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Are crude Oil, Gas and Coal Prices Cointegrated?

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Abstract

This study examines the existence of long run relation between crude oil, natural gas and coal prices. Energy data for US is used and Based on the result of The Augmented Dickey-Fuller (ADF) tests, autoregressive distributed lag (ARDL) approach is adapted to cointegration analysis. Underlying ARDL model is specified in logarithmic form, so that the coefficients indicate the elasticities. Long run relationship and error correction model (ECM) are estimated for selected ARDL. Moreover, to confirm the stability of the model, CUSUM and CUSUMSQ tests are also conducted with the results that the estimated model is completely stable. The results confirm the existence of long run relation between coal, gas and oil prices. However, in short run gas prices have no effects on the oil prices as its coefficient is insignificant.

Keywords: energy (Oil, Gas, Coal) prices; unit root; cointegration; autoregressive distributed lag (ARDL; ECM model.

1- Introduction

One characteristic of commodity prices is the presence of a unit root in their univariate time series representation, implying that price movements are better characterized as being the sum of permanent and transitory components where the permanent component is a random walk.

However, this study is to examine the long-run relation between crude oil, gas and coal prices. In doing so, tests for unit roots in the univariate time series representation of monthly prices are performed to determine their integration degrees- a prerequisite for the analysis of cointegration. Cointegration is designed to deal explicitly with the analysis of the

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relationship between non-stationary time series. In particular, it allows individual time series to be non-stationary but requires a linear combination of the series to be stationary. Therefore, the basic idea behind cointegration is to search for linear combinations of individually non-stationary time series that are themselves stationary. The methodology used to study common trends in these series is based on the autoregressive distributed lag (ARDL) approach proposed by Pesaran and Shin (Pesaran and Shin, (1995, 1998); Pesaran et al., (1996); Pesaran et al. (2001)).

This paper is developed in six sections. Section two is a short literature review. Section three reports the results of unit root and stationarity tests using Augmented Dickey-Fuller (ADF) approach. Section four describes the methodology of autoregressive distributed lag (ARDL) approach. Section five presents empirical results and the last section reports the main conclusions.

2- Literature Review

What price linkages exist between oil, coal, and natural gas? The main theory here is based on economic substitution. As Bachmeier & Griffin (2006) assert clearly, in the short run coal, oil, and natural gas are not fungible and direct fuel competition is limited. In the long run, these fuels become much closer economic substitutes depending on their respective costs of conversion technologies (Griffin (1979)).

It likes to be probable conjecture that long run relationship between oil, gas and coal price exist. But existence of short run relationship is doubtful.

Serletis (1992) tested for unit roots in the univariate time-series representation of the daily crude oil, heating oil, and unleaded gasoline spot-month future prices. The results showed that the random walk hypothesis for daily energy future prices can be rejected if allowance is made for the possibility of a one-time break in the intercept and the slope of the trend function at an unknown point in time.

Serletis (1994) reported that the maximum likelihood cointegration analysis of daily spot-month crude oil, heating oil and unleaded gasoline future prices covering the period 3 December 1984 to 30 April 1993 led to the conclusion that all three spot-month future prices are driven by only one common trend, suggesting that it is appropriate to model energy future prices as a cointegrated system.

De Vany and Walls (1995) analyzed the degree of integration of the North American gas market and the way price dynamics evolved as these markets were progressively embedded in a larger web of open pipelines and interconnected markets. With the two-step Engle-Granger test for co-integration, spot prices were found to be increasingly co-integrated as open access to the pipelines expands through the network.

King and Cuc (1996) investigated the strength of spot price integration between various natural gas producing basins of North America, from the mid 1980's until the mid 1990's and with time varying parameter (Kalman Filter) and cointegration analysis. Bivariate cointegration tests (Engle-Granger procedure) results were qualitatively similar to De Vany and Walls (1995). Time varying parameter analysis results indicated that price convergence has been emerging in regional markets.

Serletis (1997), in a slightly different manner, tested for shared stochastic trends in the North American markets. Evidence concerning the shared stochastic trends in eight North American natural gas spot markets, using monthly data (1990: 06 - 1996: 01), was obtained by the Engle-Granger approach and the Johansen maximum likelihood approach. Prices within eastern and western areas were found to be driven by different stochastic trends.

Serletis and Herbert (1999) investigated the dynamics of North American natural gas, fuel oil and power prices in the area of eastern Pennsylvania, New Jersey, Maryland and Delaware, using daily data (1996: 10 - 1997: 11) on the Henry Hub and Transco Zone 6 natural gas prices, the PJM (Pennsylvania, New-Jersey and Maryland) power market for electricity price and the fuel oil price for New York Harbor. Correlation between prices in log levels was first investigated and the stationary properties of the prices were analysed using the ADF test. The Engle-Granger Bivariate cointegration test for the pairs of integrated series reported that each pair cointegrates, leading to the conclusion that the same underlying stochastic component affects the three markets.

Asche et al. (2000) investigated the degree of market integration for France, Germany and Belgium. Cointegration tests highlighted that the different border prices for gas to France move proportionally over time and without any significant differences in mean. Furthermore, national markets in Germany, France and Belgium were found to be highly integrated.

Asche et al. (2002) examined whether the German market was integrated by investigating time series of Norwegian, Dutch and Russian Gas monthly export prices to Germany from January 1990 to December 1997. The Johansen multivariate procedure results showed that gas from the three suppliers compete closely in the same markets since the prices move proportionally over time, but at different price levels.

Hirschhausen et al. (2004) examined the degree of natural gas market integration in Europe, North America and Japan, between the mid 1990's and 2002. Corresponding hypothesis was that there was a certain split of prices between Europe and North America. The relationship between the international gas marker prices and their relation to the oil price, are investigated through principal component analysis and Johansen likelihood-based procedures. Both of them showed a high level of integration within the European/Japanese and North American markets and that the European/Japanese and the North American markets are connected to a much lesser extent.

Warell (2006) tested the hypothesis of the existence of a single economic market for the international coal industry, separated for coking and steam coal, and has investigated market integration over time. This were conducted by applying cointegration and error-correction models on quarterly price series data in Europe and Japan over the time period 1980-2000. Both the coking and the steam coal markets showed evidence of global market integration, as demonstrated by the stable long-run cointegrating relationship between the respective price series in different world regions.

Bachmeier and Griffin (2006) evaluated the degree of market integration both within and between crude oil, coal, and natural gas markets. Their approach yields parameters that can be readily tested against a priori conjectures. Using daily price data for five very different crude oils, they concluded that the world oil market is a single, highly integrated economic market. On the other hand, coal prices at five trading locations across the United States are cointegrated, but the degree of market integration is much weaker, particularly between Western and Eastern coals. Finally, they showed that crude oil, coal, and natural gas markets are only very weakly integrated.

Theodore and Emilie (2007) examined the relationship between UK wholesale gas prices and the Brent oil price over the period 1996–2003 in order to investigate whether oil and gas prices ‘decoupled’ during this period as orthodox gas market liberalisation theory had suggested. Tests for unit roots and cointegration were carried out and it was discovered that a long-run equilibrium relationship between UK gas and oil prices exists. it was found that the cointegrating relationship is present throughout the sample period. However, the long-run solutions seem to be more volatile. Evidence was provided that the short-run relationship is linear and impulse response functions are used to examine the effects that a shock in oil would have on gas. These findings do not support the assumption that gas prices and oil prices ‘decouple’.

Hammoudeh et al. (2008) examined the dynamic relationship between pairs of four oil benchmark prices (i.e., West Texas Intermediate, Brent, Dubai, and Maya). The results indicated that there is a long-run equilibrium relationship between different benchmarks, regardless of their properties and locations.

3- The Data and Unit Roots

We used data for US energy markets. The Crude Oil Domestic First Purchase Price, the natural gas Wellhead Price and the Cost of Coal Receipts at Electric Generating Plants for coal price were employed. The time period of the analysis extends from October 1983 to October 2008, involving 301 observations[1].

The results of unit roots tests reported by Microfit based on Schwarz Bayesian Criterion (SBC) are as follow:

Table 1: Augmented Dickey-Fuller (ADF) test

variables	an intercept but not a trend		an intercept and a linear trend	
	Critical values	Statistic	Critical values	Statistic
Oil	-2.8714	-2.8683	-3.4264	-3.7656
Gas	-2.8714	-1.5382	-3.4264	-3.6957
Coal	-2.8714	3.0999	-3.4264	3.2806
D1Oil	-2.8718	-5.2030	-3.4270	-5.6448
D1Gas	-2.8718	-5.3603	-3.4270	-5.6208

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[1] www.eia.doe.gov.

D1Coal	-2.8718	1.1232	-3.4270	-.72409
D2Coal	-2.8722	-1.2675	-3.4276	-1.5834
D3Coal	-2.8727	-1.4362	-3.4283	-1.4883
D4Coal	-2.8732	-3.1544	-3.4291	-3.3907
D5Coal	-2.8738	-7.9277	-3.4300	-8.0053

Based on the results of ADF test, oil, gas and coal are integrated processes of degree one, one and five or I (1), I (1) and I (5), respectively.

