Anna Moenke, MA
Collegium of Economic Analysis
Warsaw School of Economics

Summary of Dissertation Research

Gas price determinants. Quantitative approach

Professor Aleksander Welfe, Corresponding Member of the Polish Academy of Sciences, Supervisor

1. Study background and significance

The dissertation analyses determinants of natural gas price with the use of VECM model and – given the changes observed on gas markets during last years - focuses on the European gas market.

Natural gas is a fossil fuel produced in XIX century as a by-product of oil extraction. Since XX century, it has been extracted also from reservoirs not associated with other hydrocarbons. After processing and purification it was transported to the final customers – mainly with the use of pipelines. Given the limitations on gas transportation, unlike in the case of oil, there is no global gas market. Sub-markets connected with the infrastructure have emerged. Each of them has its own specificity and dominating price formation mechanism. Since the end of XX century, in the US gas is sold mainly on spot market. In Europe, most buyers sign long term contracts (LTC) with price being indexed to oil. On Asian market gas is bought on spot markets, but price for final customers is oil-indexed. Given that, the researchers analyzing gas market have examined mainly the sub-markets - both in US (see e.g. Ramberg, Parsons, 2012), Asia and Europe (see Nick, Thoenes, 2014; Guerra, Shen, Zhao, 2012; Brown, Yuckel, 2007).

Thanks to both: technological progress leading to advancements in natural gas liquefaction and gas price increase, LNG shipments became more profitable. As a result, the share of LNG transactions in total number of gas contracts has been rising from year 2000. Moreover, in the beginning of XXI century so-called "shale-gas" revolution in the US has made it possible to produce unconventional-gas form reservoirs perceived earlier as inaccessible.

The changes aimed at European gas market liberalization and harmonization of EU's member states markets have started in the 90's. The exploration and production segments were disengaged (so-called unbundling) and the obligatory Third Party Access rule applies to distribution and storage services on all national markets. New infrastructure was build – both interconnectors and LNG terminals, which enabled physical connection between the markets and raised their competitiveness. Moreover, rise in number of spot transactions, development of gas markets, rising popularity of futures and forwards on gas have modified the mechanism of gas price formation. As a result, share of gas bought at regulated prices has dropped and share of spot contracts has increased.

Due to the lack of one European gas market and not fully developed market in Poland, at first the research focused on German gas market, which is perceived as a highly competitive and developed one. However, in the next step, the analysis was re-carried for Polish gas market. Despite domination on the market of Polish Oil and Gas Company (PO&GC), the liberalization, which started in 2010, lead to increase in the number of gas trading companies.

In effect, obtained results allowed to compare price formation mechanisms on both markets.

2. Dissertation theses

Dissertation theses are:

1) Price of gas is determined by demand and supply.

Gas demand is driven by economic activity and - due to the significant share of heating in final gas use - is subject to seasonality. Supply comes from domestic production, import and change of stock.

2) Gas price is influenced by: inflation rate (see Akram 2009; Frankel, 2014; Arora, Tanner, 2013), exchange rate (see Bencivenga, D'Ecclesia, Triulzi, 2012; Fratzscher, Schneider, Robays, 2014), stock exchange index (see Nick, Thoenes, 2013).

Increase in volume of gas sold through gas exchange and rising number of futures, forward contracts or gas options allows to treat the energy resources as financial instruments. Gas derivatives can be used to diversify the portfolio of assets, which leads to the conclusion that price of gas may be subject to changes in the value of stock exchange indexes and interest rates.

Gas is sold in US dollars. Appreciation of American currency makes gas sold in Europe more expensive, which leads to drop in demand. Supply does not adjust easily which causes the price to fall.

3) Gas price is determined by price of oil and thermal coal.

Long term gas contracts signed in Europe assumed calculating gas price according to so-called “oil price related formulas”. Therefore, increase in oil price leads to rise in gas price. Moreover, some of the final customers may switch between gas and coal. The possibility to replace gas with substitutes – oil and coal justifies joint analysis of the tree markets. The existence of a long term relationship between prices of oil and gas was confirmed both in US (see Villar, Joutz, 2006; Erdos, 2012), Germany and UK (see Asche, Oglend, Osmundsen, 2012; Papież, Śmiech, 2015). The research on the long term relationship between prices of gas, oil and coal on the American market proved their cointegration (see Pindyck, 1999; Bachmeier, Griffin, 2006).

3. Econometric tools

Since the variables proved to be integrated of order one, long term equilibrium was examined with the use of two step Engle-Granger method and CVAR models.

First, the order of integration of the variables was tested with ADF and KPSS tests. In case of ADF test, tree test regressions were used (see Dickey, Fuller, 1981):

$$\Delta y_t = (\alpha_1 - 1)y_{t-1} + \sum_{s=1}^{S} \gamma_s \Delta y_{t-s} + \varepsilon_t$$

$$\Delta y_t = \alpha_0 + (\alpha_1 - 1)y_{t-1} + \sum_{s=1}^{S} \gamma_s \Delta y_{t-s} + \varepsilon_t$$

$$\Delta y_t = \alpha_0 + (\alpha_1 - 1)y_{t-1} + \alpha_2 t + \sum_{s=1}^{S} \gamma_s \Delta y_{t-s} + \varepsilon_t$$

where: $\varepsilon_t \sim IID$.

Optimal lag length was selected basing on the Akaike Information Criterion and the analysis of the results was carried out starting with the most general variant of the regression. In case of failing to reject the null hypothesis, the form of regression was simplified (see Welfe, 2009) and testing was continued.

In case of ADF test, probability of type I error for I(2) variable is higher than the nominal level of significance (see Caner, Killian, 2001), power of the test is small when the root is near but not one (see Dejong, 1989) and test results lead to failing to reject the null hypothesis more often than in a situation in which the null hypothesis assumes stationarity of the process (see Nelson, Plosser, 1982). Therefore KPSS test was used (see Kwiatkowski, Phillips, Schmidt, Shin, 1992). Null hypothesis assumes stationarity of the variable and alternative one – it’s integration of order one. For the variables in case of which the results of ADF and KPSS tests did not allow to determine the order of integration, additional tests – PP (see Philips, Perron, 1988) and ERS (see Elliot, Rothenberg, Stock, 1996) were carried out.

