

## Modelling Fuel Prices. An I(1) Analysis

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### Abstract

This article analyses fuel pricing in Poland in the period January 2000 - March 2011. Two levels of prices are considered: wholesale prices set by Polish refineries and retail prices paid at petrol stations. Because refinery product prices are strongly dependent on the zloty exchange rate, a large part of the article deals with the modelling of the PLN/EUR exchange rate, in which process a CHEER model is used.

The multivariate cointegration analysis showed that the wholesale and retail prices of fuels and the exchange rate are linked through long-run relationships. As demonstrated, the wholesale price of fuel depends on the crude-oil price and the PLN/EUR exchange rate. Another finding is that changes in the wholesale price are fully transmitted to retail prices. As far as the exchange rate is concerned, the real interest rate parity hypothesis has been confirmed, as well as the significance of the risk as perceived by financial investors.

**Keywords:** fuel prices, real exchange rate, CHEER model, cointegration

**JEL Classification:** C51, D40, F31.

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## 1 Introduction

The interest in the fuel market as a research area has been growing partly because of fuel price rises at petrol stations which are directly transmitted to consumers and partly due to the strategic role that the fuel sector is deemed to have in the national economy (see, for instance, Asche, Gjolberg, Volker 2003; Chen, Finney, Lai 2005; Kaufmann, Laskowski 2005; Radchenko 2005; Al Gudhea, Kenc, Dibooglu 2007; Grasso, Manera 2007; Badr, Nasr, Dibeh 2008; Kilian 2008; Honarvar 2009; Rao, Rao 2009; Douglas 2010; Park, Zhao 2010). Because fuels are an important factor of production in transport and industry, etc., they determine the rate of overall price growth and so they have a significant effect on the course of economic growth.

The fuel industry is important because crude oil-based products actually do not have substitutes. This means that economies are heavily dependent on crude oil and its products, which makes it crucial to know the factors driving the prices of refinery products. This study mainly differs from the earlier studies on the Polish market for fuels in that it analyses the long-run relationships within a multivariate system using the Johansen procedure (see, e.g. Sobiechowska-Ziegert 2001, 2009; Bejger, Bruzda 2001; Miłobędzki 2008, Waściński, Przekota, Sobczak 2010).

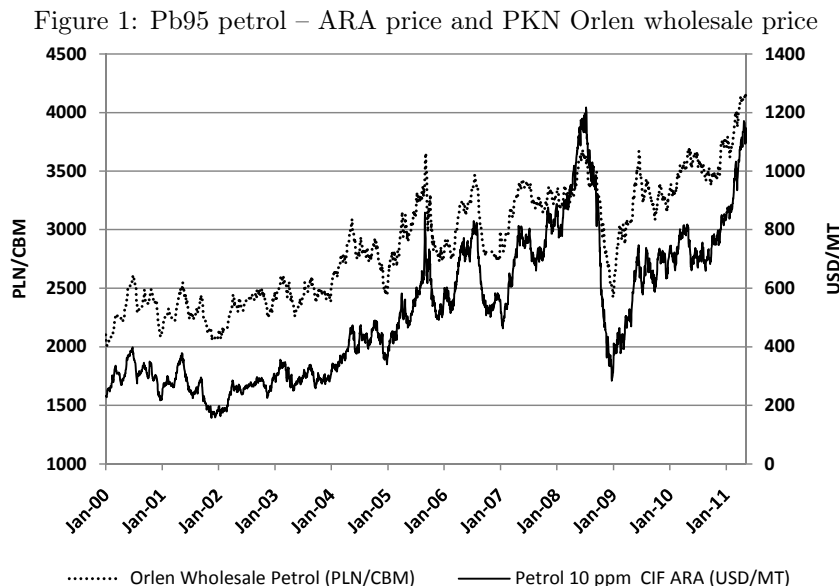
The main purpose of the analysis is to quantify the fuel-pricing processes in Poland. Because of linkages between the crude oil-based products and the key macroeconomic variables, much attention is given to the modelling of the exchange rate. The inference process utilizes a multivariate cointegration analysis with time series spanning the period between January 2000 and March 2011.

## 2 Pricing mechanisms in the fuel sector

An analysis of the fuel sector in Poland reveals that the world crude oil prices, the PLN/USD exchange rate and taxes are among the key drivers of fuel prices. The first driver is important because crude oil is a major natural resource used in the production of various fuels, such as petrol, diesel oil and kerosene. Considering that the world markets price a barrel of crude oil in the US dollars, the exchange rate is important for Polish refineries in setting their own wholesale prices. For instance, between July 2008 and March 2011 the price of a barrel of Brent crude oil decreased by 20% and the PLN/USD exchange rate dropped by 34%, which ultimately increased the crude oil prices in zlotys by around 7%. As regards taxes, their large proportion in fuel prices in Poland explains why they are important as a pricing factor in the refinery sector.

In order to reach reliable conclusions, the wholesale (producer) prices and the retail (consumer) prices of fuels must be considered. This distinction must be made, because prices at different levels of aggregation are influenced by different factors. A wholesale price is paid by petrol stations to refineries. In practice, Polish refineries do not price their fuels against the purchase cost of the crude oil they process. Their

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Source: BM Reflex

wholesale prices are calculated based on the fuel spot prices quoted daily at the ARA (Amsterdam-Rotterdam-Antwerp) market, converted into zlotys, which are treated as the reference prices. After the conversion, the applicable Polish taxes (excise tax and fuel charge) are added. This can be written as (the small letters represent the logarithms of the appropriate variables):

$$wp_t = \delta_1^{wp} (ara_t + rer_t) + \delta_2^{wp} tax_t, \quad (1)$$

where  $wp$  – fuel wholesale price,  $ara$  – fuel reference price from the ARA market,  $rer$  – real exchange rate,  $tax$  – wholesale taxes (excise tax and fuel charge).

