Non-linear effects of energy commodities on the EUR/USD spot exchange rate: An Oil and Gas Perspective on Parity Conditions.

Seminar in Applied Financial Economics: Applied Econometrics of FX Markets - Professor Reitz

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Kiel - 14.11.2025

Outline

Intro: Energy Commodities and Exchange Rates

This has led some to suggest that an unidentified real factor may be causing persistent shifts in real equilibrium exchange rates.
— R.A. Amano, S. van Norden[1]

This may in fact be the case or it is also possible that the relationship between exchange rates and oil shocks is non-linear and not being detected by a linear regression framework.
— S. A. Basher, A. A. Haug, P. Sadorsky[2]

The long-run real exchange rate of these 'commodity currencies' is not constant (as would be implied by purchasing power parity-based models) but is time varying, being dependent on movements in the real price of commodity exports.
— P. Cashin, L. F. Cespedes, R. Sahay[3]

[1] Oil prices and the rise and fall of the US real exchange rate, R.A. Amano, S. van Norden, Journal of International Money and Finance 17 (1998) 299-316, p.301

[2] The impact of oil shocks on exchange rates: A Markov-switching approach, S. A. Basher, A. A. Haug, P. Sadorsky, Energy Economics 54 (2016) 11–23, p.17

[3] Commodity currencies and the real exchange rate, P. Cashin, L. F. Cespedes, R. Sahay, Journal of Development Economics 75 (2004) 239–268, p.239

Intro: The PPP puzzle and Commodity Currencies

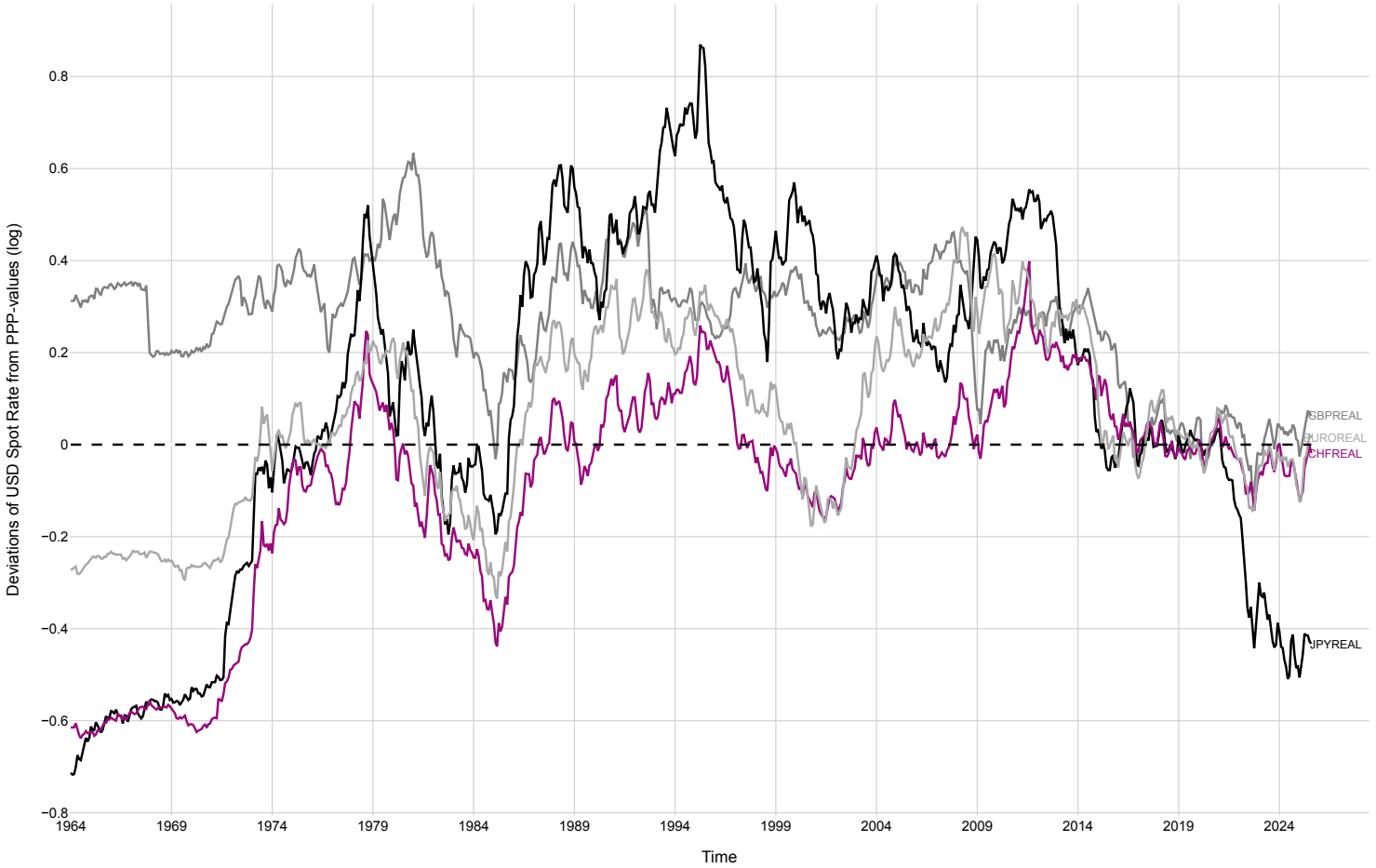

Figure: Monthly deviations of USD Spot Rate from PPP-values (in log terms) over the time: 1964 - 2025.[4]

[4] Own Illustration based on XYZ (2000), page 7 and data accessed 10.09.25.

This puzzle concerns the finding of many researchers that the speed of mean reversion of real exchange rates is too slow to be

Modern Energy Commodity Markets
The current state

Oil: Global Production and Consumption over time

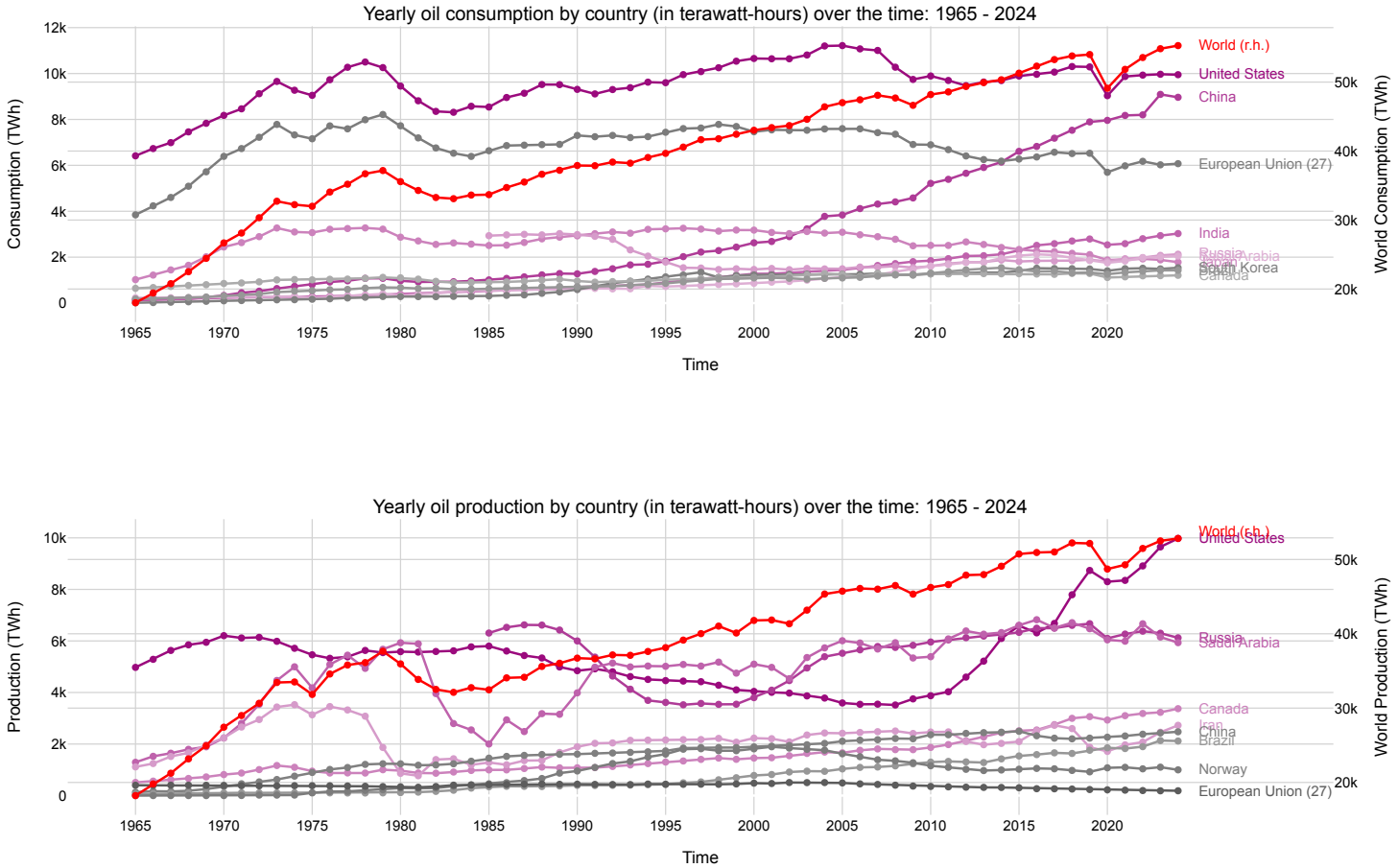

Figure: Yearly oil consumption and production by country over the time: 1965 - 2024 (in terawatt-hours).[5]

[5] Own Illustration based on XYZ (2000), page 7 and data accessed 10.09.25.

Gas: Global Production and Consumption over time

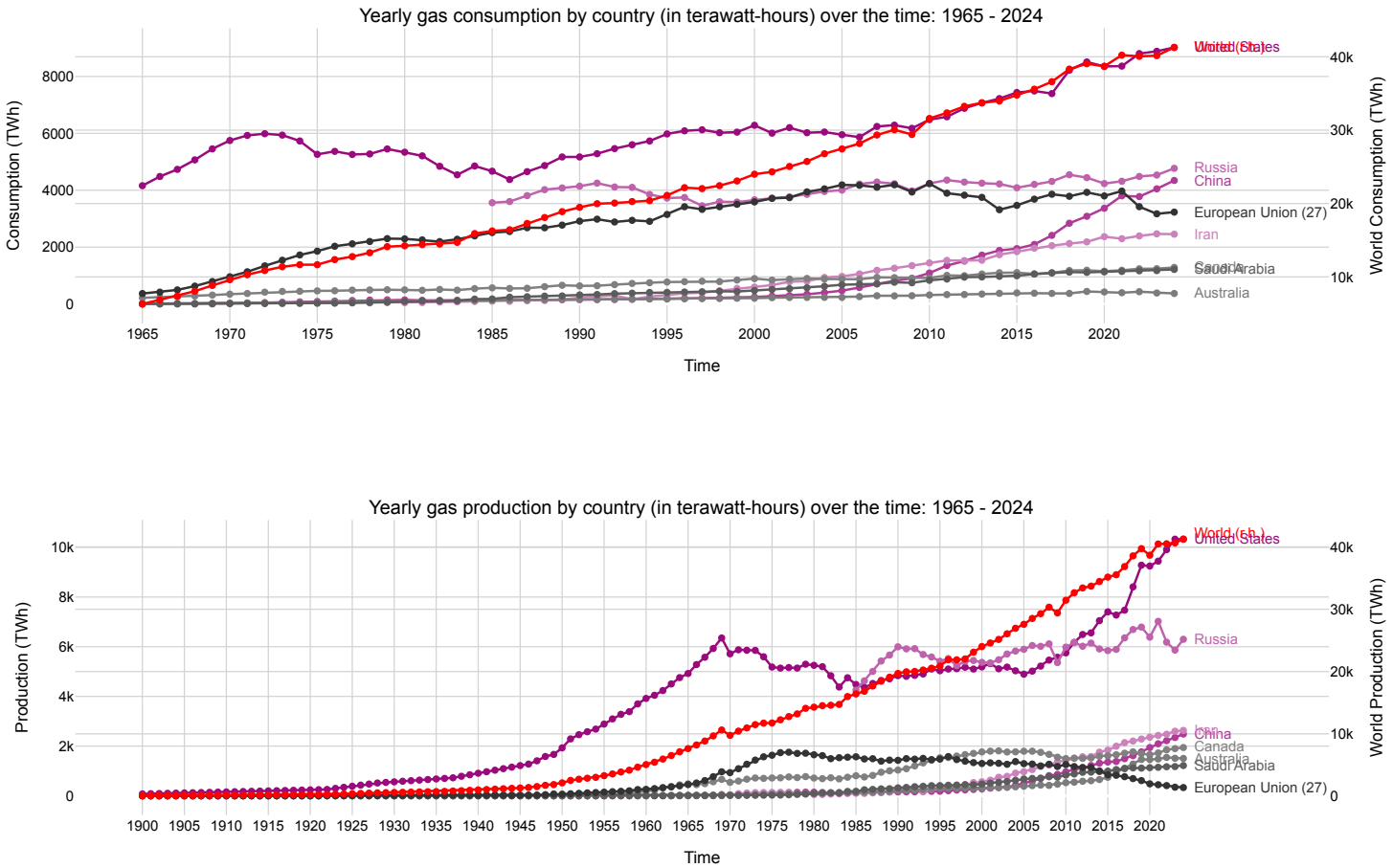

Figure: Yearly gas consumption and production by country over the time: 1965 - 2024 (in terawatt-hours).[6]

[6] Own Illustration based on XYZ (2000), page 7 and data accessed 10.09.25.