4- Methodology

There are various techniques for conducting the cointegration analysis. Econometric literature has abundant econometric techniques to investigate cointegration relationships among economic variables. The popular approaches are the well-known residual based approach proposed by Engle and Granger (1987) and the maximum likelihood-based approach proposed by Johansen and Julius (1990) and Johansen (1992).

In applying the cointegration technique, we need to determine the order of integration for each variable. When there are more than two I (1) variables in the system, the maximum likelihood approach of Johansen and Julius has the advantage over residual-based approach of Engle and Granger; however, both of the approaches require that the variables have the same order of integration. This requirement often causes difficulty to the researchers when the system contains the variables with different orders of integration- such as in this study. To overcome this problem, Pesaran et al. (1996, 2001) proposed a new approach known as Autoregressive Distributed Lag (ARDL) for cointegration test that does not require the classification of variables into I(0) or I(1). More recent studies have indicated that the ARDL approach to cointegration is preferable to other conventional cointegration approaches. The ARDL is applicable irrespective of whether the underlying regressors are purely I(0), purely I(1) or mutually cointegrated. The statistic underlying the procedure is the Wald or F-statistic in a generalized Dickey–Fuller type regression, which is used to test the significance of lagged levels of the variables under consideration in a conditional unrestricted equilibrium correction model (ECM) (Pesaran et al, 2001). Besides, ARDL approach is more robust and performs better for small sample sizes than other cointegration techniques.

The ARDL approach involves estimating the conditional error correction version of the ARDL model. The augmented ARDL (p, $q_1, q_2, \ldots, q_k$) is given by the following equation (Pesaran and Pesaran, 1997; Pesaran and Shin, 2001):

$$\alpha(L,p)y_t = \alpha_0 + \sum_{i=1}^{k} \beta_i (L,q_i) x_{it} + \lambda' w_t + \varepsilon_t \qquad \forall t = 1,2, \ldots, n \tag{3}$$

Where

$$\alpha(L,p) = 1 - \alpha_1 L - \alpha_2 L^2 - \ldots - \alpha_p L^p$$

$$\beta_i(L,q_i) = \beta_{i0} - \beta_{i1}L - \beta_{i2}L^2 - \ldots - \beta_{iq_i} L^{q_i} \qquad \forall \mathrm{i} = 1, 2, \ \ldots, \mathrm{k}$$

y_t is the dependent variable, α_0 is the constant term, ***L*** is the lag operator, w_t is $1 \times \mathrm{s}$ vector of deterministic variables such as intercept term, time trends, or exogenous variables with fixed lags. x_t is the *k*-dimensional forcing variables which are not cointegrated among themselves. ε_t is a vector of stochastic error terms, with zero means and constant variance-covariance.

The long-run coefficients are estimated by:

$$\pi = \frac{\hat{\lambda}(\hat{p}, \hat{q}_1, \hat{q}_2, \ldots, \hat{q}_k)}{1 - \hat{\alpha}_1 - \hat{\alpha}_2 - \ldots - \hat{\alpha}_{\hat{p}}}$$

where $\hat{\lambda}(\hat{p}, \hat{q}_1, \hat{q}_2, \ldots, \hat{q}_k)$ denotes the OLS estimates of λ' in equation (1) for the selected ARDL model.

The error correction model (ECM) related to the $\mathrm{ARDL}(\hat{\mathrm{p}}, \hat{\mathrm{q}}_1, \hat{\mathrm{q}}_2, \ldots, \hat{\mathrm{q}}_\mathrm{k})$ can be obtained by writing equation (3) in terms of lagged levels and the first difference of $y_t, x_{1t}, x_{2t}, \ldots, x_{kt}$ and w_t:

$$\Delta y_t = \Delta\alpha_0 - \alpha(1,\hat{p})ECM_{t-1} + \sum_{i=1}^{k} \beta_{i0} x_{it} + \lambda' \Delta w_t - \sum_{j=1}^{\hat{p}-1} \alpha^{*} j \Delta y_{t-1} - \sum_{i=1}^{k} \sum_{j=1}^{\hat{q}_i - 1} \beta_{ij} \Delta x_{i,t-1} + \varepsilon_t \tag{5}$$

where ECM is the error correction model and it is defined as follows:

$$ECM_t = y_t - \hat{\alpha} - \sum \hat{\beta}_{i0} x_{it} - \lambda' w_t$$

The ARDL approach involves two steps for estimating the long-run relationship (Pesaran et al., 2001). The first step is to examine the existence of long–run relationship among all variables in the equations under estimation. The second step is to estimate the long-run and the short-run coefficients of the same equation. We run the second step only if we find a long-run relationship in the first step (Narayan, et al. 2004).

5- Autoregressive Distributed Lag (ARDL) Model and Empirical Results

Because underlying variables (Oil, Gas and Coal) have different integration degrees, ARDL approach is adopted for cointegration analysis.

Our ARDL model to estimate long-run relationship among underlying variables, in logarithmic form, is specified as follows:

$$LOil_t = \alpha_0 + \alpha_1 t + \sum_{i=1}^{p-1} \beta_i LOil_{t-i} + \sum_{j=0}^{q-1} \theta_{1j} LGas_{t-j} + \sum_{j=0}^{q-1} \theta_{2j} LCoal_{t-j} + \varepsilon_t \qquad (7)$$

Where α_0 is the constant term, and t is time trend.

Using Microfit for estimation, ARDL (2, 0, 0) is selected based on Schwarz Bayesian Criterion (SBC). Table (2) shows the results for the selected ARDL model.

Table 2: Autoregressive Distributed Lag Estimates

ARDL (2,0,0) selected based on Schwarz Bayesian Criterion

Regressor	Coefficient	T-Ratio	Standard Error
LOil(-1)	1.3854	26.2829	.052712
LOil(-2)	-.48740	-9.1044	.053534
LGas	.039038	1.7886	.021826
LCoal	.021046	3.4231	.061481
Constant	.15225	3.5821	2.3791
Time trend	.32883	3.1119	.10563
R-Squared = .98078		R-Bar-Squared = .98044	
F-statistic F(5, 281) = 2868		Schwarz Bayesian Criterion = 333.9134	

As the table indicates all the statistics of the estimated model, except for gas price coefficient, are satisfactory.

To confirm the stability of the estimated model, the tests of Cumulative Sum of Recursive Residuals (CUSUM) and Cumulative Sum of Squares of Recursive Residuals (CUSUMSQ) are employed in this paper. Figures (1) and (2) provide the graphs of CUSUM and CUSUMSQ tests, respectively.

These figures indicate that the plots of CUSUM and CUSUMQ are completely stable within 5% of critical bands.

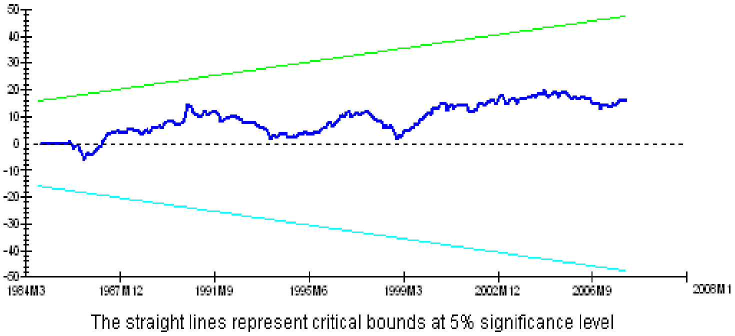

Figure 1: Cumulative Sum of Recursive Residuals (CUSUM)

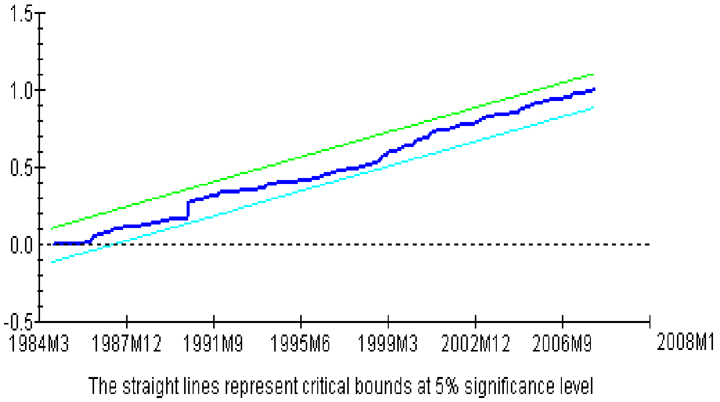

Figure 2: Cumulative Sum of Squares of Recursive Residuals (CUSUMSQ)

The results of estimated long run regression and the corresponding ECM model are reported in tables (3) and (4).

