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A Tripolar Model of Gas Price Formation in Germany. Does the Shale Revolution in the US Matter?

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Abstract: Presented analysis of gas price formation mechanism in Germany was prompted by changes brought about by technological advancements and the liberalization and harmonization of natural gas markets in the European Union after the year 2000. Because the data used in the study is generated by nonstationary stochastic processes, the cointegrated vector autoregressive model was applied as the most appropriate. The analysis pointed out that the price of natural gas, oil and the USD/EUR exchange rate influence each other in the long run and thus should be modelled together. Gas price in Germany is driven by both fundamental and financial factors, and so it rises with economic expansion, oil price increases, and the depreciation of the USD. It also reacts to changes in short-term interest rates and the volume of gas production in the US, which confirms that the shale revolution in this country has been consequential for gas prices in Europe, like any other supply shock would have been.

Keywords: gas price determinants, German natural gas market, shale revolution, CVAR model

JEL Classification: C32, C51, Q41

1 Introduction

In the 19th c. natural gas was extracted as a by-product of oil exploitation. It was only in the 20th c. that a technology enabling gas withdrawal from reservoirs not

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associated with other hydrocarbons was developed. Traditionally, after processing and purification gas was transported to final consumers by pipelines.

Due to infrastructure limitations three gas sub-markets, characterized by prevalent price formation mechanisms have emerged: North America, Europe and Asia (Brown and Yucel 2008; Guerra et al. 2012; Nick and Thoenes 2014; Ramberg and Parsons 2012). In the US, gas was mostly traded on spot markets. Its contract gas price was indexed to prices quoted at one of the gas hubs, mainly the Henry Hub. In Asia, gas was also purchased on the spot market, but the price of gas acquired by final customers based on long-term contracts (LTC) was oil-indexed. In Europe most of the gas was traded under LTC, meaning that it was priced according to the so-called "oil price related formulas". The reason for signing such bilateral agreements, including a take-or-pay clause (requiring customers to pay for the contracted amount of gas regardless of whether or not it was actually delivered) and a no-resale clause was the industry structure. The limited number of sellers and the lack of alternative routes of transport hindered signing of spot gas contracts under which commodities are delivered at a specified price to the destination on the same or next day.

Natural gas is a fossil fuel that is mainly used to generate heat and electricity, as well as in industry and transport. Even though it fulfills the condition of fungibility, unlike crude oil, it is only recently that a global market for this commodity started to emerge.

There are several factors that contributed to significant changes on gas markets in the early 2000s. Firstly, the shale revolution in the US took place. Technological advancements enabled gas extraction from reservoirs that had been deemed unexploitable. The exploration of the Barnett Shale in 2005 with the use of horizontal drilling and fracking has proven this technology effective. The next years witnessed a decline in gas production costs and a shale gas boom, resulting in a sharp rise in gas production in the US. The shale boom made US the world's top gas producer, the leading exporter of fuels and increased its exports of liquefied natural gas (LNG) to Europe and Asia.

Secondly, the natural gas industry's infrastructure changed when technological progress increased the efficiency of natural gas liquefaction processes and, consequently, the profitability of LNG shipments. The development of new LNG export and import terminals worldwide was accompanied by the construction of new gas pipelines, gas storage facilities, and interconnectors to link the previously isolated national markets. As the barriers to gas transport were removed the number of its sellers increased.

Thirdly, the regulatory changes introduced to liberalize the natural gas markets with the aim of lowering prices for consumers and increasing energy security gained momentum. In the EU, the process of demonopolisation, unification and harmonization of national gas markets was initiated in the 1990s. The adoption of the First Energy Package was followed by two other legislative packages. The main goal was to open up the gas market by changing the gas industry structure and liberalizing network access conditions, imposing a separation of the ownership of gas production from gas supply to unbundle gas companies, and implementing the Third Party Access (TPA) rule.

Fourthly, a fast development of gas-related derivatives such as futures, forwards, and swaps or options took place. The possibility of buying and selling an asset at a specified future price reduced the price-risk exposure (Sedlar 2017) and enabled hedging and speculation transactions. All this resulted in the partial decoupling of gas prices from oil prices and the so-called financialization of energy resource markets that gave financial agents more power over gas prices (Akram 2009, Frankel 2014; Fratzscher et al. 2014). The increasing importance of spot gas markets and gas derivatives was accompanied by a falling number of long-term contracts (Chyong 2019) and renegotiations of the existing agreements. The LTCs signed today span periods of several years, whereas those concluded in the past may stand as many as 25 years, and use a hybrid gas pricing mechanism where one part of the volume is oil-indexed and the other is sold at spot prices.

Consequently, the European gas market became more liquid (Asche et al. 2012; Growitsch et al. 2015) and the national markets started to converge (L'Hegaret et al. 2005; Wu 2011; Growitsch et al. 2015).

Because the gas market in Europe is not yet completely unified (CEER 2011), this analysis concentrates on the German gas market, the largest and most developed one in the European Union. Germany's consumption of natural gas from 2005 to 2020 is estimated at an average of 89.7 bn m^3 annually. Its main users were households (42%) and industry (38%). The principal sources of gas supplies were domestic production (declining after 2004), imports and a change of stock. Net gas imports in that period accounted for an average of ca 86% of Germany's total gas consumption. The key suppliers of gas were the Russian Federation, Norway, and the Netherlands (ca 43%, 23% and 20% of total gas imports, respectively).

After Germany amended its "Energy Law" (EnWG – Energiewirtschaftsgesetz) in 2005, the share of gas purchased at prices set under the so-called "gas-on-gas-competition" (GOG) mechanism (i.e. market prices) started to increase at the cost of gas bought using the "oil-price-escalation" (OPE) mechanism (linking oil prices to the prices of other energy resources, mainly oil). In 2019, almost 95% of natural gas in Germany was purchased through the GOG mechanism.