The research consists to analyzing a long term relationship between the variables and the equilibrium toward which the system tends after the short term fluctuations ease out (see Welfe, 2009). It is thought that variables are linked in the long term if they are cointegrated.

In accordance with Engle-Granger approach, in the first step the parameters of a long term relationship were estimated. Stationarity of the residuals was tested with the ADF test in case of which the critical values are adjusted for the number of variables (see MacKinnon, 2010). In the second step of the procedure – in order to calculate parameters of the short term relationship – parameters of the ECM model were estimated.

Two step Engle-Granger method allows to obtain only one cointegrating vector. Therefore a multi-equation approach was applied and parameters of VAR model were estimated. Optimal lag length was chosen based on criteria: Akaike Information Criterion (AIC), Schwarz Criterion (SC), Hannan-Quinn (HQ), Final Prediction Error (FPE) and Likelihood Ratio (LR). It was accounted for that AIC overstates the lag length, and the results of SC and HQ are consisted not only for stationary variables but also for I(1) variables (see Paulsen, 1984). Since the order of lags should be sufficient to ensure that the error terms are IDD, autocorrelation was tested with the use of LM-test and Portmanteau test, and the normality of the regressions' residuals was verified with the use of Jarque-Bera and Doornik-Hansen tests. It was also taken into consideration that lack of autocorrelation is more important than homoscedasticity. The lag length being too small does not guarantee the proper distribution of the error term and being too great - leads to the loss of power.

VAR model can be represented in a form of a cointegrated vector autoregressive model - CVAR:

$$\Delta \mathrm{Y_t} = \Pi \mathrm{Y_{t-1}} + \sum_{s=1}^{s-1} \Gamma_s \Delta \mathrm{Y_{t-s}} + \Psi \mathrm{X_t} + \Xi_t$$

where: Y_t – matrix of endogenous variables, X_t – matrix of exogenous variables, Π, Γ_s, Ψ - parameters of the model, Ξ_t - matrix of random errors.

Order of the matrix $\Pi = AB^T$ equals to the number of cointegrating vectors among M variables. If $r(\prod) = R$, where $R \in < 0, M)$ the stochastic process can be presented in a M-dimensional space as R base stationary linear combinations of the underlying cointegrating relations and M-R common stochastic trends. Columns of the B matrix form parameters of cointegrating vectors, and the columns of A matrix are weights that are attributed to the cointegrating vectors.

Parameters of the model were estimated with the use of Johansen procedure (see Johansen, 1988), which consists to building concentrated likelihood functions. Order of integration $R,\ R \in < 0, M)$ was tested with the use of trace test and maximum eigenvalue test. Moreover, it was assumed that there were no structural changes, which means that the only deterministic element is the intercept in the cointegration space. Data generating process can be written as: $v_t = y_t + h_1$ (see Welfe, 2009), and the model as:

$$\mathbf{\Delta}\tilde{v}_t = A\tilde{B}^T\tilde{v}_{t-1} + \sum_{s=1}^{3}\Gamma_s\mathbf{\Delta}v_{t-s} + \xi_t$$

where: $\tilde{v}_{t-1} = \begin{bmatrix} v_{t-1} \\ 1 \end{bmatrix}$, $\tilde{B}^T = \begin{bmatrix} B^T & g_{\mathbf{1}} \end{bmatrix}$, $g_{\mathbf{1}} = -B^T h_1$.

Having tested the order of cointegration, model was marginalized. To determine the set of weakly-exogenous variables, excluding restrictions imposed on the parameters of *A* matrix in the row corresponding to the selected variable were tested. The LR statistic was used (see Luthkepohl, 2007):

$$LR_H = T\sum_{i=1}^{r}[\log(1-\lambda_i^H) - \log(1-\lambda_i)]$$

where: λ_i i λ_i^H - results of: $\left|\lambda\mathbf{S_{11}} - \mathbf{S}_{01}^T\mathbf{S_{00}^{-1}}\mathbf{S_{01}}\right| = 0$, for the model without and with restrictions respectively.

Critical values of the test for the size of the cointegration space depend on the number of weakly-exogenous variables. Therefore, having included each of the variables into the set of weakly-exogenous ones, it is necessary to re-test the number of cointegrating vectors.

Johansen's method allows to determine cointegrating vectors which have no economic interpretation. Therefore it is necessary to impose restrictions on the parameters of *B* matrix. Normalization and exclusion restrictions based on economic theory were tested with the use of likelihood ratio tests. Finally, the properties of the residuals were tested.

4. Results of the research

Analyses concerning the determinants of gas prices were carried out with the use of monthly data series. In case of German and Polish markets data comprised respectively: years 2005-2015 and period from January 2010 to November 2016.

Data on German and Polish markets were obtained from the German Federal Statistical Office, German Federal Ministry of Economic Affairs and Energy and Central Statistical Office of Poland. Data on oil and gas production in the US were obtained from U.S. Energy Information Administration. Data on financial markets were gained from OECD and Eurostat. The data was transformed and symbols originated from English decriptions of the variables: p_gg_t and p_gp_t – price of gas in Germany and in Poland, p_ow_t and p_owp_t – nominal Brent oil price deflated by the CPI of Germany and Poland respectively, p_cg_t and p_cp_t – coal prices in Germany and Poland, ex_de_t and ex_dz_t – exchange rates USD/EUR and USD/PLN, dax_t and wig_t – stock exchange indexes: in Germany (DAX) and in Poland (WIG), $pr\_g\_usa_t$ – deseasonalized production of gas in the US. According to the results of ADF, KPSS, PP and ERS stationarity tests, all subsequently used variables were integrated of order one.

