

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 but is time varying, being dependent on movements in the real price of commodity exports.

— P. Cashin, L. F. Cespedes, R. Sahay³

¹[AN98], p.301

²[BHS16], p.17

³[CCS04], p.239

Intro: The PPP puzzle⁵ and Commodity Currencies

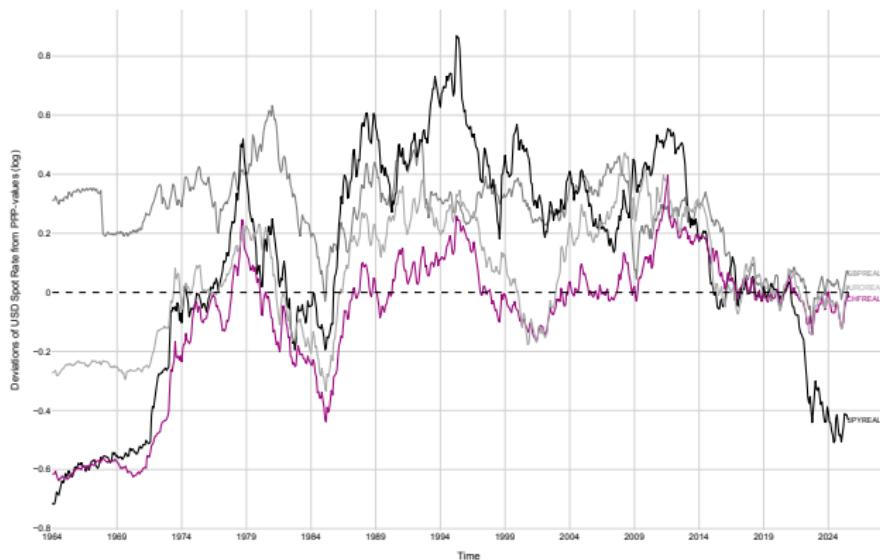


Figure: Monthly deviations of USD Spot Rate from PPP-values (in log terms) over the time: 1964 - 2025.⁴

⁴ Own Illustration based on [Rei25], section "Modeling Trends: Unit Roots in Time Series", page 18/18 and data taken from [Int25], last accessed 24.10.25.

⁵This puzzle concerns the finding of many researchers that the speed of mean reversion of real exchange rates is too slow to be consistent with PPP, which is the proposition that exchange rates are determined by movements in relative prices.

Modern Energy Commodity Markets The current state

Oil: Global Production and Consumption over time

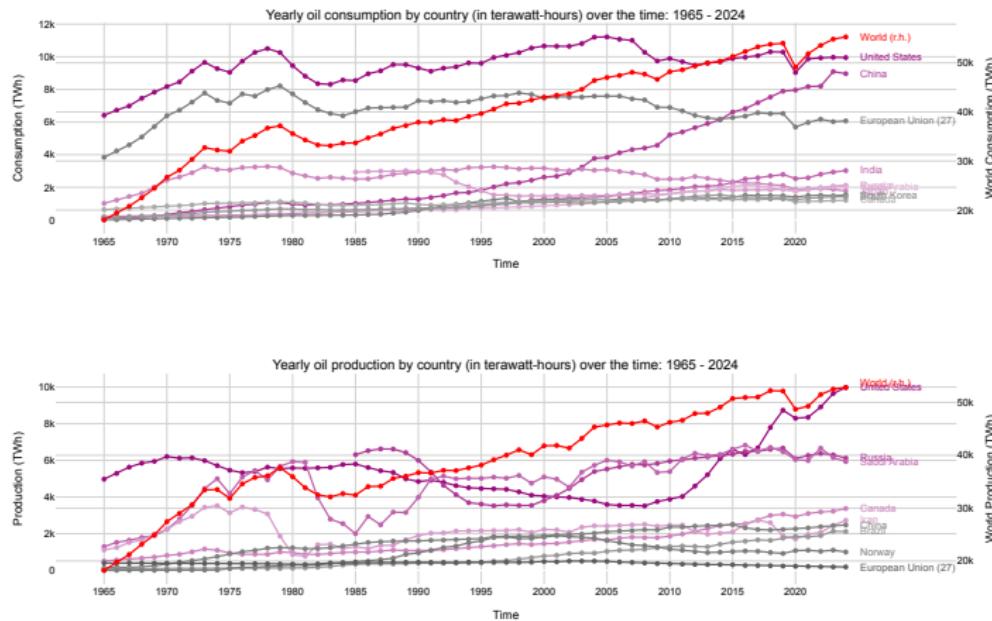


Figure: Yearly oil consumption and production by country over the time: 1965 - 2024 (in terawatt-hours).⁶