Given the above, a natural hypothesis for this study was that the price of gas in Germany is driven by fundamental and financial factors and that the shale revolution in the US influences the gas price formation mechanism. The sample spans the period of the COVID-19 pandemic that sharply reduced economic activity and, following that, caused a fall in the prices of energy resources. Although the economic mechanisms accompanying the pandemics are not unique, its aftermath may still affect the gas markets in the coming years.

The paper is organized as follows. Section 2 discusses the theoretical aspects of the gas price formation mechanism. Section 3 explains the data and research methodology. Section 4 presents the empirical results. The last section presents the conclusions of the paper.

2 Hypotheses on Gas Price Formation Mechanism

Because of gas transportation restrictions and a lack of a unified gas market, the focus of the early research was on the oil and coal markets. It was only at the beginning of 21st c. that natural gas price formation mechanisms attracted more interest.

The early works underlined the role of demand pressure (Brown and Yücel 2008) determined by gas volumes consumed by industry and households, which change depending on the level of economic activity (Guerra et al. 2012) and fluctuate seasonally due to weather conditions (Nick and Thoenes 2014; Ramberg and Parsons 2012).

The supply of gas was not given much attention until recently because it was fairly stable. The shale revolution and technological innovations enabling gas to be extracted from previously unexploitable deposits resulted in a supply shock. After 2005, gas production in the US started to influence the gas price formation in Germany (and other countries).

Between 2005 and 2019, most gas purchase transactions in Europe were concluded based on the OPE mechanism. As a result, a long-term association between oil and gas prices occurred not only in Germany but also, for example, in the UK (Asche et al. 2012; Bachmeier and Griffin 2006; Erdos 2012; Pindyck 1999; Villar and Joutz 2006). Moreover, a long lasting impact of oil price shocks on gas prices was observable (Nick and Thoenes 2014).

The prices of raw energy resources can be used as financial instruments (see the pioneering work by Hotelling 1931), which implies that they go up following an increase in interest rates. However, the empirical evidence is inconclusive: some authors point to a positive relationship (Arora and Tanner 2013) while others indicate that falling prices of natural resources are accompanied by interest rate rises (for the explanation of this phenomenon, see Akram 2009; Frankel 2014). In this study, a negative relationship between gas prices and interest rates is expected for two reasons. Firstly, when interest rates are rising, investing in treasury bonds becomes more profitable than in commodities. Because natural gas becomes a flexible asset on the commodity market, returns on investments in gas and financial assets should be the same. A negative relationship means the absence of arbitrage opportunities. Secondly, rising interest rates increase borrowing costs and suppress investment activity. As a result, the price of gas drops too.

Gas derivatives are used as both hedging and speculation instruments. As most transactions are cleared in cash and do not necessarily involve the physical movement of the commodity, the volume of future contracts and options must affect gas prices (KEMA 2013; Fratzscher et al. 2014; Sedlar 2017). It is also argued that gas prices can react to changes in stock exchange indexes because investors can use gas derivatives in order to diversify their asset portfolios (Akram 2009; Nick and Thoenes 2014), as well as to exchange rate variations since transactions are denominated in the US dollar (Bencivenga et al. 2012; Fratzscher et al. 2014). The appreciating US dollar increases the Euro price of gas sold in Europe (Akram 2009).

The unit cost of gas production mainly depends on the type of the reservoir, the type of gas being extracted, and the employed technology. Consequently, it is practically constant or changes extremely slowly without contributing to gas price fluctuations.

Concluding, this empirical investigation tests the following hypothesis: in the years from 2005 to 2021, the price of natural gas in Germany was determined by economic activity, the price of oil, gas production in the US, short term interest rate in US and the USD/EUR exchange rate, which can be formally written as the following long-run relationship:

$$p_t^{\mathrm{g}} + \beta_{12} p_t^{\mathrm{o}} - \beta_{13} \mathrm{ex}_t^{\mathrm{de}} + \beta_{14} y_t^{\mathrm{act}} - \beta_{16} r_t^{\mathrm{us}} - \beta_{17} \mathrm{prod}_t^{\mathrm{us}} = \epsilon_{1t} \tag{1}$$

where P^{g} represents the price of gas; P_t^{o} – the price of oil, $\mathrm{ex}_t^{\mathrm{de}}$ – the USD/EUR real exchange rate, Y_t^{act} – economic activity, R_t^{us} – the short-term interest rate, $\mathrm{PROD}_t^{\mathrm{us}}$ – gas production in the US. The real USD/EUR exchange rate ($\mathrm{ex}^{\mathrm{de}}$) is defined as: $\mathrm{ex}_t^{\mathrm{de}} = p_t - pe_t - s_t$, where P_t and PE_t are the US and German CPIs, respectively, S_t stands for the nominal USD/EUR exchange rate (Kębłowski and Welfe 2012). The small letters denote natural logarithms, β_{k} are positive long-run parameters, and ε_t is astationary disturbance term.

Although this analysis focuses on the price of gas, oil prices and the USD/EUR exchange rate formation also need to be considered because all these variables tend to interact with each other in the long run.

The price of oil increases, like the price of gas, when the USD/EUR exchange rate falls or the volume of futures contracts and options declines. Because most derivatives are cleared in cash, the latter relationship is explained through an additional supply of oil resulting from a rising number of contracts. Therefore, the same amount of commodity can be re-sold multiple times. A drop in the short-term interest rate increases the price of oil as it encourages investment in commodities rather than in government bonds. It also lowers the cost of credit, which boosts investment activity that also raises the price of oil. These arguments can be summarized by the following interdependency:

$$p_t^{\mathrm{o}} - \beta_{13}\mathrm{ex}_t^{\mathrm{de}} + \beta_{14}y_t^{\mathrm{act}} - \beta_{16}r_t^{\mathrm{us}} - \beta_{18}\mathrm{vol}_t = \epsilon_{2t} \tag{2}$$

where $\mathrm{VOL_t}$ denotes the volume of futures and options contracts on energy products.