The analysis on the determinants of gas price in Germany carried out with the use of two step Engle-Granger method proved existence of a long term relationship between gas, oil, coal prices and the exchange rate. Estimated parameters of the long term relationship are as follows:

$$\begin{aligned} p\_gg_t = 0{,}67 + 0{,}37 * p\_ow_t + 0{,}55 * p\_cg_t - 0{,}45 * ex\_de_t + 0{,}16 * U1 + \\ +0{,}27 * U2 - 0{,}19 * U3 - 0{,}10 * U4 \end{aligned} \tag{1}$$

where: variables *U1-U4* – dummy variables allowing to account for the outliers in the sample. *U1* variable being one in period May 2006-February 2007 is connected with the Ukrainian gas crisis. *U2* variable being one in period October 2008-February 2009 accounts for drop of economic activity resulting from a financial crisis. *U3* variable being one in period June 2009-June 2010 accounts for increase in demand for gas as a result of the end of the crisis and abnormally low air temperatures in winter period, which caused rise of households' consumption. Variable *U4* being one in period September 2010 – April 2011 accounts for the further rise in demand.

The value of ADF test statistic is -6,09 and it is lower than the critical value (being -3,788 for the significance level 5%, por. MacKinnon, 2010). Null hypothesis on the residuals being integrated of order one was rejected, which proves existence of a long term relationship.

In order to determine a short term relationship, parameters of the ECM model were estimated (see Engle, Granger, 1987). Maximal lag length was set to 6 and following the methodology "from general to specific", significance of the parameters was verified. Optimal lag length was chosen according to the AIC. Obtained results are as follows:

$$\Delta p\_gg_t = -0.25\, v_{t-1} + 0.27 * \Delta p\_gg_{t-1} + 0.28 * \Delta p\_gg_{t-2} + 0.24 * \Delta p\_gg_{t-3} +$$
$$\quad (-5.85) \qquad (3.67) \qquad (3.70) \qquad (3.15) \tag{2}$$
$$+0.09 * \Delta p\_ow_{t-1} + 0{,}16 * \Delta p\_cg_t - 0.14 * \Delta ex\_de_{t-1}$$
$$\quad (2.83) \qquad (2.41) \qquad (-1{,}60)$$

where: v_{t-1} – residuals of the long term relationship calculated in the first step of Engle-Granger procedure, figures in parentheses are t-Student statistics.

The results lead to the conclusion that gas price in period *t* is determined by coal price from the same period and that rise in price of coal leads to gas' price increase. Other variables influence gas price with delay. Increase in oil price makes gas price rise in the next period, which was explained by oil-indexation price mechanism. Moreover, gas price is influenced by price of gas in periods *t-1*, *t-2* and *t-3* and exchange rate USD/EUR from the period *t-1*.

In case of analysis of a long term relationship on Polish market carried out according to the Engle-Granger procedure, the results are as follows:

$$p\_gp_t = 7{,}12 + 0{,}03 * p\_owp_t - 0{,}32 * p\_cp_t - 0{,}25 * ex\_dz_t - 0{,}11 * U1 + \\ +0{,}08 * U2 + 0{,}04 * U3 - 0{,}09 * U4 \tag{3}$$

where: *U1* is a dummy variable being one in period January-September 2011 and accounts for the demand rise after the financial crisis. *U2* being one in period August 2011-December 2012 is connected with gas price variation after implementation of the III Energy Package in Poland in March 2011. Variable *U3* being one in period February-October 2014 accounts for drop of oil prices as a result of "shale revolution". *U4* being one in period March-October 2016 accounts for increase of turnover on Polish Power Exchange.

ADF statistic for the residuals of model (3) states that there is a long term relationship between the variables. However the sign of the parameter related to the coal price is negative. It was attributed to the fact that two step Engle-Granger method is not an optimal tool for analyzing a long term relationship between three or more variables. Therefore estimation of short term relations was not carried out. Instead, multi-equation analysis for both German and Polish markets was done.

In case of German market VAR model parameters were estimated:

$$Y_t = \sum_{s=1}^{S} \Pi_s \mathrm{Y}_{t-s} + \Xi_t, \tag{4}$$

where: $\mathbf{Y}_t = \begin{bmatrix} \boldsymbol{p\_gg}_t \\ \boldsymbol{p\_ow}_t \\ \boldsymbol{p\_cg}_t \\ \boldsymbol{ex\_de}_t \\ \boldsymbol{dax}_t \\ \boldsymbol{pr\_g\_usa}_t \end{bmatrix}$ - matrix of observations.

Judging by the outcome of the analysis of the residuals' properties, i.e. LM autocorrelation test and Jarque-Bera normality test, lag length was set to 4. Johansen cointegration test shows presence of two cointegrating vectors. It was also stated, at 5% significance level, that prices of oil and coal are weakly-exogenous variables. First cointegrating vector was normalized with respect to gas price, the second one – to exchange rate USD/EUR. The results of the Johansens' method estimation are as follows (t-Student statistics are provided in parenthesis):

$$\hat{A}(\hat{B}'Y_{t-1}) = \begin{bmatrix} -0{,}45 & 0{,}15 \\ (-2{,}48) & (1{,}40) \\ 0 & 0 \\ 0 & 0 \\ -0{,}40 & 0{,}26 \\ (-3{,}12) & (3{,}46) \\ 1{,}55 & -0{,}92 \\ (4{,}11) & (-4{,}04) \\ -0{,}30 & 0{,}17 \\ (-4{,}48) & (4{,}25) \end{bmatrix} * \tag{5}$$

$$\begin{bmatrix} p\_gg - 0{,}61p\_ow - 0{,}36p\_cg + 0{,}72ex\_de + 0{,}29pr\_g\_usa - 2{,}71 \\ \quad (-12{,}68) \quad (-6{,}79) \quad (15{,}40) \quad (6{,}44) \quad (-7{,}91) \\ 1{,}62p\_gg - 0{,}97p\_ow - 0{,}46p\_cg + ex\_dz + 0{,}20dax - 3{,}31 \\ (39{,}92) \quad (-11{,}52) \quad (-4{,}96) \quad (6{,}90) \quad (-7{,}46) \end{bmatrix}$$

It was stated that increase in oil price, coal price and drop of exchange rate USD/EUR and gas production in the US lead to rise in gas price in Germany. At the same time, increase of gas price and rise of DAX index make the exchange rate USD/EUR fall. US dollar appreciation is caused in that case by the investors trying to put money in currency when the stocks' value falls. The analysis of the properties of the CVAR model's residuals states that there is no autocorrelation. However, the hypothesis concerning normality of the residuals' distribution was rejected at 5% significance level. It was caused probably by considerate number of outliers in the sample. Given that the dummy variables may modify the distribution of the test statistics they were not included in analyzed CVAR models.