Table 3: Estimated Long Run Coefficients using the ARDL Approach

ARDL (2, 0, 0) selected based on Schwarz Bayesian Criterion

Regressor	Coefficient	T-Ratio	Standard Error
LGas	.38281	2.2419	.17076
LCoal	2.0638	4.2164	.48946
Constant	1.4930	7.8976	.18904
Time trend	.0032238	2.9587	.0010896

Table (4): Error Correction Representation for the Selected ARDL Model

ARDL (2,0,0) selected based on Schwarz Bayesian Criterion

Regressor	Coefficient	T-Ratio	Standard Error
D2LOil	.48740	9.1044	.053534
D1LGas	.039038	1.7886	.021826
D1LCoal	.21046	3.4231	.061481
DConstant	.15225	3.5821	.042502
DTime trend	.32883	3.1119	.10563
ECM(-1)	-.10198	-4.4794	.022765
R-Squared = .25578		R-Bar-Squared = .24254	
F-statistic F(5, 281) 19.3156		Schwarz Bayesian Criterion = 333.9134	

As table (3) indicates, the coefficients (Gas prices and Coal prices) are statistically significant.

From table (4), it is clear that the error correction term (ECM (-1)) has the right sign (negative) and is statistically significant. Specifically, the estimated value of EC_{t-1} is -.10198.

The absolute value of the coefficient of EC_{t-1}, indicating the speed of adjustment to equilibrium, denotes that 10% of any shocks dumps out in each period, converging back to the long run equilibrium. Bannerjee, Dolado and Mestre (1998), hold that a highly significant error correction term is further proof of the existence of a stable long-term relationship, which is the case here.

Except coefficient of D1LGas (first difference of LGas), all other short run coefficients are significant with positive signs as it is expected.

6- Conclusion

This paper investigates the existence of long-run relation between crude oil, gas and coal prices. The data for us energy market is used in this study. The time period of the analysis extends from October 1983 to October 2008, involving 301 observations. Augmented Dickey-Fuller (ADF) approach employed for existence of unit root. In brief, Augmented Dickey-Fuller (ADF) tests indicate that Oil and Gas prices are integrated processes of degree one or I (1) and Coal prices is integrated processes of degree five or I (5). As integration degree of variables are not same the Autoregressive Distributed Lag (ARDL) approach to cointegration adapted to cointegration analysis on Oil, Gas and coal prices. The ARDL model was specified in logarithmic form which coefficients mean as elasticities. The model selection fulfilled by Schwarz Bayesian Criterion (SBC) and so ARDL (2, 0, 0) was selected. Moreover, to confirm the stability of the model, CUSUM and CUSUMSQ tests are also conducted with the results that the estimated model is completely stable.

At short run coefficient of D1LGas (first difference of LGas), are statistically insignificant but in long run LGas (logarithm of gas prices) have a significant coefficient. LCoal (logarithm of coal prices) at long run and D1LCoal (first difference of LCoal) at short run have significant coefficients. The results provide that second difference of LOil (D2LOil), indicating short run own price elasticity of oil prices, have a significant coefficient.

The estimated value of EC_{t-1} is -.10198 indicating about 10% speed of adjustment toward equilibrium. It is clear from estimated value of EC_{t-1} that the error correction term (ECM (-1)) has the right sign (negative) and is statistically significant.

Based on the result of cointegration analysis, we can found the long run relationship between oil, gas and coal prices.

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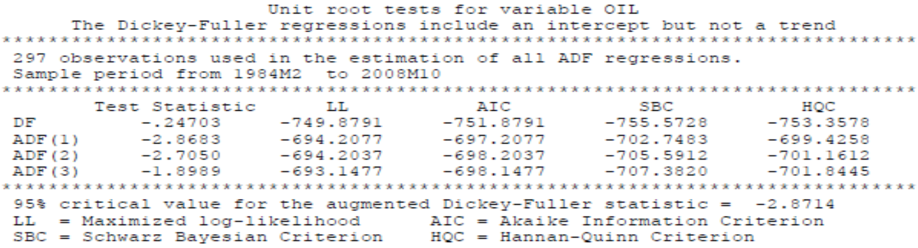
Appendix.1



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                      Unit root tests for variable OIL
      The Dickey-Fuller regressions include an intercept but not a trend
*******************************************************************************
 297 observations used in the estimation of all ADF regressions.
 Sample period from 1984M2  to 2008M10
*******************************************************************************
        Test Statistic       LL           AIC          SBC          HQC
 DF          -.24703     -749.8791    -751.8791    -755.5728    -753.3578
 ADF(1)      -2.8683     -694.2077    -697.2077    -702.7483    -699.4258
 ADF(2)      -2.7050     -694.2037    -698.2037    -705.5912    -701.1612
 ADF(3)      -1.8989     -693.1477    -698.1477    -707.3820    -701.8445
*******************************************************************************
 95% critical value for the augmented Dickey-Fuller statistic =  -2.8714
 LL  = Maximized log-likelihood      AIC = Akaike Information Criterion
 SBC = Schwarz Bayesian Criterion    HQC = Hannan-Quinn Criterion
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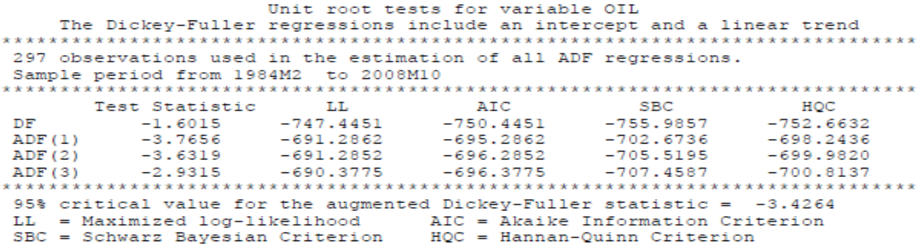

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                      Unit root tests for variable OIL
     The Dickey-Fuller regressions include an intercept and a linear trend
*******************************************************************************
 297 observations used in the estimation of all ADF regressions.
 Sample period from 1984M2  to 2008M10
*******************************************************************************
        Test Statistic       LL           AIC          SBC          HQC
 DF          -1.6015     -747.4451    -750.4451    -755.9857    -752.6632
 ADF(1)      -3.7656     -691.2862    -695.2862    -702.6736    -698.2436
 ADF(2)      -3.6319     -691.2852    -696.2852    -705.5195    -699.9820
 ADF(3)      -2.9315     -690.3775    -696.3775    -707.4587    -700.8137
*******************************************************************************
 95% critical value for the augmented Dickey-Fuller statistic =  -3.4264
 LL  = Maximized log-likelihood      AIC = Akaike Information Criterion
 SBC = Schwarz Bayesian Criterion    HQC = Hannan-Quinn Criterion
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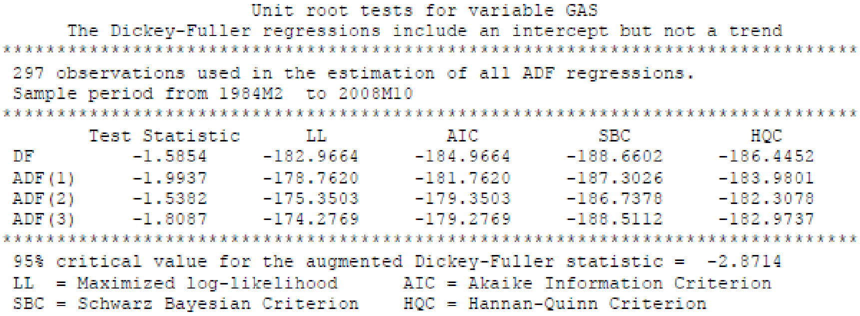