An association between an increase in the USD/EUR exchange rate and a rising oil price also needs to be noted (Kębłowski et al. 2020). There are two explanations for it. Firstly, the US economy is bigger than the EU's, which implies that it is relatively less vulnerable to oil price changes (Sartore et al. 2002). Secondly, the US and the EU can be treated as an exporter country and an importer country, respectively, which determines the terms of trade between them (Fratzscheret al. 2014; Kilian and Zhou 2020). When the US gas production goes up, the USD appreciates and American gas exporters post bigger profits. Furthermore, an increase in the (relative) stock index may also have a bearing on the USD/EUR exchange rate, because the German stock exchange uses the US stock exchange as a benchmark. Investors expecting the German stock indexes to rise usually choose Europe rather than the US to invest, which causes the USD to depreciate. As the volume of futures contracts and options on the ICE decreases, the USD/EUR exchange rate falls and capital is withdrawn from the US market, which contributes to an even deeper depreciation in the USD. These insights allow the following long-run equation to be written:

$$\mathrm{ex}_t^{\mathrm{de}} + \beta_{31}p_t^{\mathrm{g}} + \beta_{32}p_t^{\mathrm{o}} - \beta_{35}\mathrm{si}_t + \beta_{37}\mathrm{prod}_t^{\mathrm{us}} - \beta_{38}\mathrm{vol}_t = \epsilon_{3t} \tag{3}$$

where SI_t stands for the relative stock exchange index.

3 Data and Methodology

Monthly data from January 2005 through December 2021 were sourced from the German Federal Statistical Office, OECD, Eurostat, the US Energy Information Administration database, and ICE databases (see Appendix).

The price of gas (P^{g}) is represented by the fixed price index (2015 = 100). The real price of oil (P^{o}) has been obtained by deflating the nominal price of Brent oil by the German CPI.

The real short-term interest rate in the US (R_t^{us}) is calculated as a three-month treasury bill rate ($\mathrm{Rn}_t^{\mathrm{us}}$) adjusted for inflation: $R_t^{\mathrm{us}} = \mathrm{Rn}_t^{\mathrm{us}} - (P_t - P_{t-1})/P_{t-1}$. The stock exchange rate index in US is measured against the Germany: $\mathrm{SI}_t = \mathrm{Rn}_t^{\mathrm{DJ}}/\mathrm{Rn}_t^{\mathrm{DAX}}$, where $\mathrm{Rn}_t^{\mathrm{DAX}}$ and $\mathrm{Rn}_t^{\mathrm{DJ}}$ represent the DAX and the Dow Jones, respectively.

Y_t^{act} is OECD's industrial production index used as a proxy for economic activity. Gas production in the US ($\text{PROD}_t^{\text{us}}$) is measured in billion cubic feet. It was deseasonalized by TRAMO-SEATS (see Gomez and Maravall 1996). VOL_t stands for the volume of futures and options contracts on the ICE exchange.

The variables are depicted in Figure 1. Because the unit root tests show that all variables are integrated of order one (see Appendix, Table 3), the cointegrated VAR (CVAR) is an appropriate tool for statistical inference:

$$\begin{bmatrix} \Delta y_{1t} \\ \Delta y_{2t} \end{bmatrix} = \begin{bmatrix} A_1 \\ A_2 \end{bmatrix} B^{\mathrm{T}} y_{t-1} + \sum_{s=1}^{S-1} \begin{bmatrix} \Gamma_{1s} \\ \Gamma_{2s} \end{bmatrix} \Delta y_{t-s} + \begin{bmatrix} \xi_{1t} \\ \xi_{2t} \end{bmatrix} \tag{4}$$

where vector $y_t = \begin{bmatrix} y_{1t} \\ y_{2t} \end{bmatrix}$ contains all variables of the model, $A = \begin{bmatrix} A_1 \\ A_2 \end{bmatrix}$ and B matrices have standard interpretation of weights and cointegrating vectors, $\Gamma_s = \begin{bmatrix} \Gamma_{1s} \\ \Gamma_{2s} \end{bmatrix}$ include short-term adjustment parameters and $\xi_t = \begin{bmatrix} \xi_{1t} \\ \xi_{2t} \end{bmatrix}$ represents normally distributed white noise errors.

Assuming that the variance-covariance matrix of errors is $\Omega = \begin{bmatrix} \Omega_{11} & \Omega_{12} \\ \Omega_{21} & \Omega_{22} \end{bmatrix}$, the above model can be rewritten as (see Habro et al. 1998):

$$\Delta y_{1t} = [A_1 - YA_2]B^T y_{t-1} + \sum_{s=1}^{S-1} [\Gamma_{1s} - Y\Gamma_{2s}]\, \Delta y_{t-s} + Y\Delta y_{2t} + \tilde{\xi}_t, \tag{5}$$

$$\Delta y_{2t} = A_2 B^T y_{t-1} + \sum_{s=1}^{S-1} \Gamma_{2s} \Delta y_{t-s} + \xi_{2t}, \tag{6}$$

where $Y = \Omega_{12}\Omega_{22}^{-1}$, $\tilde{\xi}_t = [\xi_{1t} - Y\xi_{2t}]$.

