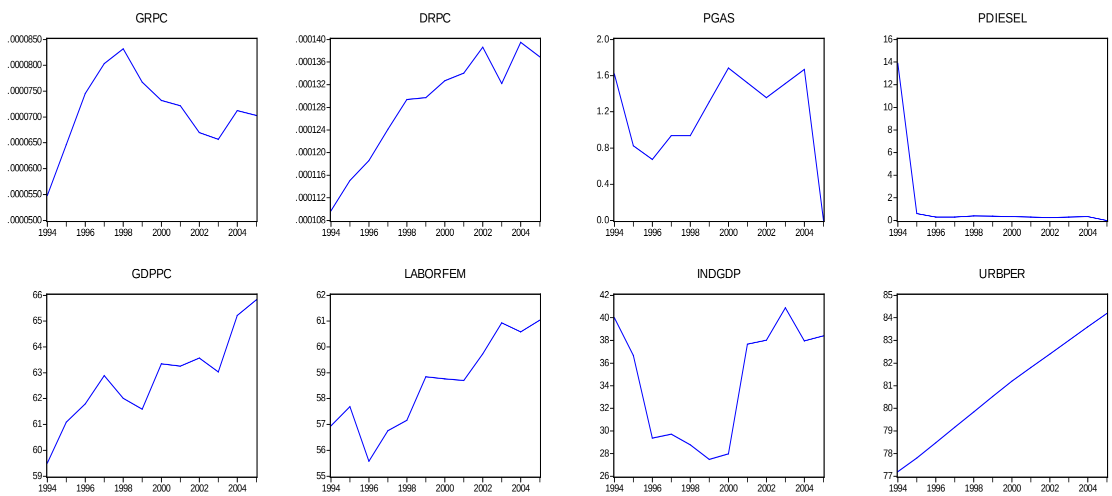
Australia



Belgium



Brazil



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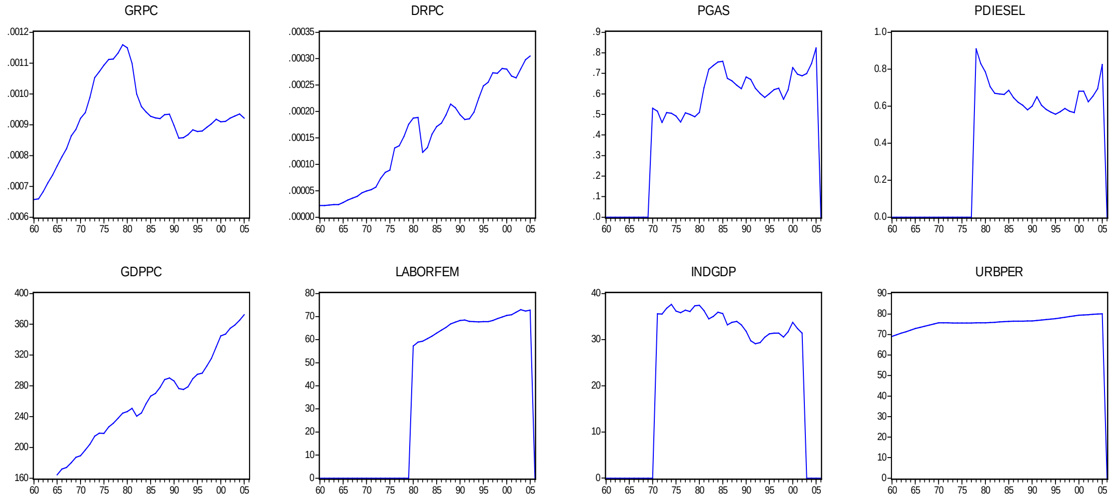