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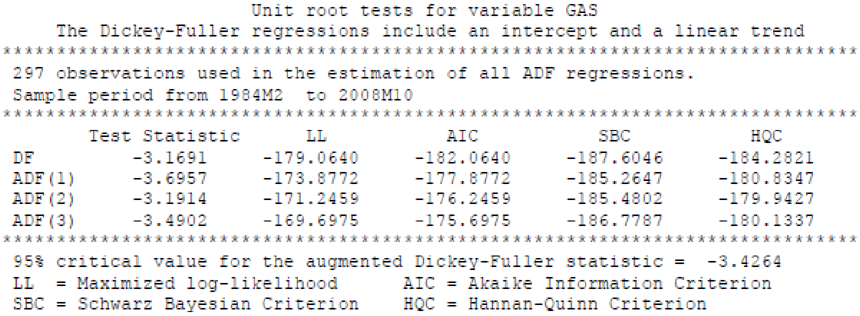
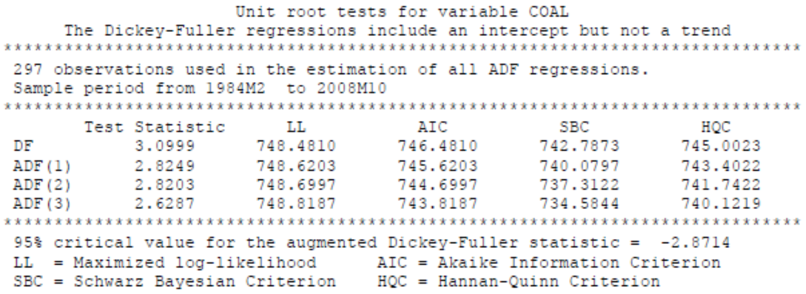
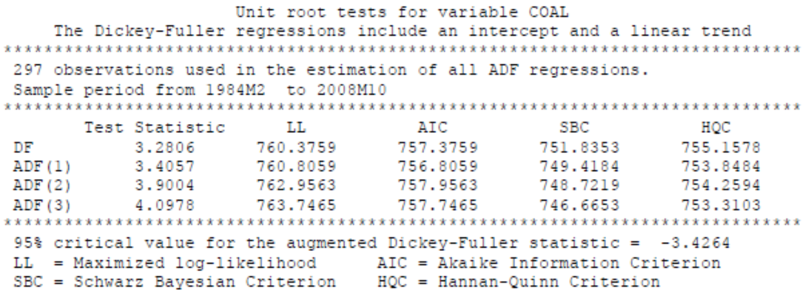
                      Unit root tests for variable GAS
      The Dickey-Fuller regressions include an intercept but not a trend
*******************************************************************************
 297 observations used in the estimation of all ADF regressions.
 Sample period from 1984M2  to 2008M10
*******************************************************************************
        Test Statistic       LL           AIC          SBC          HQC
 DF          -1.5854     -182.9664    -184.9664    -188.6602    -186.4452
 ADF(1)      -1.9937     -178.7620    -181.7620    -187.3026    -183.9801
 ADF(2)      -1.5382     -175.3503    -179.3503    -186.7378    -182.3078
 ADF(3)      -1.8087     -174.2769    -179.2769    -188.5112    -182.9737
*******************************************************************************
 95% critical value for the augmented Dickey-Fuller statistic =  -2.8714
 LL  = Maximized log-likelihood      AIC = Akaike Information Criterion
 SBC = Schwarz Bayesian Criterion    HQC = Hannan-Quinn Criterion
```



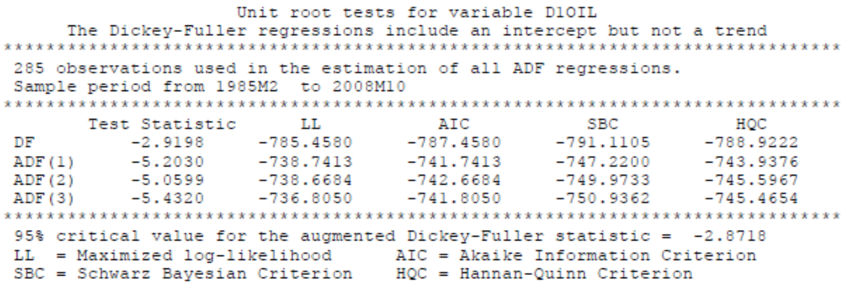
```
                      Unit root tests for variable GAS
     The Dickey-Fuller regressions include an intercept and a linear trend
*******************************************************************************
 297 observations used in the estimation of all ADF regressions.
 Sample period from 1984M2  to 2008M10
*******************************************************************************
        Test Statistic       LL           AIC          SBC          HQC
 DF          -3.1691     -179.0640    -182.0640    -187.6046    -184.2821
 ADF(1)      -3.6957     -173.8772    -177.8772    -185.2647    -180.8347
 ADF(2)      -3.1914     -171.2459    -176.2459    -185.4802    -179.9427
 ADF(3)      -3.4902     -169.6975    -175.6975    -186.7787    -180.1337
*******************************************************************************
 95% critical value for the augmented Dickey-Fuller statistic =  -3.4264
 LL  = Maximized log-likelihood      AIC = Akaike Information Criterion
 SBC = Schwarz Bayesian Criterion    HQC = Hannan-Quinn Criterion
```



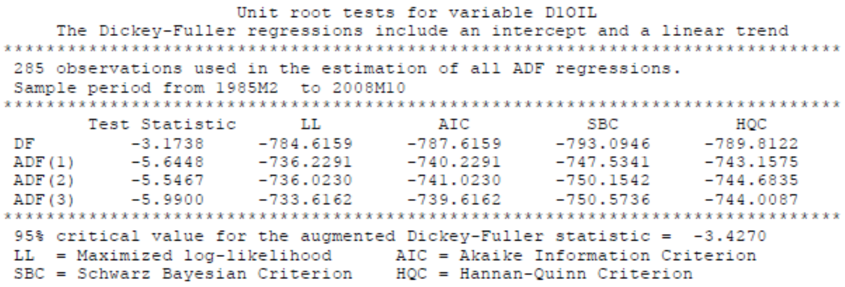
```
                    Unit root tests for variable COAL
      The Dickey-Fuller regressions include an intercept but not a trend
******************************************************************************
 297 observations used in the estimation of all ADF regressions.
 Sample period from 1984M2  to 2008M10
******************************************************************************
        Test Statistic      LL           AIC          SBC          HQC
 DF           3.0999      748.4810     746.4810     742.7873     745.0023
 ADF(1)       2.8249      748.6203     745.6203     740.0797     743.4022
 ADF(2)       2.8203      748.6997     744.6997     737.3122     741.7422
 ADF(3)       2.6287      748.8187     743.8187     734.5844     740.1219
******************************************************************************
 95% critical value for the augmented Dickey-Fuller statistic =  -2.8714
 LL  = Maximized log-likelihood      AIC = Akaike Information Criterion
 SBC = Schwarz Bayesian Criterion    HQC = Hannan-Quinn Criterion
```



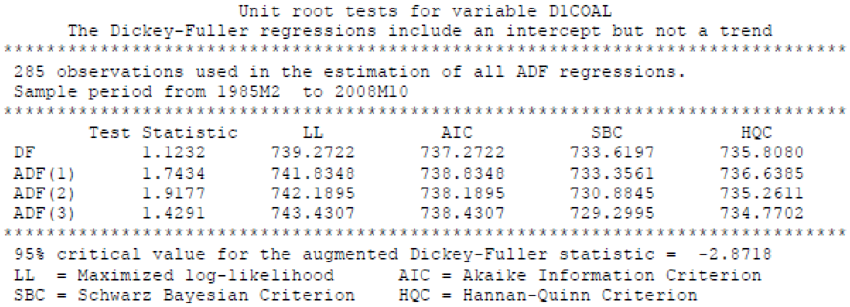
```
                    Unit root tests for variable COAL
     The Dickey-Fuller regressions include an intercept and a linear trend
******************************************************************************
 297 observations used in the estimation of all ADF regressions.
 Sample period from 1984M2  to 2008M10
******************************************************************************
        Test Statistic      LL           AIC          SBC          HQC
 DF           3.2806      760.3759     757.3759     751.8353     755.1578
 ADF(1)       3.4057      760.8059     756.8059     749.4184     753.8484
 ADF(2)       3.9004      762.9563     757.9563     748.7219     754.2594
 ADF(3)       4.0978      763.7465     757.7465     746.6653     753.3103
******************************************************************************
 95% critical value for the augmented Dickey-Fuller statistic =  -3.4264
 LL  = Maximized log-likelihood      AIC = Akaike Information Criterion
 SBC = Schwarz Bayesian Criterion    HQC = Hannan-Quinn Criterion
```



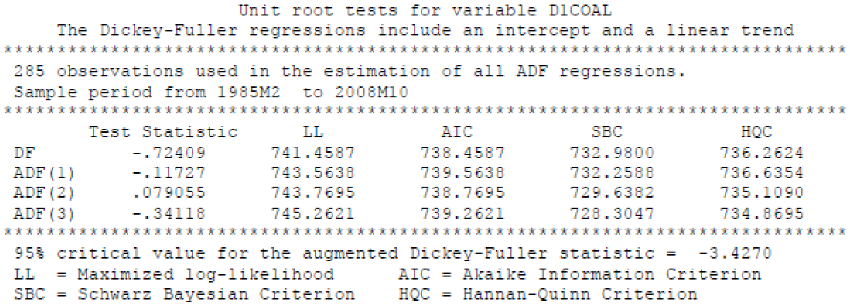
```
                    Unit root tests for variable D1OIL
      The Dickey-Fuller regressions include an intercept but not a trend
******************************************************************************
 285 observations used in the estimation of all ADF regressions.
 Sample period from 1985M2  to 2008M10
******************************************************************************
        Test Statistic      LL           AIC          SBC          HQC
 DF          -2.9198     -785.4580    -787.4580    -791.1105    -788.9222
 ADF(1)      -5.2030     -738.7413    -741.7413    -747.2200    -743.9376
 ADF(2)      -5.0599     -738.6684    -742.6684    -749.9733    -745.5967
 ADF(3)      -5.4320     -736.8050    -741.8050    -750.9362    -745.4654
******************************************************************************
 95% critical value for the augmented Dickey-Fuller statistic =  -2.8718
 LL  = Maximized log-likelihood      AIC = Akaike Information Criterion
 SBC = Schwarz Bayesian Criterion    HQC = Hannan-Quinn Criterion
```



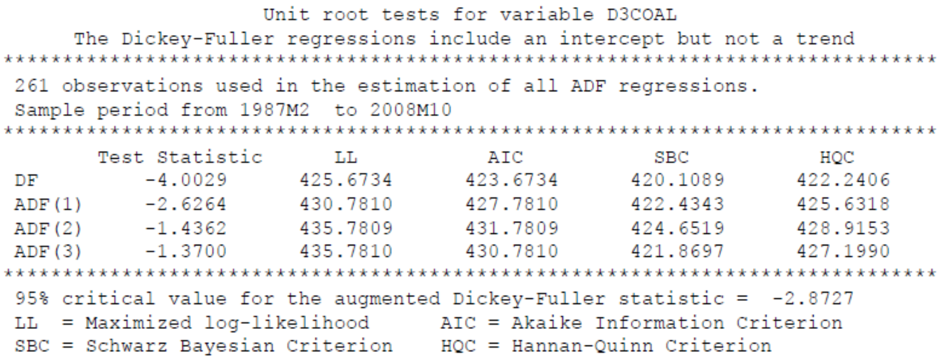
```
                    Unit root tests for variable D1OIL
     The Dickey-Fuller regressions include an intercept and a linear trend
******************************************************************************
 285 observations used in the estimation of all ADF regressions.
 Sample period from 1985M2  to 2008M10
******************************************************************************
        Test Statistic      LL           AIC          SBC          HQC
 DF          -3.1738     -784.6159    -787.6159    -793.0946    -789.8122
 ADF(1)      -5.6448     -736.2291    -740.2291    -747.5341    -743.1575
 ADF(2)      -5.5467     -736.0230    -741.0230    -750.1542    -744.6835
 ADF(3)      -5.9900     -733.6162    -739.6162    -750.5736    -744.0087
******************************************************************************
 95% critical value for the augmented Dickey-Fuller statistic =  -3.4270
 LL  = Maximized log-likelihood      AIC = Akaike Information Criterion
 SBC = Schwarz Bayesian Criterion    HQC = Hannan-Quinn Criterion
```



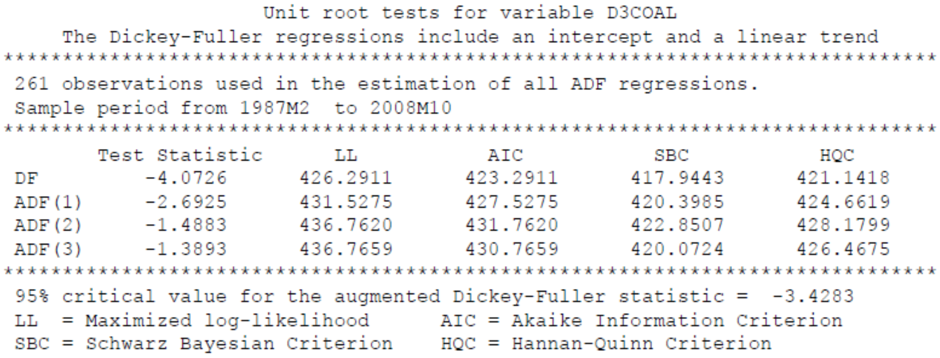
```
                      Unit root tests for variable D1COAL
      The Dickey-Fuller regressions include an intercept but not a trend
*******************************************************************************
 285 observations used in the estimation of all ADF regressions.
 Sample period from 1985M2  to 2008M10
*******************************************************************************
        Test Statistic      LL           AIC          SBC           HQC
 DF          1.1232      739.2722      737.2722     733.6197      735.8080
 ADF(1)      1.7434      741.8348      738.8348     733.3561      736.6385
 ADF(2)      1.9177      742.1895      738.1895     730.8845      735.2611
 ADF(3)      1.4291      743.4307      738.4307     729.2995      734.7702
*******************************************************************************
 95% critical value for the augmented Dickey-Fuller statistic =  -2.8718
 LL  = Maximized log-likelihood      AIC = Akaike Information Criterion
 SBC = Schwarz Bayesian Criterion    HQC = Hannan-Quinn Criterion
```



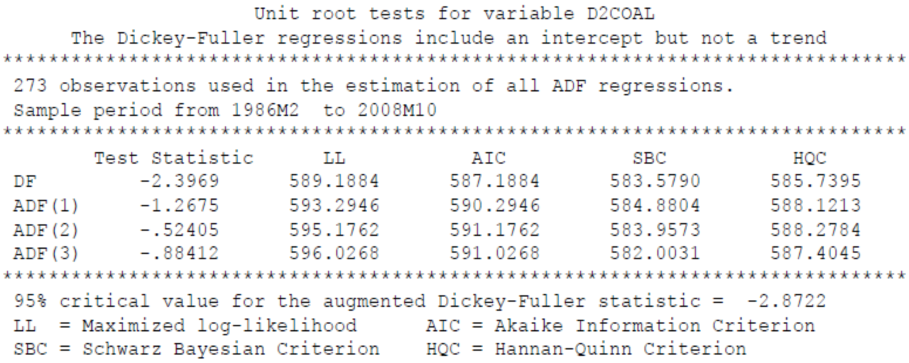
```
                      Unit root tests for variable D1COAL
     The Dickey-Fuller regressions include an intercept and a linear trend
*******************************************************************************
 285 observations used in the estimation of all ADF regressions.
 Sample period from 1985M2  to 2008M10
*******************************************************************************
        Test Statistic      LL           AIC          SBC           HQC
 DF         -.72409      741.4587      738.4587     732.9800      736.2624
 ADF(1)     -.11727      743.5638      739.5638     732.2588      736.6354
 ADF(2)     .079055      743.7695      738.7695     729.6382      735.1090
 ADF(3)     -.34118      745.2621      739.2621     728.3047      734.8695
*******************************************************************************
 95% critical value for the augmented Dickey-Fuller statistic =  -3.4270
 LL  = Maximized log-likelihood      AIC = Akaike Information Criterion
 SBC = Schwarz Bayesian Criterion    HQC = Hannan-Quinn Criterion
```



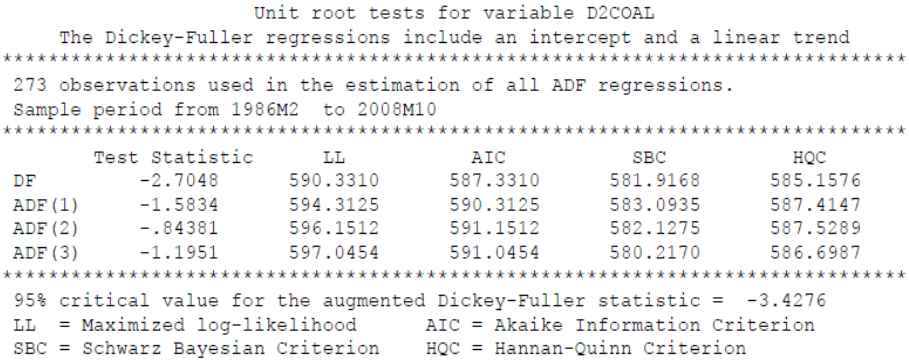
```
                      Unit root tests for variable D3COAL
      The Dickey-Fuller regressions include an intercept but not a trend
*******************************************************************************
 261 observations used in the estimation of all ADF regressions.
 Sample period from 1987M2  to 2008M10
*******************************************************************************
        Test Statistic      LL           AIC           SBC           HQC
 DF          -4.0029     425.6734      423.6734      420.1089      422.2406
 ADF(1)      -2.6264     430.7810      427.7810      422.4343      425.6318
 ADF(2)      -1.4362     435.7809      431.7809      424.6519      428.9153
 ADF(3)      -1.3700     435.7810      430.7810      421.8697      427.1990
*******************************************************************************
 95% critical value for the augmented Dickey-Fuller statistic =  -2.8727
 LL  = Maximized log-likelihood      AIC = Akaike Information Criterion
 SBC = Schwarz Bayesian Criterion    HQC = Hannan-Quinn Criterion
```



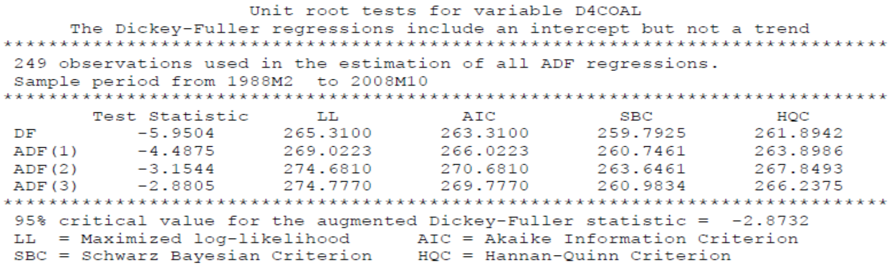
```
                      Unit root tests for variable D3COAL
     The Dickey-Fuller regressions include an intercept and a linear trend
*******************************************************************************
 261 observations used in the estimation of all ADF regressions.
 Sample period from 1987M2  to 2008M10
*******************************************************************************
        Test Statistic      LL           AIC           SBC           HQC
 DF          -4.0726     426.2911      423.2911      417.9443      421.1418
 ADF(1)      -2.6925     431.5275      427.5275      420.3985      424.6619
 ADF(2)      -1.4883     436.7620      431.7620      422.8507      428.1799
 ADF(3)      -1.3893     436.7659      430.7659      420.0724      426.4675
*******************************************************************************
 95% critical value for the augmented Dickey-Fuller statistic =  -3.4283
 LL  = Maximized log-likelihood      AIC = Akaike Information Criterion
 SBC = Schwarz Bayesian Criterion    HQC = Hannan-Quinn Criterion
```



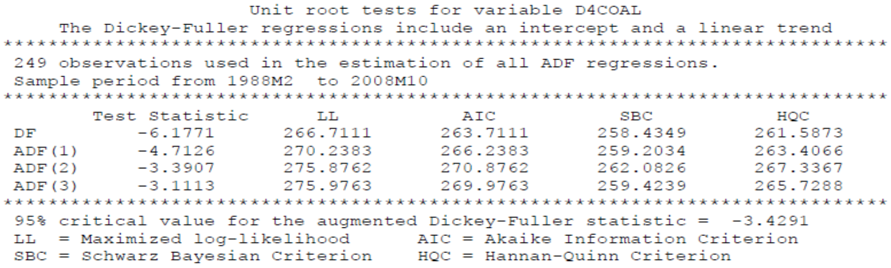
```
                      Unit root tests for variable D2COAL
      The Dickey-Fuller regressions include an intercept but not a trend
*******************************************************************************
 273 observations used in the estimation of all ADF regressions.
 Sample period from 1986M2  to 2008M10
*******************************************************************************
        Test Statistic      LL          AIC          SBC          HQC
 DF          -2.3969      589.1884     587.1884     583.5790     585.7395
 ADF(1)      -1.2675      593.2946     590.2946     584.8804     588.1213
 ADF(2)      -.52405      595.1762     591.1762     583.9573     588.2784
 ADF(3)      -.88412      596.0268     591.0268     582.0031     587.4045
*******************************************************************************
 95% critical value for the augmented Dickey-Fuller statistic =  -2.8722
 LL  = Maximized log-likelihood      AIC = Akaike Information Criterion
 SBC = Schwarz Bayesian Criterion    HQC = Hannan-Quinn Criterion
```



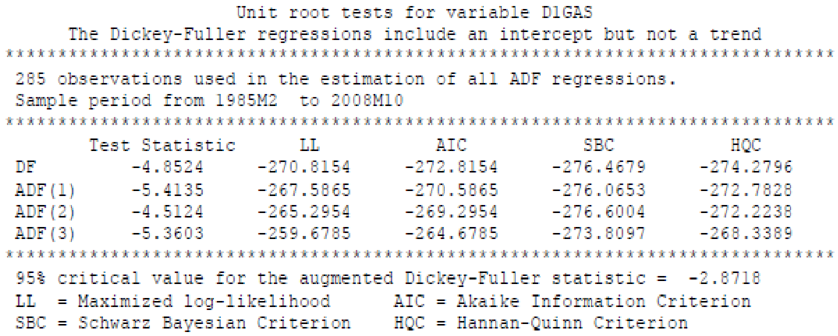
```
                      Unit root tests for variable D2COAL
     The Dickey-Fuller regressions include an intercept and a linear trend
*******************************************************************************
 273 observations used in the estimation of all ADF regressions.
 Sample period from 1986M2  to 2008M10
*******************************************************************************
        Test Statistic      LL          AIC          SBC          HQC
 DF          -2.7048      590.3310     587.3310     581.9168     585.1576
 ADF(1)      -1.5834      594.3125     590.3125     583.0935     587.4147
 ADF(2)      -.84381      596.1512     591.1512     582.1275     587.5289
 ADF(3)      -1.1951      597.0454     591.0454     580.2170     586.6987
*******************************************************************************
 95% critical value for the augmented Dickey-Fuller statistic =  -3.4276
 LL  = Maximized log-likelihood      AIC = Akaike Information Criterion
 SBC = Schwarz Bayesian Criterion    HQC = Hannan-Quinn Criterion
```



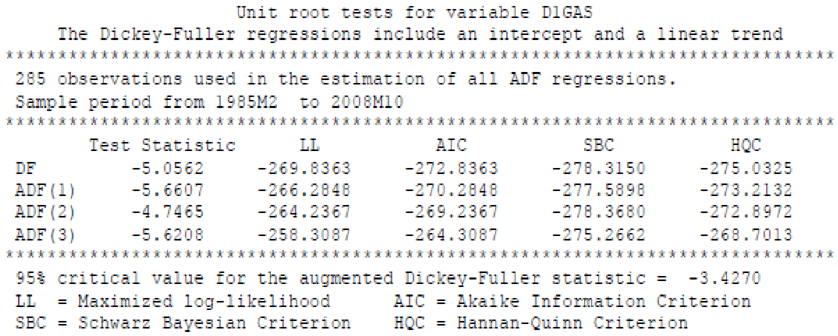
```
                      Unit root tests for variable D4COAL
      The Dickey-Fuller regressions include an intercept but not a trend
*******************************************************************************
 249 observations used in the estimation of all ADF regressions.
 Sample period from 1988M2  to 2008M10
*******************************************************************************
        Test Statistic       LL            AIC            SBC            HQC
 DF          -5.9504      265.3100       263.3100       259.7925       261.8942
 ADF(1)      -4.4875      269.0223       266.0223       260.7461       263.8986
 ADF(2)      -3.1544      274.6810       270.6810       263.6461       267.8493
 ADF(3)      -2.8805      274.7770       269.7770       260.9834       266.2375
*******************************************************************************
 95% critical value for the augmented Dickey-Fuller statistic =  -2.8732
 LL  = Maximized log-likelihood      AIC = Akaike Information Criterion
 SBC = Schwarz Bayesian Criterion    HQC = Hannan-Quinn Criterion
```