Parameter α_{11} equals -0,45, which proves that gas price adjusts to the first long run cointegration relation. Parameter α_{42} is positive and equals 0,26 which means that variable *ex_de* does not adjust to the second long run cointegrating relation. However, this may be connected with the fact that first long run cointegrating relation is the key one in analyzed system (parameter α_{41} equals -0,40). To verify this hypothesis, parameters of the model (4) without the variable *pr_g_usa* were estimated. Despite the rejection of null hypothesis concerning weak-exogeneity of gas production in the US, it was stated that the outcome of this test may have been biased with the small sample effect. Skipping variable *pr_g_usa* is equivalent to imposing excluding restrictions on all CVAR model's parameters related to this variable. The system included enumerated variables: *p_gg*, *p_ow*, *p_cg*, *ex_de* and *dax*. Lag length was set to 3. The results of trace test and maximum eigenvalue test suggest existence of one cointegrating relationship. At 5% level of significance it was stated that there are no grounds to reject the hypothesis on weak-exogeneity of oil price, coal price and DAX index. Cointegrating vector was normalized with respect to gas price and the results are as follows:

$$\hat{A}\left(\hat{B}'Y_{t-1}\right) = \begin{bmatrix} -0{,}17 \\ (-7{,}33) \\ 0 \\ 0 \\ 0{,}02 \\ (1{,}28) \\ 0 \end{bmatrix} * \begin{bmatrix} p\_gg - 0{,}64p\_ow - 0{,}25p\_cg + 0{,}75ex\_de + 0{,}14dax - 2{,}15 \\ \qquad (-8{,}74) \qquad (-3{,}87) \qquad (3{,}14) \qquad (2{,}53) \quad (-4{,}28) \end{bmatrix} \tag{6}$$

The results have confirmed the outcome obtained earlier. Gas price in Germany increases as a result of rise in oil and coal prices and drops when the exchange rate USD/EUR increases. Long term relationship parameters are statistically significant and their signs are consistent with the economic theory. The sign of the parameter corresponding to the *dax* variable is negative which means that DAX index is not a symptomatic variable for economic activity in analyzed system. It rather proves that investors treat forward, futures contracts and gas options as an alternative way of money saving. When the stocks' value drops, they buy gas market derivatives, which leads to the gas price increase. Parameter α_{11} equals -0,17 which proves existence of the error correction mechanism. Cointegrating relation plays an important role in explaining the German gas price level.

In case of Polish market, parameters of VAR model consisting of the following variables: p_gp_t, p_owp_t, p_cp_t, ex_dz_t, wig_t were estimated. Lag length was set to 3. The results of trace test and maximum eigenvalue test have proved existence of one cointegrating relationship. The model was marginalized. At 5% level of significance there is no grounds to reject the hypothesis concerning weak-exogeneity of oil price, coal price and WIG index. Cointegrating vector was normalized with respect to gas price and after estimation of the parameters, following results were obtained:

$$\hat{A}(\hat{B}'Y_{t-1}) = \begin{bmatrix} -0{,}16 \\ (-4{,}48) \\ 0 \\ 0 \\ 0{,}07 \\ (1{,}93) \\ 0 \end{bmatrix} * \begin{bmatrix} p\_gp - 0{,}05p\_owp - 0{,}31p\_cp + 0{,}27ex\_dz - 0{,}09wig + 0{,}96 \\ \quad\quad (-1{,}47) \quad\quad (-1{,}86) \quad\quad (1{,}03) \quad\quad (-0{,}95) \quad\quad (0{,}38) \end{bmatrix} \tag{7}$$

It was stated that increase in coal price leads to rise in gas price. Similar relation concerns variables *p_gp* and *p_owp*, which is explained by significant share of oil-indexed contracts in the total number of gas related transactions in Poland. Fall of exchange rate USD/PLN leads to gas price increase, which proves the already analyzed existence of a long term relationship between those variables. Increase in WIG index level leads to increase of gas price which suggests that *wig* is a symptomatic variable for economic activity in Poland. Parameter α_{11} equals to -0,16 which proves existence of an error correction mechanism. The analysis of the properties of the CVAR model residuals shows that there is no autocorrelation of error terms – the LM test statistic equals 36,53 The hypothesis on the normality of the distribution was rejected on 5% level of significance which was connected with the specifics of the sample period.

5. Conclusions

Methods of analysis concerning the casual relations between cointegrated stochastic processes used in the paper allowed to examine determinants of gas price and verify the research hypotheses.

The empirical research that was carried out consisted to estimating parameters of one equation and mutli-equation models with the use of respectively: two step Engle-Granger method and CVAR models. Obtained results lead to the conclusion that long term cointegrating relations between gas, coal, oil prices and exchange rates (USD/EUR and USD/PLN) exist both – on German and Polish gas markets. The direction of influence of natural resources' prices on gas price is the same. Despite the fact that Poland buys over 70% of gas from Russian Federation, in which case the price is oil-indexed, the force of influence of oil price is higher in Germany. It was stated that the result may be connected with gas price regulation in Poland. Polish Energy Regulatory Office (URE) sets tariffs for different groups of final customers and gas' price depends not only on cost of exploration, production and imports but is being negotiated by the key seller – PO&GC and the regulator. Therefore, this regulatory body's activity may influence the relationship between oil and gas prices.

