

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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Summary Project Summary

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 Norden¹

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. Sadorsky²

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. Sahay³

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

⁴Own 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

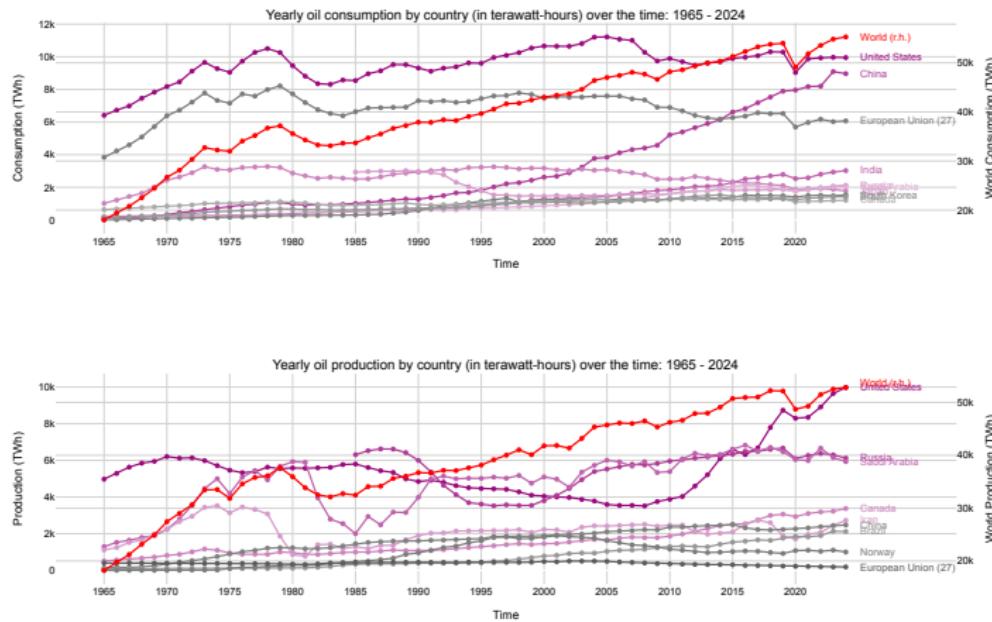


Figure: Yearly oil consumption and production by country over the time: 1965 - 2024 (in terawatt-hours).⁵

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

Gas: Global Production and Consumption over time

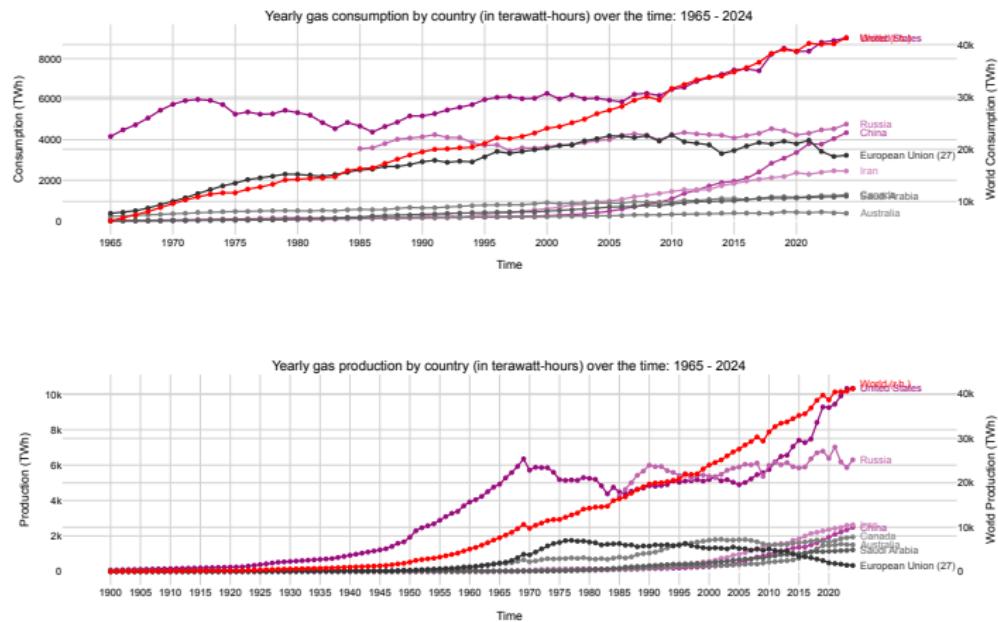


Figure: Yearly gas consumption and production by country over the time: 1965 - 2024 (in terawatt-hours).⁶