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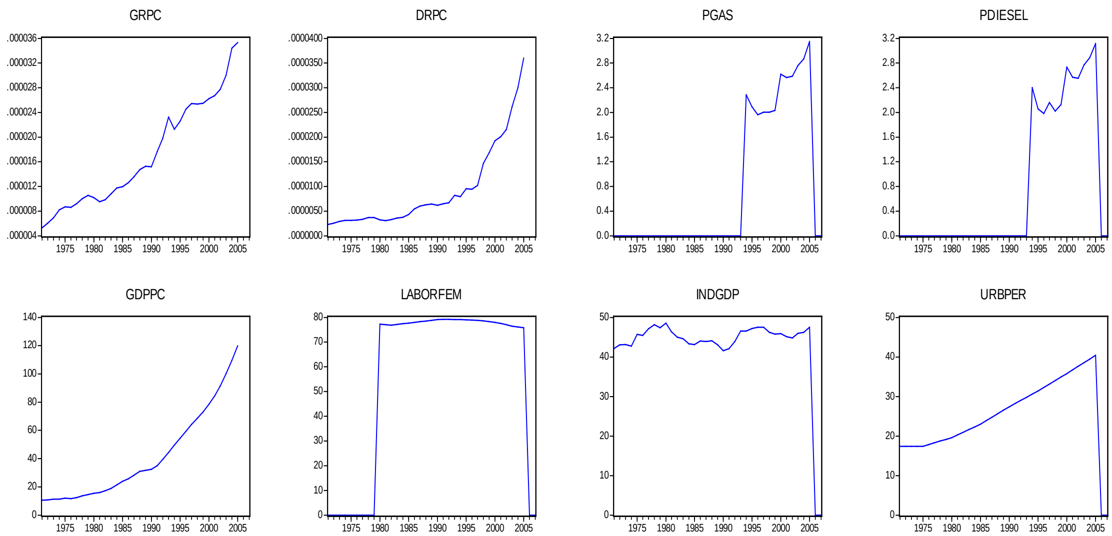
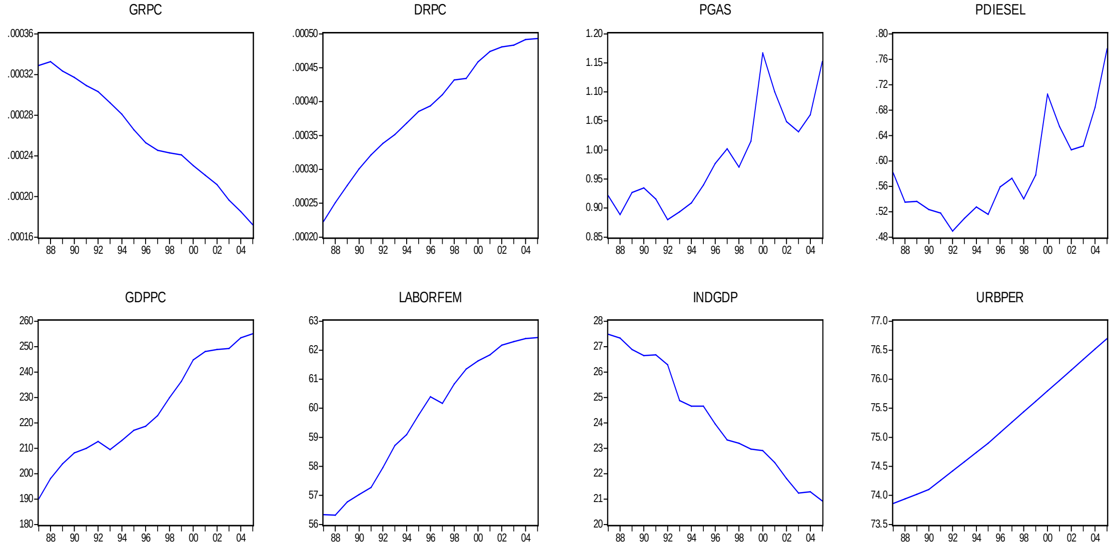
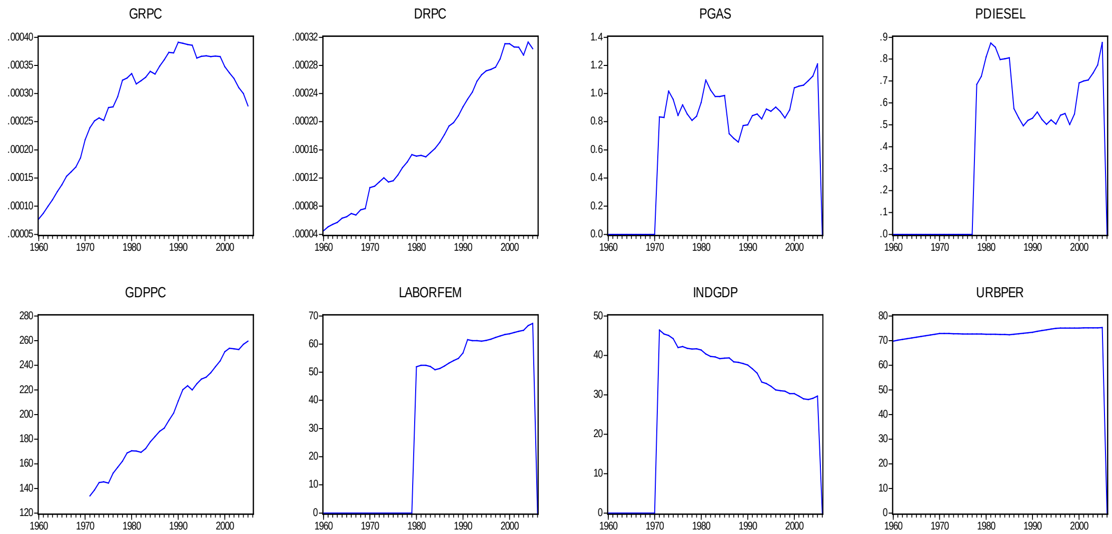