⁶Own Illustration based on XYZ (2000), page 7 and data taken from [Ins25b], last accessed 24.10.25

Gas: Global Production and Consumption over time

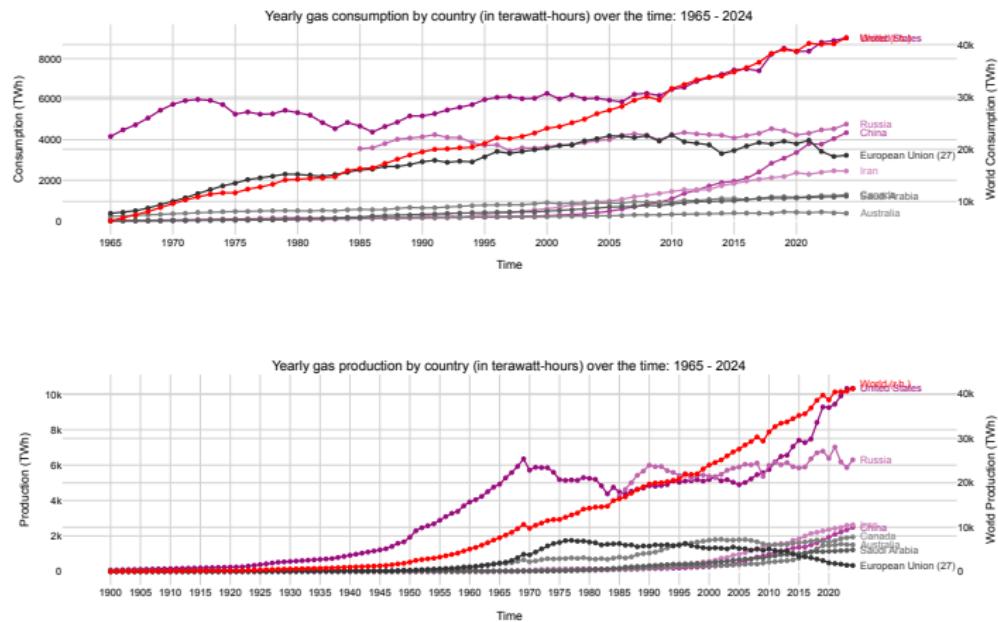


Figure: Yearly gas consumption and production by country over the time: 1965 - 2024 (in terawatt-hours).⁷

⁷ Own Illustration based on XYZ (2000), page 7 and data taken from [Ins25a], last accessed 24.10.25