If the variables making up vector y_{2t} fail to adjust to the long-term trajectories (are weakly exogenous), which is a testable hypothesis, then $A_2 = 0$ and the system reduces to:

$$\Delta y_{1t} = A_1 B^{\mathrm{T}} y_{t-1} + \sum_{s=1}^{S-1} [\Gamma_{1s} - Y\Gamma_{2s}]\, \Delta y_{t-s} + Y\Delta y_{2t} + \tilde{\xi}_t \tag{7}$$

$$\Delta y_{2t} = \sum_{s=1}^{S-1} \Gamma_{2s} \Delta y_{t-s} + \xi_t \tag{8}$$

The estimation of conditional model (7) yields significantly better results for limited samples, which is why it has been used in this analysis. Although economic knowledge implies the presence of exogenous variables in the analyzed system; this is a testable hypothesis which will be verified empirically.

4 Empirical Results

The CVAR model consists of 8 variables comprising the following vector: $y_t^{\mathrm{T}} = [p_t^{\mathrm{g}} p_t^{\mathrm{o}} \mathrm{ex}_t^{\mathrm{de}} \mathrm{prod}_t^{\mathrm{us}} y_t^{\mathrm{akt}} \mathrm{si}_\mathrm{t} r_t^{\mathrm{us}} \mathrm{vol}_\mathrm{t}]$, where (small letters denote natural logarithms): p_t^{g} – the price of gas, p_t^{o} – the price of oil, $\mathrm{ex}_t^{\mathrm{de}}$ – the USD/EUR exchange rate, $\mathrm{prod}_t^{\mathrm{us}}$ – gas production in US, y_t^{akt} – economic activity, si_t – the US stock exchange rate index measured against the German index, r_t^{us} – a short-term interest rate in the US, vol_t – the volume of futures and options contracts on the ICE exchange. The optimal lag length of 2 months was selected based on the information criteria (AIC, SC, HQ, FPE, LR).

The preliminary results pointed out that two dummies were necessary: one representing the collapse of the Lehman Brothers bank (with a value of 1 in September 2008) and the other accounting for the events following the COP 21 summit, decisions of which affected both upstream and downstream sectors (with a value of 1 in November and December 2015). Introduction of a dummy (with a value of 0 until September 2014 and 1 from October 2014) representing a rise of volume of future and forward contracts on ICE exchange (as a result of its acquiring Super Derivatives company in October 2014) did not change significantly the results.

The constant was restricted to the cointegrating space. We have also repeated the analyses with a constant outside cointegrated space, however the results were not satisfying. This may result from the fact that only 2 out of 8 variables present in the system seemed to exhibit upward trending behaviour.

The trace cointegration test indicated 4 cointegrating vectors in the system, while the maximum eigenvalue test showed 2 (Table 1). Given that the first of the tests tends to overestimate and the second one to underestimate the rank of the cointegration space (Lütkepohl et al. 2001), the model was assumed to have three long-term relationships. This assumption is validated by economic reasoning.

Based on the economic rationale, the null restrictions were imposed on the appropriate rows of the A matrix. The procedure was carried out in a sequential manner; first, the economic activity was assumed to be weakly exogenous ($LR = 3.64$; $p = 0.3$), and then the volume of futures and options contracts on the ICE exchange ($LR = 5.94$; $p = 0.43$).

Considering that the critical values of the cointegrating tests depend on the number of weakly exogenous variables, the size of the cointegrating space was tested again after the exogeneity restrictions were imposed. The trace and maximum eigenvalue tests confirmed the previous results (i.e., the existence of 4 and 2 long-term relationships, respectively).

Table 1: Cointegration tests.

Unrestricted cointegration rank test (trace)				
Hypothesized no. of CE(s)	**Eigenvalue**	**Trace statistic**	**0.05 critical value**	**Prob.**
None	0.240771	220.2490	169.5991	0.0000
At most 1	0.212866	164.8831	134.6780	0.0003
At most 2	0.159217	116.7724	103.8473	0.0053
At most 3	0.146516	81.91465	76.97277	0.0200
At most 4	0.084243	50.07058	54.07904	0.1087
At most 5	0.074405	32.38171	35.19275	0.0975
At most 6	0.067761	16.84069	20.26184	0.1386
At most 7	0.013526	2.737263	9.164546	0.6309
Unrestricted cointegration rank test (maximum eigenvalue)				
Hypothesized no. of CE(s)	**Eigenvalue**	**Max-eigen statistic**	**0.05 critical value**	**Prob.**
None	0.240771	55.36582	53.18784	0.0295
At most 1	0.212866	48.11075	47.07897	0.0386
At most 2	0.159217	34.85773	40.95680	0.2066
At most 3	0.146516	31.84407	34.80587	0.1083
At most 4	0.084243	17.68886	28.58808	0.6023
At most 5	0.074405	15.54102	22.29962	0.3321
At most 6	0.067761	14.10343	15.89210	0.0935
At most 7	0.013526	2.737263	9.164546	0.6309

The normalization of the cointegrating vectors with respect to gas prices, oil prices, and the exchange rate finally yielded the following results (the figures in the parentheses are the t-Student statistics):

$$A_1 B^{\mathrm{T}} y_{t-1} = \begin{bmatrix} -0.008 & -0.002 & 0.389 \\ (-2.07) & (-0.73) & (3.15) \\ -0.005 & -0.006 & 0.33 \\ (-0.77) & (-1.13) & (1.45) \\ 0.001 & 0.002 & -0.144 \\ (0.53) & (1.29) & (-2.68) \\ -0.003 & 0.004 & 0.037 \\ (-2.17) & (4.63) & (0.86) \\ 0 & 0 & 0 \\ 0.008 & 0.004 & -3.999 \\ (3.10) & (2.13) & (-4.54) \\ -0.031 & 0.014 & 0.294 \\ (-3.47) & (2.04) & (0.97) \\ 0 & 0 & 0 \end{bmatrix} * \tag{9}$$