Financial Markets: Oil and Gas OI over time

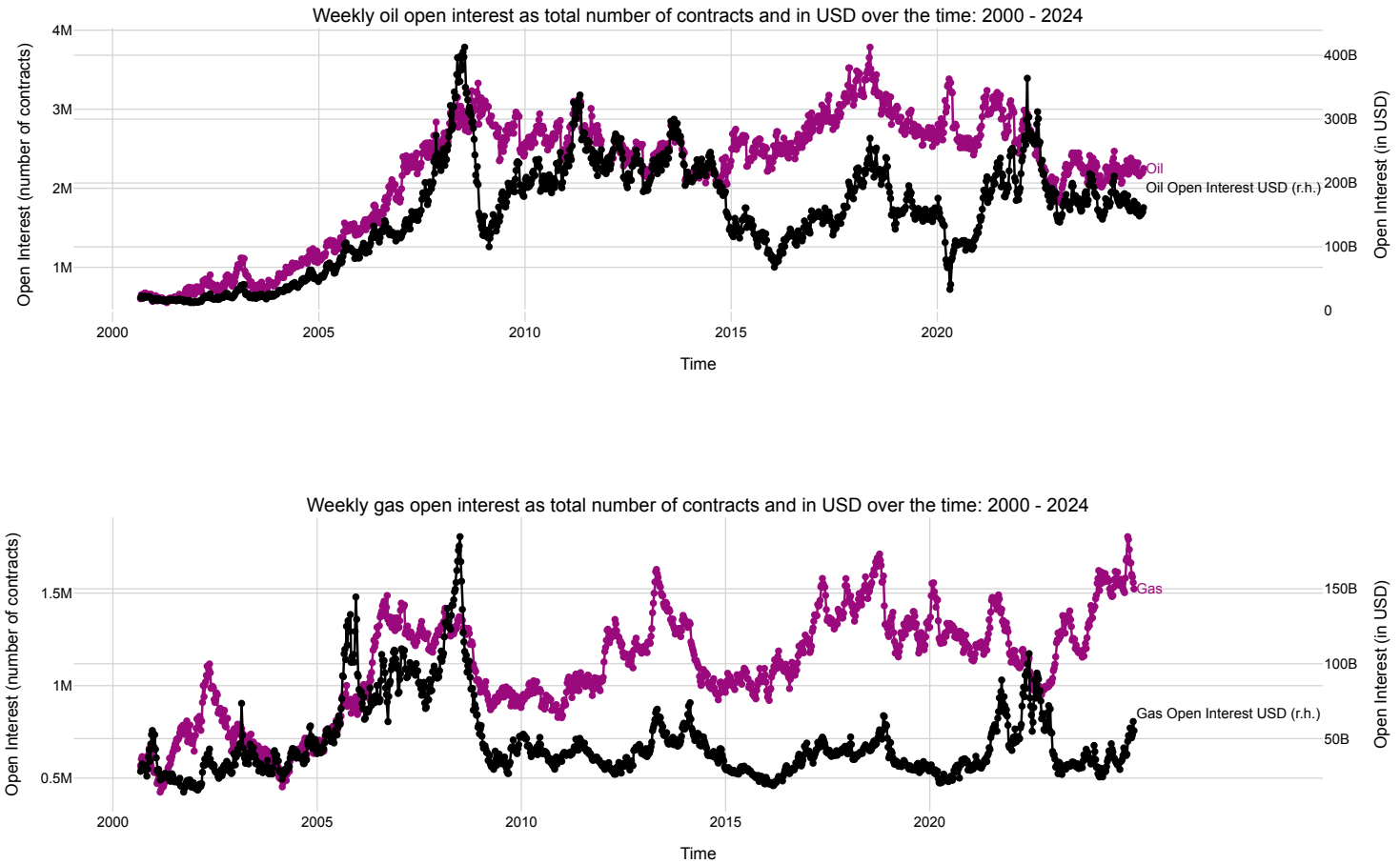

Figure: Weekly open interest of oil and gas products over the time: 2000 - 2024[7]

[7] Own Illustration based on XYZ (2000), page 7 and data accessed 10.09.25.

Research Hypothesis

Energy Price Contributions to Inflation - USA

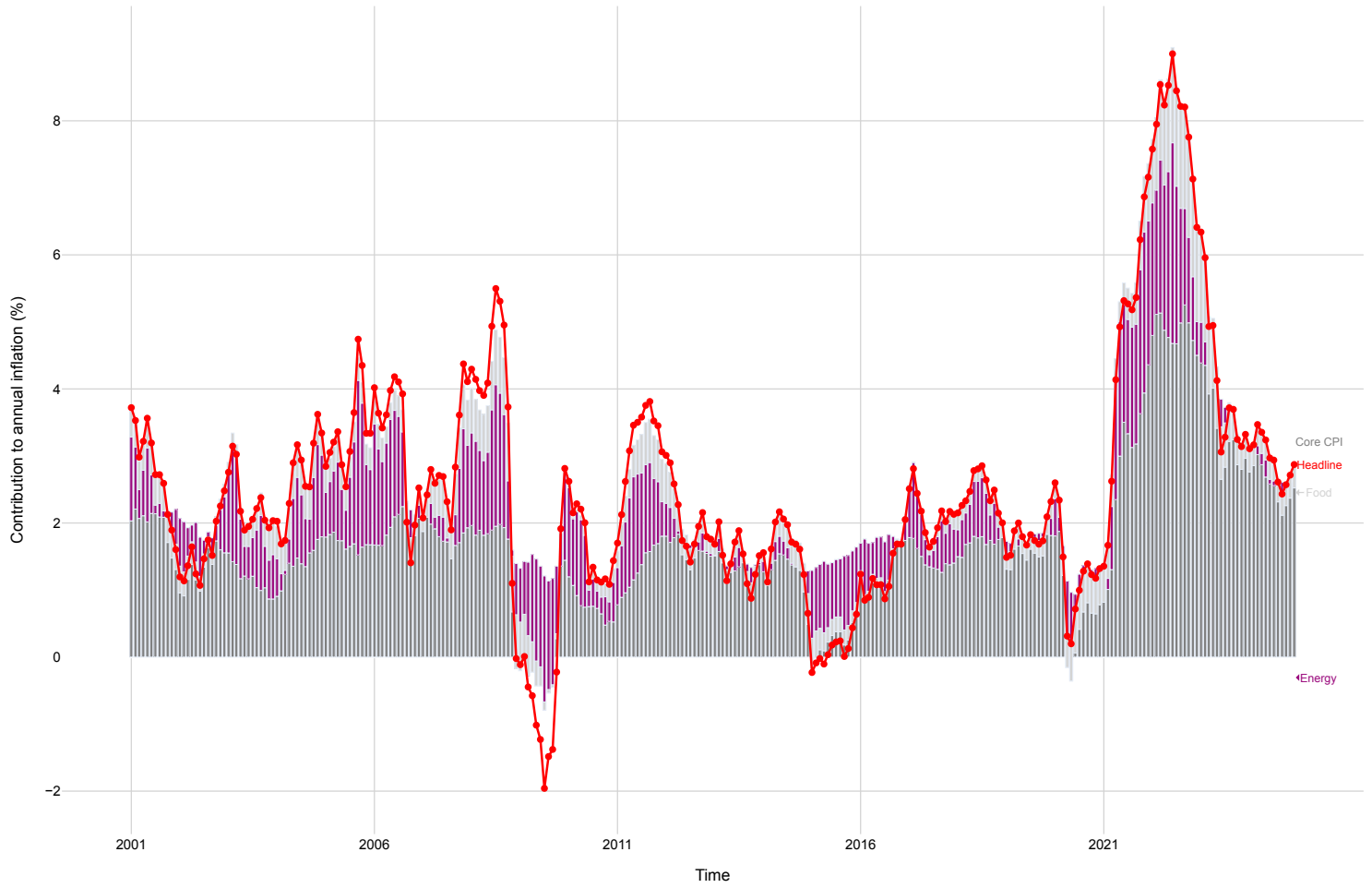

Figure: US CPI: Headline and component contributions over the time: 2001 - 2024.[8]

[8] Own Illustration based on U.S. Bureau of Labor Statistics (2025), page 7 and data accessed 10.09.25.

Energy Price Contributions to Inflation - EU area

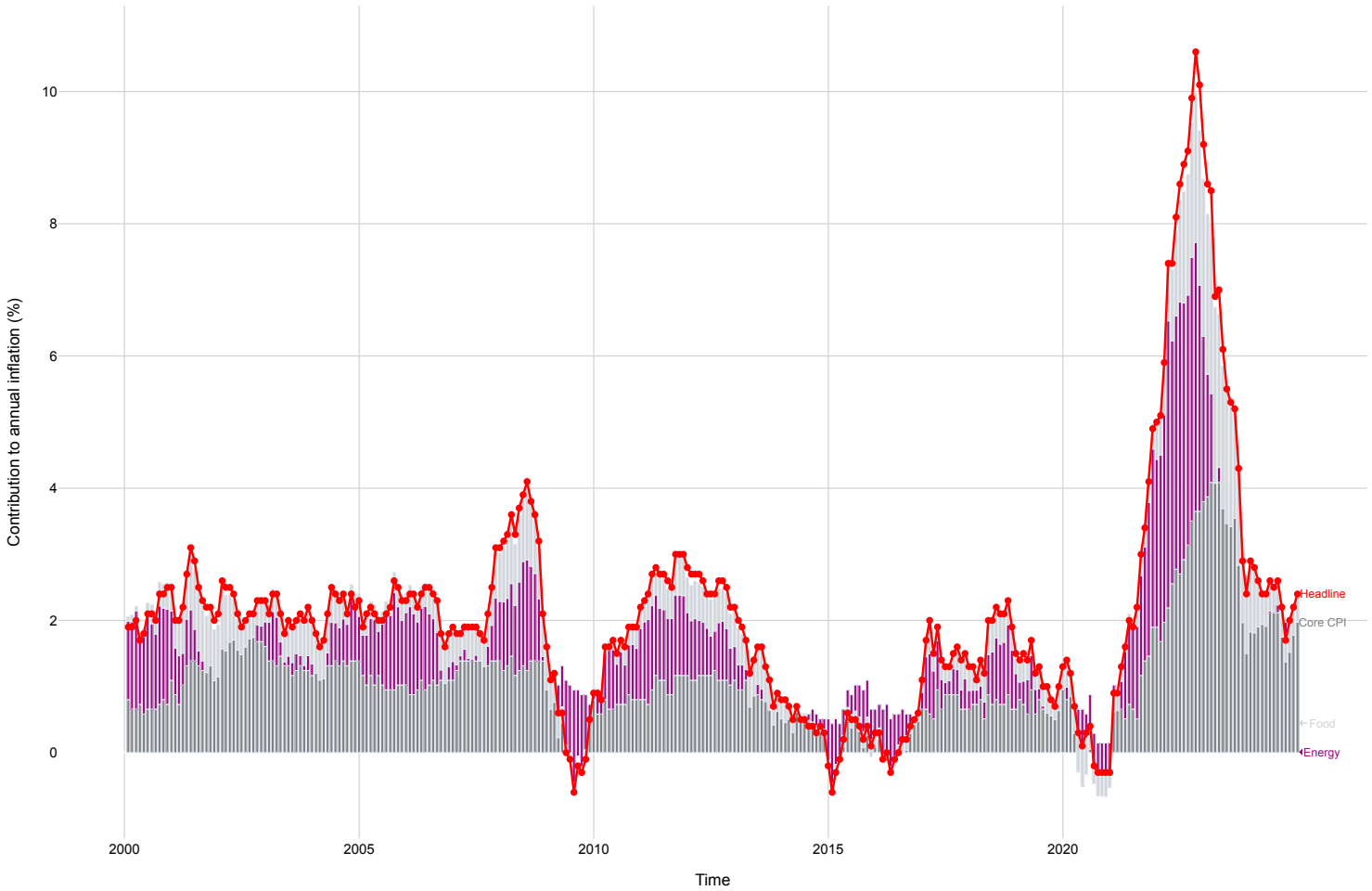

Figure: EU Area CPI: Headline and component contributions over the time: 2000 - 2024.[9]

Normalized Exchange Rate and Oil Volatility with Crisis Periods highlighted over the time: 1997 - 2024

Formulated Research Hypothesis

Main Research Hypothesis

"Exchange Rates and energy commodity prices are interconnected over several time frequencies and horizons, predominantly during times of (financial market) distress. Energy commodity price shocks primarily enter through the inflation dynamics channel, influencing both short-term price levels and long-term inflation expectations, thereby also affecting monetary policy decisions."

Additional Research Hypothesis I

"The pass-through effect of energy commodity price shocks to overall inflation is asymmetric, non-linear and time-varying, with price increases having a more pronounced effect than price decreases."

Additional Research Hypothesis II

"The pass-through effect intensified with growing financialization of energy commodity markets, leading to stronger correlations between

Literature Review

The connection between Energy Commodity Prices and Inflation

- Energy prices have been a significant driver of inflation in recent years, particularly due to geopolitical tensions and supply chain disruptions.
- The volatility in energy markets has led to increased costs for transportation, manufacturing, and household energy consumption.
- Central banks face challenges in managing inflation expectations while considering the transitory nature of energy price shocks.