```
                      Unit root tests for variable D4COAL
     The Dickey-Fuller regressions include an intercept and a linear trend
*******************************************************************************
 249 observations used in the estimation of all ADF regressions.
 Sample period from 1988M2  to 2008M10
*******************************************************************************
        Test Statistic       LL            AIC            SBC            HQC
 DF          -6.1771      266.7111       263.7111       258.4349       261.5873
 ADF(1)      -4.7126      270.2383       266.2383       259.2034       263.4066
 ADF(2)      -3.3907      275.8762       270.8762       262.0826       267.3367
 ADF(3)      -3.1113      275.9763       269.9763       259.4239       265.7288
*******************************************************************************
 95% critical value for the augmented Dickey-Fuller statistic =  -3.4291
 LL  = Maximized log-likelihood      AIC = Akaike Information Criterion
 SBC = Schwarz Bayesian Criterion    HQC = Hannan-Quinn Criterion
```

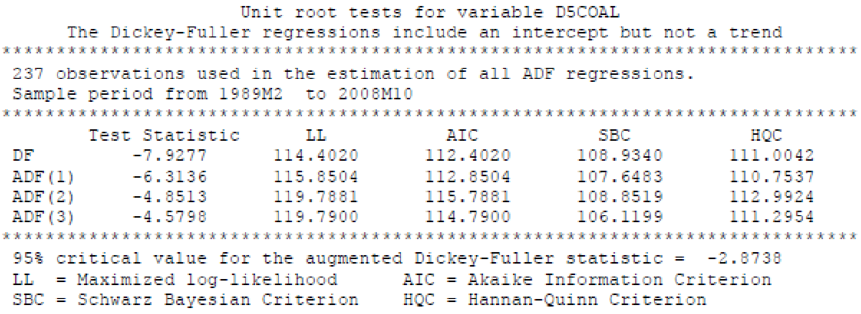