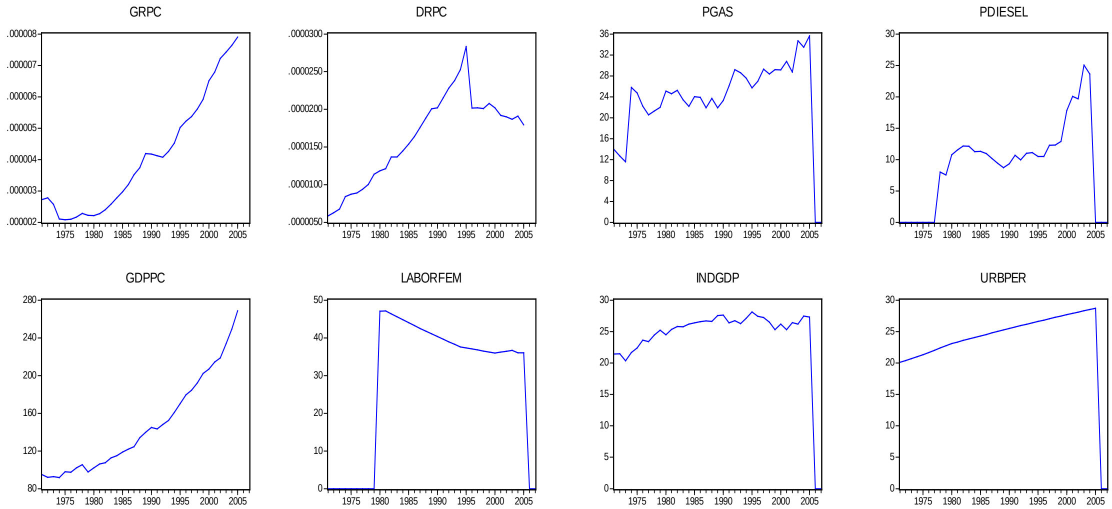
France



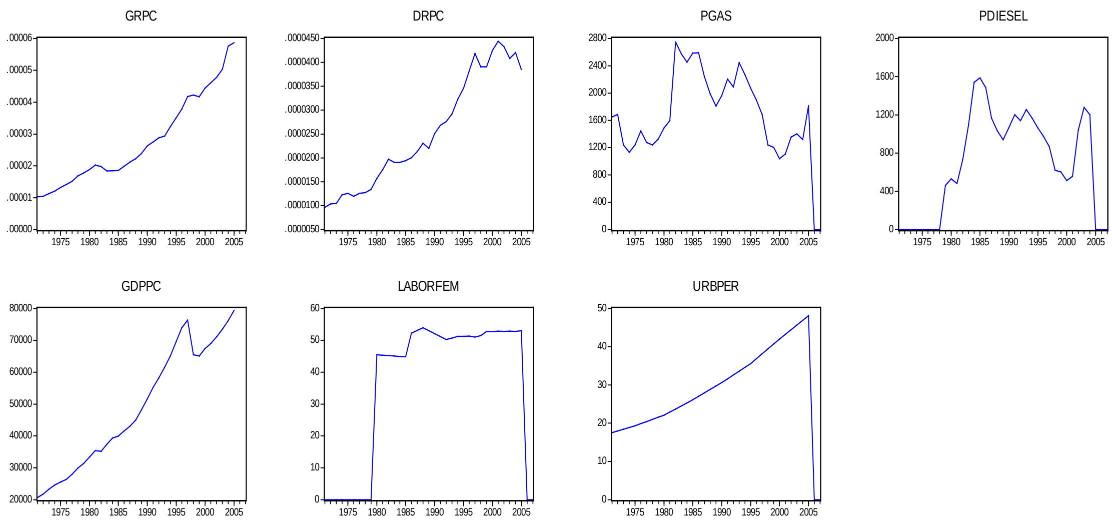
Germany



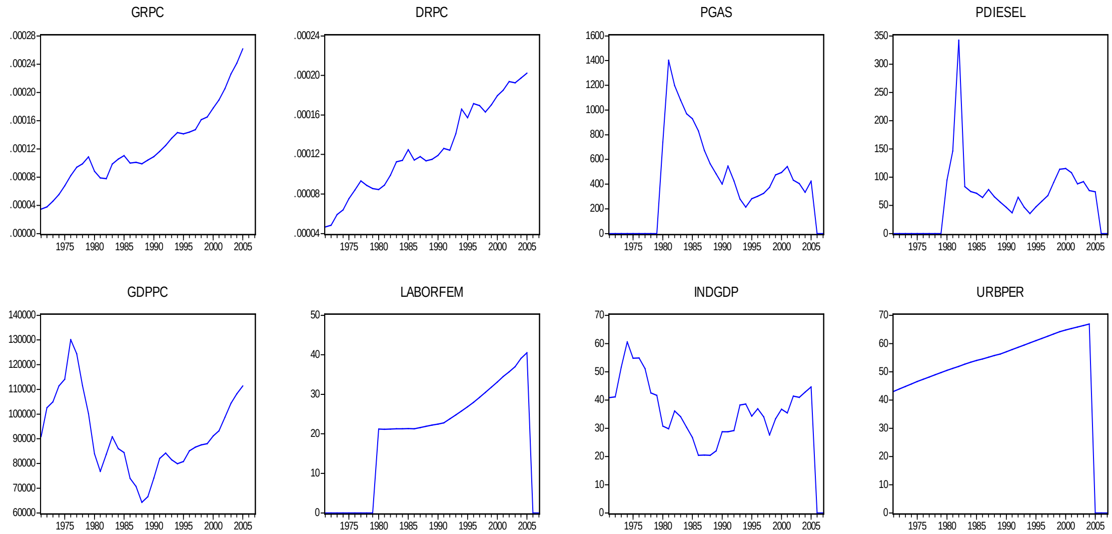
India



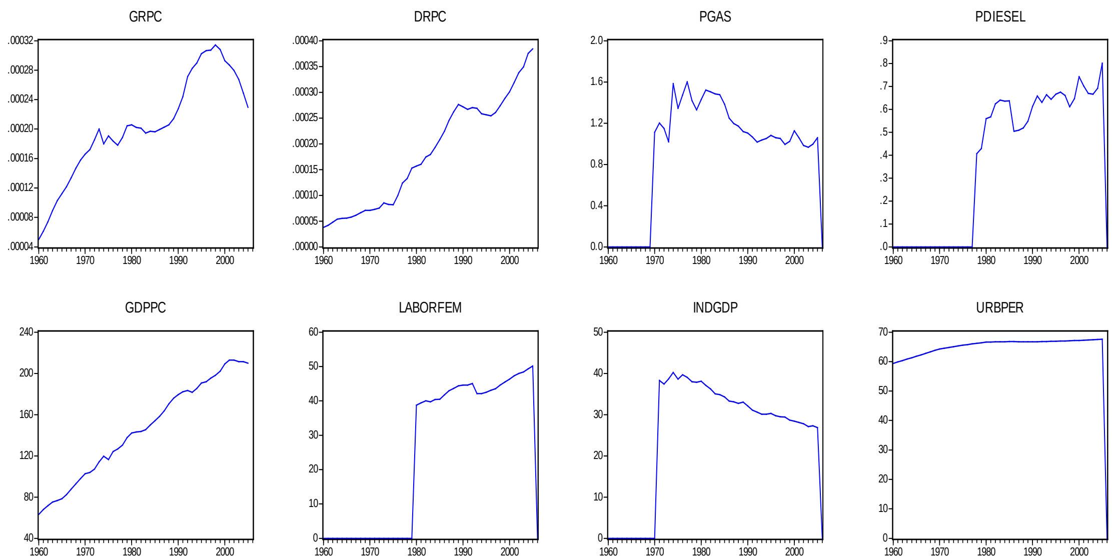
Indonesia



Iran


GRPC
DRPC
PGAS
PDIESEL
GDPPC
LABORFEM
INDGDP
URBPER

Italy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DRPC
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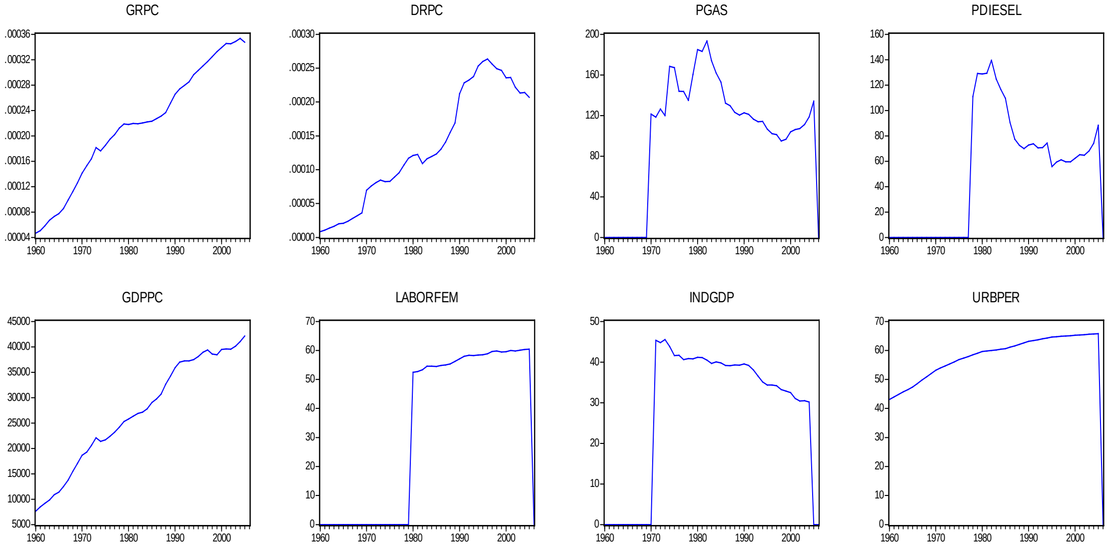
LABORFEM
INDGDP
URBPER