Systematic Literature Overview: Main Approaches

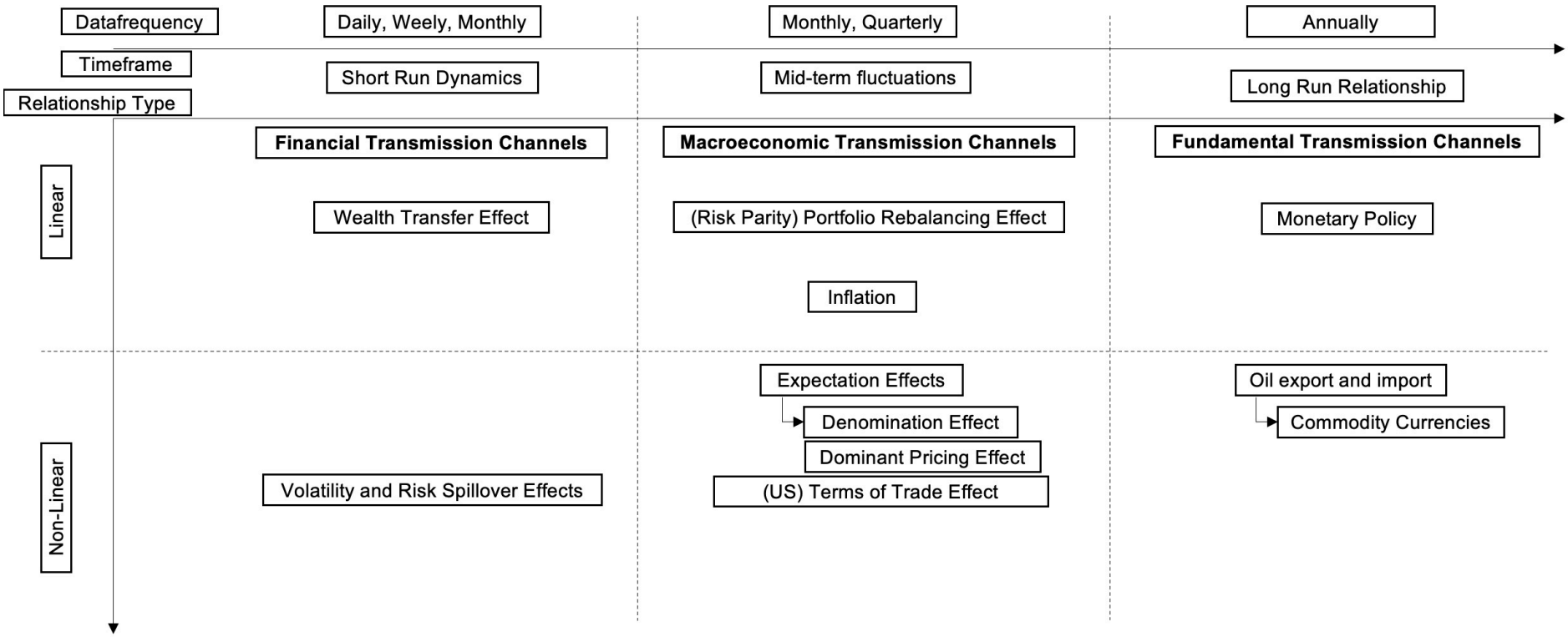

Figure: Systematic Overview about main approaches.[12]

[12] Own Illustration based on XYZ (2000), page 7 and data accessed 10.09.25.

Theoretical Framework

Definitions - prices and measurements

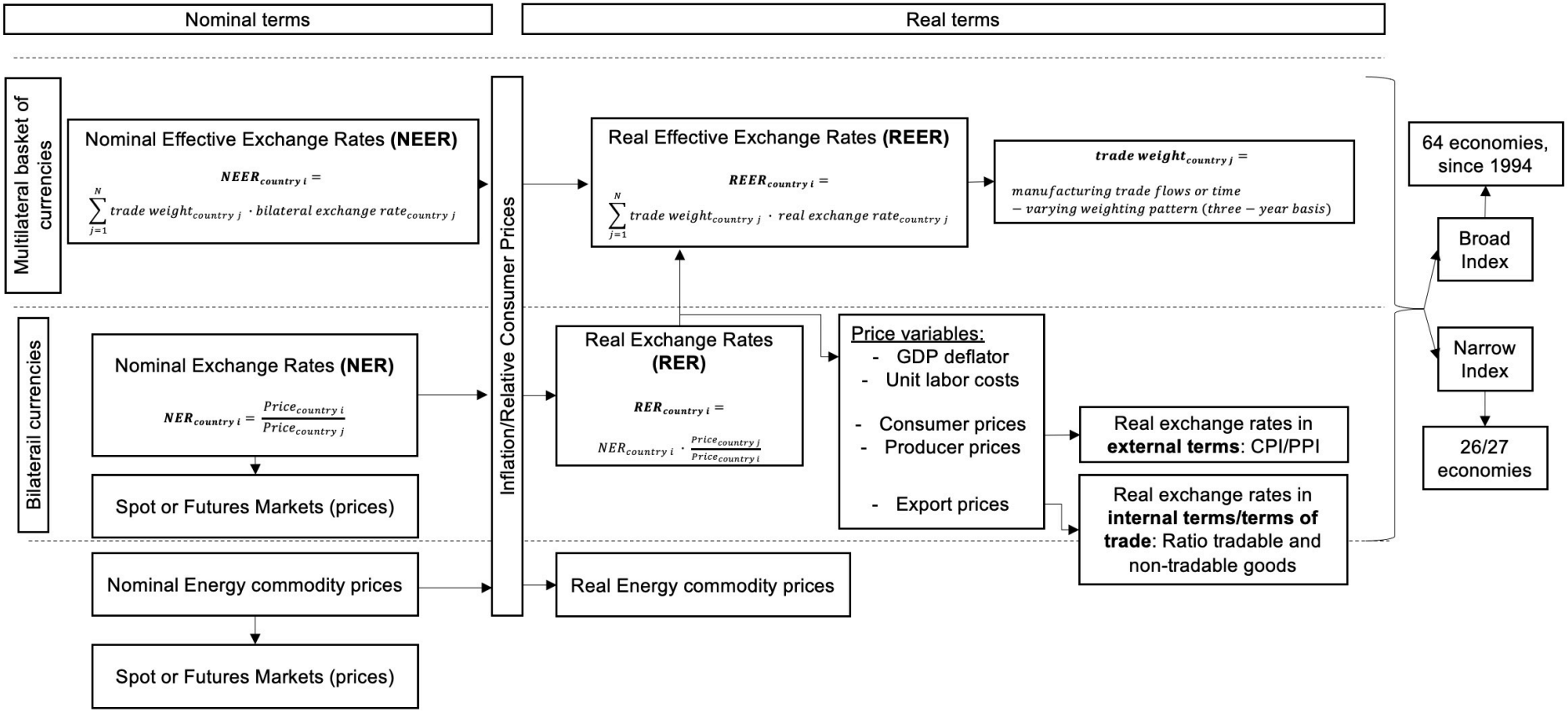

Figure: Schematic overview of prices and measurements of various exchange rate types.[13]

[13] Own Illustration based on XYZ (2000), page 7 and data accessed 10.09.25 exchange rates in natural logarithm (geometric averages).

Definitions - prices and measurements

No.	Exchange Rate	Basket	Data Frequency	Data Availability	Exchange Rate Type	Bilateral/Multilateral	Source	Data ID	Link
1	Real effective exchange rate	broad	monthly	1994-01	REER	Multilateral	BIS	M.R.B.US	Link
2	Real effective exchange rate	narrow	monthly	1964-01	REER	Multilateral	BIS	M.R.N.US	Link
3	Nominal effective exchange rate	broad	monthly	1994-01	NEER	Multilateral	BIS	M.N.B.US	Link
4	Nominal effective exchange rate	narrow	monthly	1964-01	NEER	Multilateral	BIS	M.N.N.US	Link
5	Nominal effective exchange rate	narrow	daily	1983-10-03	NEER	Multilateral	BIS	D.N.N.US	Link
6	Nominal effective exchange rate	broad	daily	1996-04-11	NEER	Multilateral	BIS	D.N.B.US	Link
7	USD-EUR Spot Rate	-	daily	1999-01-04	NER	Bilateral	FRED	DEXUSEU	Link
8	Nominal Broad U.S. Dollar Index	broad	daily	2006-01-02	NEER	Multilateral	FRED	DTWEXBGS	Link
9	Real Broad Dollar Index	broad	monthly	2006-01-01	REER	Multilateral	FRED	RTWEXBGS	Link

Table: Various exemplary exchange rate data sources for the USD.[14]

[14] See: XXX

A simple model of exchange rates and commodity prices

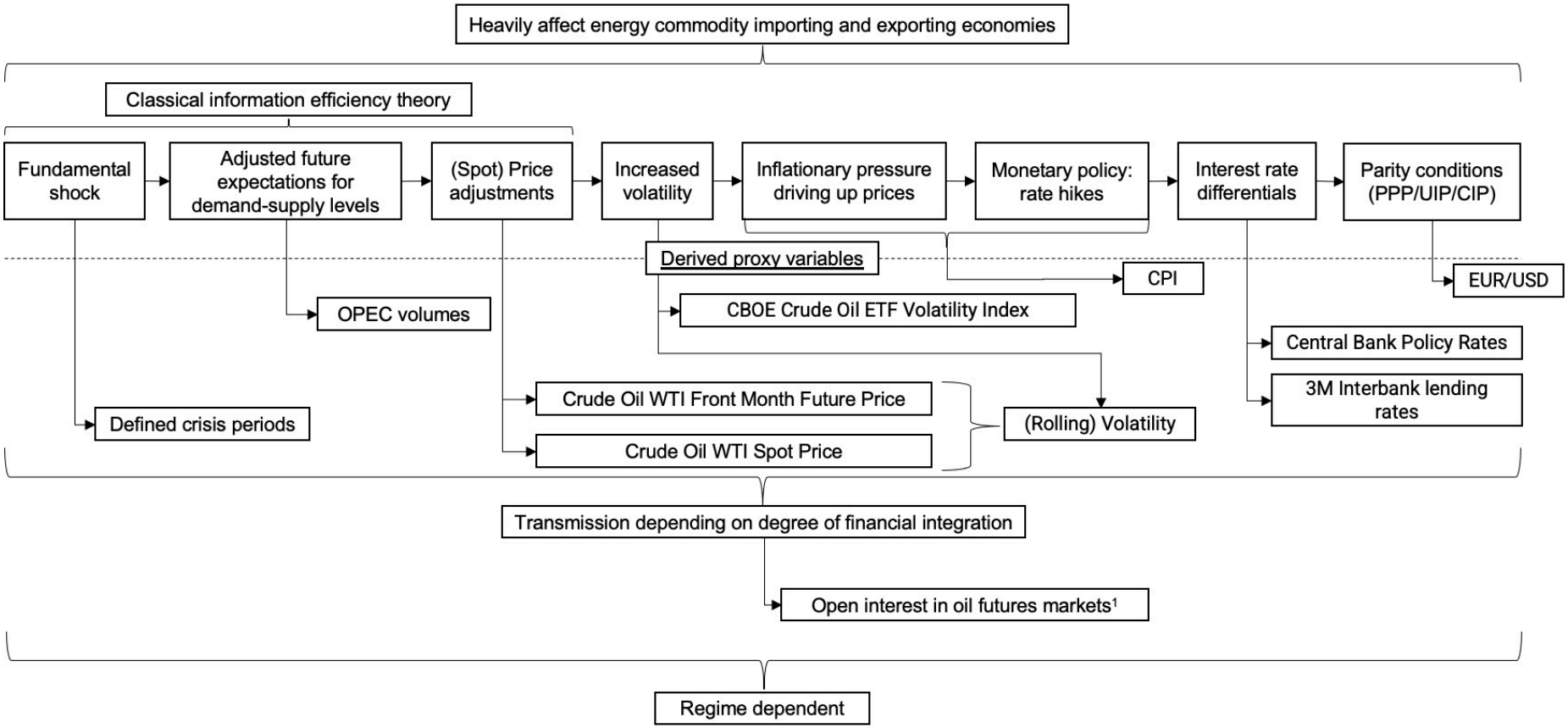

Figure: Global Oil Production and Consumption over time - in terawatt-hours (TWh).[15]

[15] Own Illustration based on XYZ (2000), page 7 and data accessed 10.09.25.