Moreover, in case of both markets appreciation of US dollar leads to drop in gas price which is consistent with the hypothesis on long term relationship between the exchange rate and prices of natural recourses.

It was also stated that there is a relationship between gas prices and stock exchange indexes. However, direction of the influence on both markets is different. In case of Germany, drop of DAX index leads to increase in gas price which suggests that buying and selling gas derivatives is an alternative form of investment. Drop of stocks' value leads to buying more gas forward, futures contracts or options and makes the gas price rise. Financial market plays a substantial role in gas price formation mechanism in Germany. In case of Polish market, drop of WIG stock exchange index leads to gas price decrease which means that *wig* is a symptomatic variable for economic activity. The rise of its value corresponds to rise in gas demand triggered by an increase in economic actor's activity and leads to gas price rise.

Despite PO&GC being a key gas supplier in Poland it can be expected that Polish gas market will evolve same as the German one. The liberalization processes will trigger further changes on the market. Its competitiveness will rise as a result of development of OTC market and thanks to liberating gas prices, which was already announced by URE. As a result, along with increase in LNG supplies and rising share of futures, forward contracts in gas transactions, the role of financial factors determining gas price in Poland will probably rise.

6. The structure of the dissertation

Preface

1. Gas market determinants
    - 1.1. Gas supply
    - 1.2. Gas demand
    - 1.3. Gas price
    - 1.4. Gas prices on US, Asian and European markets
    - 1.5. Tendencies of gas markets' development
2. The determinants of gas price on German market in years 2005-2015
    - 2.1. Preface
    - 2.2. Fundamental factors determining gas price on German market in years 2005-2015
    - 2.3. Financial factors determining gas price on German market in years 2005-2015
    - 2.4. Oil market. Oil price determinants in years 2005-2015
    - 2.5. Coal market. Coal price determinants in Germany in years 2005-2015

7. References

Abbott P., Hurt C., Tyner W. (2008), What’s Driving Food Prices?, Farm Foundation Issue Report.

Ahn S. K. (1988), Distribution for Residual Autocovariate in Multivariate Autoregressive Models with Structured Parameterization, *Biometrika*, Vol. 75, No. 3, pp. 590-593.

Akaike H. (1973), Information theory as an extension of the maximum likelihood principle, Second International Symposium on Information Theory, Akademiai Kiado, pp. 267–281.

Akram Q. (2009), Commodity prices, interest rates and the dollar, *Energy Economics*, Vol. 31, Issue 6, pp. 838-851.

Al-Yousef, N. A. (1998), Saudi Arabia. Oil policy 1976-1996, PhD thesis. University of Surry, Guildford U.K.

Al-Yousef, N. A. (2012), Determinants of Crude Oil Prices between 1997 – 2011, Paper presented at the 31st Conference of the United States Association for Energy Economics and the International Association of Energy Economists.

Arora V., Tanner M. (2013), Do oil prices respond to real interest rates? *Energy Economics*, Vol. 36, Issue C, pp. 546-555.

Asche F., Oglend A., Osmundsen P. (2012), Gas versus Oil Prices. The impact of shale gas, *Energy Policy*, Vol. 47, Issue C, pp. 117-124.

Bachmeier L., Griffin J. M. (2006), Testing for market integration crude oil, coal and natural gas, *The Energy Journal*, Vol. 27, No. 2, pp. 55-71.

Bencivenga C, D’Ecclesia R. L., Triulzi U. (2012), Oil prices and the financial crisis, *Review of Managerial Science*, Vol. 6, pp. 227-238.

Bjornmose J., Roca F., Turgot T., Hansen D. S. (2009), An Assessment of the Gas and Oil Pipelines in Europe, Direcotrate General for International Policies, European Parlament.

Borowik-Trymucha H. (2010), Kluczowe regulacje w III Pakiecie Energetycznym, *Rynek Energii*, Nr I (V)-2010, pp. 49-56.

Bros T. (2012), European Gas supply: on the Verge of Being Mostly Spot-Indexed, *Oxford Energy Forum,* Issue 89, pp. 3-4.

Brown S. P. A., Yücel M. K. (2008), What Drives Natural Gas Prices?, *The Energy Journal*, Vol. 29, Issue 2, pp. 45-60.

Caner M., Kilian L. (2001), Size of distortions of tests of the null hypothesis of stationarity: evidence of implications for the PPP debate, *Journal of International Money and Finance,* Vol. 20, Issue 5, pp. 639-657.

Cifarelli G., Paladino G. (2010), Oil price dynamics and speculation: a multivariate financial approach, *Energy Economics,* Vol. 32, Issue 2, pp. 363-372.

Charemza W.W., Deadman D.F. (1997), *Nowa Ekonometria*, PWE, Warszawa.

Conforto G. (2010), What drives natural gas prices in the British market? A comparative study of the most common rules of thumbs of the American market applied to the British one (online: www.academia.edu).

Cunningham N. (2013), The geopolitical implications of U.S. Natural Gas Export, American Security Project.

Damodaran A. (2001), *Investment Valuation: Tools and Techniques for Determining the Value of Any Asset*, Willey Finance, New York.

Dauvin M. (2013), Energy prices and the real exchange rate of commodity-exporting countries, Working Paper No. 2013-28, Centre d'Etudes Prospectives et d' Informations Internationales.

Dąbrowski T. (2014), Przełamując Bariery. Transformacja Środkowoeuropejskich Rynków Gazu, *Punkt Widzenia,* Nr 45, OSW, Warszawa.

Dées S., Gasteuil A., Kaufmann R., Mann, M. (2008), Assessing the factors behind oil price changes, Working Paper Series No. 855, European Central Bank.

DeJong P. (1989), Smoothing and Interpolation with the State-Space Model, *Journal of the American Statistical Association,* Vol. 84, pp. 1085-1088.

Dickey D.A., Fuller W.A. (1981), Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root, *Econometrica,* Vol. 49, No. 4, pp. 1057-1072.