Japan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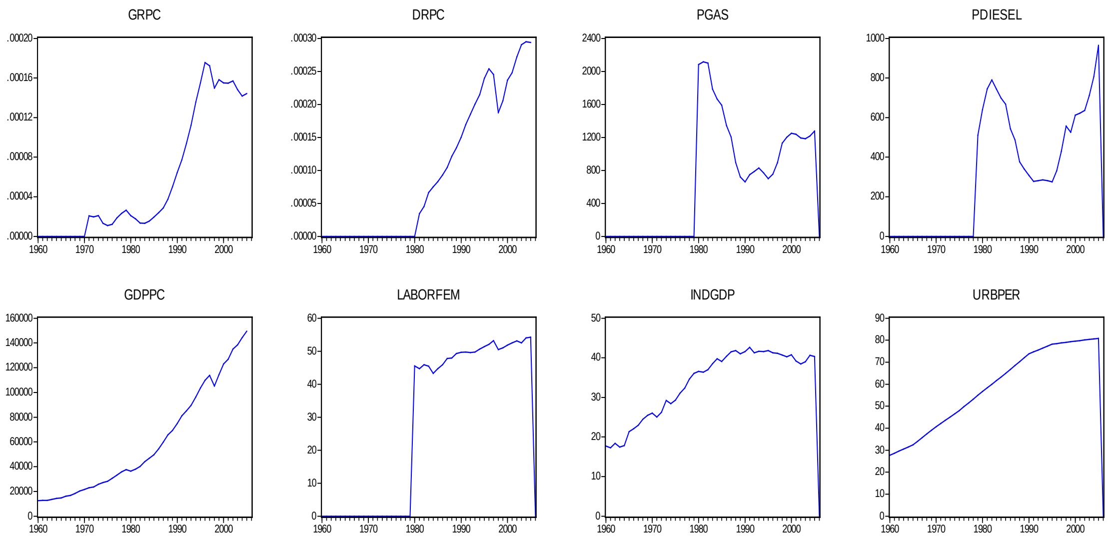
LABORFEM
INDGDP
URBPER

Korea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DRPC
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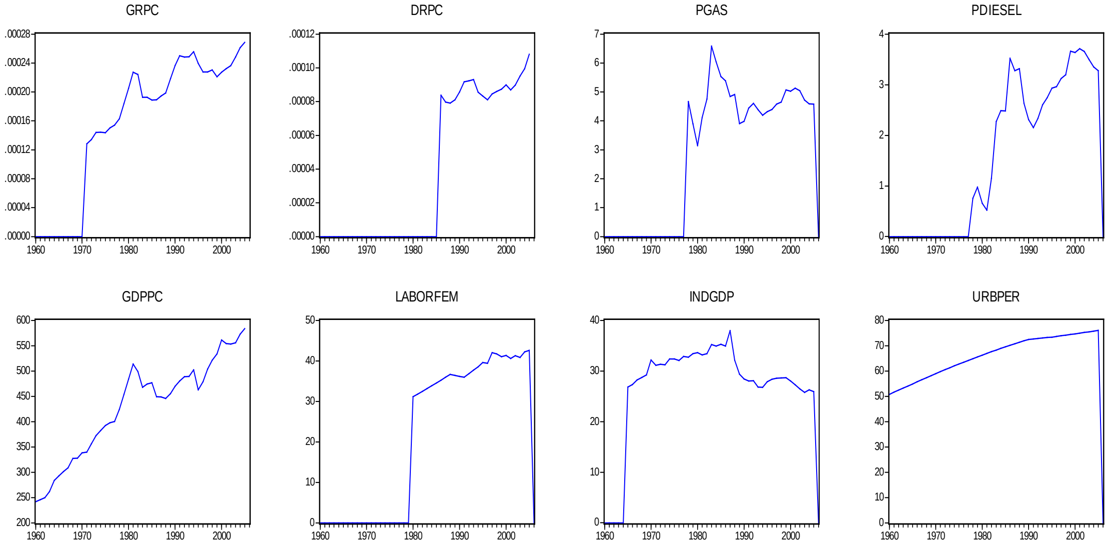
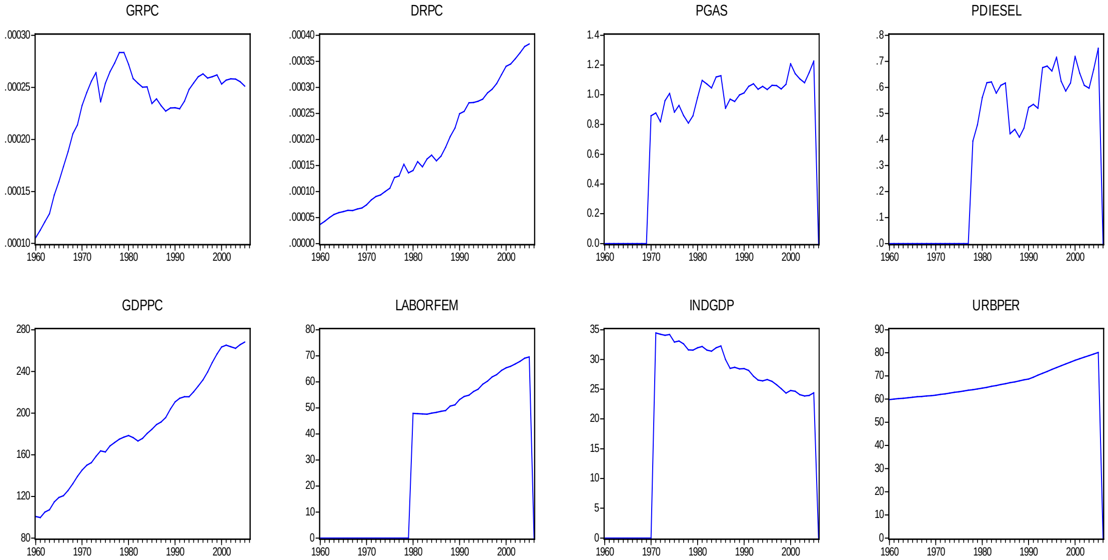
LABORFEM
INDGDP
URBPER