$$\begin{bmatrix} p^{g} - 2.31p^{o} + 35.43\text{ex}^{de} + 15.91\text{prod}^{us} - 22.46y^{akt} + 1.03r^{us} - 22.14 \\ \quad (-2.08) \quad (11.01) \quad (6.34) \quad (-3.65) \quad (5.19) \quad (-0.88) \\ p^{o} + 22.48\text{ex}^{de} + 0.37y^{akt} + 0.88r^{us} + 1.95\text{vol} - 42.6 \\ \quad (5.97) \quad (0.05) \quad (3.55) \quad (4.13) \quad (-1.33) \\ \text{ex}^{de} - 0.02p^{g} - 0.06p^{o} - 0.28\text{prod}^{us} + 0.49\text{si} + 0.07\text{vol} + 0.74 \\ \quad (-0.55) \quad (-1.97) \quad (-2.24) \quad (5.89) \quad (3.72) \quad (1.08) \end{bmatrix}$$

All restrictions imposed to identify economically interpretable cointegrating vectors are supported by the data: the LR statistics is 11.38 ($p = 0.12$).

The results of the analysis fully confirm the hypotheses about gas price formation in Germany, especially the one pointing to the significance of the US shale revolution. From the first cointegrating vector (the first row in the $B^{T}y_{t-1}$ matrix, Eq. (9)) it follows that, firstly, the gas price in Germany is driven in the long run by the price of oil, not only because gas purchases are still being made under the OPE mechanism (so, in many contracts, its price is indexed to the price of oil), but also because the market mechanisms tie the prices of energy resources together. Secondly, that the price of gas rises when the USD/EUR exchange rate falls means that a depreciating USD reduces the euro-denominated prices of gas, boosting demand for it. In the wake of a growing demand, the USD price of gas rises as well. Demand for gas, and consequently its price, may also go up as a result of an economic upturn. Thirdly, a rise in gas production in the US increases its global supply and causes its price to fall, which explains the response of the market to the shale revolution in the US. Fourthly, gas price increases are also driven by falling interest rates in the US that makes investors abandon government bonds in favor of commodity investments.

According to the second cointegrating vector (the second row of the $B^{T}y_{t-1}$ matrix, Eq. (9)), the depreciating US dollar causes the price of oil to go up. This effect is similar to the influence of the USD/EUR exchange rate on the price of gas. A falling short-term interest rate makes government bonds less profitable, as a result of which investors take interest in the commodity market, following which the price of oil starts to rise. A falling interest rate also makes credit more available, which encourages companies to invest more. With the expansion of economic activity, the price of oil increases. The sign of the parameter on economic activity seems to be incorrect; however, the impact of economic activity is not statistically significant. It is also confirmed that a rising volume of futures contracts and options decreases the price of oil. Multiple sales of commodities can be treated as an additional supply of oil that makes its price go down.

The last cointegrating vector (the third row of the $B^{T}y_{t-1}$ matrix, Eq. (9)) shows that a falling price of oil and an increasing stock index ratio decrease the USD/EUR exchange rate. Moreover, an increasing volume of futures contracts and options on the ICE causes the USD/EUR exchange rate to fall following the retreat of capital

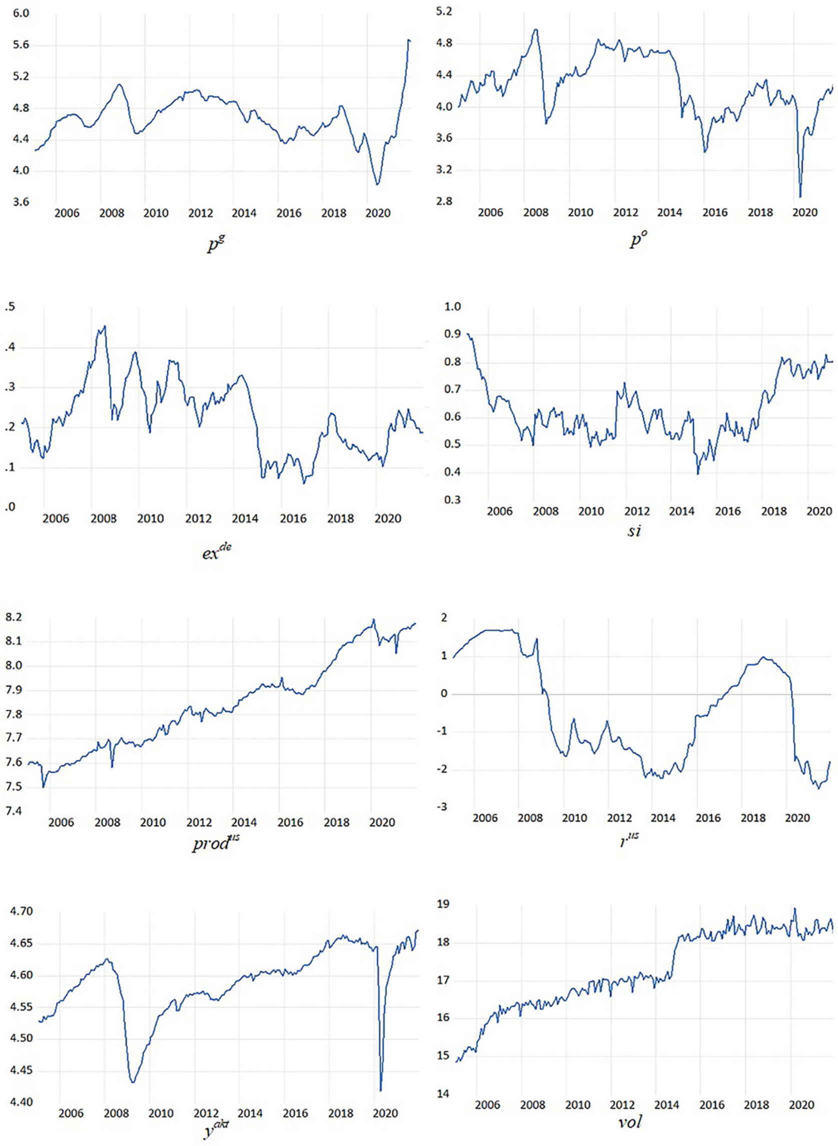

Figure 1: Time series.

from the US market, which further adds to the depreciation of the US dollar. The influence of the price of gas is not statistically significant, probably because of the limited sample size.