```
                      Unit root tests for variable D1GAS
      The Dickey-Fuller regressions include an intercept but not a trend
*******************************************************************************
 285 observations used in the estimation of all ADF regressions.
 Sample period from 1985M2  to 2008M10
*******************************************************************************
        Test Statistic       LL            AIC            SBC            HQC
 DF          -4.8524     -270.8154      -272.8154      -276.4679      -274.2796
 ADF(1)      -5.4135     -267.5865      -270.5865      -276.0653      -272.7828
 ADF(2)      -4.5124     -265.2954      -269.2954      -276.6004      -272.2238
 ADF(3)      -5.3603     -259.6785      -264.6785      -273.8097      -268.3389
*******************************************************************************
 95% critical value for the augmented Dickey-Fuller statistic =  -2.8718
 LL  = Maximized log-likelihood      AIC = Akaike Information Criterion
 SBC = Schwarz Bayesian Criterion    HQC = Hannan-Quinn Criterion
```

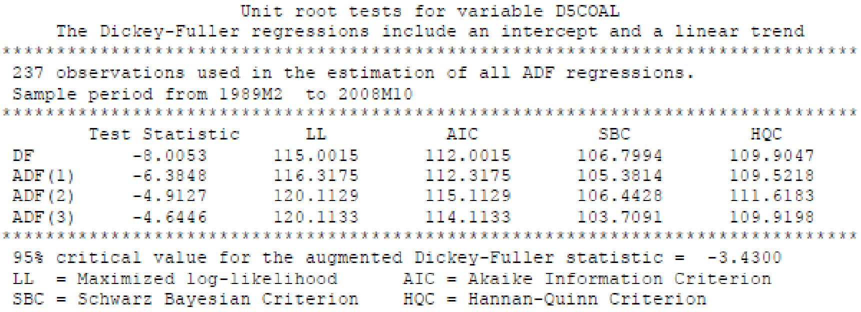