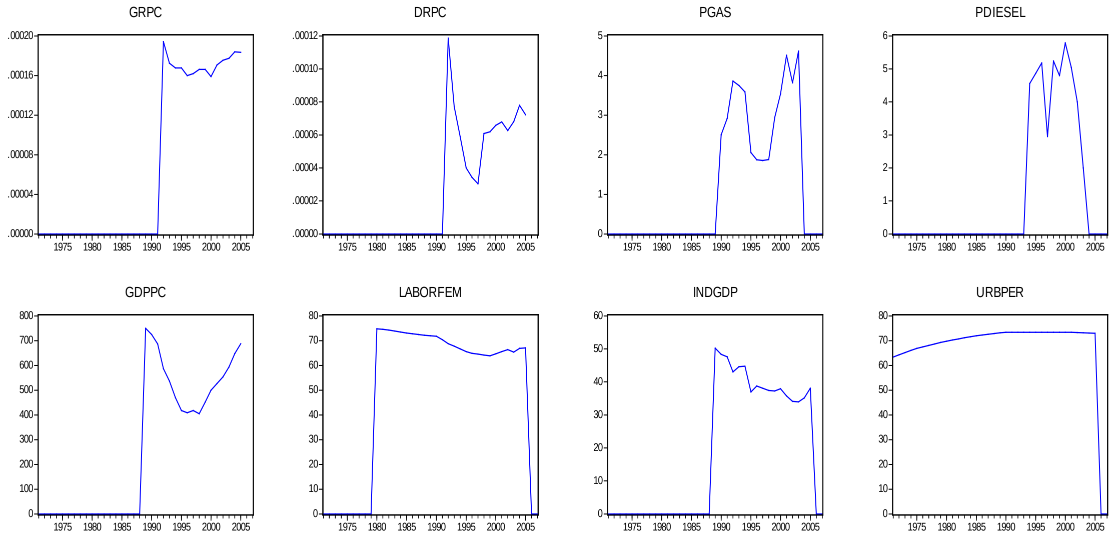
Mexico



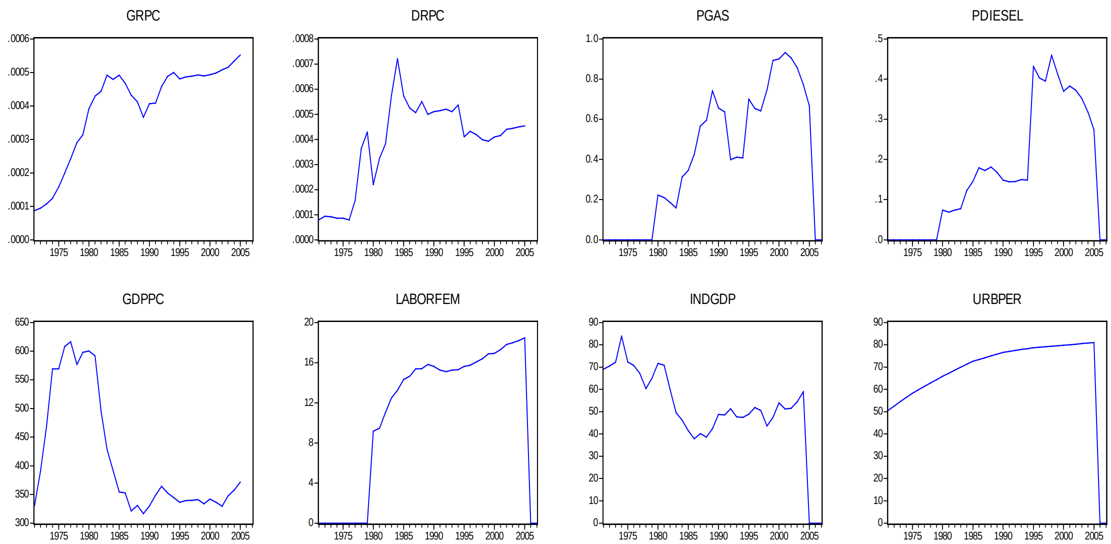
Netherland



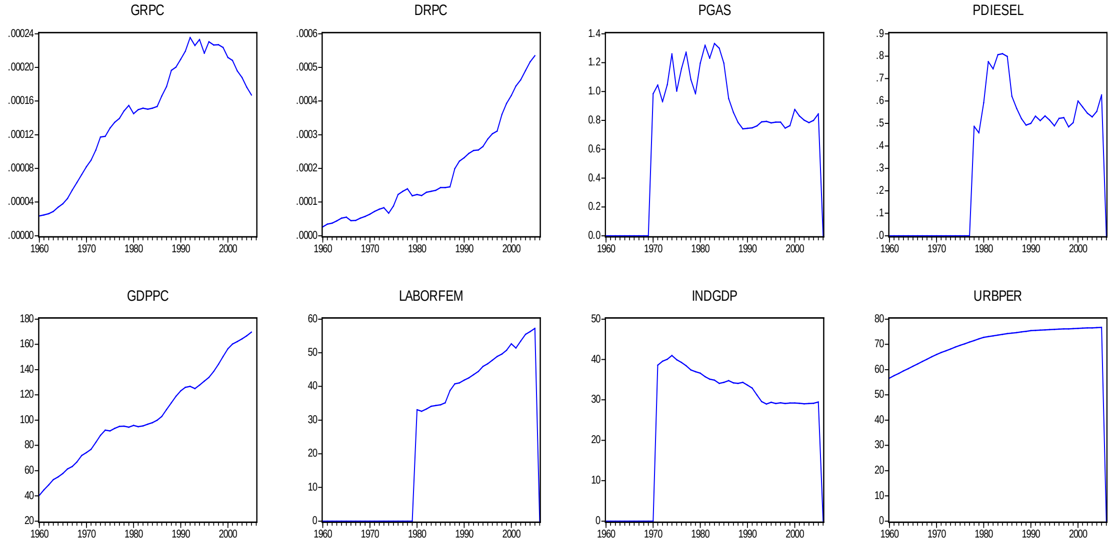
Russia



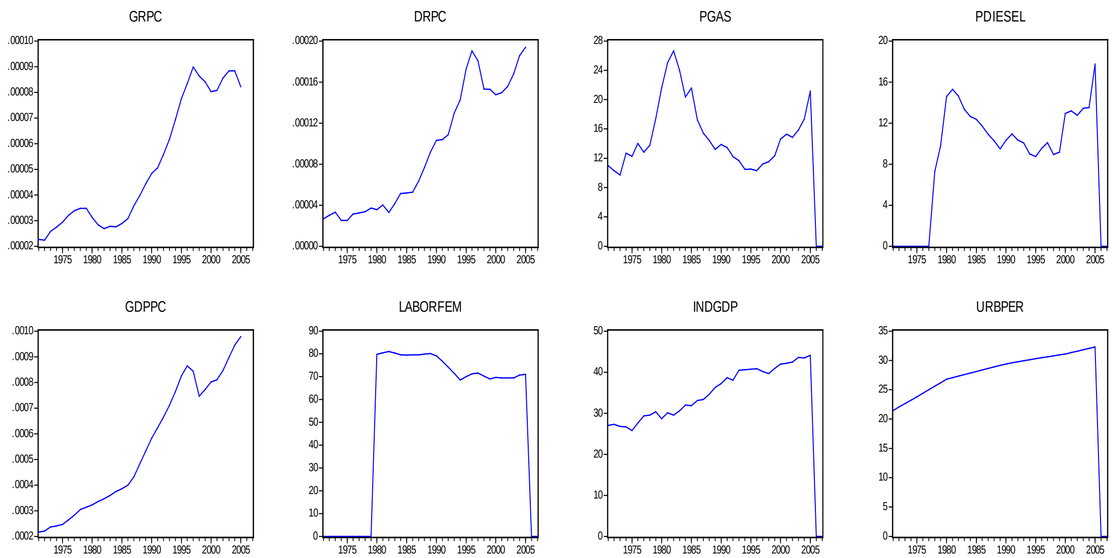
Saudi Arabia