It is important to note that the system displays a tendency to adjust to the equilibrium path (the relevant parameters included in matrix A_1 associated with cointegrating vectors normalized with respect to the explained variables are $\alpha_{11} = -0.007$, $\alpha_{22} = -0.005$, $\alpha_{33} = -0.144$). Given that the value of t-Statistics for α_{22} is –1.13 and the results of the maximum eigenvalue test imply that only two cointegrating relationships exist, the analysis was repeated for a model with two long-run relationships (Figure 1). The results are discussed in Appendix.

The impulse-response analysis (see Figure 2) shows that shocks coming from p^{o}, ex^{de}, y^{akt}, si, r^{us}, $prod^{us}$, vol that affect gas prices die out (the growth rates are falling). As a result, the system stabilizes.

Several findings deserve emphasis. Firstly, the price of gas immediately reacts to shocks brought about by the oil price, which is attributed to the existence of the OPE pricing mechanism. Secondly, the reaction of the system to the other shocks is much slower: the appreciating US dollar significantly increases the euro price of gas after 5 months and the impact of gas production in the US (the effect of the shale revolution) lessens after 7 months.

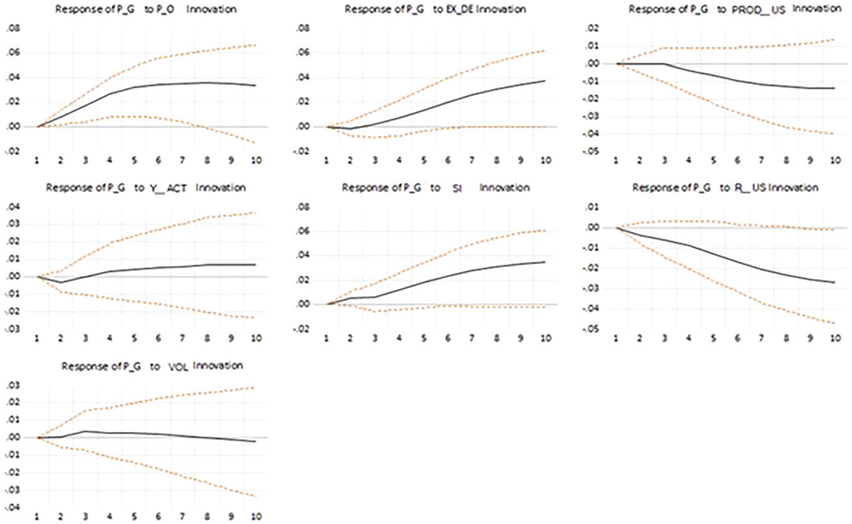

Figure 2: Impulse-response analysis. Response of p^{g} to innovations using Cholesky (d.f. adjusted) factors, 95% CI using standard percentile bootstrap with 499 bootstrap repetitions; ordering for the Cholesky decomposition: p^{o}, ex^{de}, $prod^{us}$, y^{akt}, si, r^{us}, vol.

5 Conclusion and Policy Implications

Unlike most commodity markets, the natural gas market did not attract much interest from researchers until the early the 21st c. for several reasons. Firstly, transportation restrictions contributed to the existence of separate submarkets and prevented the emergence of a global market. Secondly, the number of gas sellers and buyers was limited. Thirdly, as a result, long-term bilateral contracts indexed to oil prices, containing a take-or-pay clause or a non-resale commitment, were signed. For all these circumstances, the natural gas market lacked the classical market mechanisms.

In the early 2000s, several developments took place that caused the gas markets to change. New technologies enabled transportation of liquefied natural gas and the shale revolution allowed access to gas reservoirs that had previously been regarded as unexploitable. New pipelines, interconnectors, terminals, and storage facilities were built, connecting once-isolated markets.

With the establishment of gas exchanges, hubs and the financialization of energy resource markets, gas-related derivatives emerged. As a result, the number of gas sellers and buyers rapidly increased. Processes initiated in Europe to demonopolize, unify, and harmonize the national gas markets substantially accelerated their liberalization. As a result of all these developments, the share of gas purchased at prices set under the so-called "gas-on-gas competition" mechanism rose from 15% in 2005 to 78% in 2019, while the share of gas bought through the „oil-price escalation" mechanism fell from 78 to 22% (IGU 2019).

As Europe does not have a single, unified market for gas, this empirical study focused on the price of natural gas in Germany, the largest EU economy that has a highly developed gas market and tops the ranking of gas consumers in Europe. The sample spanned the years from 2005 to 2021. There are two reasons why 2005 was selected as the start year: the implementation of EU gas directives and energy packages in Germany and the beginning of the shale revolution in the US. Using data covering years before 2005 would have resulted in a non-homogenous sample.