Theoretical Framework (I)

1) Identify relevant regimes in the data

$K = 2$ regimes (high volatility vs. low volatility)

Alternative approaches: Multivariate Clustering using additional variables

Classical approaches: Univariate econometric modelling (benchmarks)

Markov Regression/Switching

Variable	Thematic area	Category
EUR/USD spot exchange rate	FX theory	spot exchange rate (NER)
log first diff of EUR/USD spot rate	FX theory	spot exchange rate log return
rolling volatilty of log first diff of EUR/USD spot rate	FX theory	spot exchange rate log return volatility
Central Bank Policy rates	FX theory	interest rate
Central Bank Policy rates differentials	FX theory	interest rate differential
3M Interbank lending rates	FX theory	interest rate
3M Interbank lending rates differentials	FX theory	interest rate differential
WTI Oil	Energy commodity	spot price
Natural Gas	Energy commodity	spot price
rolling volatilty of log first diff of WTI Oil	Energy commodity	rolling log return volatility
rolling volatilty of log first diff of Natural Gas	Energy commodity	rolling log return volatility
Futures Trading Open Interest	Degree of Financial Integration	Open Interest
Futures Trading Volume	Degree of Financial Integration	Trading Volume
VIX Index	(Market-) Volatility	Volatility Index

B1

Variable	Thematic area	Category
log first diff of EUR/USD spot rate	FX theory	spot exchange rate log return
Central Bank Policy rates differentials	FX theory	interest rate differential
rolling volatilty of log first diff of WTI Oil	Energy commodity	rolling log return volatility
rolling volatilty of log first diff of Natural Gas	Energy commodity	rolling log return volatility

B2

Variable	Thematic area	Category
log first diff of EUR/USD spot rate	FX theory	spot exchange rate log return
Central Bank Policy rates differentials	FX theory	interest rate differential
rolling volatilty of log first diff of WTI Oil	Energy commodity	rolling log return volatility
rolling volatilty of log first diff of Natural Gas	Energy commodity	rolling log return volatility

Figure: Global Oil Production and Consumption over time - in terawatt-hours (TWh).[16]

[16] Own Illustration based on XYZ (2000), page 7 and data accessed 10.09.25.

Theoretical Framework (II)

1) Identify relevant regimes in the data

$K = 2$ regimes (high volatility vs. low volatility)

Alternative approaches: Multivariate Clustering using additional variables

Classical approaches: Univariate econometric modelling (benchmarks)

Algorithm	Source package (version)	Category
KMeans	scikit-learn (1.7.2)	Clustering
AgglomerativeClustering	scikit-learn (1.7.2)	Clustering
DBSCAN	scikit-learn (1.7.2)	Clustering
SpectralClustering	scikit-learn (1.7.2)	Clustering
MeanShift	scikit-learn (1.7.2)	Clustering
GaussianMixture	scikit-learn (1.7.2)	Clustering
Birch	scikit-learn (1.7.2)	Clustering
AffinityPropagation	scikit-learn (1.7.2)	Clustering
OPTICS	scikit-learn (1.7.2)	Clustering
MiniBatchKMeans	scikit-learn (1.7.2)	Clustering

Markov Regression/Switching

Algorithm	Source package (version)	Category
MarkovRegression	statsmodels (0.14.5)	Regime Switching Regression

$$Pr(I_t = 1|I_{t-1} = 1) = P$$
$$Pr(I_t = 2|I_{t-1} = 1) = 1 - P$$
$$Pr(I_t = 2|I_{t-1} = 2) = Q$$
$$Pr(I_t = 1|I_{t-1} = 2) = 1 - Q$$
$$Pr(I_{t-1} = 1|\Delta s_{t-}$$

- Hamilton suggests that Bayesian inference is an unbiased and efficient way to infer regime probabilities

$$Pr(I_{t-1} = 1|\Delta s_{t-1}) = \frac{f(\Delta s_{t-1}|I_{t-1} = 1)p_{1t-1}}{f(\Delta s_{t-1}|I_{t-1} = 1)p_{1t-1} + f(\Delta s_{t-1}|I_{t-1} = 2)(1 - p_{1t-1})}$$

- and

$$Pr(I_{t-1} = 2|\Delta s_{t-1}) = \frac{f(\Delta s_{t-1}|I_{t-1} = 2)(1 - p_{1t-1})}{f(\Delta s_{t-1}|I_{t-1} = 1)p_{1t-1} + f(\Delta s_{t-1}|I_{t-1} = 2)(1 - p_{1t-1})}$$

- where p_{1t-1} and $p_{2t-1} = 1 - p_{1t-1}$ are called prior probabilities

- Using the posteriors we can calculate an expectation of the next periods regime probability as

$$p_{1t} = P\ Pr(I_{t-1} = 1|\Delta s_{t-1}) + (1 - Q)\ Pr(I_{t-1} = 2|\Delta s_{t-1})$$

- or

$$p_{1t} = P\left[\frac{f_{1t-1}p_{1t-1}}{f_{1t-1}p_{1t-1} + f_{2t-1}(1 - p_{1t-1})}\right] + (1 - Q)\left[\frac{f_{2t-1}(1 - p_{1t-1})}{f_{1t-1}p_{1t-1} + f_{2t-1}(1 - p_{1t-1})}\right]$$

- and

$$p_{2t} = 1 - p_{1t}$$

- Estimation of the model by maximizing the log-likelihood:

$$L = \sum_{t=1}^{T} \log\left[p_{1t}\frac{1}{\sqrt{2\pi h_{1t}}}exp(\Theta_1) + (1 - p_{1t})\frac{1}{\sqrt{2\pi h_{2t}}}exp(\Theta_2)\right]$$

- and

$$\Theta_1 = \frac{-(\Delta s_t - \mu_{1t})^2}{2h_{1t}}, \Theta_2 = \frac{-(\Delta s_t - \mu_{2t})^2}{2h_{2t}}$$

- Second step: Specification of the regime dependent distribution

$$f(\Delta s_{t-1}|I_{t-1} = 1, 2, \Phi)$$

- Simplest case:

$$\mu_{1t} = c_1;\ \mu_{2t} = c_2$$
$$h_{1t} = \sigma_1^2;\ h_{2t} = \sigma_2^2$$

- Alternatively: e.g.

$$\mu_{1t} = c_1 + \beta_1 \Delta s_{t-1};\ \mu_{2t} = c_2 + \beta_2 \Delta s_{t-1}$$
$$h_{1t} = b_{01} + b_{11}u_{t-1}^2 + b_{21}h_{1t-1}$$
$$h_{2t} = b_{02} + b_{12}u_{t-1}^2 + b_{22}h_{1t-1}$$

- We may suggest that UIP holds in 'normal' times, but is violated in 'non-normal' times
- The sequences of switching between the two states may help us learning what drives the UIP puzzle
- Therefore we need two separate mean equations to be estimated

$$Regime1: \mu_{1t} = \alpha_1 + \beta_1(i_{t-1} - i_{t-1}^*);\ h_{1t} = \sigma_1^2$$
$$Regime2: \mu_{2t} = \alpha_2 + \beta_2(i_{t-1} - i_{t-1}^*);\ h_{2t} = \sigma_2^2$$

- Coefficients estimated by maximizing the Log Likelihood as specified above

Figure: Global Oil Production and Consumption over time - in terawatt-hours (TWh).[17]

[17] Own Illustration based on XYZ (2000), page 7 and data accessed 10.09.25.

Theoretical Framework (III)

2) Analyze and compare the regimes

Model evaluation and selection

Evaluation metric	Source package (version)	Category	Value range	Interpretation
Silhouette Score	scikit-learn (1.7.2)	Clustering Scores	[-1, 1]	1 being best, -1 being worst, values near 0 indicate overlapping clusters.
RCM	Paper		[0, 100]	
Crisis overlap percentage	Own computation			

Theoretically affecting crisis periods - major global shocks and us recessions

No.	Start-date	End-date	Event-Type	Event	Source
1	1970-01-01	1970-12-01	US-Recession	US Recession 1970-1970	FRED: USREC
2	1971-08-15	1973-03-19	Major Global Crisis	Bretton Woods Breakdown	Various
3	1971-08-15	1973-03-19	Major Global Crisis	Nixon Shock	Various
4	1973-10-17	1974-03-01	Major Global Crisis	Oil Crisis I	Various
5	1973-12-01	1975-04-01	US-Recession	US Recession 1973-1975	FRED: USREC
6	1979-01-01	1981-03-01	Major Global Crisis	Oil Crisis II	Various
7	1980-02-01	1980-08-01	US-Recession	US Recession 1980-1980	FRED: USREC
8	1981-08-01	1982-12-01	US-Recession	US Recession 1981-1982	FRED: USREC
9	1987-10-19	1987-10-19	Major Global Crisis	Black Monday Crash	Various
10	1990-08-01	1991-04-01	US-Recession	US Recession 1990-1991	FRED: USREC
11	1997-07-02	1998-12-31	Major Global Crisis	Asian Financial Crisis	Various
12	1998-08-17	1998-09-01	Major Global Crisis	Russian Crisis	Various
13	2000-03-01	2002-10-01	Major Global Crisis	Dot-com Bubble	Various
14	2001-04-01	2001-12-01	US-Recession	US Recession 2001-2001	FRED: USREC
15	2007-08-09	2009-03-09	Major Global Crisis	Global Financial Crisis	Various
16	2008-01-01	2009-07-01	US-Recession	US Recession 2008-2009	FRED: USREC
17	2008-11-25	2014-12-31	Major Global Crisis	US QE	Various
18	2009-10-01	2012-12-31	Major Global Crisis	European Debt Crisis	Various
19	2011-08-20	2011-08-05	Major Global Crisis	US Debt Ceiling Crisis	Various
20	2018-03-22	2020-01-15	Major Global Crisis	US-China Trade War	Various
21	2020-02-20	2021-11-16	Major Global Crisis	COVID-19 Pandemic	Various
22	2020-03-01	2020-05-01	US-Recession	US Recession 2020-2020	FRED: USREC
23	2022-02-24	2022-06-01	Major Global Crisis	Russia-Ukraine War	Various

Figure: Global Oil Production and Consumption over time - in terawatt-hours (TWh).[18]

[18] Own Illustration based on XYZ (2000), page 7 and data accessed 10.09.25.

Methodology Overview

Systematic Methodology Overview: Linear vs. Non-linear approaches

(Financial) Market Distress: Important periods and their characteristics

Data Characteristics and Stylized Facts

Spot exchange rate distributions (raw data - normalized)

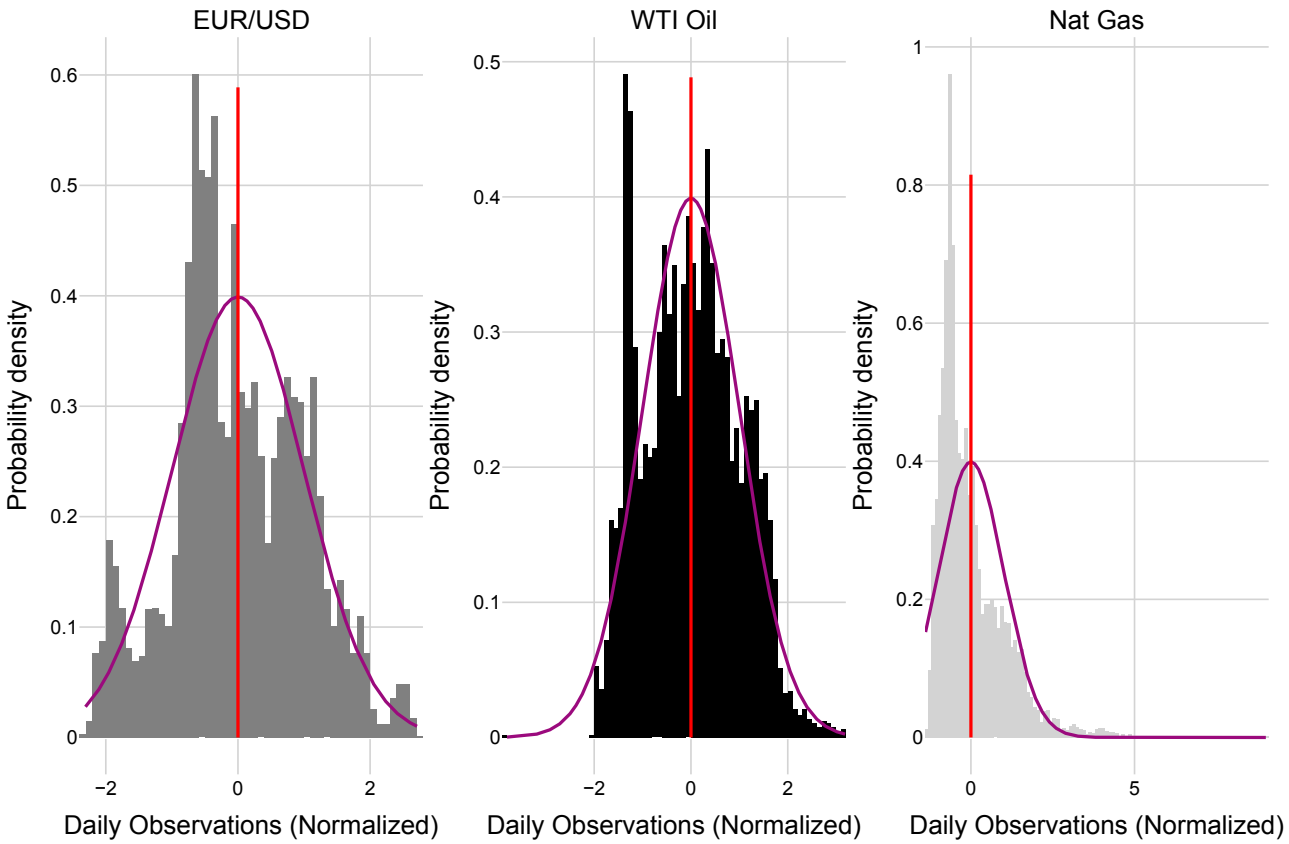

Figure: Normalized daily EUR/USD spot exchange rate, oil and gas over the time range: 1999 - 2025.[19]

Spot exchange rate distributions (log first differences)