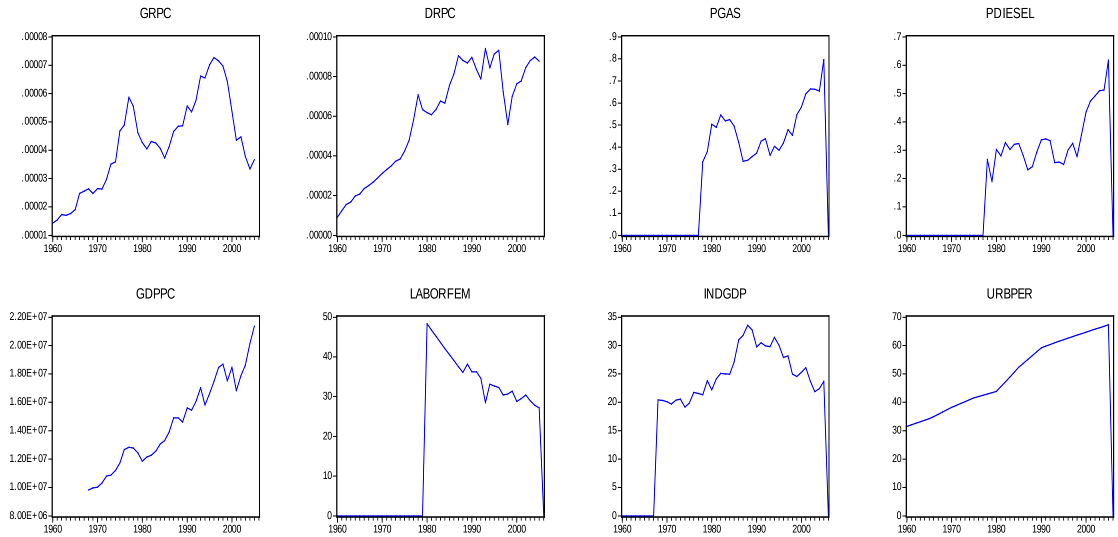
Spain



Thailand



Turkey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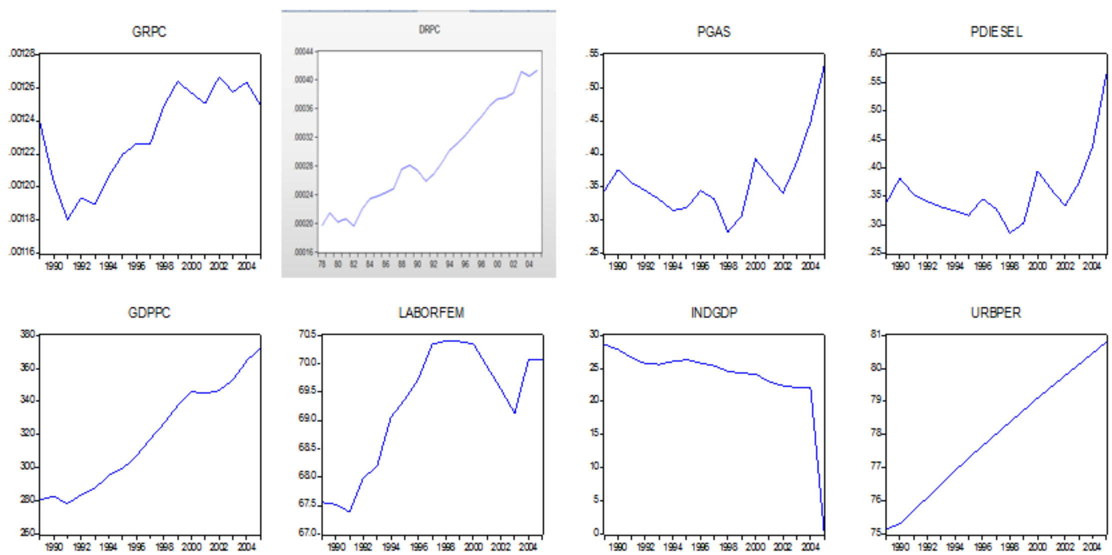
PGAS
PDIESEL
GDPPC
LABORFEM
INDGDP
URBPER