Figures 1 and 2 present ARA and PKN Orlen wholesale prices of diesel oil and unleaded 95 petrol between January 2000 and April 2011. It is worth noting that the ARA prices were strongly varying in 2008, because crude oil prices were reaching record-high levels in the world markets then (the Brent oil price rose to 147 USD per barrel). However, the zloty wholesale prices did not rise that much, the direct reason being the strong position of the zloty in the forex market. In other words, the appreciation of the Polish currency partly absorbed speculative increases in crude oil prices.

Because the availability of the data from the ARA wholesale market is limited, a proxy had to be found for the reference price used by Polish refineries. It was assumed that the changes in the crude oil prices appropriately explained the fluctuations in the wholesale prices of fuels in Poland, as crude oil-based products are strongly dependent on the prices of this raw material (see figure 3).

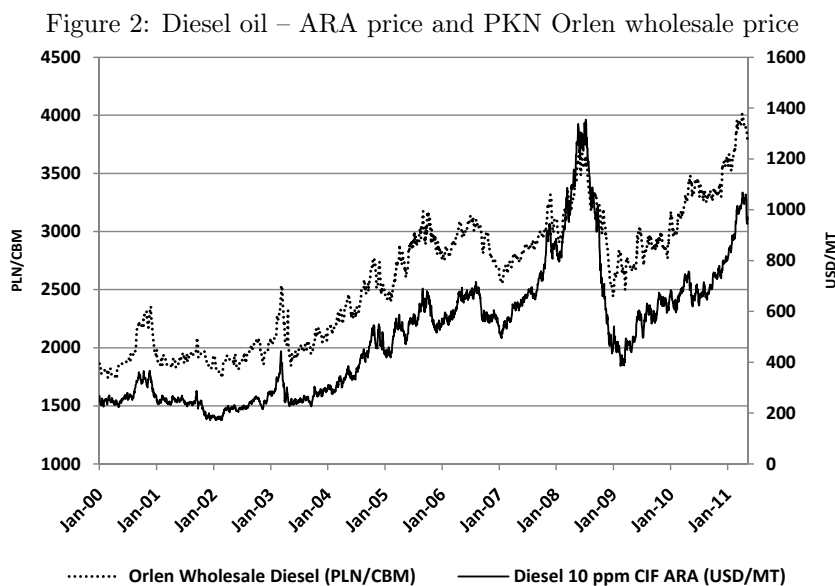
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The retail price is calculated by adding a retail margin and value added tax (VAT) to the wholesale price. The relationship for a net retail price can therefore be written as:

$$rp_t - vat_t = wp_t + margin_t, \quad (2)$$

where  $rp$  – fuel retail price,  $margin$  – retail margin,  $vat$  – VAT rate.

For the retail price to maintain long-run equilibrium (see Grabowski, Welfe 2010) with respect to the wholesale price, its elasticity with respect to the wholesale price should be one. Otherwise price acceleration could be infinite.



Source: BM Reflex

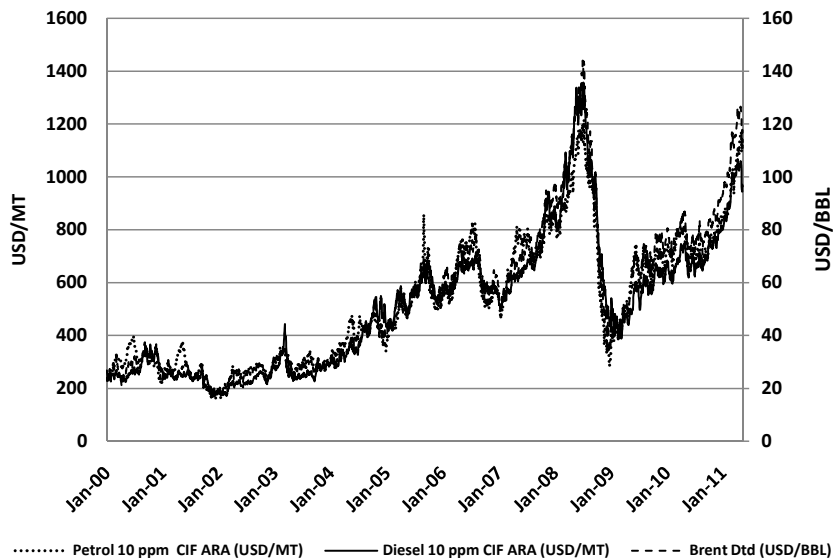
### 3 Modelling the exchange rate – the CHEER approach

Capital enhanced equilibrium exchange rate (CHEER) models are popular tools that are frequently used in explaining the behaviour of exchange rates and in empirical testing of numerous economic theories (see Juselius 1991, 1995; Johansen, Juselius 1992; Juselius, MacDonald 2000, 2004, 2006; for the Polish zloty exchange rate: Welfe, Karp, Kębłowski 2006; Stażka 2008; Kębłowski, Welfe 2010a, 2010b; Kelm 2011; Wdowiński 2011).

A CHEER model is a combination of two hypotheses: a purchasing power parity

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Figure 3: Price of Brent crude oil and ARA wholesale price for Pb95 and ON



Source: BM Reflex

(PPP) hypothesis:

$$er_t = p_t - p_t^*, \quad (3)$$

where  $er$  – nominal exchange rate (the price of a foreign currency unit in terms of a domestic currency),  $p$  – domestic price index,  $p^*$  – foreign price index and an uncovered interest rate parity hypothesis (UIP):

$$E_t(er_{t+1}) - er_t = IR_t - IR_t^*, \quad (4)$$

where  $E$  – expectations operator,  $IR$  – domestic nominal interest rate,  $IR^*$  – foreign nominal interest rate.