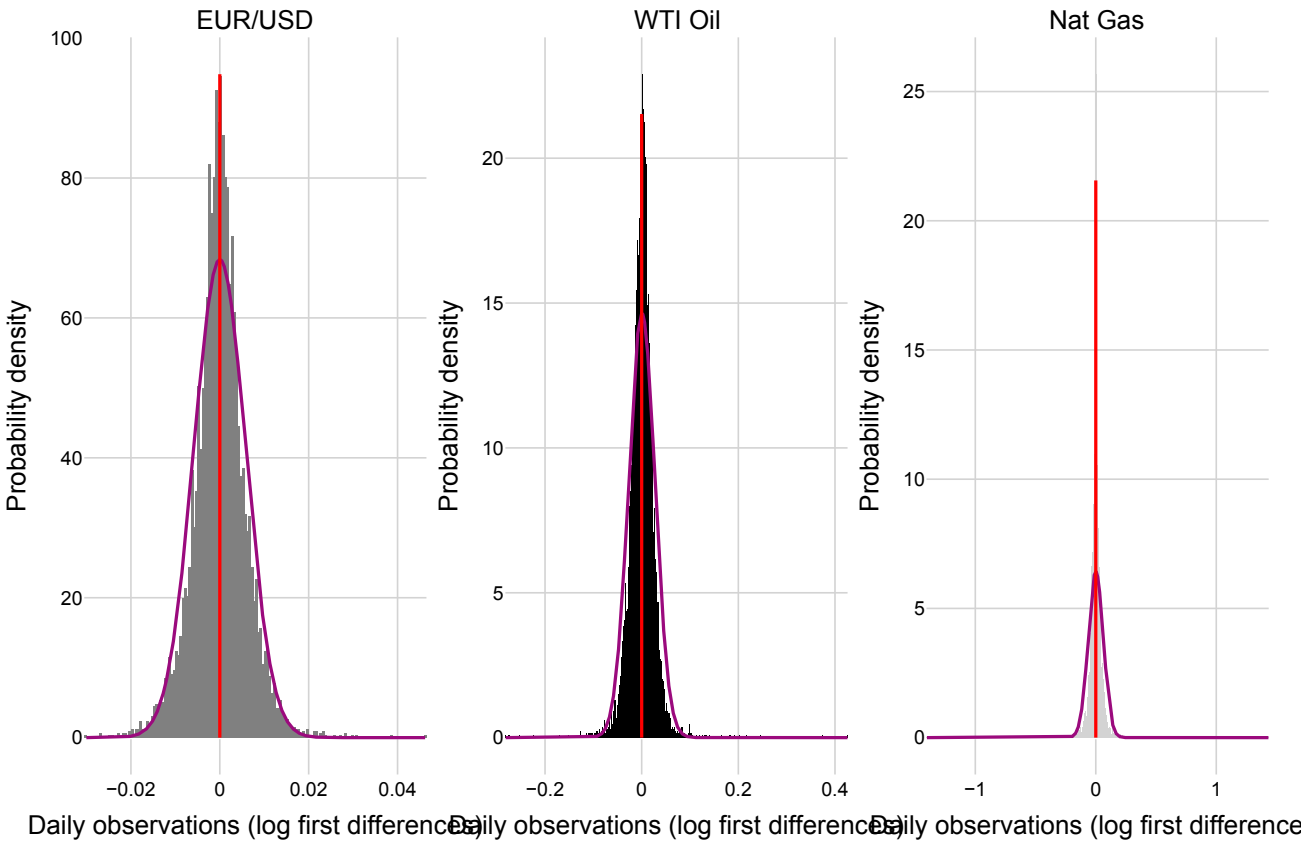

Figure: Log first differences of daily EUR/USD spot exchange rate, oil and gas over the time range: 1999 - 2025.[20]

[20] Own Illustration based on XYZ (2000), page 7 and data accessed 10.09.25.

Tests for Normality (raw data)

Variable	Test	Statistic	p-value	Significance-level	p-value ¡ 0.05	Result
EUR/USD	Shapiro-Wilk	0.989	0.000	0.050	True	Not-Normal
EUR/USD	Kolmogorov-Smirnov	0.799	0.000	0.050	True	Not-Normal
EUR/USD	D'Agostino's K^2	55.280	0.000	0.050	True	Not-Normal
WTI Oil	Shapiro-Wilk	0.981	0.000	0.050	True	Not-Normal
WTI Oil	Kolmogorov-Smirnov	1.000	0.000	0.050	True	Not-Normal
WTI Oil	D'Agostino's K^2	340.085	0.000	0.050	True	Not-Normal
Nat Gas	Shapiro-Wilk	0.8640	0.000	0.050	True	Not-Normal
Nat Gas	Kolmogorov-Smirnov	0.938	0.000	0.050	True	Not-Normal
Nat Gas	D'Agostino's K^2	2130.008	0.000	0.050	True	Not-Normal

Table: Shapiro-Wilks, Kolmogorov-Smirnov, D'Agostino's K^2 test for normality for the EUR/USD spot exchange rate, WTI Oil and Natural Gas daily observations over the time 1999 - 2025.[21]

[21] See: XXX

Tests for Stationarity - ADF Tests (raw data)

ADF Statistic	p-value	Start Time	End Time	Regression Type	Observations	Variable	Result
-1.847	0.357	04-01-1999	04-01-1999	c	6640	EUR/USD	Non-Stationary
-1.846	0.682	04-01-1999	04-01-1999	ct	6640	EUR/USD	Non-Stationary
-2.655	0.480	04-01-1999	04-01-1999	ctt	6640	EUR/USD	Non-Stationary
-0.254	0.594	04-01-1999	04-01-1999	n	6640	EUR/USD	Non-Stationary
-2.789	0.059	04-01-1999	04-01-1999	c	6624	WTI Oil	Non-Stationary
-2.770	0.208	04-01-1999	04-01-1999	ct	6624	WTI Oil	Non-Stationary
-3.060	0.267	04-01-1999	04-01-1999	ctt	6624	WTI Oil	Non-Stationary
-0.697	0.413	04-01-1999	04-01-1999	n	6624	WTI Oil	Non-Stationary
-4.341	0.000	04-01-1999	04-01-1999	c	6633	Nat Gas	Stationary
-4.743	0.001	04-01-1999	04-01-1999	ct	6633	Nat Gas	Stationary
-4.742	0.003	04-01-1999	04-01-1999	ctt	6633	Nat Gas	Stationary
-1.897	0.055	04-01-1999	04-01-1999	n	6633	Nat Gas	Non-Stationary

Table: Augmented-Dickey-Fuller (ADF) test for stationarity in various variants for the EUR/USD spot exchange rate, WTI Oil and Natural Gas daily observations over the time 1999 - 2025.[22]

[22] See: XXX

Tests for Stationarity - ADF Tests (log first differences)

ADF Statistic	p-value	Start Time	End Time	Regression Type	Observations	Variable	Result
-80.613	0.000	05-01-1999	05-01-1999	c	6637	EUR/USD	Stationary
-80.607	0.000	05-01-1999	05-01-1999	ct	6637	EUR/USD	Stationary
-80.601	0.000	05-01-1999	05-01-1999	ctt	6637	EUR/USD	Stationary
-80.619	0.000	05-01-1999	05-01-1999	n	6637	EUR/USD	Stationary
-14.504	0.000	05-01-1999	05-01-1999	c	6603	WTI Oil	Stationary
-14.525	0.000	05-01-1999	05-01-1999	ct	6603	WTI Oil	Stationary
-14.547	0.000	05-01-1999	05-01-1999	ctt	6603	WTI Oil	Stationary
-14.463	0.000	05-01-1999	05-01-1999	n	6603	WTI Oil	Stationary
-20.094	0.000	05-01-1999	05-01-1999	c	6616	Nat Gas	Stationary
-20.102	0.000	05-01-1999	05-01-1999	ct	6616	Nat Gas	Stationary
-20.121	0.000	05-01-1999	05-01-1999	ctt	6616	Nat Gas	Stationary
-20.095	0.000	05-01-1999	05-01-1999	n	6616	Nat Gas	Stationary

Table: Augmented-Dickey-Fuller (ADF) test for stationarity in various variants for the EUR/USD spot exchange rate, WTI Oil and Natural Gas daily observations (log first differences) over the time 1999 - 2025.[23]

[23] See: XXX

Tests for Cointegration (raw data)

Cointegration Score	p-value	Start Time	End Time	Observations	Trend	Variable X	Variable Y	Result
-2.967000	0.118000	04-01-1999	01-10-2025	6641	c	EUR/USD	WTI Oil	Not Cointegrated
-3.364000	0.134000	04-01-1999	01-10-2025	6641	ct	EUR/USD	WTI Oil	Not Cointegrated
-3.635000	0.167000	04-01-1999	01-10-2025	6641	ctt	EUR/USD	WTI Oil	Not Cointegrated
-3.268000	0.013000	04-01-1999	01-10-2025	6641	n	EUR/USD	WTI Oil	Cointegrated
-2.416000	0.317000	04-01-1999	01-10-2025	6641	c	EUR/USD	Nat Gas	Not Cointegrated
-2.634000	0.446000	04-01-1999	01-10-2025	6641	ct	EUR/USD	Nat Gas	Not Cointegrated
-3.530000	0.204000	04-01-1999	01-10-2025	6641	ctt	EUR/USD	Nat Gas	Not Cointegrated
-4.182000	0.001000	04-01-1999	01-10-2025	6641	n	EUR/USD	Nat Gas	Cointegrated

Table: Engle and Granger Cointegration test for the EUR/USD spot exchange rate, WTI Oil and Natural Gas daily observations over the time 1999 - 2025.[24]

[24] See: XXX

Tests for Cointegration (log differences)

Cointegration Score	p-value	Start Time	End Time	Observations	Trend	Variable X	Variable Y	Result
-4.293000	0.003000	17-02-1999	01-10-2025	6609	c	EUR/USD	WTI Oil	Cointegrated
-4.805000	0.002000	17-02-1999	01-10-2025	6609	ct	EUR/USD	WTI Oil	Cointegrated
-4.830000	0.006000	17-02-1999	01-10-2025	6609	ctt	EUR/USD	WTI Oil	Cointegrated
-5.724000	0.000000	17-02-1999	01-10-2025	6609	n	EUR/USD	WTI Oil	Cointegrated
-4.001000	0.007000	17-02-1999	01-10-2025	6609	c	EUR/USD	Nat Gas	Cointegrated
-4.348000	0.009000	17-02-1999	01-10-2025	6609	ct	EUR/USD	Nat Gas	Cointegrated
-4.341000	0.030000	17-02-1999	01-10-2025	6609	ctt	EUR/USD	Nat Gas	Cointegrated
-4.246000	0.000000	17-02-1999	01-10-2025	6609	n	EUR/USD	Nat Gas	Cointegrated

Table: Engle and Granger Cointegration test for the EUR/USD spot exchange rate, WTI Oil and Natural Gas daily observations (log first differences) over the time 1999 - 2025.[25]

[25] See: XXX

Tests for Autocorrelation (raw data)

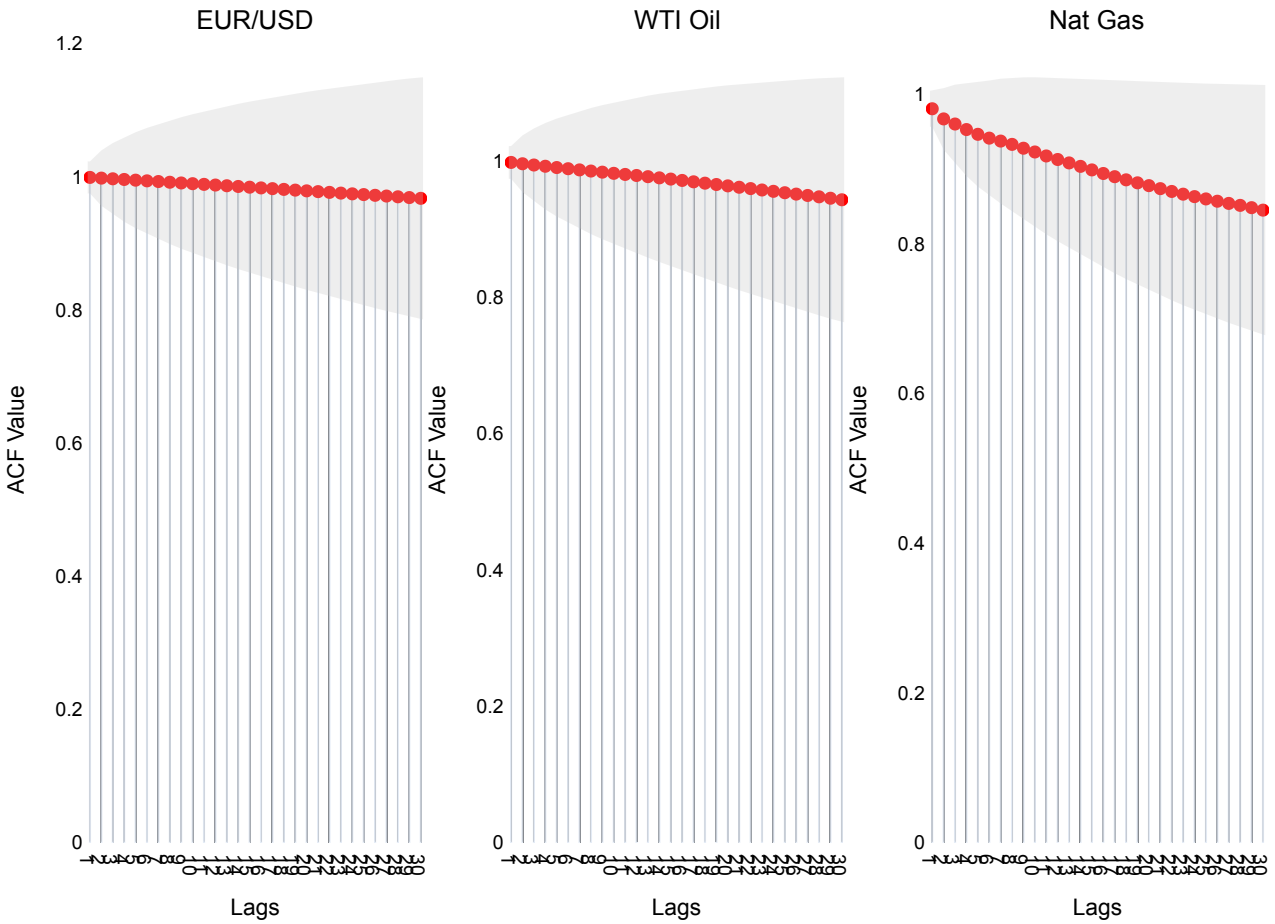

Figure: ACF values for daily observations of the EUR/USD spot exchange rate, oil and gas over the time: 1999 - 2025.[26]

[26] Own Illustration based on XYZ (2000), page 7 and data accessed 10.09.25.