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

Financial Markets: Oil and Gas OI over time

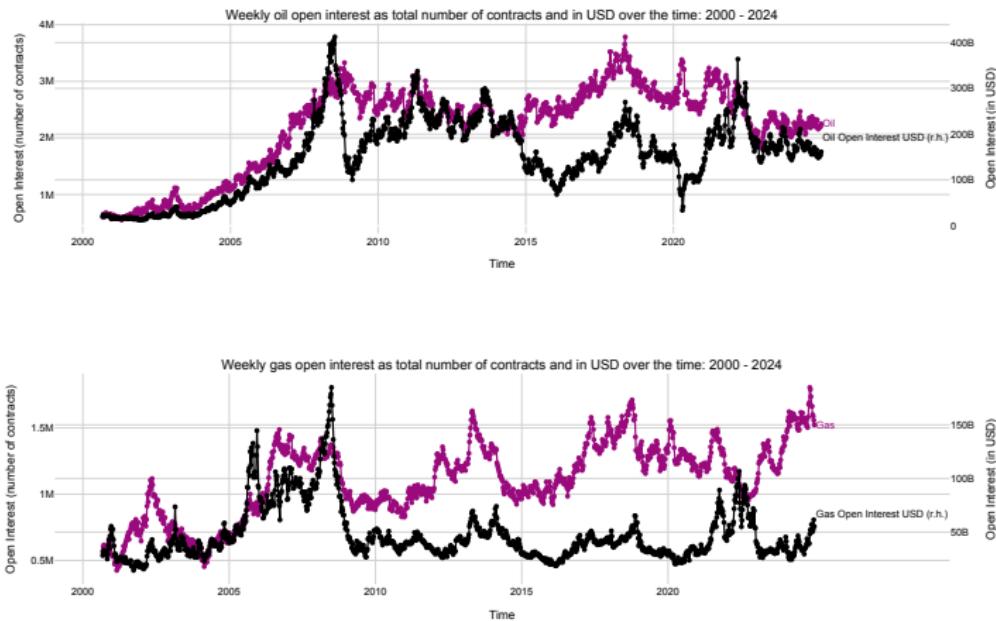


Figure: Weekly open interest of oil and gas products over the time: 2000 - 2024⁷

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

Research Hypothesis

Energy Price Contributions to Inflation - USA

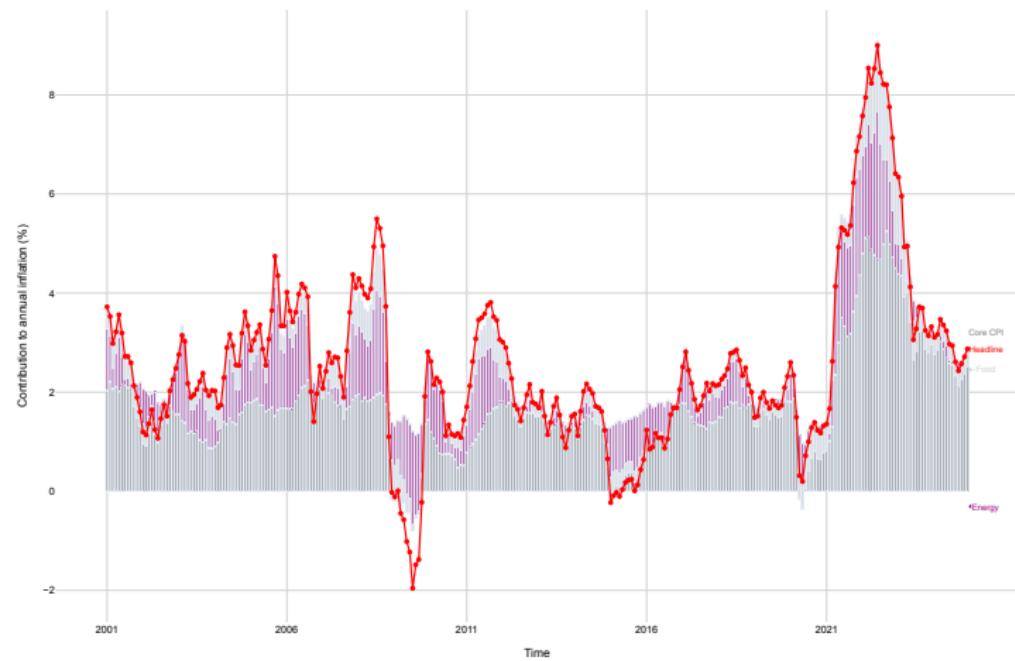


Figure: US CPI: Headline and component contributions over the time: 2001 - 2024.⁸

⁸Own 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

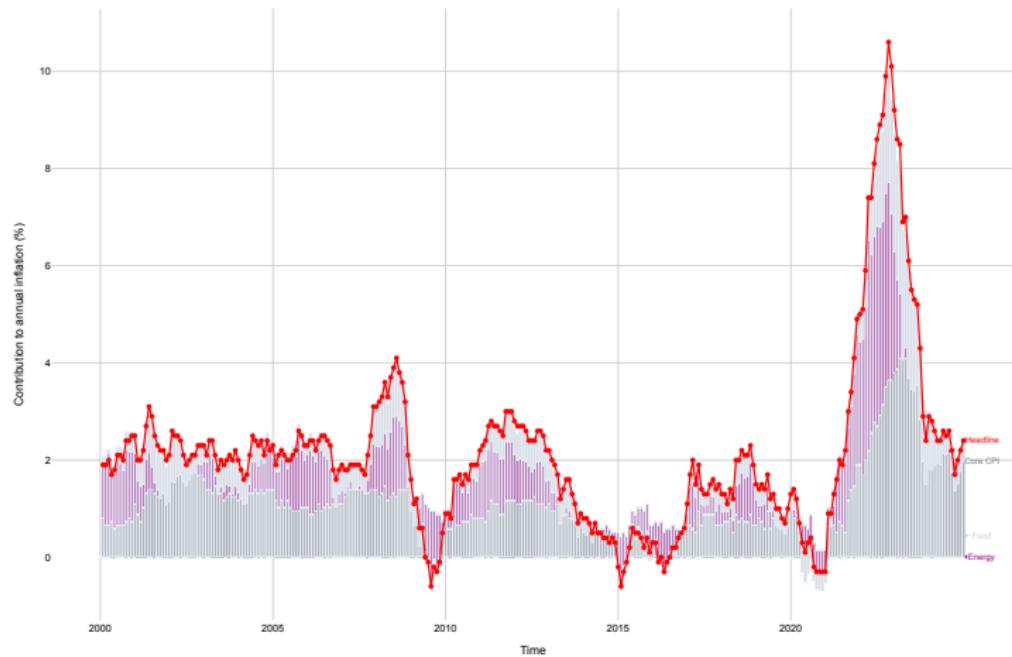


Figure: EU Area CPI: Headline and component contributions over the time: 2000 - 2024.⁹