An assumption following the CHEER approach is that PPP holds true in the long run, so the exchange rate value directly results from relation (3). In the short run, though, the exchange rate may deviate from its long-run path because of a non-zero disparity between interest rates.

If an assumption about currencies' purchasing power parity is made, then the real exchange rate can be defined as a nominal exchange rate adjusted for the ratio between the domestic and foreign prices:

$$rer_t = er_t - p_t + p_t^*, \quad (5)$$

Finally, the basic exchange rate model resulting from the CHEER approach can be written as:

$$rer_t = \delta_1^{er} (IR_t - IR_t^*), \quad (6)$$

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Juselius and MacDonald (2000) who studied the DM/USD exchange rate extended the CHEER approach by stretching their analysis to include inflation rates and by distinguishing the short- and long-term interest rates:

$$rer_t = \delta_1^{rer} (\Delta p_t - \Delta p_t^*) + \delta_2^{rer} (IR_t^S - IR_t^{S*}) + \delta_3^{rer} (IR_t^L - IR_t^{L*}), \quad (7)$$

where superscripts  $S$  and  $L$  denote short- and long-term variables, respectively. This modification offers a better explanation of the behaviour of an exchange rate, as well as allowing an empirical verification of successive economic hypotheses, such as the term structure of interest rates, the Fisher decomposition and real interest rate parity (see Juselius, MacDonald 2000, 2004, 2006; Kębłowski, Welfe 2010a, 2010b; Kelm 2011).

If imperfect substitution between domestic and foreign securities is assumed, then relationship (7) must be extended to a measure of risk perceived by financial investors:

$$rer_t = \delta_1^{rer} (\Delta p_t - \Delta p_t^*) + \delta_2^{rer} (IR_t^S - IR_t^{S*}) + \delta_3^{rer} (IR_t^L - IR_t^{L*}) + \delta_4^{rer} rpr_t, \quad (8)$$

where  $rpr$  stands for a risk premium.

The risk factor can be approximated in two ways. One uses as a risk premium fundamental variables concerning the fiscal situation, particularly the total debt volume or government sector debt (see Giorgianni 1997; Clark, Macdonald 1999; Kelm, Bęza-Bojanowska 2005; Kelm 2011). An alternative approach is based on market measures of risk, e.g. the credit default swap (CDS) values (see Kębłowski, Welfe 2010b):

$$rer_t = \delta_1^{rer} (\Delta p_t - \Delta p_t^*) + \delta_2^{rer} (IR_t^S - IR_t^{S*}) + \delta_3^{rer} (IR_t^L - IR_t^{L*}) + \delta_4^{rer} (CDS_t - CDS_t^*), \quad (9)$$

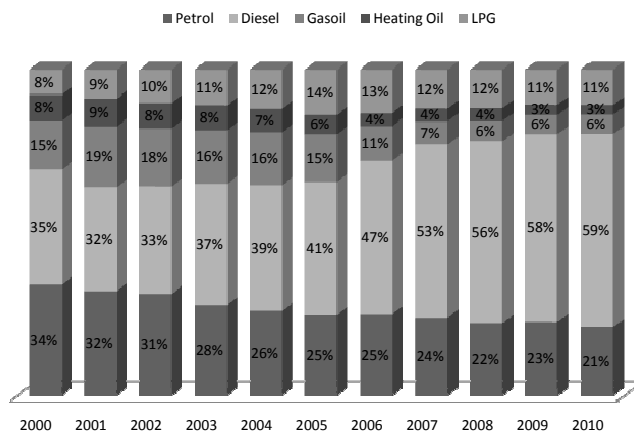
where  $CDS$  and  $CDS^*$  represent, respectively, the values of indices of the domestic and foreign CDS.

## 4 Statistical data

The fuels sector in Poland delivers a broad range of liquid fuels: petrols (Pb95, Pb98), diesel oil, furnace oil (classified according to its density and sulphur content into light, medium and heavy) and LPG. Because many products are available in the market, the product whose prices would be analysed empirically was selected using the structure of fuels consumption in Poland. Diesel oil was found to be gradually expanding its share among all fuels used in Poland, unlike petrols whose proportion is decreasing (in 2010 diesel oil accounted for 59% of total fuel consumption, growing by 24 percentage points from 2000) (see figure 4). Considering these circumstances, a decision was

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Figure 4: Structure of fuel consumption in Poland, years 2000–2010



Source: BM Reflex

made that the diesel oil prices would be used in this analysis as representative of the wholesale and retail prices of fuel in Poland.

The reason why the PLN/EUR exchange rate is used here also needs explanation. Firstly, in the Polish foreign trade structure the Euro area accounts for over 50%; Germany alone holds a 25% share, which makes it Poland's biggest trade partner. Besides, a large number of capital and investment transactions are settled in the European currency, so the PLN/EUR exchange rate has a strategic position in Polish economy. Another argument for using this exchange rate is that the US dollar plays the role of a global currency. Therefore, its exchange rate responds to risk aversion changes induced by shocks occurring in the world economy (e.g. disturbances in financial markets, natural disasters, wars). As a result, the prices of the dollar and the fundamental factors become inconsistent more and more often, which makes it difficult to use the causal relationships in modelling the PLN/USD exchange rate.

This empirical analysis uses the January 2000 - March 2011 monthly time series (see figures 5-12). The data was transformed into real terms using the overall consumer price index with base period in January 2000.