Diebold F. X., Rudebusch G. D. (1990), A nonparametric investigation of duration dependence in the American business cycle, *Journal of Political Economy,* Vol. 98, No. 3, pp. 596–616.

Einloth J. (2009), Speculation and Recent Volatility in the Price of Oil, Working Paper No. 2009-08, FDIC Center for Financial Research.

Elliott G., Rothenberg T., Stock J. (1996), Efficient tests for an autoregressive unit root, *Econometrica*, Vol. 64, No. 4, pp. 813-836.

Engle R.F., Granger W.J. (1987), Co-Integration and Error Correction: Representation, Estimation, and Testing, *Econometrica,* Vol. 55, No. 2. pp. 251-276.

Engle R. F., Yoo B.S. (1987), Forecasting and testing in co-integrated systems, *Journal of Econometrics,* Vol. 35, pp. 143-159.

Erdos P. (2012), Have oil and gas prices got separated?, *Energy Policy,* Vol. 49, Issue C, pp. 707-718.

Fernandez-Perez A., Frijns B., Tourani – Rad A. (2015), Precious Metals, Oil and the Exchange Rate: Contemporaneous Spillover Effects, Department of Finance, Auckland University of Technology.

Fesharaki S. (2013), Implications of North American LNG Exports for Asia's Pricing Regime, Pacific Energy Summit Working Papers.

Festic M., Repina S., Volcjak R. (2010), Estimating Coal Price Dynamics with the Principal Components Method, *Romanian Journal of Economic Forecasting*, Vol. 13, Issue 2, pp. 188-212.

Frankel J. A. (2014), Effects of speculation and interest rates in a "carry trade" model of commodity proces, *Journal of International Money and Finance*, Vol. 42, pp. 88-112.

Fratzscher M., Schneider D., Robays I. (2014), Oil prices, exchange rates and asset prices, Working Paper Series No. 1689, European Central Bank.

Gomez V., Maravall A. (1996), Programs TRAMO and SEATS, Instructions for the users, Working Paper No. 9628, Banco de Espana.

Granger C.W.J. (1969), Investing Casual Relations by econometric models and cross-spectral methods, *Econometrica*, Vol. 37, No. 3, pp. 424-438.

Growitsch C., Stronzik M, Nepal R. (2012), Price convergence and information efficiency in German natural gas Market, EWI Working Paper No. 05/12.

Guerra A., Shen A., Zhao T. (2012), Determinants of Natural Gas Spot Prices, FMI 3560-01

Gujarati D.N. (1995), *Basic Econometrics*, McGraw-Hill, New York.

Gutierrez C. E. C., Souza R. C., Guillen O. T. (2007), Selection of Optimal Lag Length in Cointegrated VAR Models with Weak Form of Common Cycylical Features, Working Paper Series No. 139, Banco Central do Brasil.

Hamilton J. (2008), Understanding Crude Oil Prices, Working Paper No. 14492, National Bureau of Economic Research.

Hannan E. J., Quinn B. G. (1979), The Determination of the Order of an Autoregression, *Journal of the Royal Statistical Society. Series B (Methodological)*, Vol. 41, No. 2, pp. 190-195.

Hassan M., College W., Nassar R. (2013), Empirical investigation and modelling of the relationship between gas price and crude oil and electricity prices, *Journal of Economics and Economic Education Research*, Vol. 14, No. 3, pp. 119-129.

Hassler U. (2006), A note on Phillips Perron type statistics for cointegration testing, *Economics Bulletin*, Vol. 3, Issue 17, pp. 1-7.

Heather P. (2012), Continental European Gas Hubs: Are they fit for purpose?, The Oxford Institute for Energy Studies, NG 63.

Henderson J. (2012), The potential Impact of North American LNG Exports, The Oxford Institute for Energy Studies, NG 68.

Hjalmarsson E., Osterholm P. (2007), Testing for Cointegration Using Johansen Methodology when Variables are Near-Integrated, IMF Working Paper WP/07/141.

Hotelling H. (1931), The Economics of Exhaustible Resources, *The Journal of Political Economy*, Vol. 39, Issue 2, pp. 137-175.

Janusz P. (2013), Aktualna sytuacja na rynku gazu ziemnego – perspektywy rozwoju, *Polityka Energetyczna*, Tom 16, Zeszyt 2, pp. 33-52.

Johansen S. (1988), Statistical Analysis of Cointegration Vectors, *Journal of Economic Dynamics and Control*, Vol. 12, Issue 2-3, pp. 231-254.

Joyeux R. (2001), How to Deal with Structural Breaks in Practical Cointegration Analysis, Research Papers No. 112, Macquarie University, Department of Economics.

Kaliski M., Nagy S., Rychlicki S., Siemek J., Szurlej A. (2010), Gaz ziemny w Polsce. Wydobycie, zużycie i import do 2030 r., *Górnictwo i Geologia,* Tom 5, Zeszyt 3, pp. 27-40.

Kardaś Sz. (2014), Przeciąganie Liny. Rosja Wobec zmian na Europejskim Rynku Gazu, *Prace OSW*, Nr 50.

Kaufmann R. K. (2010), The role of market fundamentals and speculation in recent price changes for crude oil, *Energy Policy,* Vol. 39, Issue 1, pp. 105-115.

Kębłowski P.(2003), Test hipotezy wspólnego potwierdzenia stopnia integracji ADF-KPSS, *Przegląd Statystyczny,* Tom 50, Nr 3, pp. 87-104.

Kębłowski P., Welfe A., (2011), A risk-driven approach to exchange-rate modelling, Working Paper No.8-11, Warsaw School of Economics, Department of Applied Econometrics Working Papers.

Kilian L. (2009), Not All Oil Price Shocks Are Alike: Disentangling Demand and Supply Shocks in the Crude Oil Market, *American Economic Review,* Vol. 99, Issue 3, pp. 1053-1069.

Kleit A. N. (2001), Are Regional Oil Markets Growing Closer Together? An Arbitrage Cost Approach, *Energy Journal,* Vol. 22, No.1, pp. 1-15.