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

Chapter 3)

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

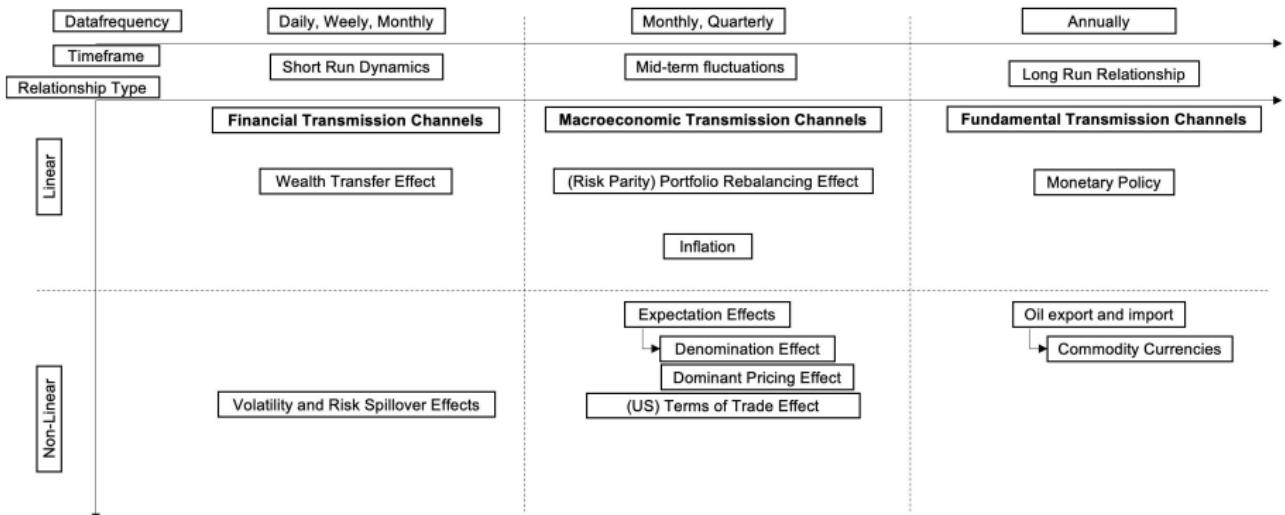


Figure: Systematic Overview about main approaches.¹²

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

Chapter 4)

Theoretical Framework

Definitions - prices and measurements

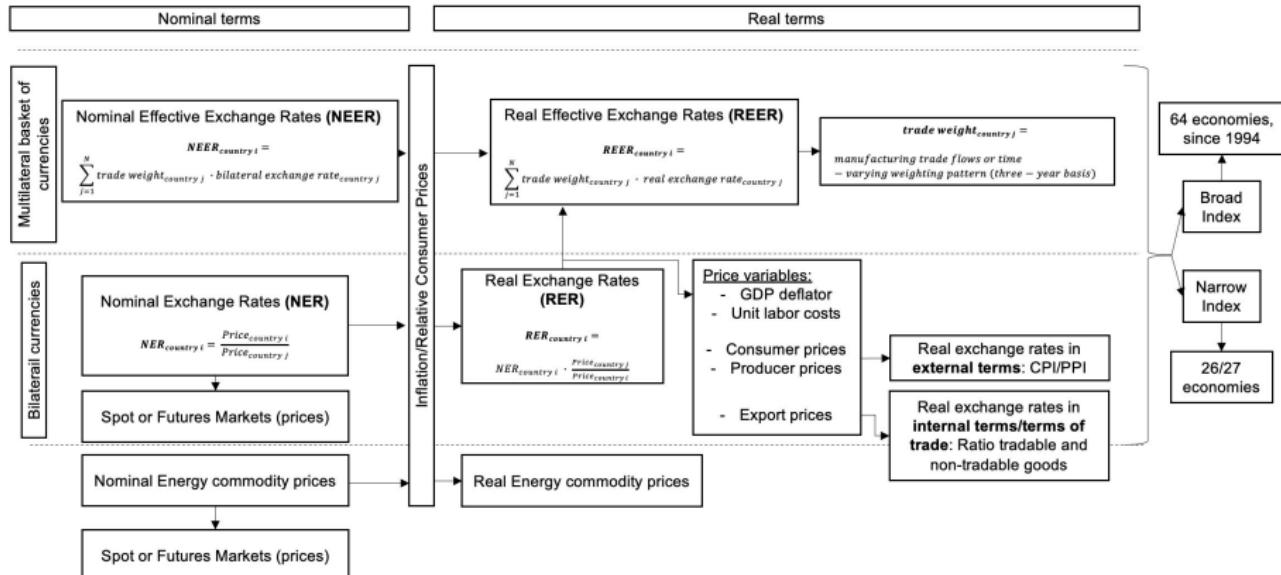


Figure: Schematic overview of prices and measurements of various exchange rate types.¹³

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	1995-04-11	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