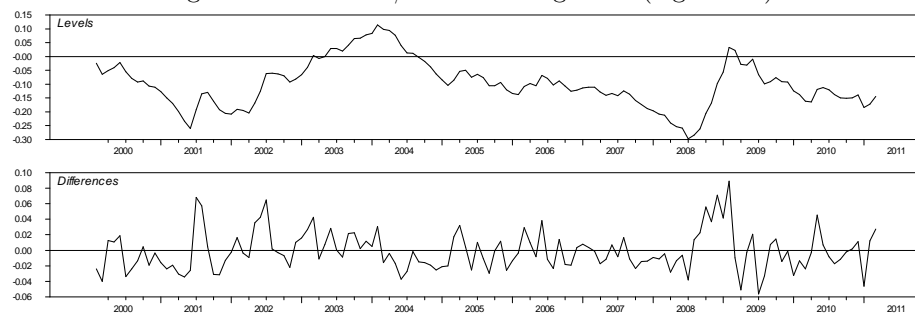
The order of integration of the variables was determined using two unit root tests, i.e. ADF and KPSS (see table 1). The tests were chosen because of opposing sets of hypotheses they use. Their results explicitly showed that all variables were integrated of order one.

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Table 1: Inference on the order of integration

Variable	Set of hypothesis	Test ADF		Test KPSS		
		Values of test statistics	Test result	Values of test statistics	Test result	
<i>dinf</i>	ADF: I(2) vs. I(1)	-7.490	I(1)	0.185	I(1)	
<i>nrp</i>		-7.459	I(1)	0.054	I(1)	
<i>wp</i>		-10.357	I(1)	0.049	I(1)	
<i>rer</i>		-7.748	I(1)	0.056	I(1)	
<i>op</i>		-9.937	I(1)	0.048	I(1)	
<i>DLTIR</i>	KPSS: I(1) vs. I(2)	-8.779	I(1)	0.177	I(1)	
<i>tax</i>		-11.678	I(1)	0.225	I(1)	
<i>DCDS</i>		-6.175	I(1)	0.042	I(1)	
<i>dinf</i>		ADF: I(1) vs. I(0)	-0.284	I(1)	3.659	I(1)
<i>nrp</i>			-1.402	I(1)	4.602	I(1)
<i>wp</i>	-1.082		I(1)	4.470	I(1)	
<i>rer</i>	-2.654		I(1)	0.599	I(1)	
<i>op</i>	-1.699		I(1)	0.936	I(1)	
<i>DLTIR</i>	KPSS: I(0) vs. I(1)	-2.003	I(1)	0.713	I(1)	
<i>tax</i>		-2.457	I(1)	0.548	I(1)	
<i>DCDS</i>		-1.872	I(1)	0.550	I(1)	

Figure 5: Real PLN/EUR exchange rate (logarithm)





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Figure 6: Average real wholesale price of diesel oil (logarithm)

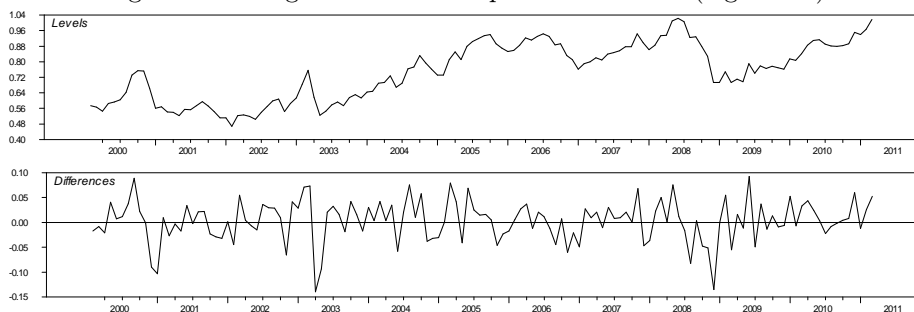


Figure 7: Average real net retail price of diesel oil (logarithm)

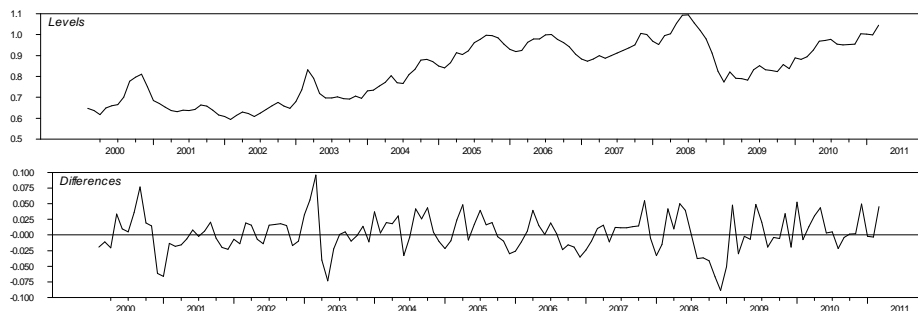
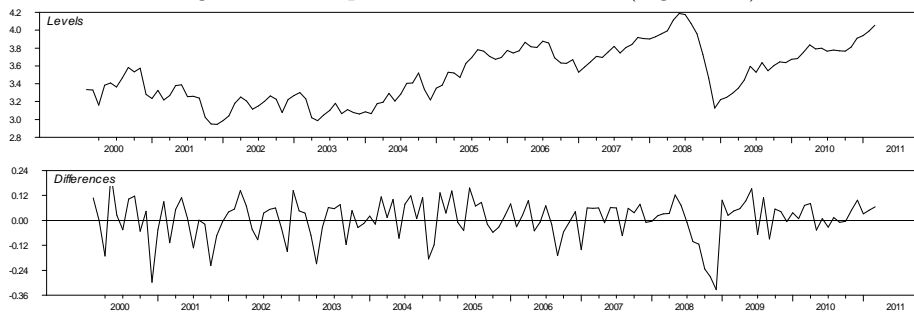