Krichene, N. (2006), Recent Dynamics of Crude Oil Prices, IMF Working Paper WP/06/299.

Kwiatkowski D., Phillips P., Schmidt P., Shin Y. (1992), Testing the null hypothesis of stationarity against the alternative of unit root, *Journal of Econometrics,* Vol. 54, Issues 1-3, pp. 159-178.

Leszkiewicz-Kędzior K. (2014), *Asymetryczne dostosowania cenowe na rynku paliw w Polsce*, Wydawnictwo Uniwersytetu Łódzkiego, Łódź.

Long D., Moore G., Wenban-Smith G. (2001*), Gas Trading Manual: A Comprehensive Guide to the Gas Markets,* Woodhead Publishing Ltd., Cambridge.

Lossau P. (2010), The Coal Market, Structure and Price Dynamics – A Cointegration Approach, Bachelor Thesis, University of St. Gallen.

Lutkepohl H. (2005), Structural Vector Autoregressive Analysis for Cointegrated Variables, EUI Working Paper, ECO No. 2005/2.

Lutkepohl H. (2007), Econometric Analysis with Vector Autoregressive Models, EUI Working Paper, ECO 2007/11.

Lutkepohl H., Kratzig M. (2004), *Applied Time Series Econometrics*, Cambridge University Press.

MacAvoy P. (2000), *The Natural Gas Market. Sixty Years of Regulation and Deregulation*, Yale University Press.

MacKinnon J.G (2010), Critical Values for Cointegration Tests, Working Papers No. 1227. Queen's University, Department of Economics.

Majsterek M. (2014), Modelowanie systemów skointegrowanych. Aspekty teoretyczne, *Bank i Kredyt,* Nr 5, pp. 433-466.

Messner J., Babies G. (2012), Unconventional Oil, Polinares Working Paper No. 23. Research and Innovation Services, University of Dundee.

Mitrova T. (2014), The Geopolitics of Russian Natural Gas, Harvard Kennedy School Belfer Center for Science and International Affairs and the Center for Energy Studies Rice University's Baker Institute.

Miyazaki K., Limam M. (2013), Will LNG exports from North America/East Africa drive global price integration?, Conference Working Paper at LNG-17, Houston 2013.

Morsheda H., College W., Nassar R. (2013), Empirical investigation and modelling of the relationship between gas price and crude oil and electricity prices, *Journal of Economics and Economic Education Research*, Vol.14, No. 3, pp. 119 – 129.

Nelson C., Plosser C. (1982), Trends and random walks in macroeconmic time series: Some evidence and implications, *Journal of Monetary Economics*, Vol. 10, Issue 2, pp. 139-162.

Nick S., Thoenes S. (2013), What Drives Natural Gas Prices? – A Structural VAR Approach, EWI Working Paper No. 2013-2.

Osińska M. (2006), *Ekonometria Finansowa*, PWE, Warszawa.

Ozga-Blaschke U. (2009), Wpływ kryzysu gospodarczego na rynki stali, węgla koksowego i koksu. *Przegląd Górniczy,* Nr 3-4 (1036-37), Wyd. ZG SITG Katowice, pp. 8-13.

Papież M., Śmiech S. (2015), *Modelowanie i prognozowanie cen surowców energetycznych,* C.H. Beck, Warszawa.

Paulsen J. (1984), Order Determination of Multivariate Autoregressive Time Series With Unit Roots, *Journal of Time Series Analysis,* Vol. 5, Issue 2, pp. 115-127.

Phillips P. C., Perron P. (1988), Testing for a unit root in time series regression, *Biometrica,* Vol.75, Issue 2, pp. 335-346.

Pindyck R. S. (1999), The long run evolution of energy prices, *The Energy Journal,* Vol. 20, Issue 2, pp. 1-27.

Ramberg D. J., Parsons J. E. (2012), The Weak Tie Between Natural Gas and Oil Prices, *The Energy Journal*, Vol. 33, Issue 2, pp. 13-35.

Sari R., S. Hammoudeh S., Soytas U. (2010), Dynamics of oil price, precious metal prices, and exchange rate, *Energy Economics,* Vol. 32, Issue 2, pp. 351-362.

Schumacher K., Cludius J., Matthes F., Diekmann J., Zaklan, A. (2012), Price Determinants of the European Carbon Market and Interactions with Energy Markets, Environmental Research of the German Federal Ministry of the Environment Nature Conservation and Nuclear Safety. Project-no. (FKZ) 3709 41 503. Report-no. (UBA-FB) 001626/E.

Schwarz G. (1978), Estimating the Dimension of a Model, *The Annals of Statistics,* Vol. 6, No. 2, pp. 461-464.

Selien D., Schryder S., Peersman G. (2012), The U.S. Dollar Exchange Rate and the Demand for Oil, Working Paper at Monetary Policy and Commodity Prices Workshop, European Central Bank 2012 r.

Stopa J., Rychlicki S., Kosowski P. (2008), Rola podziemnego magazynowania gazu w kawernach solnych, *Gospodarka Surowcami Mineralnymi,* Tom 24, Zeszyt 3/2, pp. 11 - 23.

Strosse T. (2011), Global gas market development and the oil-gas link, Market Report by Bergen Energi.

Toda H. Y, Yamamoto T. (1995), Statistical inference in vector autoregressions with possibly integrated processes, *Journal of Econometrics*, Vol. 66, Issues 1-2, pp. 225-250.

Trostle R. (2008), Global Agricultural Supply and Demand: Factors Contributing to the Recent Increase in Food Commodity Prices, A Report from the Economic Research Service, WRS-0801, United States Department of Agriculture.

Villar J. A., Joutz F. L. (2006), The relationship between crude oil and natural gas prices, Energy Information Administration, Office of Oil and Gas.

Warell. L. (2006), Market Integration in the international coal industry: a cointegration approach, *The Energy Journal*, Vol. 27, No. 1, pp. 99-118.