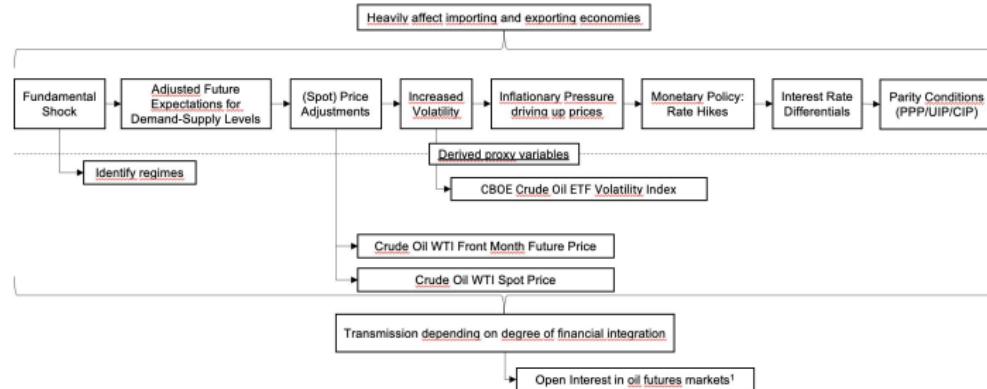


Figure: Global Oil Production and Consumption over time - in terawatt-hours (TWh).¹⁵

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

Theoretical Framework (I)

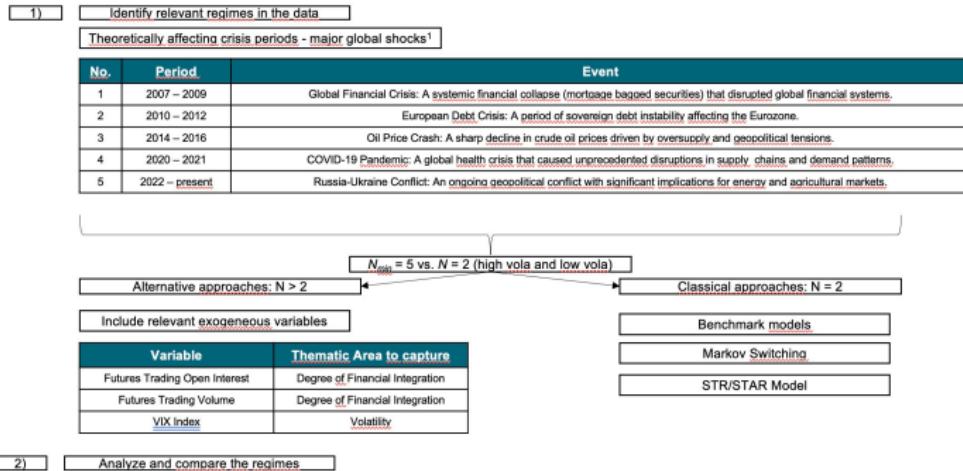


Figure: Global Oil Production and Consumption over time - in terawatt-hours (TWh).¹⁶

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

Theoretical Framework (II)

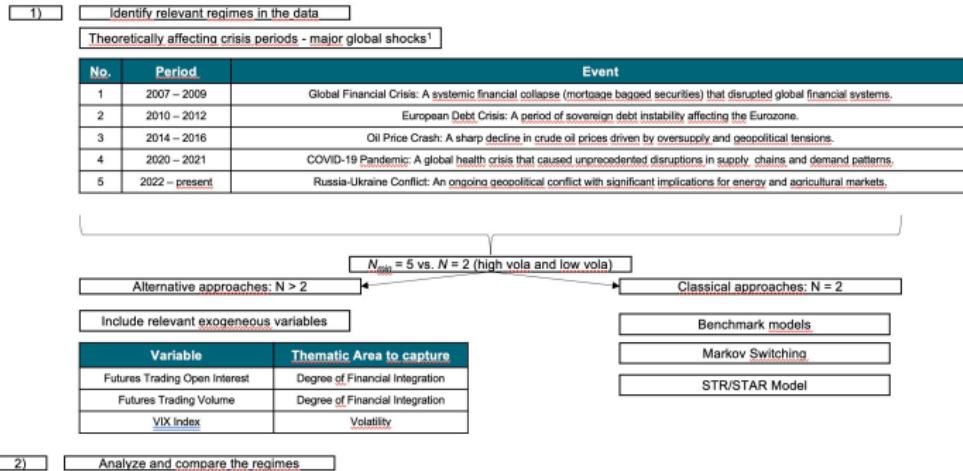


Figure: Global Oil Production and Consumption over time - in terawatt-hours (TWh).¹⁷

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

Chapter 5

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)

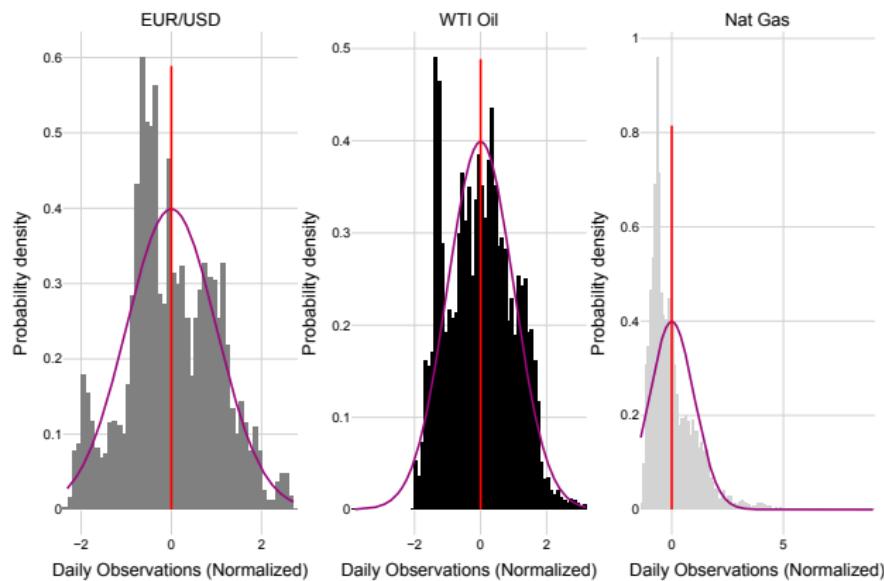


Figure: Normalized daily EUR/USD spot exchange rate, oil and gas over the time range: 1999 - 2025.¹⁸