Figure 8: Real price of Brent crude oil (logarithm)



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Figure 9: Real fiscal charges (excise tax and fuel charge) on wholesale price (logarithm)

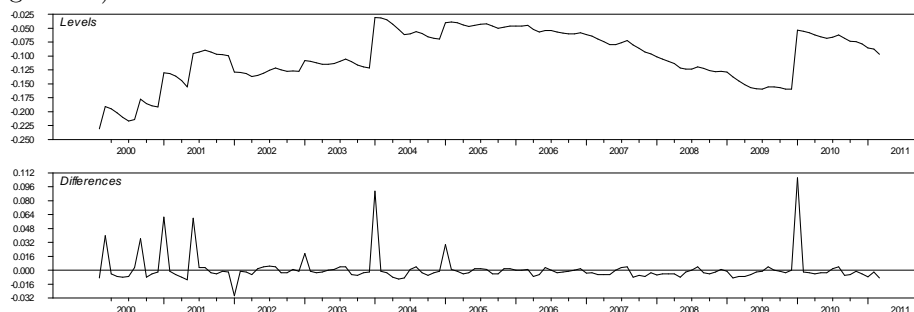


Figure 10: Differences between the Polish and Euro area inflation rates (logarithm)

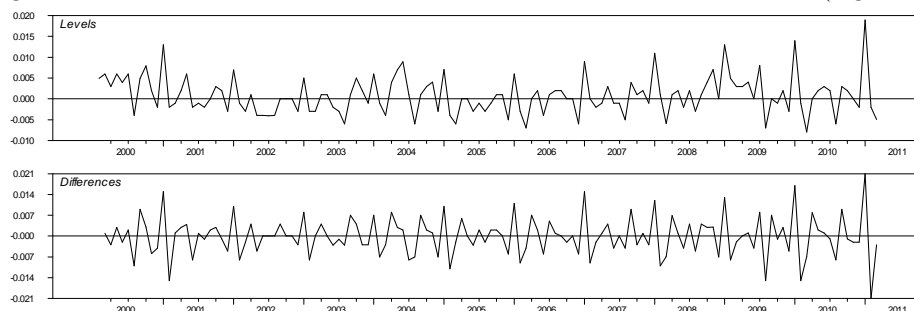
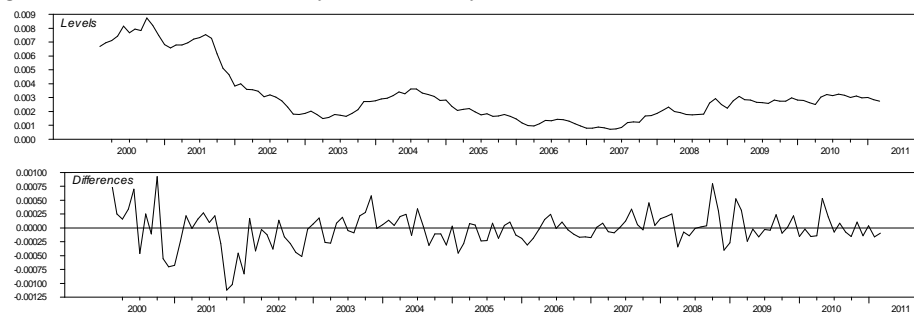


Figure 11: Differences in the yields of five year T-bonds in Poland and the Euro area



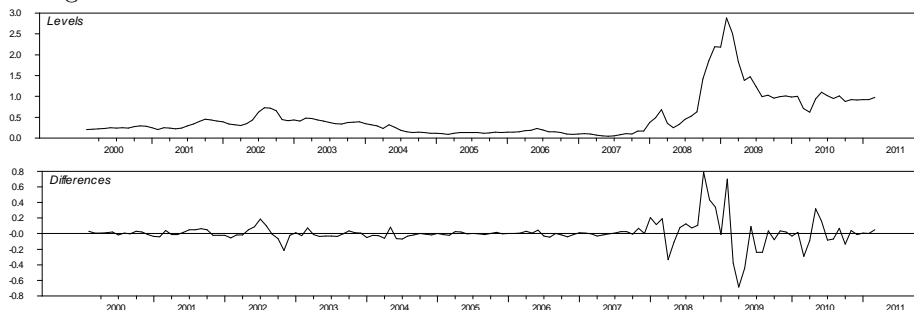
## 5 Empirical analysis

Since all the variables proved to be integrated of order one, the transmission mechanisms in the fuel market were conducted using the standard form of the vector equilibrium correction model (VEqCM) (see, for instance, Welfe 2003; Juselius 2006; Majsterek 2008):

$$\Delta y_t = \alpha \beta' y_{t-1} + \sum_{s=1}^{S-1} \Gamma_s \Delta y_{t-s} + \Psi d_t + \xi_t, \quad (10)$$

where  $y_t$  – vector of  $M$  endogenous variables ( $M \times 1$ ),  $\alpha$  – matrix of adjustment parameters ( $M \times R$ ),  $\beta$  – matrix containing the coefficients of cointegrating vectors ( $M \times R$ ),  $\Gamma_s$  – matrices of the short-run parameters ( $M \times M$ ),  $\Psi$  – matrix of the deterministic variables' parameters ( $M \times J$ ),  $d_t$  – vector of deterministic variables ( $M \times J$ ),  $\xi_t$  – vector of white-noise disturbances ( $M \times 1$ ).