```
                      Unit root tests for variable D1GAS
     The Dickey-Fuller regressions include an intercept and a linear trend
*******************************************************************************
 285 observations used in the estimation of all ADF regressions.
 Sample period from 1985M2  to 2008M10
*******************************************************************************
        Test Statistic       LL            AIC            SBC            HQC
 DF          -5.0562     -269.8363      -272.8363      -278.3150      -275.0325
 ADF(1)      -5.6607     -266.2848      -270.2848      -277.5898      -273.2132
 ADF(2)      -4.7465     -264.2367      -269.2367      -278.3680      -272.8972
 ADF(3)      -5.6208     -258.3087      -264.3087      -275.2662      -268.7013
*******************************************************************************
 95% critical value for the augmented Dickey-Fuller statistic =  -3.4270
 LL  = Maximized log-likelihood      AIC = Akaike Information Criterion
 SBC = Schwarz Bayesian Criterion    HQC = Hannan-Quinn Criterion
```

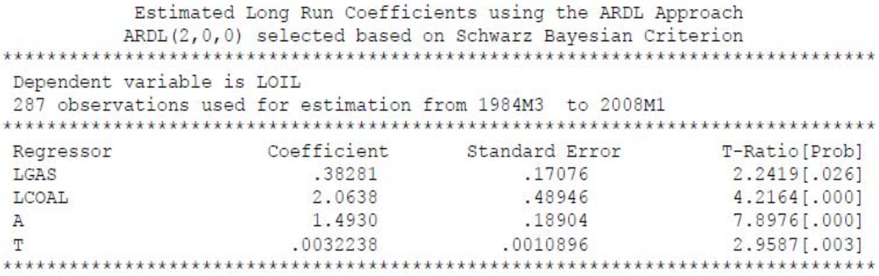
Appendix.2



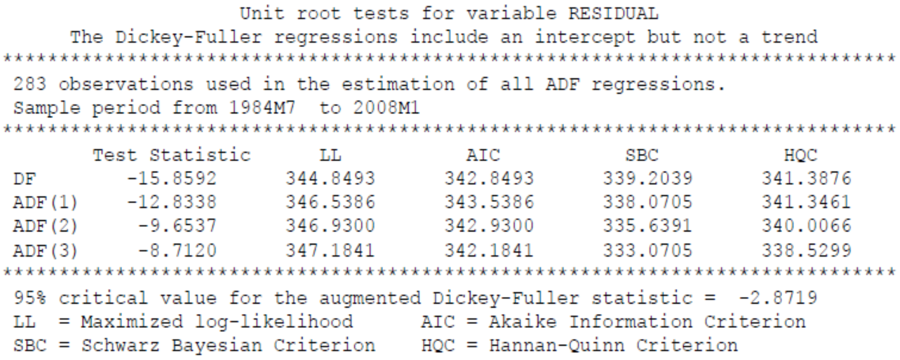
```
                     Unit root tests for variable D5COAL
      The Dickey-Fuller regressions include an intercept but not a trend
*******************************************************************************
 237 observations used in the estimation of all ADF regressions.
 Sample period from 1989M2  to 2008M10
*******************************************************************************
        Test Statistic      LL           AIC           SBC           HQC
 DF          -7.9277      114.4020      112.4020      108.9340      111.0042
 ADF(1)      -6.3136      115.8504      112.8504      107.6483      110.7537
 ADF(2)      -4.8513      119.7881      115.7881      108.8519      112.9924
 ADF(3)      -4.5798      119.7900      114.7900      106.1199      111.2954
*******************************************************************************
 95% critical value for the augmented Dickey-Fuller statistic =  -2.8738
 LL  = Maximized log-likelihood      AIC = Akaike Information Criterion
 SBC = Schwarz Bayesian Criterion    HQC = Hannan-Quinn Criterion
```



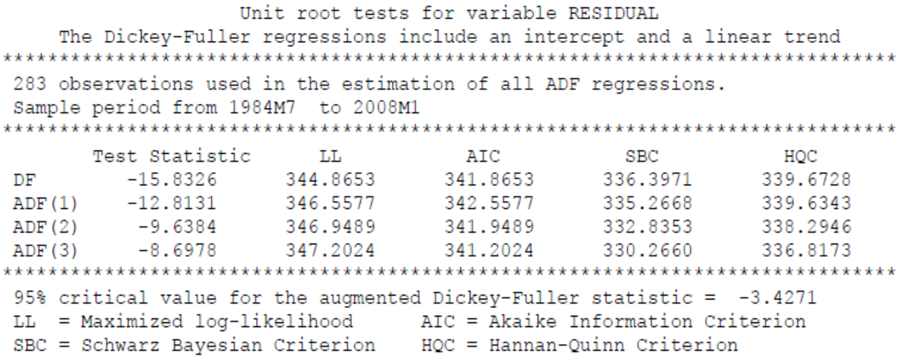
```
                     Unit root tests for variable D5COAL
     The Dickey-Fuller regressions include an intercept and a linear trend
*******************************************************************************
 237 observations used in the estimation of all ADF regressions.
 Sample period from 1989M2  to 2008M10
*******************************************************************************
        Test Statistic      LL           AIC           SBC           HQC
 DF          -8.0053      115.0015      112.0015      106.7994      109.9047
 ADF(1)      -6.3848      116.3175      112.3175      105.3814      109.5218
 ADF(2)      -4.9127      120.1129      115.1129      106.4428      111.6183
 ADF(3)      -4.6446      120.1133      114.1133      103.7091      109.9198
*******************************************************************************
 95% critical value for the augmented Dickey-Fuller statistic =  -3.4300
 LL  = Maximized log-likelihood      AIC = Akaike Information Criterion
 SBC = Schwarz Bayesian Criterion    HQC = Hannan-Quinn Criterion
```



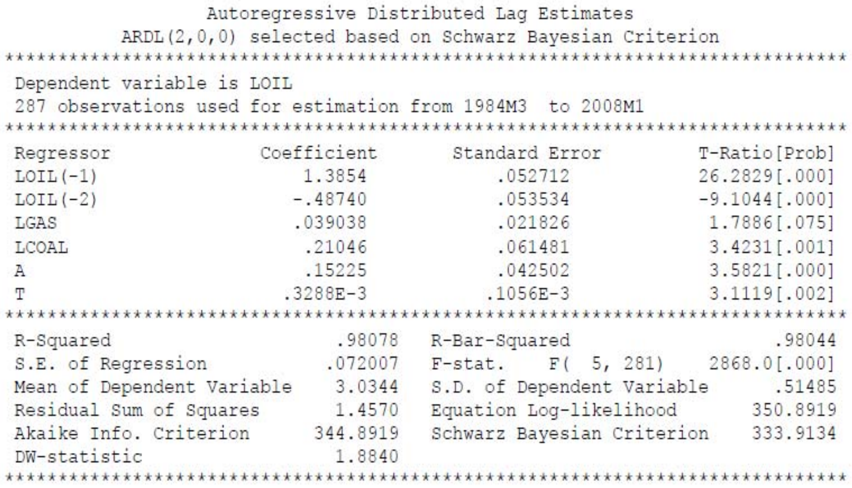
```
           Estimated Long Run Coefficients using the ARDL Approach
           ARDL(2,0,0) selected based on Schwarz Bayesian Criterion
*******************************************************************************
 Dependent variable is LOIL
 287 observations used for estimation from 1984M3  to 2008M1
*******************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 LGAS                       .38281            .17076             2.2419[.026]
 LCOAL                      2.0638            .48946             4.2164[.000]
 A                          1.4930            .18904             7.8976[.000]
 T                        .0032238          .0010896             2.9587[.003]
*******************************************************************************
```



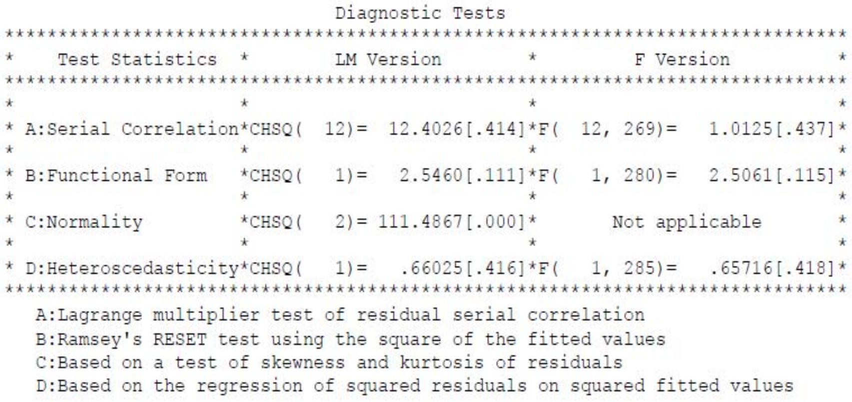
```
                     Unit root tests for variable RESIDUAL
      The Dickey-Fuller regressions include an intercept but not a trend
*******************************************************************************
 283 observations used in the estimation of all ADF regressions.
 Sample period from 1984M7  to 2008M1
*******************************************************************************
        Test Statistic      LL           AIC           SBC           HQC
 DF        -15.8592      344.8493      342.8493      339.2039      341.3876
 ADF(1)    -12.8338      346.5386      343.5386      338.0705      341.3461
 ADF(2)     -9.6537      346.9300      342.9300      335.6391      340.0066
 ADF(3)     -8.7120      347.1841      342.1841      333.0705      338.5299
*******************************************************************************
 95% critical value for the augmented Dickey-Fuller statistic =  -2.8719
 LL  = Maximized log-likelihood      AIC = Akaike Information Criterion
 SBC = Schwarz Bayesian Criterion    HQC = Hannan-Quinn Criterion
```



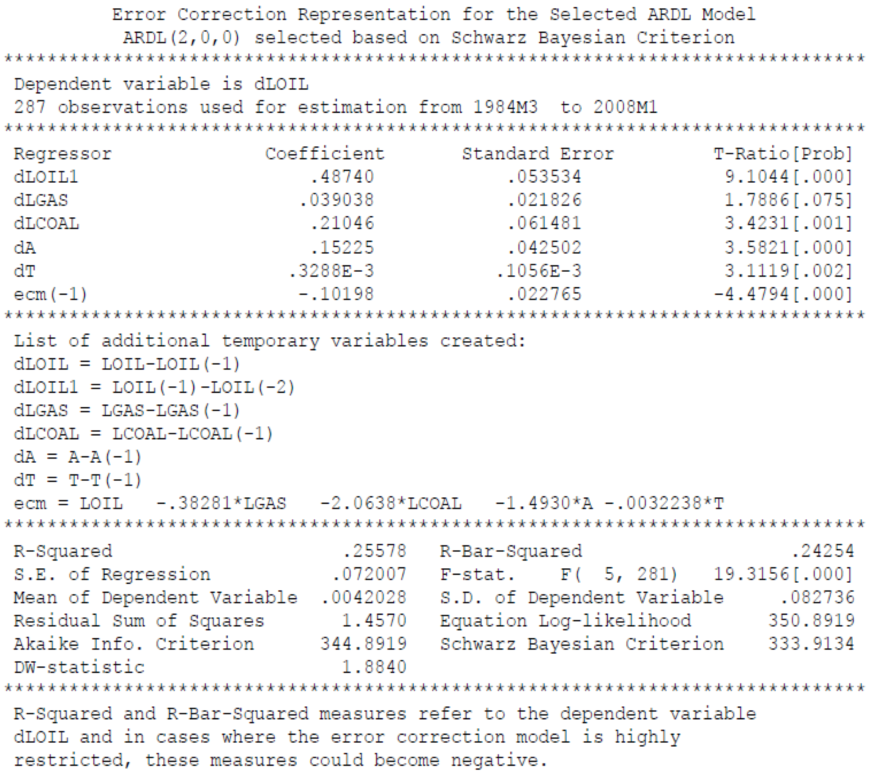
```
                     Unit root tests for variable RESIDUAL
     The Dickey-Fuller regressions include an intercept and a linear trend
*******************************************************************************
 283 observations used in the estimation of all ADF regressions.
 Sample period from 1984M7  to 2008M1
*******************************************************************************
        Test Statistic      LL           AIC           SBC           HQC
 DF        -15.8326      344.8653      341.8653      336.3971      339.6728
 ADF(1)    -12.8131      346.5577      342.5577      335.2668      339.6343
 ADF(2)     -9.6384      346.9489      341.9489      332.8353      338.2946
 ADF(3)     -8.6978      347.2024      341.2024      330.2660      336.8173
*******************************************************************************
 95% critical value for the augmented Dickey-Fuller statistic =  -3.4271
 LL  = Maximized log-likelihood      AIC = Akaike Information Criterion
 SBC = Schwarz Bayesian Criterion    HQC = Hannan-Quinn Criterion
```