Spot exchange rate distributions (log first differences)

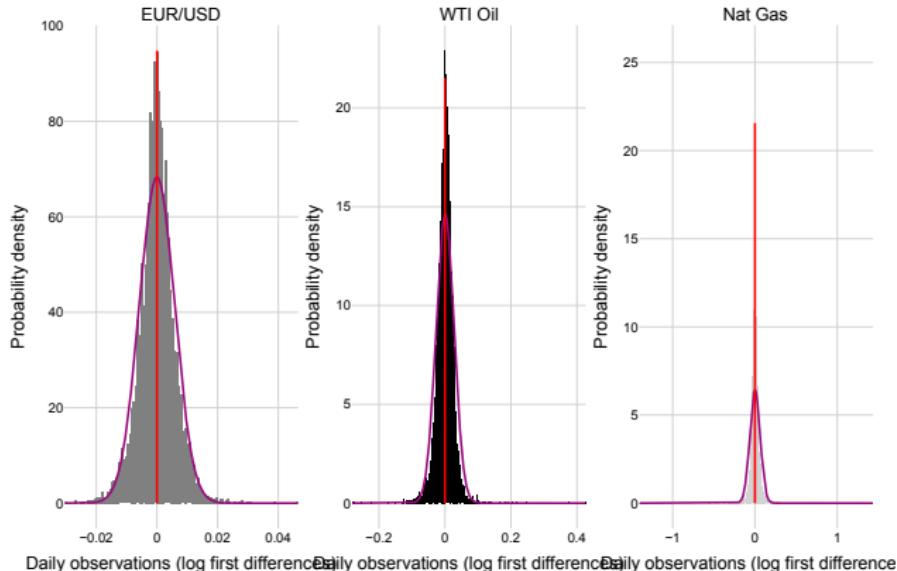


Figure: Log first differences of daily EUR/USD spot exchange rate, oil and gas over the time range: 1999 - 2025.¹⁹

¹⁹ 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 - 2025.²⁰

²⁰ 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 - 2025.²¹

²¹ 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 - 2025.²²

²²See: 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 - 2025.²³

²³See: 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 - 2025.²⁴

²⁴See: XXX

Tests for Autocorrelation (raw data)

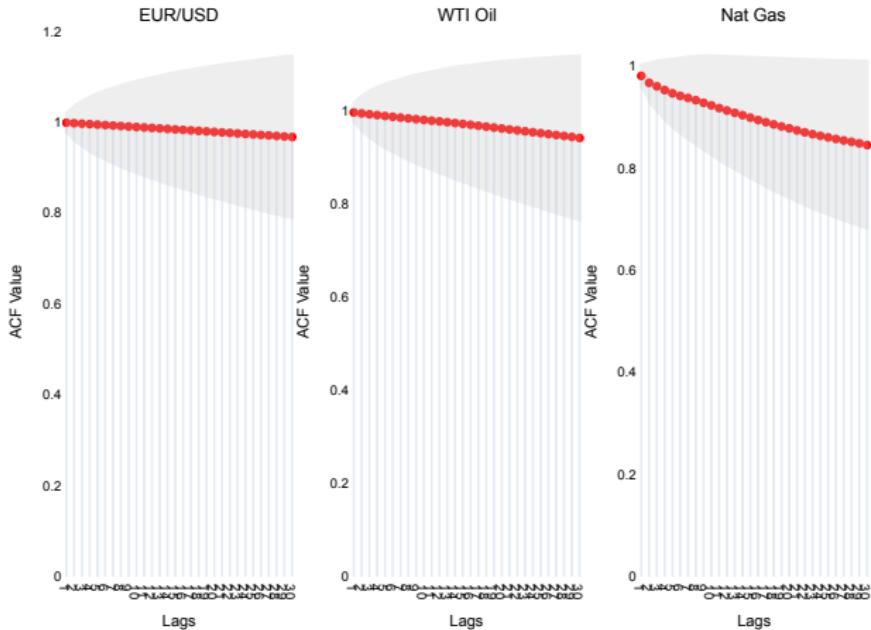


Figure: ACF values for daily observations of the EUR/USD spot exchange rate, oil and gas over the time: 1999 - 2025.²⁵

²⁵Own Illustration based on XYZ (2000), page 7 and data accessed 10.09.25.

Tests for Autocorrelation (log first differences)