The natural gas price, the oil price, and the USD/EUR exchange rate were found to influence each other in the long run. It is, therefore, appropriate that these variables should be modeled together, which was done by means of a cointegrated VAR model. The results we obtained confirmed that the gas price in Germany is influenced by both fundamental and financial factors. As economic activity intensifies, the demand for gas goes up, and so does its price. The fact that increasing gas production in the US brings down gas price in Germany indicates that the shale revolution in the US did have an effect on the gas price formation mechanism in

Europe and answers the title’s question in the affirmative. It proves that even though the shale revolution was widely viewed in the early 2000s as a ‘game-changer’ on the US gas market, it has in fact affected also the global energy system and redrawn the global energy map (Auping et al. 2016). It is interesting to note that because some amounts of gas are still purchased through the OPE mechanism, a rise in the crude oil price increases the price of gas. On the other hand, a depreciating US dollar lowers the euro price of gas and spurs demand for it. Furthermore, a falling interest rate causes more investments to be directed to the commodity market, consequently increasing the price of gas.

The demand and supply shocks generated by the coronavirus pandemic have had a dramatic and sweeping effect on many economies and significantly influenced many economic mechanisms. The consequences of this are likely to persist for a long time into the future. In an effort to mitigate problems associated with the lockdowns, the fiscal and monetary authorities introduced numerous non-standard measures that greatly contributed to exchange rate fluctuations and accelerated inflation. The concurrent uncertainty over the prices of oil, gas and energy triggered inflationary expectations, further increasing their volatility. It seems that in these circumstances the empirical analyses of processes shaping the gas market will increasingly gain interest in the years to come.

This analysis of gas price formation used the existing theoretical framework to make an empirical contribution to the field of gas price modeling. It seems very timely given the political consequences of the war in Ukraine, such as the EU announcing its readiness to lessen its dependence on Russian energy resources. The plans to make a new gas pipeline (Nord Stream 2, NS2) operational soon will require a major revision in the face of the German government refusing to approve the project. The effect of the NS2 on the German gas market will ultimately and obviously depend on the provisions of the buy-sell agreement, i.e., on whether the GOG or OPE mechanism will be deployed. It seems, however, that even if the pipeline starts to operate, Germany – like many other European countries – may wish to look for alternative import sources of gas. The idea of constructing LNG terminals for gas imported from the US is being seriously considered and may gain momentum. There are preliminary plans for the joint funding of the project by the public lender KfW, the Dutch state-owned gas company Gasunie, and the German RWE energy group. Given these circumstances, we strongly believe that the conclusions of our empirical analysis will be valid also in the future.

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Appendix A

A.1. Tables and figures

Table 2 presents the definitions of variables used in the empirical analysis. Figure 3 depicts the residuals of CVAR equations explaining prices of gas, oil and exchange rate. Table 3 presents the results of unit root tests.

Table 2: The definitions of variables used in the empirical analysis.

Symbol	Name	Description	Source
P^g	Natural gas price	Import price index (excluding taxes, duties etc.)	Federal statistical office – www.destatis.de
P^o	Crude oil price	To calculate real price of oil, nominal price of Europe brent spot price FOB (dollars per barrel) was deflated by the EU's CPI	Energy information administration www.eia.gov (data on brent spot price); OECD https://stats.oecd.org (data on CPI)
ex_t^{de}	USD/EUR real exchange rate	The real USD/EUR exchange rate was calculated as: $ex_t^{de} = p_t - pe_t - s_t$, where P_t and PE_t are the US and German CPIs, respectively. S_t stands for the nominal USD/EUR exchange rate. Small letters denote natural logarithms	https://www.investing.com (data on nominal interest rate), ECD – https://stats.oecd.org (data on CPIs)
Y_t^{act}	Economic activity	Y_t^{act} is a OECD's industrial production index. It accounts for the output of the mining, manufacturing, electricity, gas and steam and air-conditioning sectors of the OECD's countries	OECD – https://stats.oecd.org
SI_t	The relative stock exchange index	The stock exchange rate index in Germany was measured against the US' stock exchange rate index $SI_t = Rn_t^{DJ}/Rn_t^{DAX}$ (Rn_t^{DAX}, Rn_t^{DJ} stand for DAX and dow Jones indexes, respectively). The monthly average value of the indexes on closing was used	https://finance.yahoo.com/
R_t^{US}	US' short term interest rate	The real short-term interest rate in the US is calculated as nominal three-month treasury bill rate adjusted for inflation according to the equation:	OECD – https://stats.oecd.org

Table 2: (continued)

Symbol	Name	Description	Source
		$R_t^{US} = Rn_t^{US} - (P_t - P_{t-s})/P_{t-1}(Rn_t^{US}$ stands for nominal interest rate, P_t is US' CPI)	
$prod_t^{us}$	Gas production in the US	U.S. Natural gas gross withdrawals (MMcf). The data were deseasonalized with TRAMO-SEATS procedure	Energy information agency – www.eia.gov
vol_t	Volume of futures and options contracts on energy products	Total monthly volume of futures and options contract on the ICE futures europe market	www.theice.com

Year 2015 is the base period for indexes.

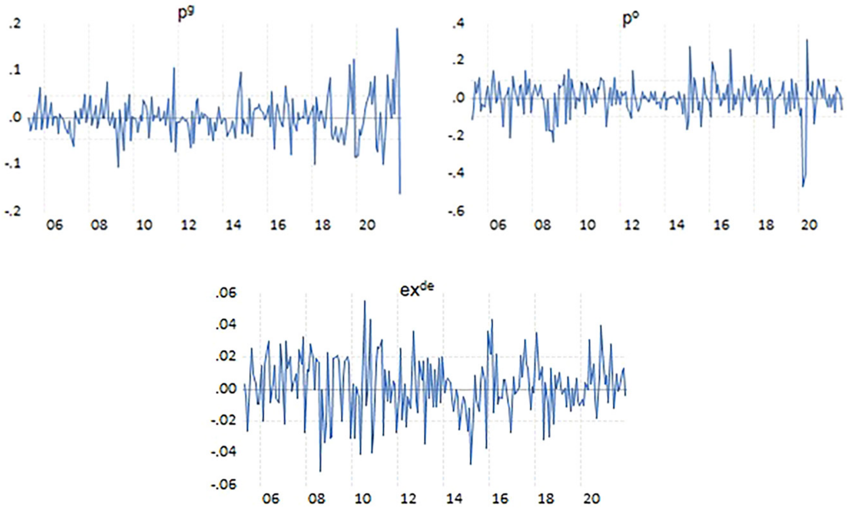

Figure 3: The residuals of CVAR equations explaining prices of gas, oil and exchange rate. In the case of the CVAR in *I*(1) domain, each equation is a linear combination of the variables; hence, the residuals must be stationary if each of the variables is *I*(0).