```
                  Autoregressive Distributed Lag Estimates
          ARDL(2,0,0) selected based on Schwarz Bayesian Criterion
******************************************************************************
 Dependent variable is LOIL
 287 observations used for estimation from 1984M3  to 2008M1
******************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 LOIL(-1)                   1.3854            .052712            26.2829[.000]
 LOIL(-2)                  -.48740            .053534            -9.1044[.000]
 LGAS                      .039038            .021826             1.7886[.075]
 LCOAL                      .21046            .061481             3.4231[.001]
 A                          .15225            .042502             3.5821[.000]
 T                        .3288E-3           .1056E-3             3.1119[.002]
******************************************************************************
 R-Squared                     .98078   R-Bar-Squared                   .98044
 S.E. of Regression           .072007   F-stat.    F(  5, 281)    2868.0[.000]
 Mean of Dependent Variable    3.0344   S.D. of Dependent Variable      .51485
 Residual Sum of Squares       1.4570   Equation Log-likelihood       350.8919
 Akaike Info. Criterion      344.8919   Schwarz Bayesian Criterion    333.9134
 DW-statistic                  1.8840
******************************************************************************
```



```
                             Diagnostic Tests
******************************************************************************
*    Test Statistics  *        LM Version        *         F Version         *
******************************************************************************
*                     *                          *                           *
* A:Serial Correlation*CHSQ(  12)=  12.4026[.414]*F(  12, 269)=   1.0125[.437]*
*                     *                          *                           *
* B:Functional Form   *CHSQ(   1)=   2.5460[.111]*F(   1, 280)=   2.5061[.115]*
*                     *                          *                           *
* C:Normality         *CHSQ(   2)= 111.4867[.000]*       Not applicable      *
*                     *                          *                           *
* D:Heteroscedasticity*CHSQ(   1)=   .66025[.416]*F(   1, 285)=   .65716[.418]*
******************************************************************************
   A:Lagrange multiplier test of residual serial correlation
   B:Ramsey's RESET test using the square of the fitted values
   C:Based on a test of skewness and kurtosis of residuals
   D:Based on the regression of squared residuals on squared fitted values
```



```
          Error Correction Representation for the Selected ARDL Model
           ARDL(2,0,0) selected based on Schwarz Bayesian Criterion
******************************************************************************
 Dependent variable is dLOIL
 287 observations used for estimation from 1984M3  to 2008M1
******************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 dLOIL1                     .48740            .053534            9.1044[.000]
 dLGAS                     .039038            .021826            1.7886[.075]
 dLCOAL                     .21046            .061481            3.4231[.001]
 dA                         .15225            .042502            3.5821[.000]
 dT                       .3288E-3          .1056E-3             3.1119[.002]
 ecm(-1)                   -.10198            .022765           -4.4794[.000]
******************************************************************************
 List of additional temporary variables created:
 dLOIL = LOIL-LOIL(-1)
 dLOIL1 = LOIL(-1)-LOIL(-2)
 dLGAS = LGAS-LGAS(-1)
 dLCOAL = LCOAL-LCOAL(-1)
 dA = A-A(-1)
 dT = T-T(-1)
 ecm = LOIL   -.38281*LGAS   -2.0638*LCOAL   -1.4930*A -.0032238*T
******************************************************************************
 R-Squared                     .25578   R-Bar-Squared                   .24254
 S.E. of Regression           .072007   F-stat.    F(  5, 281)   19.3156[.000]
 Mean of Dependent Variable  .0042028   S.D. of Dependent Variable     .082736
 Residual Sum of Squares       1.4570   Equation Log-likelihood       350.8919
 Akaike Info. Criterion      344.8919   Schwarz Bayesian Criterion    333.9134
 DW-statistic                  1.8840
******************************************************************************
 R-Squared and R-Bar-Squared measures refer to the dependent variable
 dLOIL and in cases where the error correction model is highly
 restricted, these measures could become negative.
```