USA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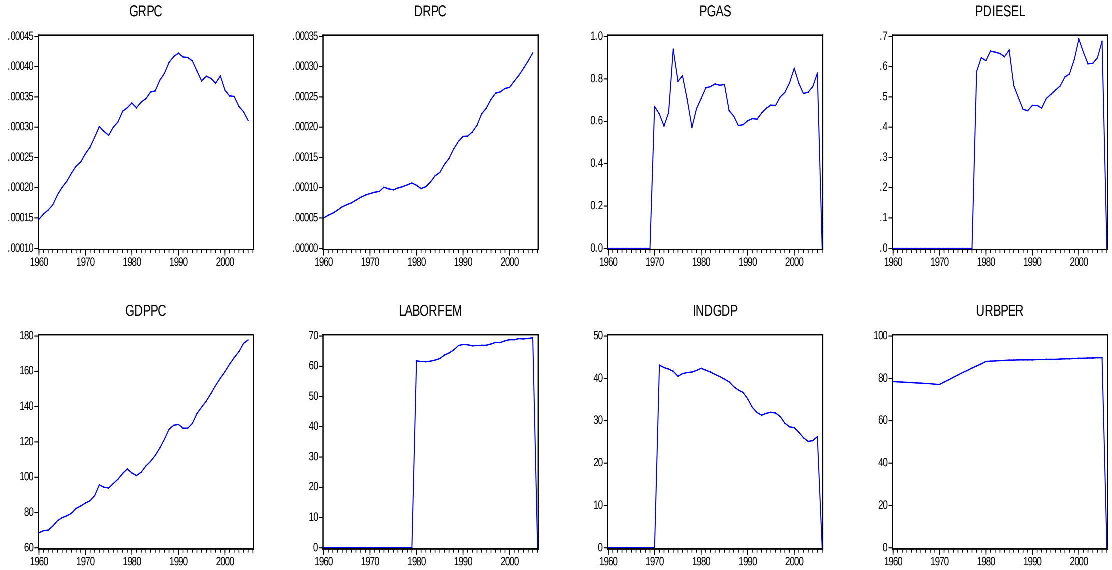
UK



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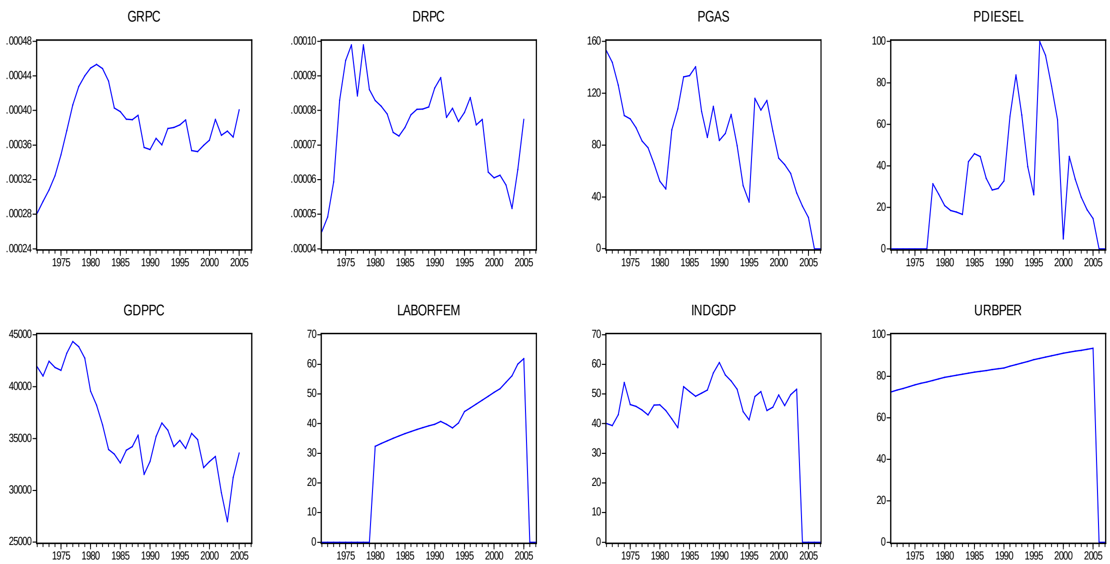
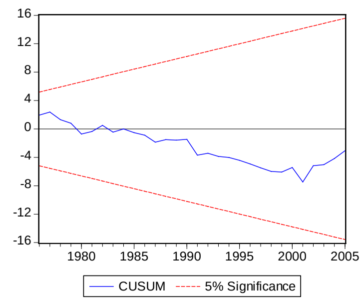


APPENDIX B STABILITY TEST (CUSUM)

Australia



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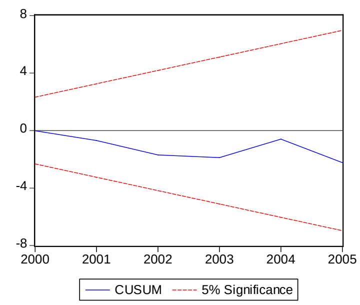
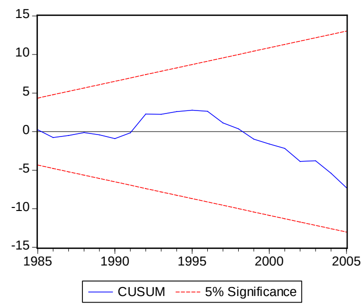


Belgium



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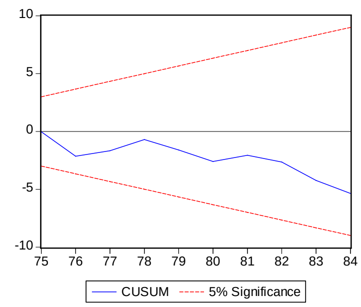
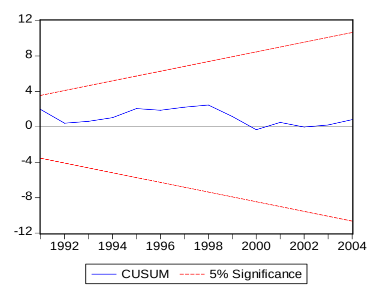


Brazil



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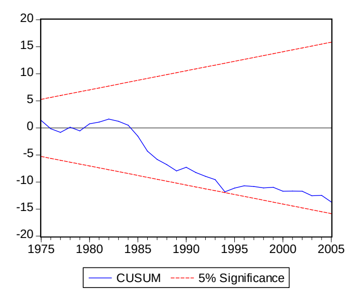
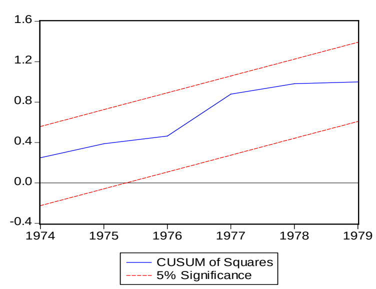