Financial Markets: Oil and Gas OI over time

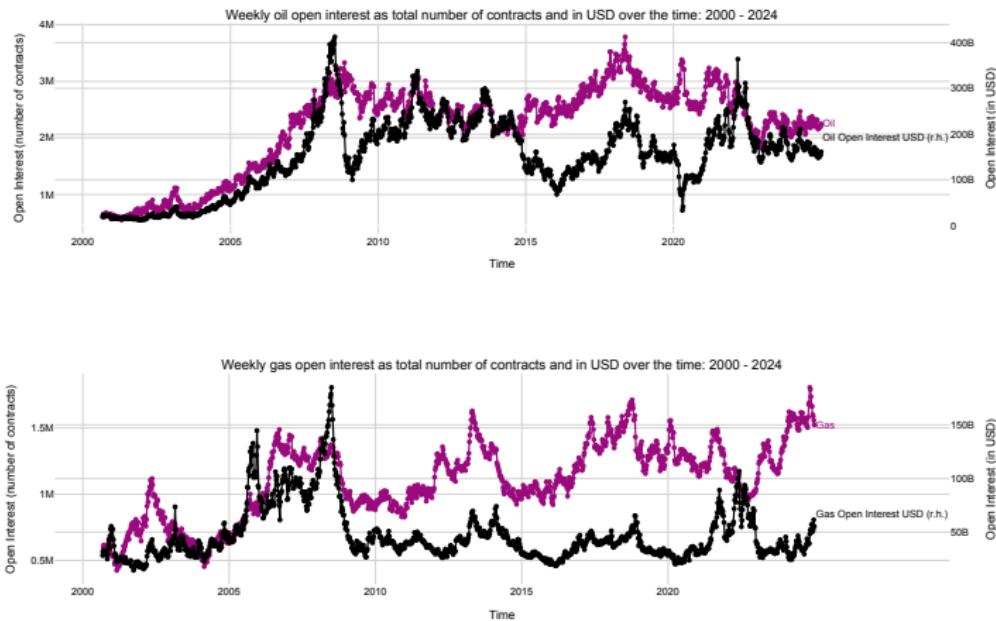


Figure: Weekly open interest of oil and gas products over the time: 2000 - 2024⁸

⁸Own Illustration based on XYZ (2000), page 7 and data taken from [Com25], last accessed 24.10.25

Research Hypothesis

Energy Price Contributions to Inflation - USA

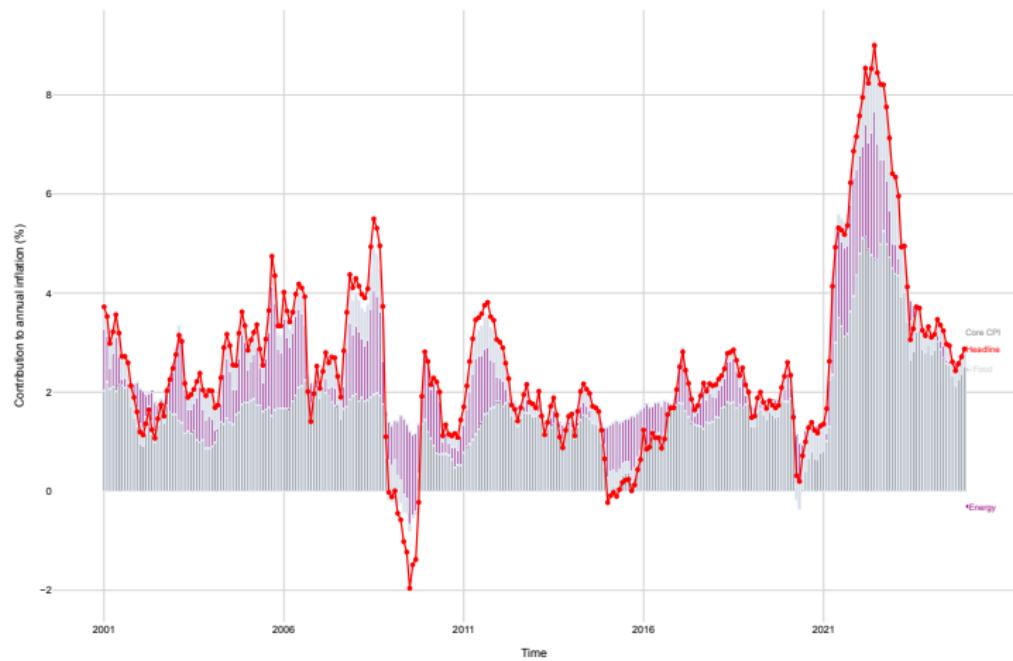


Figure: Monthly US CPI: Headline and component contributions over the time: 2001 - 2024.⁹

⁹Own Illustration based on [Ban22], Chart A and data taken from [St 25], last accessed 24.10.25.