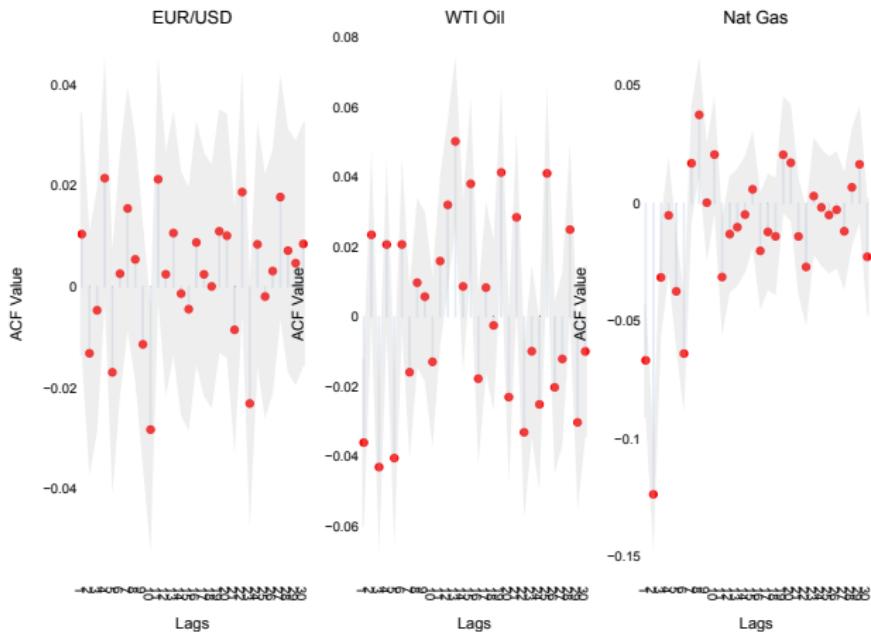


Figure: ACF values for daily observations (log first differences) of the EUR/USD spot exchange rate, WTI Oil and Natural Gas over the time: 1999 - 2025.²⁶

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

Tests for Partial Autocorrelation (raw data)

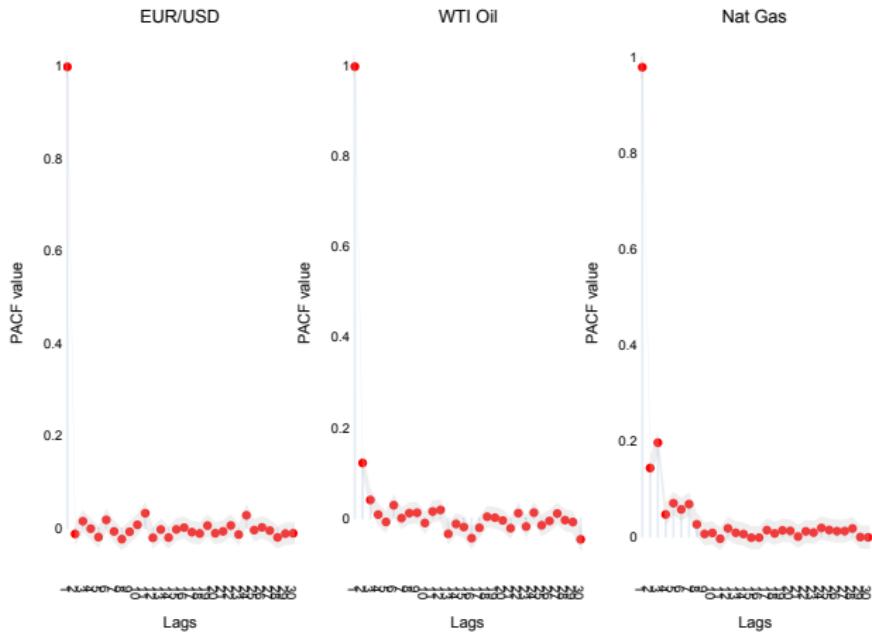


Figure: PACF values for daily observations of the EUR/USD spot exchange rate, WTI Oil and Natural Gas over the time: 1999 - 2025.²⁷

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

Tests for Partial Autocorrelation (log first differences)

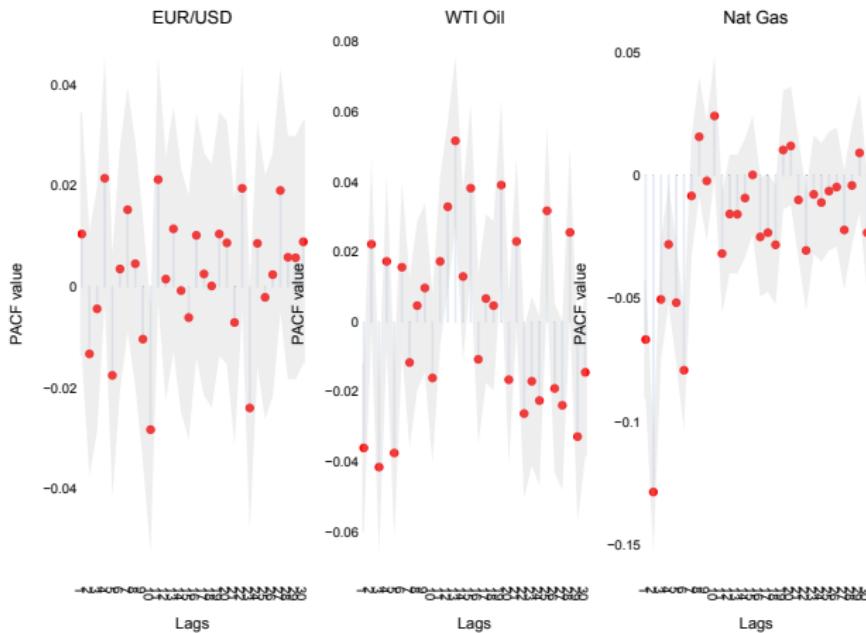


Figure: PACF values for daily observations (log first differences) of the EUR/USD spot exchange rate, WTI Oil and Natural Gas over the time: 1999 - 2025.²⁸