Figure 12: Differences between CDS indices in Poland and the Euro area



The analysis started with a vector autoregression model (VAR) which had a vector of eight variables:

$$y_t = [rer_t \quad wp_t \quad nrp_t \quad op_t \quad tax_t \quad dinf_t \quad DLTIR_t \quad DCDS_t], \quad (11)$$

where:  $rer$  – real PLN/EUR exchange rate,  $wp$  – real wholesale price of diesel oil (PLN/1 lit.),  $nrp$  – real net retail price of diesel oil (PLN/1 lit.),  $op$  – real price of Brent crude oil (EUR/bbl),  $tax$  – total taxes in real terms, including excise tax and fuel charge (PLN/1 lit.),  $dinf$  – difference between CPI inflation rates in Poland and the Euro area,  $DLTIR$  – difference between the yields of 5-year bonds in Poland and the Euro area,  $DCDS$  – difference between CDS indices on government bonds in Poland and Germany, with the latter country standing here for the Euro area substitute, and a set of deterministic variables, which contained a constant restricted to the cointegration space and dummy variables lying outside the long-run structure: seasonal variables for the monthly data and six 0-1 dummies, necessary to ensure the desired stochastic properties of the model.

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In order to select the lag length for the VAR model the Schwarz and Hannan-Quinn information criterion were used, as well as the results yielded by the Lagrange multiplier test for  $k$ -th order autocorrelation of the error term. The data in table 2 show that the optimal lag length in the model is 2.

The long-run structure of the system in question was identified using the modelling strategy proposed by Greenslade, Hall, Henry (2002). In the first step, the standard Johansen procedure was applied to find the cointegration rank. Then, assuming that the system has  $R$  long-run relationships, the weak exogeneity hypotheses were tested. Because the exogeneity tests are sensitive to the cointegration rank, the procedure was iteratively repeated. In the third step, economic restrictions were imposed so that the structure of the long-run model could be determined, and then the long-run parameters were estimated. In the last step, the parameters of the short-run adjustments were estimated.

Table 2: Lag selection for the initial VAR model

VAR model lag	Information criterion		Lagrange multiplier test	
	Schwarz criterion	Hannan-Quinn criterion	LM(1)	LM(k)
5	-64.331	-70.438	0.123	0.154
4	-65.461	-70.725	0.117	0.075
3	-66.676	-71.098	0.407	0.033
2	-68.305	-71.885	0.493	0.087
1	-65.599	-68.337	0.000	0.000

The cointegration rank was determined using the standard trace test and the trace test with Bartlett correction (see table 3). Because dummy variables were introduced into the system, the appropriate critical values were simulated first, using the Johansen's (1996) method. The preliminary empirical results of both trace tests indicate that three independent cointegrating relationships are present in the system.

Then a weak exogeneity test was conducted on the assumption that the cointegration rank was three (see table 4). At a significance level of 0.05 its results gave no reasons for rejecting the hypothesis that the real exchange rate, the real price of Brent crude oil, wholesale taxes and the differences between long-term interest rates and inflation rates in Poland and the Euro area are exogenous in the long run. Because the result concerning the real exchange rate was surprising, a decision was made to leave it in the set of endogenous variables.

After the system was marginalized it turned out that two lags in the system were not enough (see table 5) - the Lagrange multiplier test indicated a higher-order autocorrelation of the error term. Accordingly, the optimal number of lags was set to three.

The trace test results were found robust to a reduction of the long-run system and they still pointed to the presence of three independent cointegrating vectors (see table

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Table 3: Inference on the cointegration rank

Cointegration rank	Trace test					
	Eigenvalue	Test statistics	Test statistics <sup>BC</sup>	Critical value	Level of significance	Level of significance
0	0.538	288.437	259.838	163.298	0.000	0.000
1	0.362	186.539	160.954	131.267	0.000	0.000
2	0.284	127.224	107.639	100.980	0.000	0.016
3	0.238	83.135	62.655	75.070	0.049	0.314
4	0.133	47.226	24.416	52.247	0.146	0.983
5	0.115	28.349	7.737	34.415	0.197	1.000
6	0.071	12.205	4.196	19.908	0.404	0.985
7	0.019	2.504	1.144	8.829	0.671	0.917

Superscript BC denotes the trace test with Bartlett correction.

Table 4: Inference on weak-exogeneity

Variable	Likelihood ratio test	
	Test statistics	Level of significance
<i>rer</i>	3.814	0.282
<i>wp</i>	13.210	0.004
<i>nrp</i>	26.614	0.000
<i>op</i>	5.176	0.159
<i>tax</i>	0.927	0.819
<i>dinf</i>	38.372	0.000
<i>DLTIR</i>	3.676	0.299
<i>DCDS</i>	6.916	0.075

Table 5: Testing for the number of lags in the marginalised system

VAR model lag	Information criterion		Lagrange multiplier test	
	Schwarz criterion	Hannan-Quinn criterion	LM(1)	LM(k)
5	-35.604	-38.868	0.574	0.539
4	-36.157	-39.000	0.937	0.267
3	-36.748	-39.169	0.823	0.914
2	-37.450	-39.451	0.260	0.009
1	-34.333	-35.912	0.000	0.000

6). On the other hand, the results of a repeated weak exogeneity test revealed that at a significance level of 0.05 all four variables were endogenous (see table 6). This means, as expected, that in a system structured like this the real exchange rate stops being exogenous and its long-run path of equilibrium becomes determinable.