Canada



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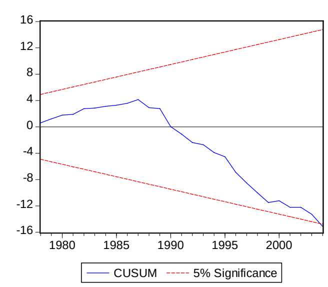
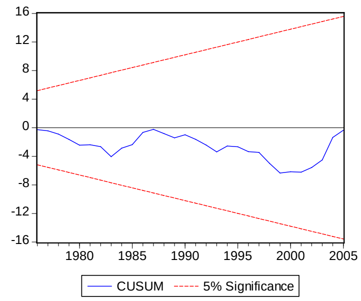
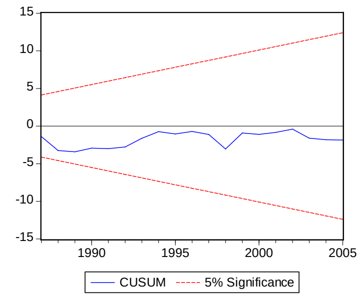


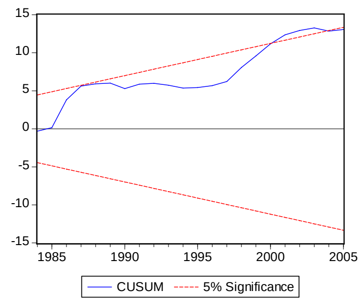
Indonesia



Korea



Iran



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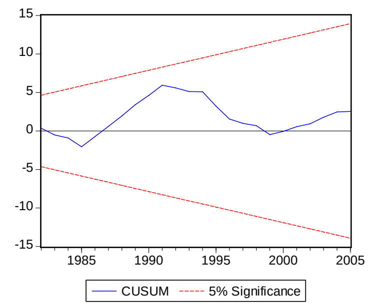

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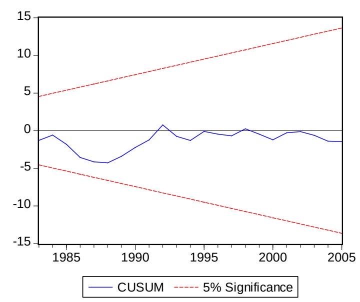

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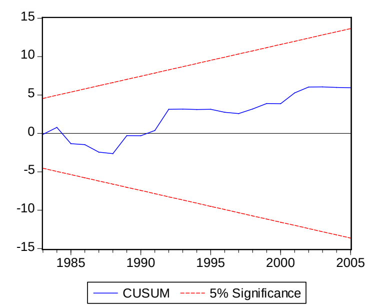

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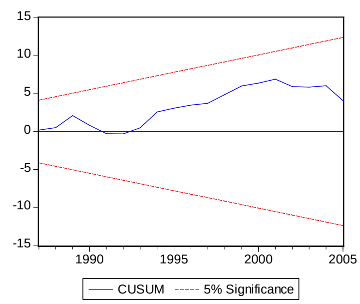

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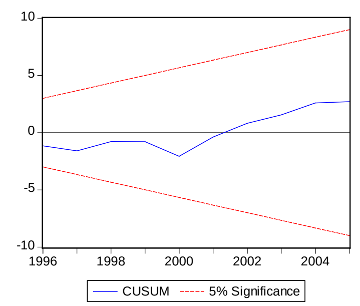
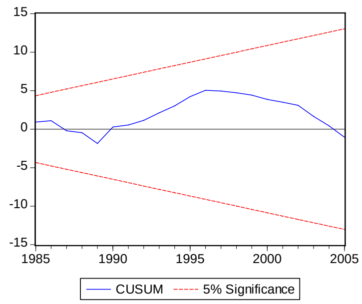
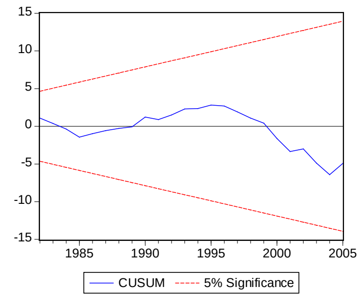


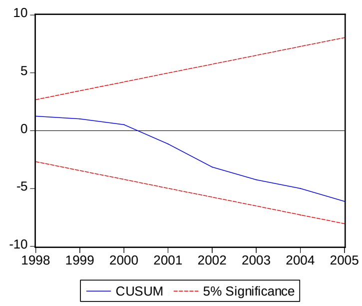
Saudi Arabia



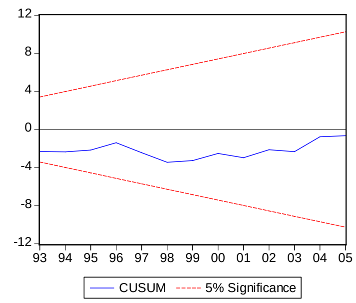
Turkey



Spain



USA



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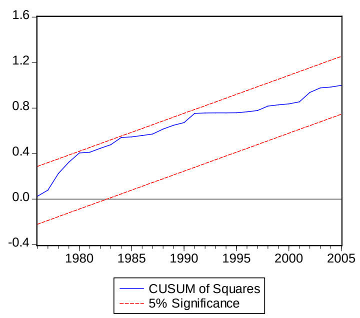
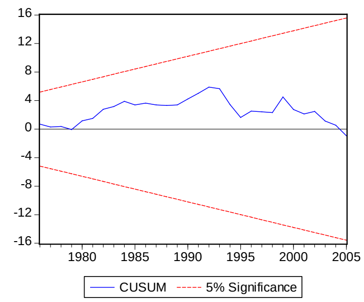
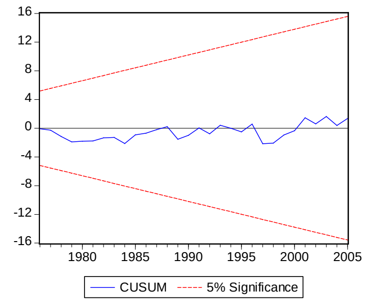


UK



Venezuela



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