Table 3: Unit root tests results.

Variable	ADF			KPSS	
	H_0: $y \sim I(1)$			H_0: $y \sim I(0)$	
	No intercept no trend	With intercept	With intercept and trend	With intercept	With intercept and trend
p^g	0.64	**−3.41**	−3.21	0.3	**0.17**
Δp^g	**−3.6**	**−3.61**	**−3.47**	–	–
p^o	−0.21	−2.55	−3	**0.63**	**0.2**
Δp^o	**−9.99**	**−9.97**	**−9.94**	–	–
ex^{de}	−0.92	−2.43	−2.87	**0.69**	**0.16**
Δex^{de}	**−10.82**	**−10.79**	**−10.77**	–	–
y^{akt}	0.56	−2.22	−2.87	**0.90**	0.11
Δy^{akt}	**−10.97**	**−10.97**	**−10.93**	–	–
si	−0.53	−2.29	−3.02	0.45	**0.32**
Δsi	**−16.39**	**−16.35**	**−16.6**	–	–
r^{us}	−1.19	−1.44	−1.56	**0.51**	**0.26**
Δr^{us}	**−9.48**	**−9.50**	**−9.47**	–	–
$prod^{us}$	2.98	0.29	−3.10	**1.74**	**0.16**
$\Delta prod^{us}$	**−12.36**	**−12.95**	**−12.97**	–	–
vol	1.72	−2.06	−2.38	**1.70**	**0.18**
Δvol	**−3.37**	**−3.91**	**−4.17**	–	–

The ADF *t*-statistic and KPSS LM-statistic are compared with the 95th quantiles of asymptotic distributions (see Davidson and MacKinnon 1993; Kwiatkowski et al. 1992). The bolded values lead to the null hypothesis rejection at 5% level of significance.

A.2. Additional Empirical Results

The CVAR model presented in section 4 of the paper has 8 variables comprising the vector: $y_t^T = \left[p_t^g \ \ p_t^o \ \ ex_t^{de} \ prod_t^{us} \ y_t^{akt} \ \ si_t \, r_t^{us} \ \ vol_t\right]$. As before, the optimal lag length of 2 months was selected and two dummy variables were included (first with a value of 1 in September 2008, and the second one taking a value of 1 in November and December 2015). Assuming that the model has only two long-run relationships (see the cointegration test results, Table 1), in the next step, the existence of weakly exogenous variables was tested. Both economic activity and the volume of futures and options contracts on the ICE exchange were found to be weakly exogenous (LR = 4.82; p = 0.31). The repeated trace test and the maximum eigenvalue test confirmed the previous results (pointing to the existence of 4 and 2 long-term relationships, respectively). After imposing the necessary restrictions, the following results were obtained (the figures in the parentheses are *t*-Student statistics):

$$A_1 B^{\mathrm{T}} y_{t-1} = \begin{bmatrix} -0.02 & 0.29 \\ (-2.73) & (3.33) \\ -0.01 & 0.18 \\ (-0.98) & (1.13) \\ 0.005 & -0.13 \\ (1.47) & (-3.41) \\ 0.008 & -0.04 \\ 3.26 & (-1.33) \\ 0 & 0 \\ 0.02 & -0.27 \\ (4.42) & (-4.31) \\ -0.04 & -0.10 \\ (-1.98) & (-0.46) \\ 0 & 0 \end{bmatrix} * \qquad (10)$$

$$\begin{bmatrix} p^{g} \underset{(-2.69)}{-1.23} p^{o} \underset{(8.37)}{+10.82} \mathrm{ex}^{de} \underset{(3.44)}{+4.06} \mathrm{prod}^{us} \underset{(-1.41)}{-3.62} y^{akt} \underset{(-0.45)}{-0.63} \mathrm{si} \underset{(2.65)}{+0.33} r^{us} \underset{(-1.69)}{-15.91} \\ \mathrm{ex}^{de} \underset{(-3.22)}{-0.12} p^{o} \underset{(-1.67)}{-0.29} \mathrm{prod}^{us} \underset{(3.59)}{+0.55} \mathrm{si} \underset{(-0.8)}{-0.01} r^{us} \underset{(2.34)}{+0.06} \mathrm{vol} \underset{(1.22)}{+1.17} \end{bmatrix}$$

The restrictions enabled all cointegrating vectors (LR = 5.09; $p = 0.40$) with full economic interpretation to be identified. The system adjusts to the equilibrium path as $\alpha_{11} = -0.02$, $\alpha_{32} = -0.13$ and the tests confirm that the residuals are stationary.

The key conclusions concerning gas price formation following from the above results and those presented in Section 4 are virtually the same. The price of gas in Germany goes up with a rising price of oil, expanding economic activity, and a depreciating US dollar. Increasing gas production in the US reduces the price of gas in Germany. A falling interest rate boosts investments in the commodity market, raising the price of gas. According to the second cointegrating vector, a rising price of oil increases the USD/EUR exchange rate and so does gas production in the US. Increases in the stock index ratio and in the volume of futures contracts and options on the ICE reduce the USD/EUR exchange rate.

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