Welfe A., (1998), *Ekonometria*, PWE, Warszawa.

Qin X., Bessler D., Leatham D., Wu X., Gan L. (2010), Fundamentals and US Natural Gas Price Dynamics, Selected Paper prepared for presentation at the Southern Agricultural Economics Association Annual Meeting, Orlando 2010.

Zawisza A, (2011), *Gaz dla Polski. Zarys historii sektora gazu ziemnego w ostatnich dwóch dekadach w Polsce*, Instytut Sobieskiego, Warszawa.

Legal regulations:

Dz.U. 1997 nr 54 poz. 348. Ustawa z dnia 10 kwietnia 1997 r. – Prawo energetyczne.

Dz.U. 2011 nr 163 poz. 981. Ustawa z dnia 9 czerwca 2011 r. — Prawo geologiczne i górnicze.

Dz.U. 2007 nr 52 poz. 343 Ustawa z dnia 16 lutego 2007 r. o zapasach ropy naftowej, produktów naftowych i gazu ziemnego oraz zasadach postępowania w sytuacjach zagrożenia bezpieczeństwa paliwowego państwa i zakłóceń na rynku naftowym.

Third Energy Package:

- Dyrektywa Parlamentu Europejskiego i Rady 2009/73/WE z dnia 13 lipca 2009 r. dotycząca wspólnych zasad wewnętrznego rynku gazu ziemnego i uchylająca dyrektywę 2003/54/WE,
- Dyrektywa PE i Rady 2009/72/WE z dnia 13 lipca 2009 r. dotycząca wspólnych zasad rynku wewnętrznego energii elektrycznej i uchylająca dyrektywę 2003/54/WE,
- Rozporządzenie Parlamentu Europejskiego i Rady (WE) nr 713/2009 z dnia 13 lipca 2009 r. ustanawiające Agencję ds. Współpracy Organów Regulacji Energetyki,
- Rozporządzenie Parlamentu Europejskiego i Rady (WE) nr 714/2009 z dnia 13 lipca 2009 r. w sprawie warunków dostępu do sieci w odniesieniu do transgranicznej wymiany energii elektrycznej i uchylające rozporządzenie (WE) nr 1228/2003,
- Rozporządzenie Parlamentu Europejskiego i Rady (WE) nr 715/2009 z dnia 13 lipca 2009 r. w sprawie warunków dostępu do sieci przesyłowej gazu ziemnego i uchylające rozporządzenie (WE) nr 1775/2005.

Dyrektywa Parlamentu Europejskiego i Rady 2014/94/UE z dnia 22 października 2014 r. w sprawie rozmieszczania infrastruktury paliw alternatywnych COM(2013)18.

Dyrektywa 2003/30/WE Parlamentu Europejskiego i Rady z dnia 8 maja 2003 r. w sprawie wspierania użycia w transporcie biopaliw lub innych paliw odnawialnych.

Dyrektywa 2009/30/WE Parlamentu Europejskiego i Rady z dnia 23 kwietnia 2009 r. zmieniająca dyrektywę 98/70/WE odnoszącą się do specyfikacji benzyny i olejów napędowych oraz wprowadzającą mechanizm monitorowania i ograniczania emisji gazów cieplarnianych oraz zmieniającą dyrektywę Rady 1999/32/WE odnoszącą się do specyfikacji paliw wykorzystywanych przez statki żeglugi śródlądowej oraz uchylająca dyrektywę 93/12/EWG.

Dyrektywa Parlamentu Europejskiego i Rady 2009/28/WE z dnia 23 kwietnia 2009 r. w sprawie promowania stosowania energii ze źródeł odnawialnych zmieniająca i w następstwie uchylająca dyrektywy 2001/77/WE oraz 2003/30/WE.

German law:

- Energiewirtschaftsgesetz (EnWG): Ustawa z dn. 07 lipca 2005 r. - Prawo energetyczne,https://www.gesetze-im-internet.de/bundesrecht/enwg_2005/gesamt.pdf;
- Energiesicherungsgesetz (EnSiG): Ustawa z dn. 20 grudnia 1974 r. dot. bezpieczeństwa dostaw energii, http://www.gesetze-im-internet.de/ensig_1975/index.html;
- Erdölbevorratungsgesetz (ErdölBevG): Ustawa z dn. 16 stycznia 2012 r. dot. strategicznych rezerw ropy naftowej, https://www.gesetze-im-internet.de/bundesrecht/erd_lbevg_2012/gesamt.pdf;
- Steinkohlefinanzierungsgesetz (SteinkohleFinG): Ustawa z dn. 20 grudnia 2007 r. dot. zakończenia subwencjonowania sektora górnictwa węgla kamiennego do 01 stycznia 2018 r., https://www.gesetze-im-internet.de/bundesrecht/steinkohlefing/gesamt.pdf.

Reports/analyses:

BP (2015), BP Statistical Review of World Energy 2015.

BP (2014), BP Statistical Review of World Energy June 2014.

CEER (2011), CEER vision for European Gas Target Model. Conclusion Paper.

FERC (2012), Energy Primer. A handbook of Energy market Basis.

IEA (1991), Natural Gas Prospects and Policies, International Energy Agency.

IEA (2010), Trends in U.S. Residential Natural Gas Consumption, http://www.eia.gov/pub/oil_gas/natural_gas/feature_articles/2010/ngtrendsresidcon/ngtrendsresidcon.pdf111.

IEA (2009), Transport Energy and CO2.

IGU (2015), World LNG Report – 2015 Edition.

IGU (2013), World LNG Report 2013.

KEMA (2013), Study on LT-ST Markets in Gas, DNV KEMA Energy & Sustainability.

PGNiG, raporty roczne: www.pgnig.pl.

TGE (2012), Rynek Gazu na Towarowej Giełdzie Energii, https://www.tge.pl/fm/upload/Rynek-Gazu/FOLDER_pl.pdf

UOKiK (2012), Kierunki rozwoju ochrony konkurencji i konsumentów na rynku gazu w Polsce.

Anna Moenke