Tests for Autocorrelation (log first differences)

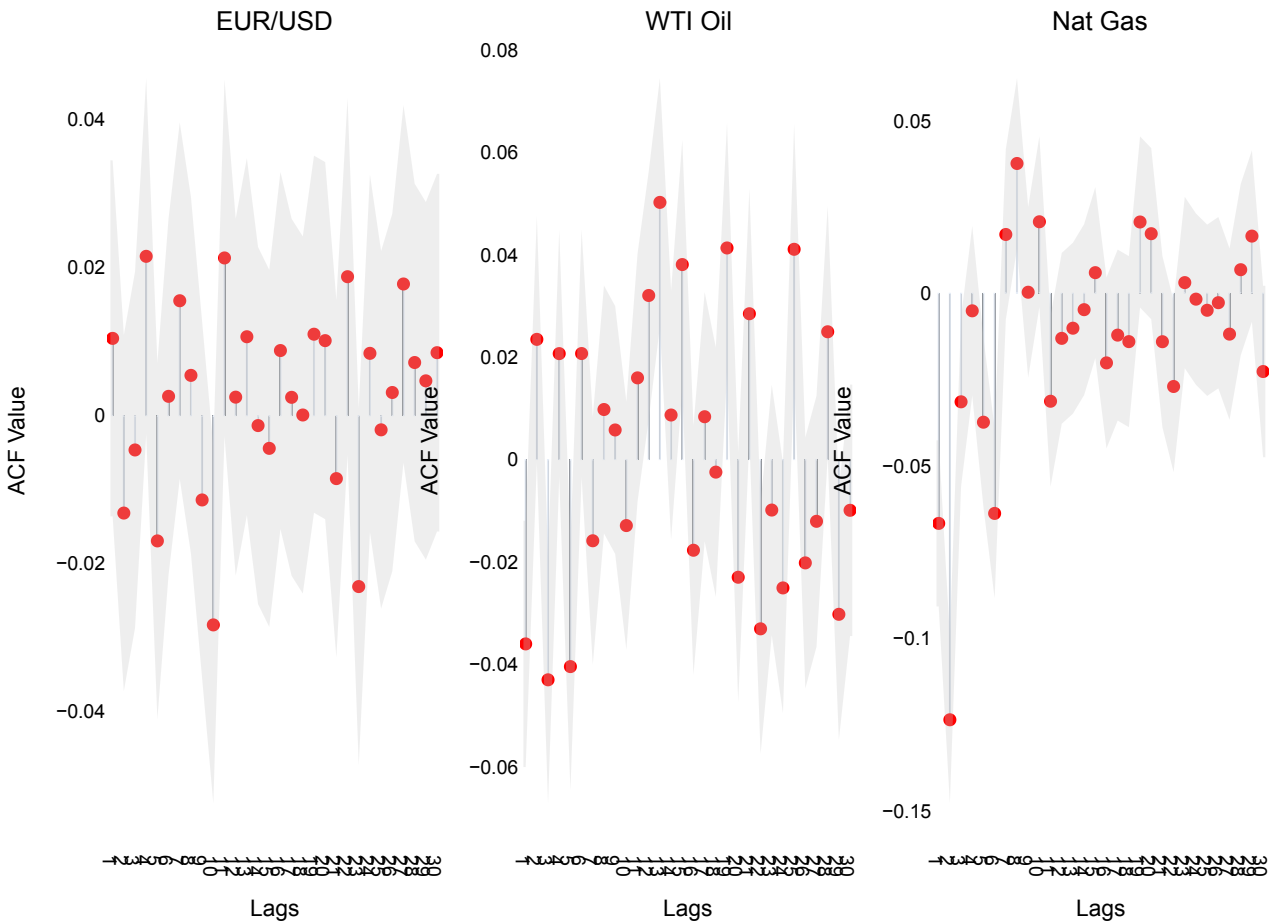

Figure: ACF values for daily observations (log first differences) of the EUR/USD spot exchange rate, WTI Oil and Natural Gas over the time: 1999 - 2025.[27]

[27] Own Illustration based on XYZ (2000), page 7 and data accessed 10.09.25.

Tests for Partial Autocorrelation (raw data)

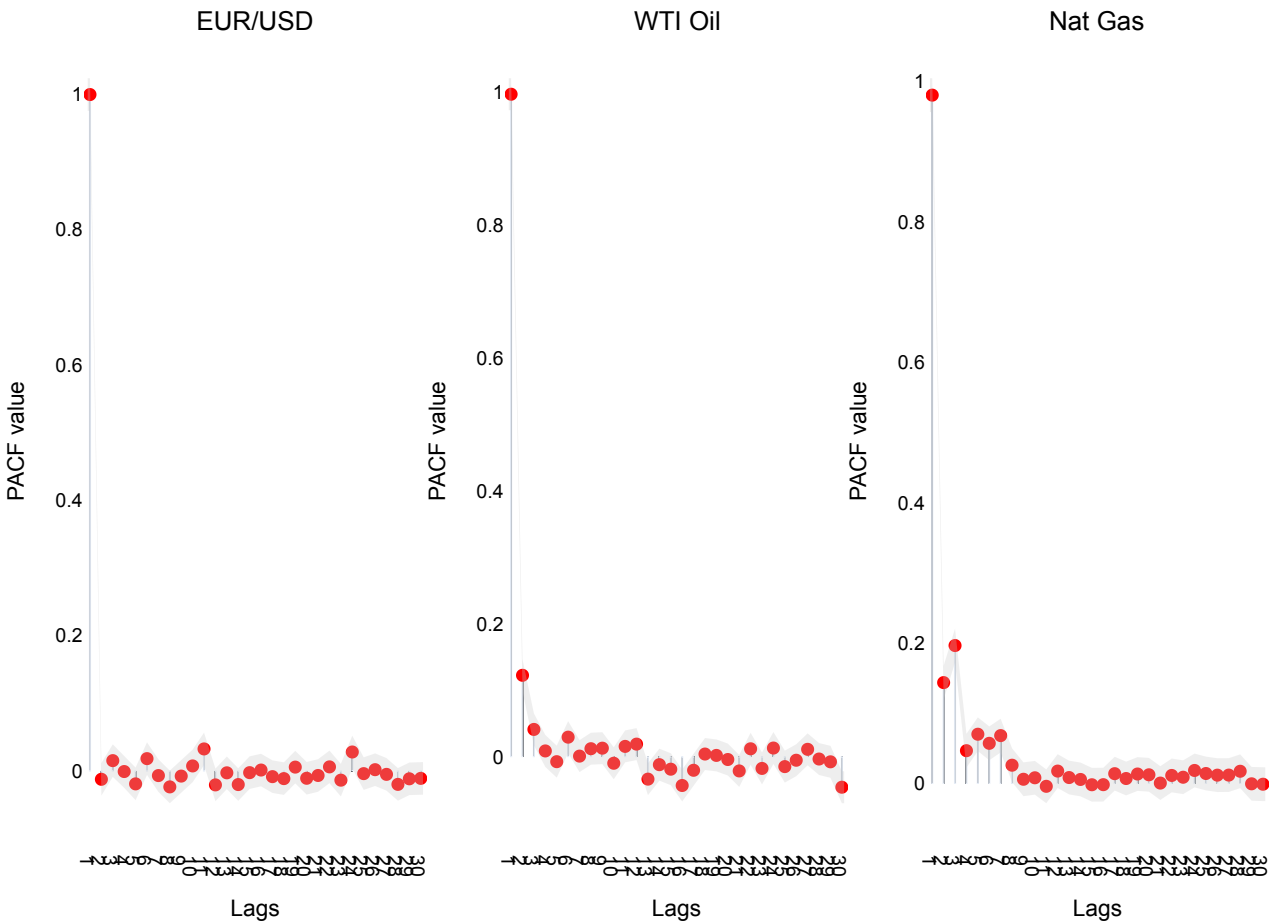

Figure: PACF values for daily observations of the EUR/USD spot exchange rate, WTI Oil and Natural Gas over the time: 1999 - 2025.[28]

[28] Own Illustration based on XYZ (2000), page 7 and data accessed 10.09.25.

Tests for Partial Autocorrelation (log first differences)

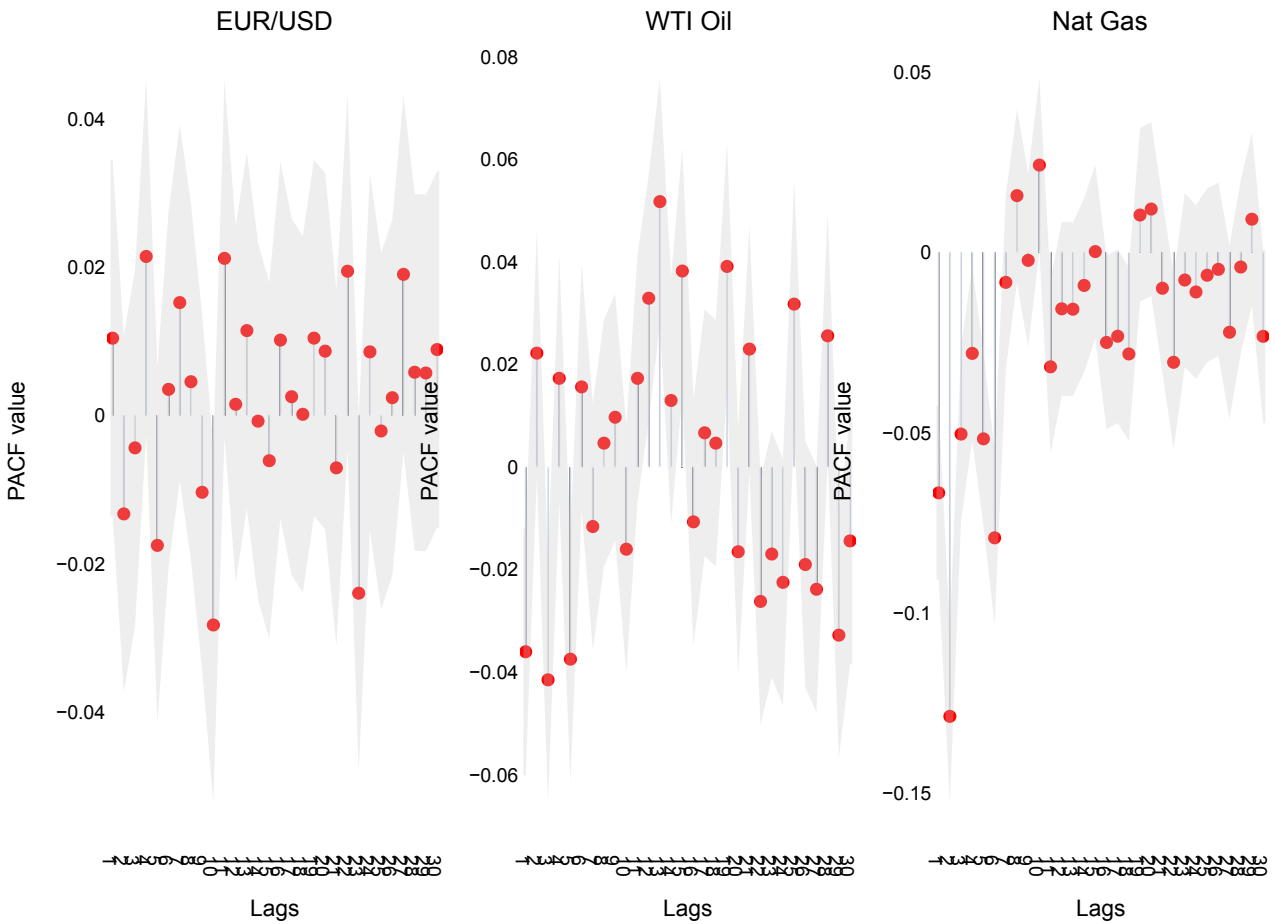

Figure: PACF values for daily observations (log first differences) of the EUR/USD spot exchange rate, WTI Oil and Natural Gas over the time: 1999 - 2025.[29]

[29] Own Illustration based on XYZ (2000), page 7 and data accessed 10.09.25.