The identified cointegrating relationships were normalised with respect to the real PLN/EUR exchange rate, the wholesale price and the retail price of diesel oil, which

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Table 6: Inference on the cointegration rank in the marginalised system

Cointegration rank	Trace test					
	Eigenvalue	Test statistics	Test statistics <sup>BC</sup>	Critical value	Level of significance	Level of significance
0	0.445	166.787	156.163	89.013	0.000	0.000
1	0.278	89.571	82.745	62.499	0.000	0.000
2	0.246	46.871	42.588	39.239	0.008	0.024
3	0.073	9.884	7.827	20.894	0.602	0.779

Table 7: Repeated test for weak exogeneity of variables

Variable	Likelihood ratio test	
	Test statistics	Level of significance
<i>rer</i>	10.964	0.012
<i>wp</i>	24.369	0.000
<i>nrp</i>	40.873	0.000
<i>dinf</i>	43.158	0.000

resulted in the following formulas:

$$rer_t = \beta_0^{rer} + \beta_2^{rer} wp_t + \beta_3^{rer} nrp_t + \beta_4^{rer} op_t + \beta_5^{rer} tax_t + \beta_6^{rer} dinf_t + \beta_7^{rer} DLTIR_t + \beta_8^{rer} DCDS_t \quad (12a)$$

$$wp_t = \beta_0^{wp} + \beta_1^{wp} rer_t + \beta_3^{wp} nrp_t + \beta_4^{wp} op_t + \beta_5^{wp} tax_t + \beta_6^{wp} dinf_t + \beta_7^{wp} DLTIR_t + \beta_8^{wp} DCDS_t \quad (12b)$$

$$nrp_t = \beta_0^{nrp} + \beta_1^{nrp} rer_t + \beta_2^{nrp} wp_t + \beta_4^{nrp} op_t + \beta_5^{nrp} tax_t + \beta_6^{nrp} dinf_t + \beta_7^{nrp} DLTIR_t + \beta_8^{nrp} DCDS_t \quad (12c)$$

To structuralize the above system, the following restrictions were imposed on particular long-run parameters:

in the real exchange rate equation:

exclusion restrictions

$$\beta_2^{rer} = \beta_3^{rer} = \beta_4^{rer} = \beta_5^{rer} = 0;$$

a symmetry restriction for the parameters of the variables representing the differences between the long-term interest rates and inflation rates in Poland and the Euro area – this consequently allows verifying the real interest rate parity

$$\beta_6^{rer} = -\beta_7^{rer};$$

in the equation of the real wholesale price of diesel oil:

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exclusion restrictions

$$\beta_3^{wp} = \beta_6^{wp} = \beta_7^{wp} = \beta_8^{wp} = 0;$$

a restriction requiring that the elasticities of the diesel oil wholesale price with respect to the real exchange rate and to the price of a barrel of Brent crude oil be equal, which directly follows from the crude oil price being expressed in domestic currency

$$\beta_4^{wp} = \beta_1^{wp};$$

in the equation of the real net retail price of diesel oil:

exclusion restrictions

$$\beta_1^{nrp} = \beta_4^{nrp} = \beta_5^{nrp} = \beta_6^{nrp} = \beta_7^{nrp} = \beta_8^{nrp} = 0;$$

a restriction calling for a unit elasticity of the net retail price with respect to the wholesale price that allows testing the hypothesis that in the long run all changes in the fuel wholesale price are transmitted to final consumers

$$\beta_2^{nrp} = 1.$$

According to the LR test results, at a borderline level of significance of 0.165 ( $LR = 11.694$ ) there are no grounds for rejecting the set of restrictions under consideration.

The estimation procedure yielded the following estimates of the long-run parameters (the values of  $t$ -Student statistics are given in the brackets):

$$rer_t = \underset{(-7.198)}{0.489} - \underset{(5.509)}{47.543} (DLTIR_t - dinf_t) + \underset{(-2.222)}{0.097} DCDS_t \quad (13a)$$

$$wp_t = \underset{(10.788)}{-0.889} + \underset{(-22.058)}{0.506} (rer_t + op_t) + \underset{(-3.575)}{0.360} tax_t \quad (13b)$$

$$nrp_t = \underset{(-23.873)}{0.075} + wp_t \quad (13c)$$

The real interest rate parity hypothesis was confirmed, which means that the exchange rate changes follow from changes in the real interest rate disparity (equation 13a). The time horizon of the exchange rate expectations estimated at around 4 years was slightly shorter than that directly arising from the UIP model. It was additionally found that risk as perceived by financial investors significantly shapes the exchange rate.

The results show that the fuel wholesale price is determined by crude oil price and the PLN/EUR exchange rate (equation 13b). That taxes represent a large proportion of the prices of domestic fuels was also confirmed. The appropriate elasticity was 0.360,

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which means that taxes constitute on average 36% of the wholesale price of diesel oil. The last equation presents that changes in the wholesale price of diesel oil are fully transmitted to final consumers. The estimate of the constant may be assumed to represent an average retail margin. Its values range in Europe from 6 to 12%, with Poland being at the lower end of the scale. In this analysis the average margin for Poland was below 8%, which is consistent with the results achieved by the experts. The analysis of the marginalized system's residuals also yielded positive results (see table 8). The Doornik-Hansen test confirmed that the error terms were normally distributed. At the standard level of significance of 0.05 there were no reasons for rejecting the hypothesis that the ARCH effect was absent. The result of the Lagrange multiplier test showing that a second-order autocorrelation of error term was present in the model was the only one that induced some reservations. Autocorrelation may be present because of incorrect dynamic structure of the model. The lag used was tested beforehand and ultimately its maximum length ensuring correct estimation was accepted (see tables 2 and 5). A higher number of lags could not be used because of the large size of the system.