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

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

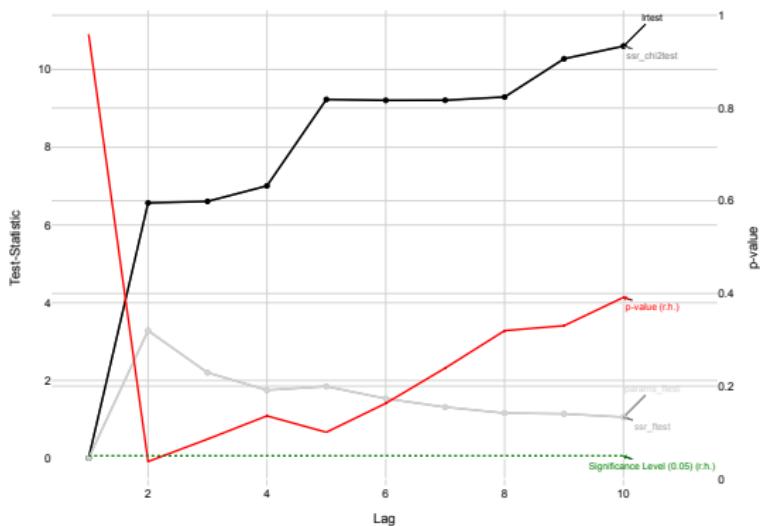


Figure: Granger causality test results testing granger causality of daily observations of oil for EUR/USD spot exchange rate over the time: 1999 - 2025.²⁹

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

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

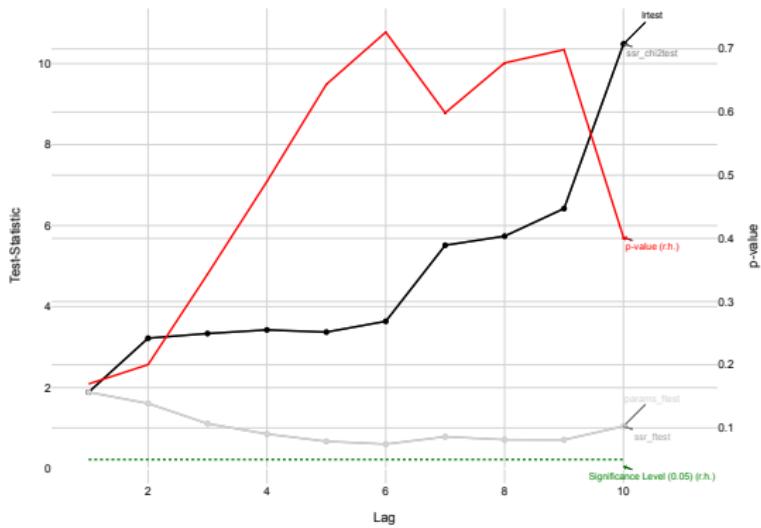


Figure: Granger causality test results testing granger causality of daily observations of gas for EUR/USD over the time: 1999 - 2025.³⁰

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

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

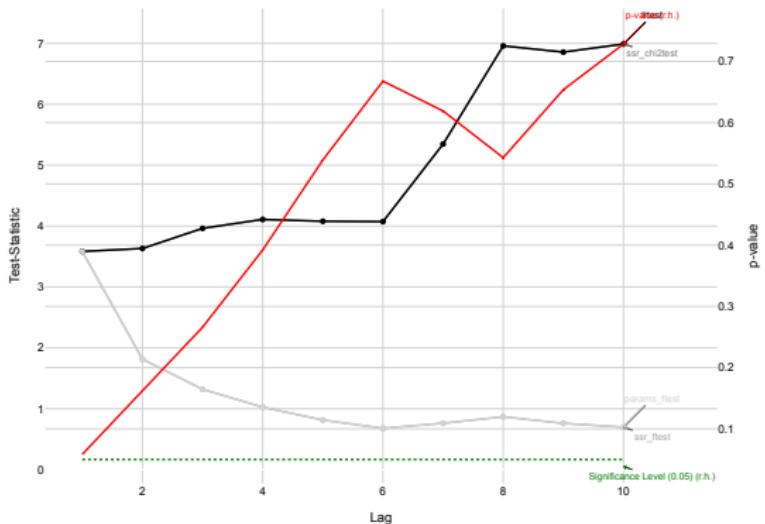


Figure: Granger causality test results testing granger causality of daily observations (log first differences) of WTI Oil for EUR/USD over the time: 1999 - 2025.³¹

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

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

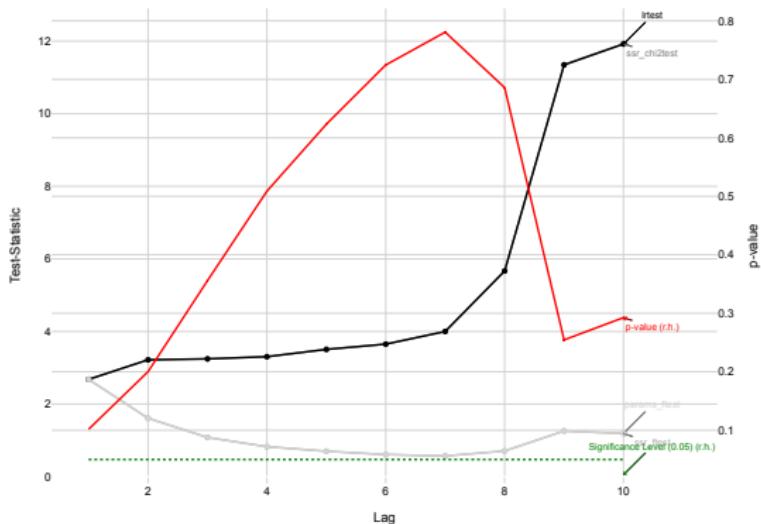


Figure: Granger causality test results testing granger causality of daily observations (log first differences) of Natural Gas for EUR/USD over the time: 1999 - 2025.³²

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

Chapter 7)