Granger Causality Tests - EUR/USD and oil (raw data)

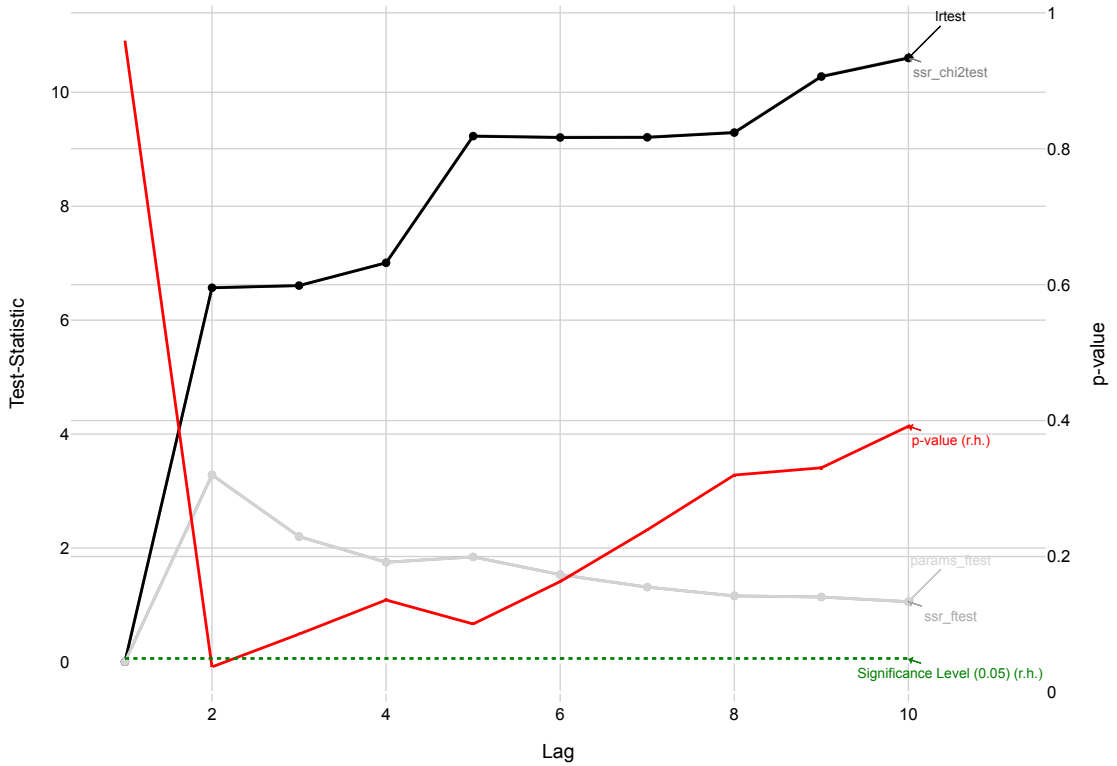

Figure: Granger causality test results testing granger causality of daily observations of oil for EUR/USD spot exchange rate over the time: 1999 - 2025.[30]

[30] Own Illustration based on XYZ (2000), page 7 and data accessed 10.09.25.

Granger Causality Tests - EUR/USD and gas (raw data)

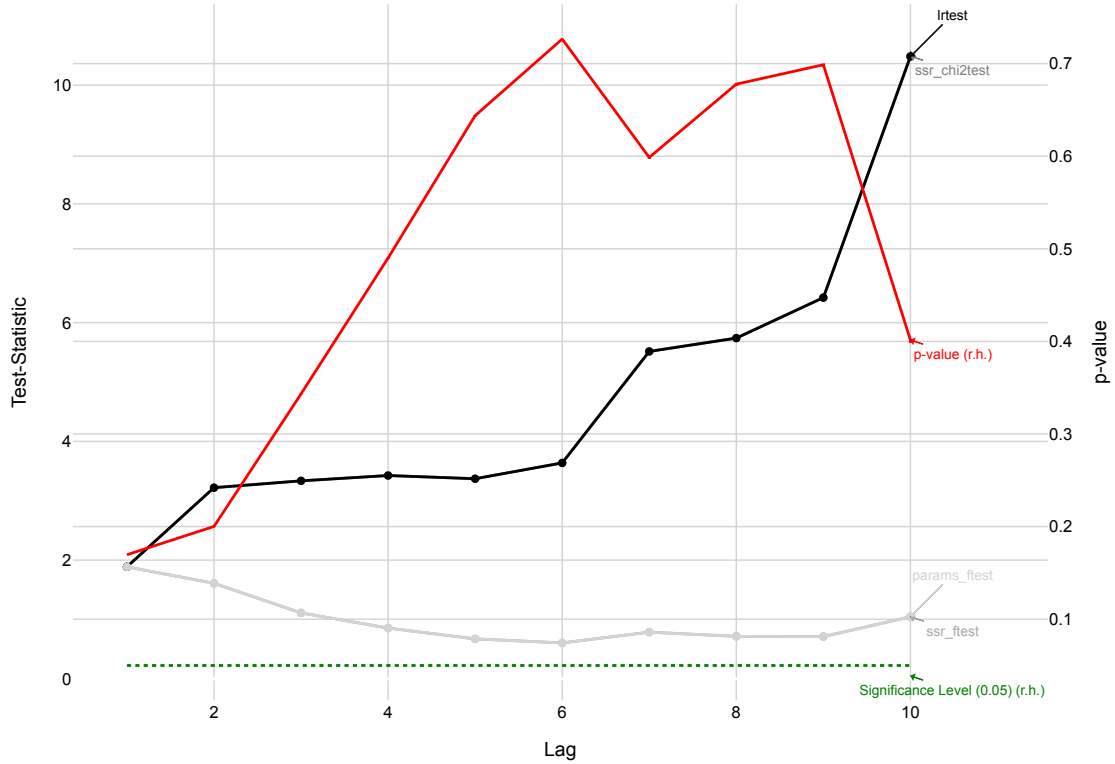

Figure: Granger causality test results testing granger causality of daily observations of gas for EUR/USD over the time: 1999 - 2025.[31]

[31] Own Illustration based on XYZ (2000), page 7 and data accessed 10.09.25.

Granger Causality Tests - EUR/USD and oil (log first differences)

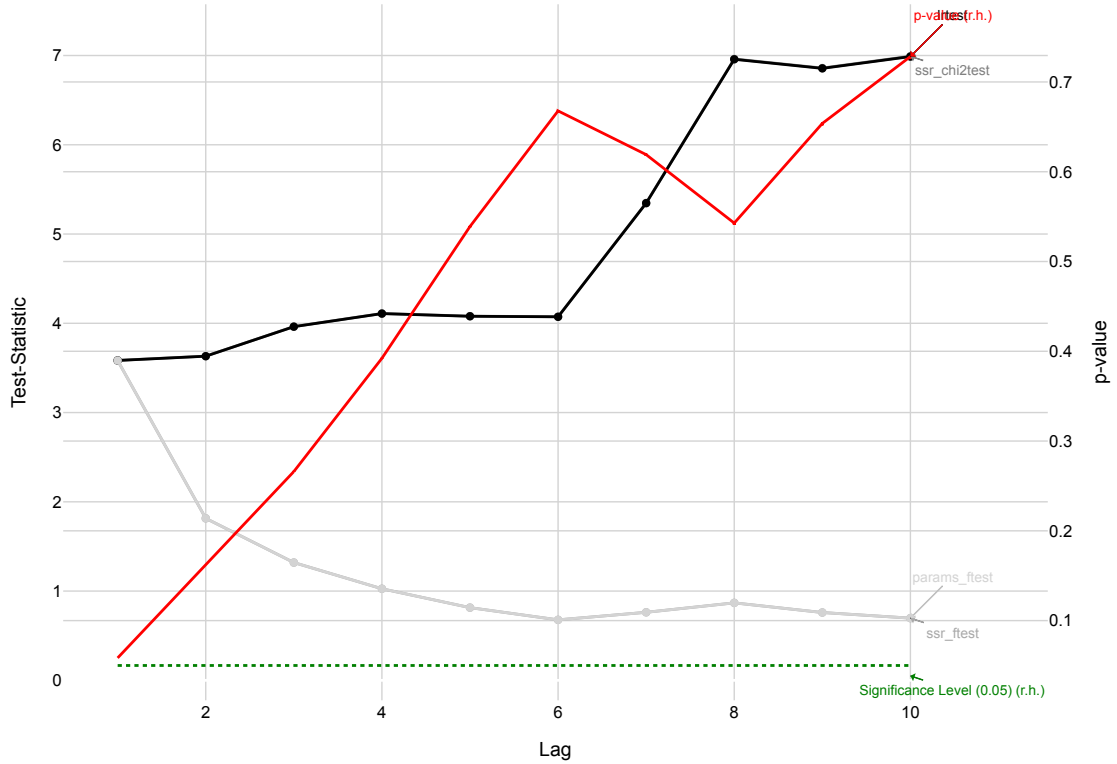

Figure: Granger causality test results testing granger causality of daily observations (log first differences) of WTI Oil for EUR/USD over the time: 1999 - 2025.[32]

[32] Own Illustration based on XYZ (2000), page 7 and data accessed 10.09.25.

Granger Causality Tests - EUR/USD and gas (log first differences)

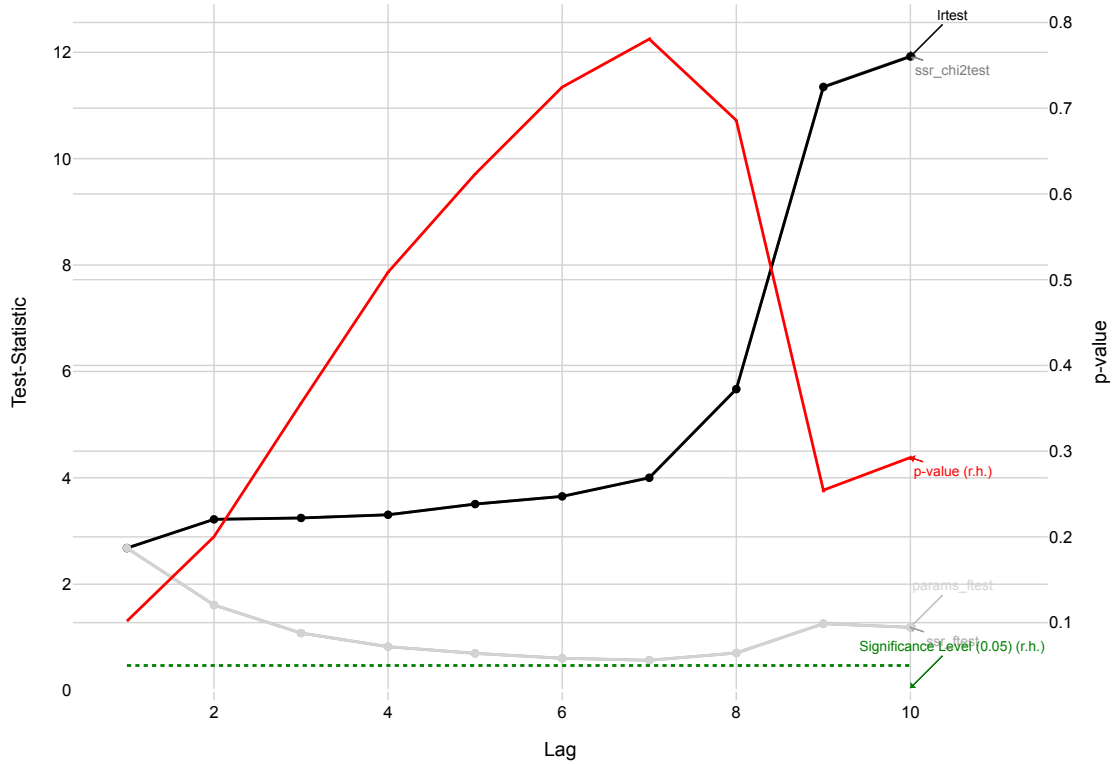

Figure: Granger causality test results testing granger causality of daily observations (log first differences) of Natural Gas for EUR/USD over the time: 1999 - 2025.[33]

[33] Own Illustration based on XYZ (2000), page 7 and data accessed 10.09.25.