Table 8: Residual analysis

Univariate tests			
Equation	Kurtosis	Test for normality of error term	Test for ARCH effect (3)
$\Delta rer$	2.658	0.236 (0.888)	5.679 (0.128)
$\Delta wp$	2.848	2.589 (0.274)	7.377 (0.061)
$\Delta nrp$	2.744	0.736 (0.692)	1.037 (0.792)
$\Delta dinf$	3.100	1.192 (0.551)	0.829 (0.843)
Multivariate tests			
Test for autocorrelation of error term			
LM(1)	LM(2)	LM(4)	LM(12)
12.622 (0.700)	39.994 (0.001)	12.327 (0.721)	10.472 (0.841)
Test for ARCH effect			
LM(1)	LM(2)	LM(4)	LM(12)
106.153 (0.318)	212.555 (0.258)	442.674 (0.069)	1310.000 (0.014)
Test for the normality of error term			
6.998 (0.537)			

After the long-run equilibrium relationships were identified (13a-13c), the parameters of the short-run dynamics were estimated (all statistically insignificant variables and



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cointegrating vectors were omitted):

$$\begin{aligned}
 \Delta rer_t = & \frac{0.037}{(-2.610)} ec_{1,t-1} + \frac{0.148}{(3.145)} ec_{2,t-1} - \frac{0.063}{(-3.473)} \Delta op_t + \\
 & + \frac{28.772}{(5.188)} \Delta DLTIR_t + \frac{0.039}{(3.368)} \Delta DCDS_t + \frac{0.356}{(4.328)} \Delta rer_{t-1} + \\
 & - \frac{0.038}{(-2.788)} \Delta DCDS_{t-1} + \frac{0.023}{(2.607)} S1_t + \frac{0.027}{(3.147)} S2_t + \frac{0.019}{(2.363)} S5_t + \\
 & + \frac{0.020}{(2.417)} S8_t + \frac{0.023}{(2.320)} S8_t + u_{1,t}
 \end{aligned} \quad (14a)$$

$$\begin{aligned}
 \Delta wp_t = & \frac{0.069}{(4.104)} ec_{1,t-1} - \frac{0.282}{(-5.081)} ec_{2,t-1} + \frac{0.382}{(3.286)} \Delta tax_t + \\
 & + \frac{0.301}{(13.956)} \Delta op_t + \frac{0.063}{(4.585)} \Delta DCDS_t - \frac{0.572}{(-3.303)} \Delta nrp_{t-1} + \\
 & + \frac{0.051}{(3.183)} \Delta DCDS_{t-2} - \frac{0.112}{(-5.265)} U0101_t + \frac{0.062}{(3.187)} U0302_t + \\
 & + \frac{0.098}{(4.998)} U0303_t + \frac{0.051}{(2.692)} U0711_t + u_{2,t}
 \end{aligned} \quad (14b)$$

$$\begin{aligned}
 \Delta nrp_t = & \frac{0.035}{(3.647)} ec_{1,t-1} - \frac{0.144}{(-4.524)} ec_{2,t-1} - \frac{0.259}{(-3.998)} ec_{3,t-1} \\
 & + \frac{0.439}{(6.556)} \Delta tax_t + \frac{0.171}{(13.844)} \Delta op_t + \frac{0.038}{(4.806)} \Delta DCDS_t + \\
 & + \frac{0.196}{(3.517)} \Delta rer_{t-1} + \frac{0.321}{(3.876)} \Delta wp_{t-1} - \frac{0.316}{(-3.185)} \Delta nrp_{t-1} + \\
 & + \frac{0.024}{(2.598)} \Delta DCDS_{t-2} - \frac{0.063}{(-5.129)} U0101_t + \frac{0.053}{(4.740)} U0302_t + \\
 & + \frac{0.087}{(7.668)} U0303_t + \frac{0.044}{(4.091)} U0412_t + \frac{0.046}{(4.187)} U0711_t + u_{3,t}
 \end{aligned} \quad (14c)$$

where  $ec_1$ ,  $ec_2$  and  $ec_3$  are cointegrating vectors given by relationships (13a), (13a) and (13a), respectively;  $S1$ ,  $S2$ ,  $S5$ ,  $S8$  represent seasonal variables for the particular months, while all other dummy variables  $U$  are 0-1 variables taking value 1 in the distinguished period.

The estimation results showed that all identified cointegrating vectors were significant in explaining the changes in the modelled variables. The exchange rate and the wholesale price of diesel oil adjust to the first and second paths of long-run equilibrium, while the net retail price of the fuel is related to each of the three cointegrating relationships. The conclusion is that the complexity of the relationships between the wholesale and retail prices of fuels and the exchange rate makes a multivariate system an appropriate tool for their analysis.

An interesting result is that showing that the dynamics of disparity between CDS contracts causes serious variations in both wholesale and retail prices of diesel oil. This relationship can be explained as follows. The world depends on crude oil because neither the resource nor its products have equivalent alternatives. It is also of limited supply, so fuel prices react strongly to all uncertainties in the world markets that affect CDS indices.

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## 6 Conclusions

The above multivariate cointegration analysis allowed determining long-run relationships between the wholesale and retail prices of fuels and the exchange rate. As demonstrated, the wholesale price depends on the price of crude oil and the PLN/EUR exchange rate. Another finding was that the changes in the two factors are only partly transmitted to the wholesale price, because the domestic fuel prices contain a high share of taxes. The study also revealed that all wholesale price fluctuations have an effect on retail prices in the long run, so they ultimately reach final users. Adopting the CHEER approach to model the exchange rate turned out to be a rational choice. Regarding the PLN/EUR exchange rate, the real interest rate parity hypothesis was confirmed and the risk as perceived by financial investors was found significant. Being an extension of the existing studies on price relations in the fuel markets, this analysis may be a starting point for further research into the relationships between the fuel sector, inflationary processes, industrial production and economic growth.

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