Model Results

Model comparison and selection

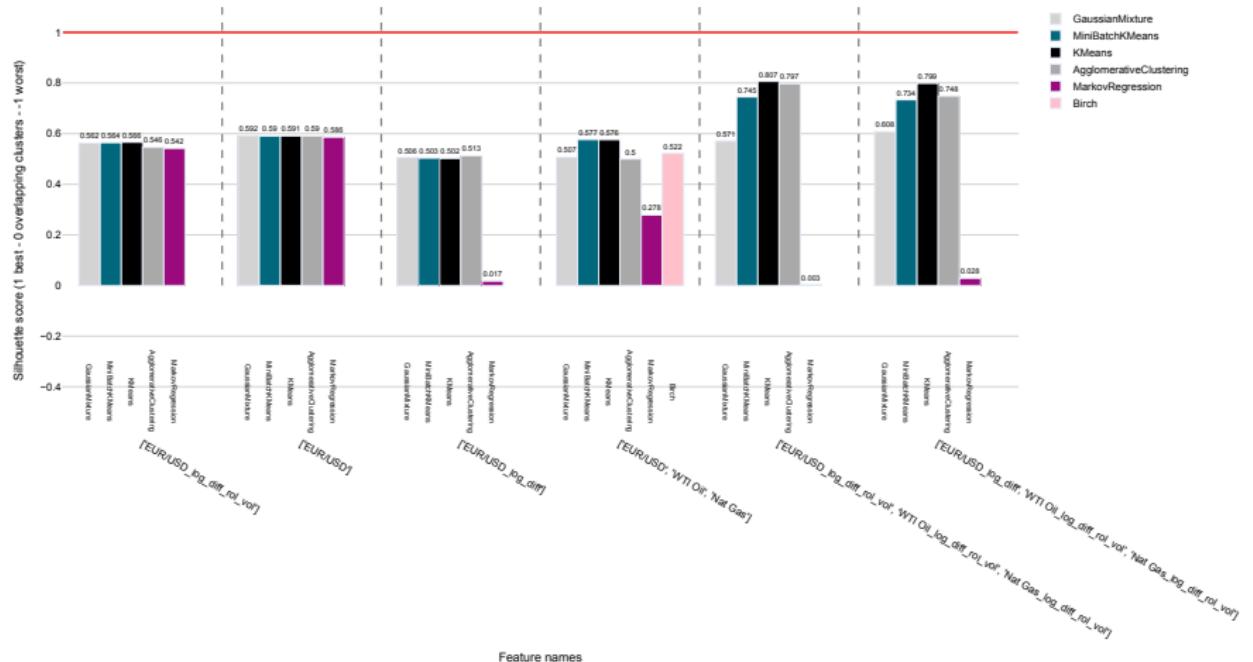


Figure: Model comparison using the silhouette score for various regime identification model configurations.³³

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

Predicted Regimes - Evolution over time with highlighted Crisis Periods

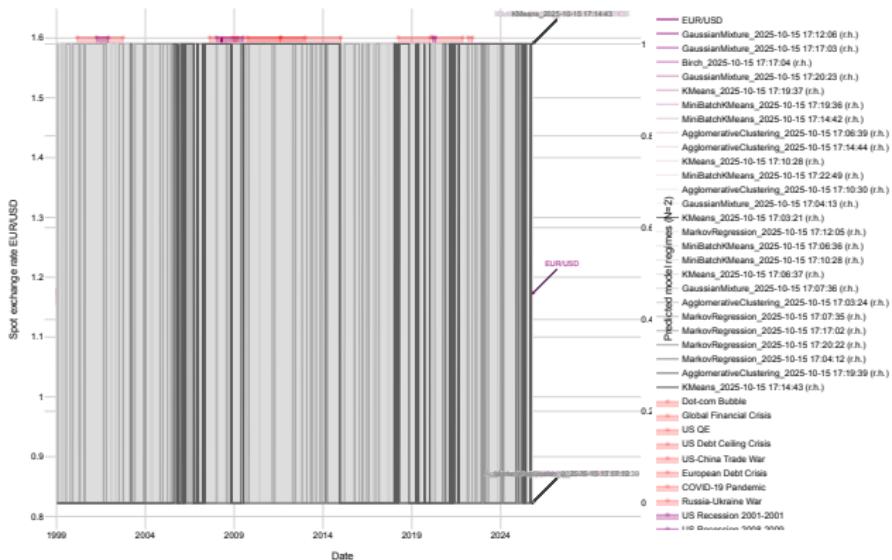


Figure: Predicted regimes over time with highlighted crisis periods.³⁴

³⁴ 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
rutm, 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 **prime number** 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

$$\cos^3 \theta = \frac{1}{4} \cos \theta + \frac{3}{4} \cos 3\theta \quad (1)$$

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 [Smith, 2022, Kennedy, 2023].

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 caption³⁵

³⁵ 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.³⁶
- Real effective exchange rates (REER): Derived by adjusting the NEER by relative consumer prices.³⁷
- Nominal exchange rates (NER): The exchange rate between two currencies without adjustment for inflation.³⁸
- Real exchange rates (RER): The nominal exchange rate adjusted for differences in price levels between countries.³⁹

³⁶ See: <https://data.bis.org/topics/EER>

³⁷ See: <https://data.bis.org/topics/EER>

³⁸ See:

³⁹ 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

- Figure??: Global Oil Production and Consumption (Slide??)
- Figure??: Global Coal Production and Consumption (Slide??)

List of tables

- Figure??: Global Oil Production and Consumption (Slide??)
- Figure??: Global Coal Production and Consumption (Slide??)

Thank you for your attention!

We await your Questions and/or Comments.

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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