Model Results

Model comparison and selection

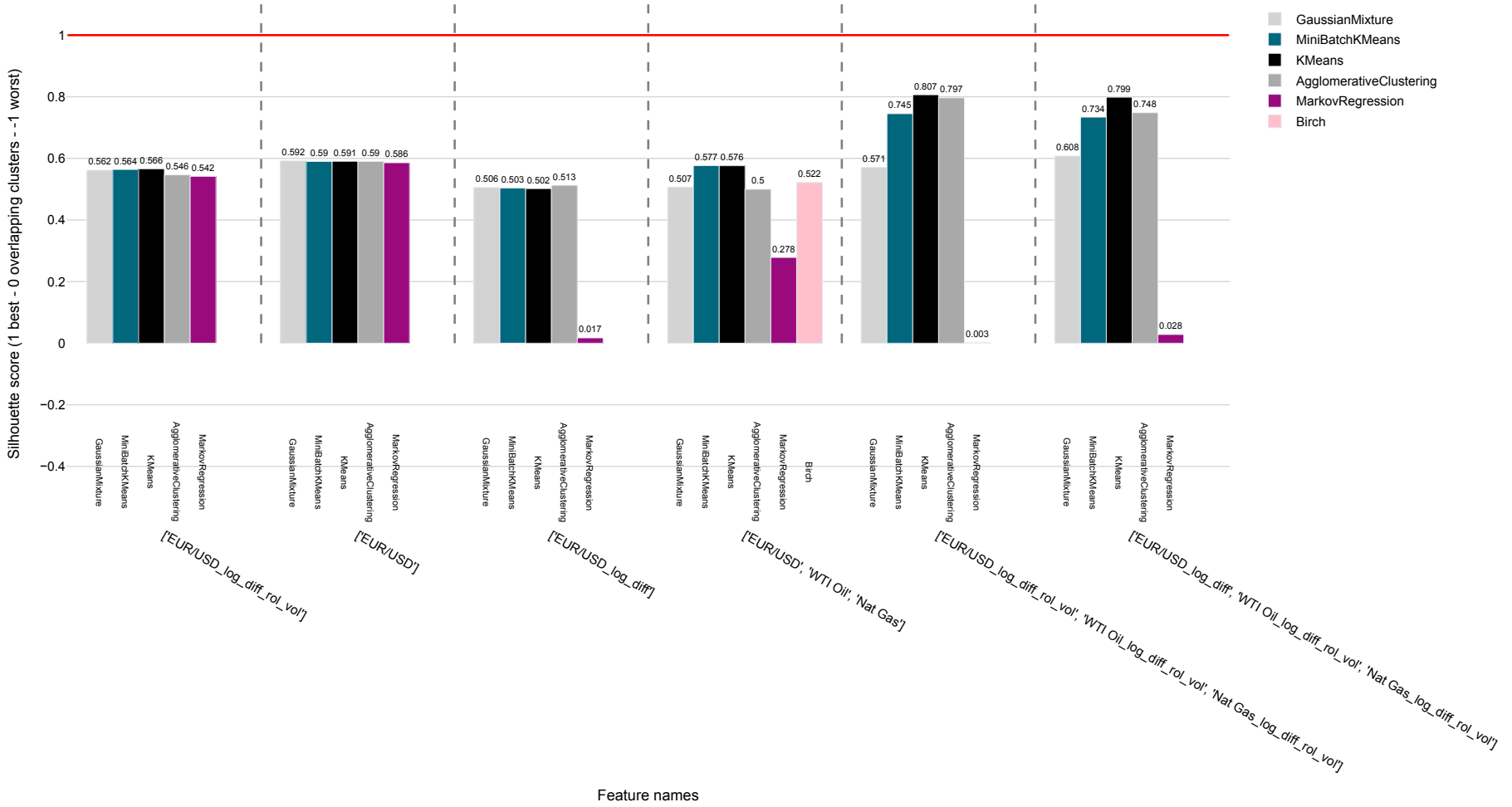

Figure: Model comparison using the silhouette score for various regime identification model configurations.[34]

[34] Own Illustration based on XYZ (2000), page 7 and data accessed 10.09.25.

Predicted Regimes - Evolution over time with highlighted Crisis Periods

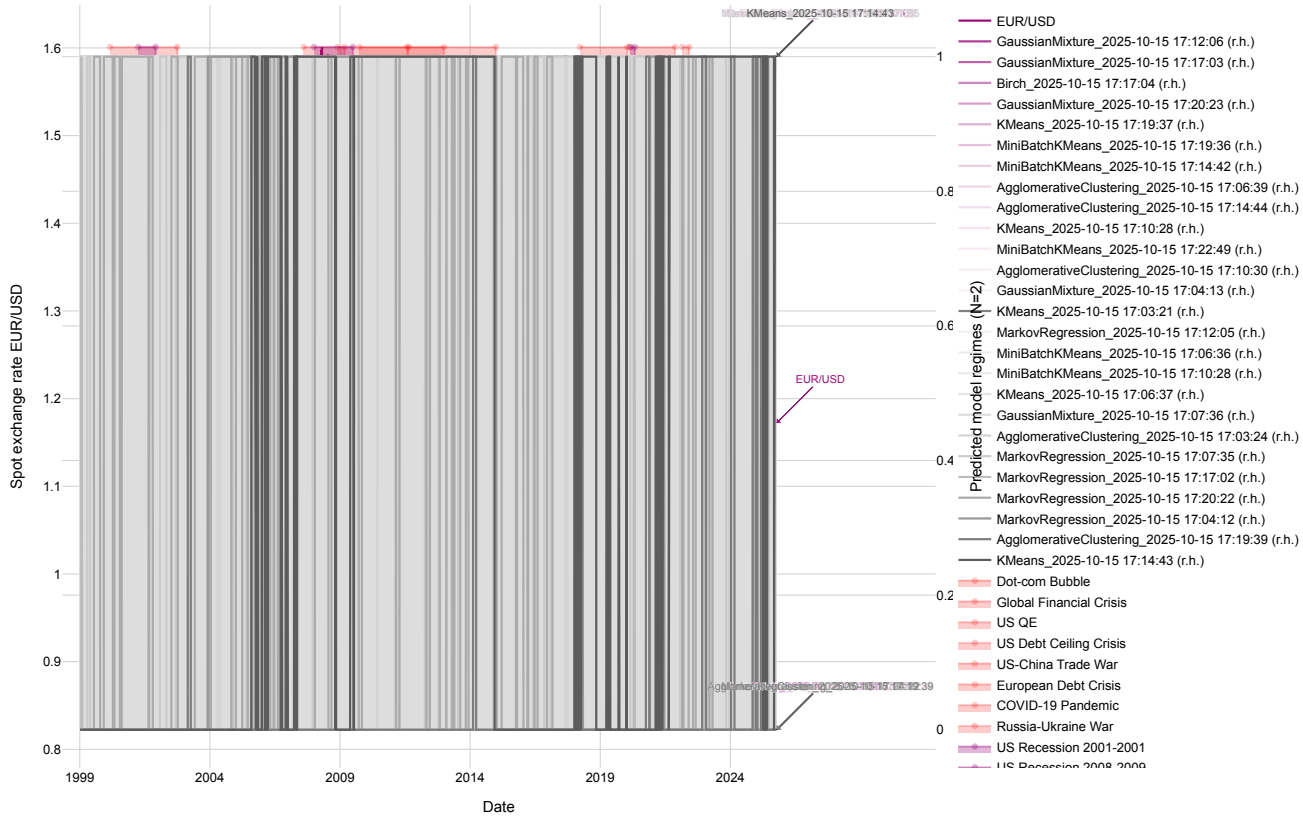

Figure: Predicted regimes over time with highlighted crisis periods.[35]

[35] Own Illustration based on XYZ (2000), page 7 and data accessed 10.09.25.

Conclusion and Discussion

Seminar Project Summary

Seminar Project Limitations

Future Research - Possible Extensions

Extend the Analysis to other Spot Exchange Rate Pairs (focus on the Commodity Currencies with a strong Commodity Linkage) Extend the Analysis to also include other Commodities (e.g. Natural Gas, Brent Oil, Gold, etc.) Extend the Analysis by incorporating other Macroeconomic Variables (e.g. Interest Rates, Inflation Rates, etc.) Extend the Analysis by using intraday data to capture more granular dynamics Apply Machine Learning Techniques to enhance predictive capabilities and better capture Non-Linearities

Paragraphs of Text

Sed iaculis dapibus gravida. Morbi sed tortor erat, nec interdum arcu. Sed id lorem lectus. Quisque viverra augue id sem ornare non aliquam nibh tristique. Aenean in ligula nisl. Nulla sed tellus ipsum. Donec vestibulum ligula non lorem vulputate fermentum accumsan neque mollis.

> *Sed diam enim, sagittis nec condimentum sit amet, ullamcorper sit amet libero. Aliquam vel dui orci, a porta odio.*
> *— Someone, somewhere. . .*

Nullam id suscipit ipsum. Aenean lobortis commodo sem, ut commodo leo gravida vitae. Pellentesque vehicula ante iaculis arcu pretium rutrum eget sit amet purus. Integer ornare nulla quis neque ultrices lobortis.

Lists

Bullet Points and Numbered Lists

- Lorem ipsum dolor sit amet, consectetur adipiscing elit
- Aliquam blandit faucibus nisi, sit amet dapibus enim tempus
  - Lorem ipsum dolor sit amet, consectetur adipiscing elit
  - Nam cursus est eget velit posuere pellentesque
- Nulla commodo, erat quis gravida posuere, elit lacus lobortis est, quis porttitor odio mauris at libero

1. Nam cursus est eget velit posuere pellentesque
2. Vestibulum faucibus velit a augue condimentum quis convallis nulla gravida

Blocks of Highlighted Text

Block Title

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Integer lectus nisl, ultricies in feugiat rutrum, porttitor sit amet augue.

Example Block Title

Aliquam ut tortor mauris. Sed volutpat ante purus, quis accumsan.

Alert Block Title

Pellentesque sed tellus purus. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos himenaeos.

Suspendisse tincidunt sagittis gravida. Curabitur condimentum, enim sed venenatis rutrum, ipsum neque consectetur orci.

Multiple Columns

Subtitle

Heading

1. Statement
2. Explanation
3. Example

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Integer lectus nisl, ultricies in feugiat rutrum, porttitor sit amet augue. Aliquam ut tortor mauris. Sed volutpat ante purus, quis accumsan dolor.

Table

Subtitle

Treatments	Response 1	Response 2
Treatment 1	0.0003262	0.562
Treatment 2	0.0015681	0.910
Treatment 3	0.0009271	0.296

Table caption

Definitions & Examples

Definition

A is a number that has exactly two divisors.

Example

- 2 is prime (two divisors: 1 and 2).
- 3 is prime (two divisors: 1 and 3).
- 4 is not prime (three divisors: 1, 2, and 4).

You can also use the `theorem`, `lemma`, `proof` and `corollary` environments.

Theorem, Corollary & Proof

Theorem (Mass–energy equivalence)

$E = mc^2$

Corollary

$x + y = y + x$

Proof.

$\omega + \phi = \epsilon$ □

Equation

$$\cos^3\theta = \frac{1}{4}\cos\theta + \frac{3}{4}\cos 3\theta \tag{1}$$

Verbatim

Example (Theorem Slide Code)

```
\begin{frame}
\frametitle{Theorem}
\begin{theorem}[Mass--energy equivalence]
$E = mc^2$
\end{theorem}
\end{frame}
```

Slide without title.

Citing References

An example of the `\cite` command to cite within the presentation:

This statement requires citation [**?**, **?**].

Appendix

Appendix - Figures and Tables

Appendix - Data

Appendix - Data

Appendix - Definitions

Appendix - Definitions

Major global crisis periods (theoretical regimes) (Slide X):

No.	Period	Event	Source
1	2007 – 2009	Global Financial Crisis	How Exchange Rate Volatility Shapes Commodity Derivatives Market: Less
2	2010 – 2012	European Debt Crisis	How Exchange Rate Volatility Shapes Commodity Derivatives Market: Less
3	2014 – 2016	Oil Price Crash	How Exchange Rate Volatility Shapes Commodity Derivatives Market: Less
4	2020 – 2021	COVID-19 Pandemic	How Exchange Rate Volatility Shapes Commodity Derivatives Market: Less
5	2022 – present	Russia-Ukraine Conflict	How Exchange Rate Volatility Shapes Commodity Derivatives Market: Less

Table caption[36]

[36] See: XXX

Appendix - Definitions

PPP Deviation Calculation

$$\text{PPP Deviation} = \frac{\text{Actual Exchange Rate} - \text{PPP Exchange Rate}}{\text{PPP Exchange Rate}} \times 100$$

Source: https://www.investopedia.com/terms/p/ppp.asp

Clustering Metrics: Silhouette Score

$$\text{Silhouette Score} = \frac{b - a}{\max(a, b)}$$

Source: https://scikit-learn.org/stable/modules/generated/sklearn.metrics.silhouette_score.html

Appendix - Definitions

Calculation of main exchange rate types (Slide XX):

- Nominal effective exchange rate (NEER): Calculated as geometric trade-weighted averages of bilateral exchange rates.[37]
- Real effective exchange rates (REER): Derived by adjusting the NEER by relative consumer prices.[38]
- Nominal exchange rates (NER): The exchange rate between two currencies without adjustment for inflation.[39]
- Real exchange rates (RER): The nominal exchange rate adjusted for differences in price levels between countries.[40]

[37] See: https://data.bis.org/topics/EER

[38] See: https://data.bis.org/topics/EER

[39] See:

[40] See:

References

References - Literature

John Smith (2022)

Publication title

Journal Name 12(3), 45 – 678.

Annabelle Kennedy (2023)

Publication title

Journal Name 12(3), 45 – 678.

References - Data

John Smith (2022)

Publication title

Journal Name 12(3), 45 – 678.

Annabelle Kennedy (2023)

Publication title

Journal Name 12(3), 45 – 678.

List of figures

List of tables

Thank you for your attention!

We await your Questions and/or Comments.

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Robert Hennings
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Public GitHub Project Repository: https://github.com/RobertHennings

Discussion

1. Have you expected this outcome?
2. What do you think about the dynamics?
3. What other variables could be potentially included?

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Further Material for Illustrations - Questions