Energy Price Contributions to Inflation - EU area

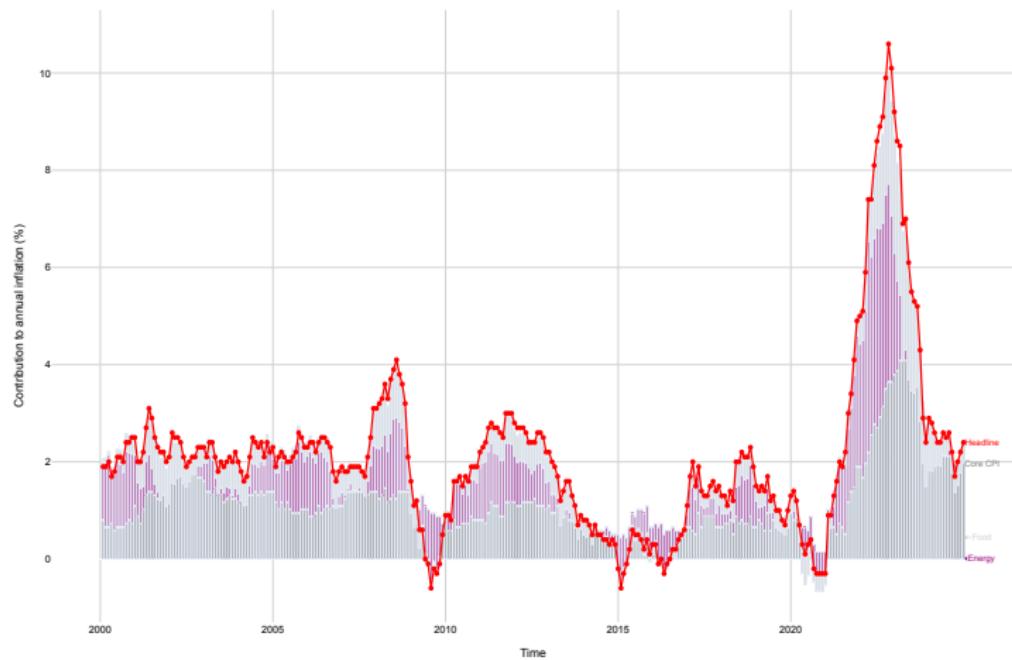


Figure: Monthly EU Area CPI: Headline and component contributions over the time: 2000 - 2024.¹⁰

¹⁰Own Illustration based on [Ban22], Chart A and data taken from [Ban25], last accessed 24.10.25.

Rolling Volatility of Exchange Rates and Energy Commodity Prices

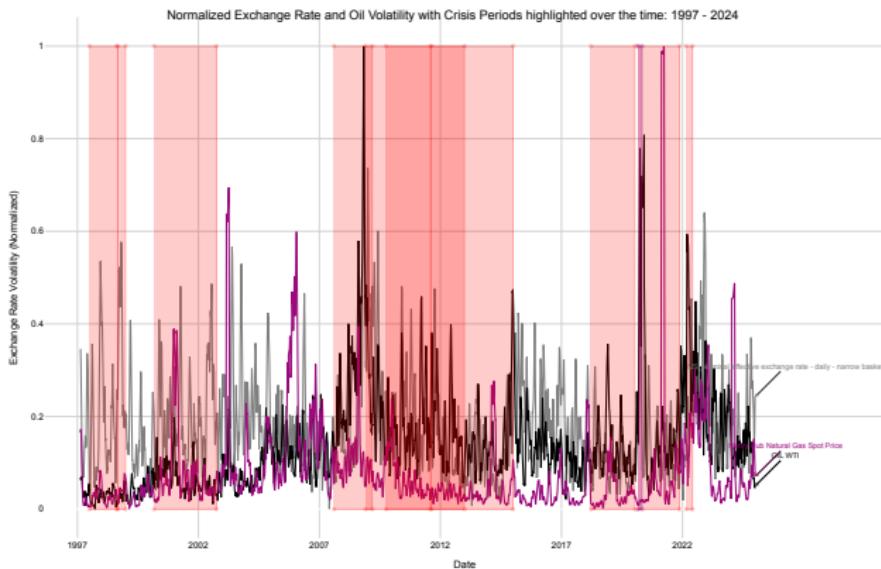


Figure: Daily normalized EUR/USD spot exchange rate, oil and gas log first differences volatility with highlighted crisis periods over the time: 2000 - 2024.¹¹

¹¹ Own Illustration based on [Zub+21], page X and data taken from [St 25], last accessed 24.10.25.

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

Systematic Literature Overview: Main Approaches

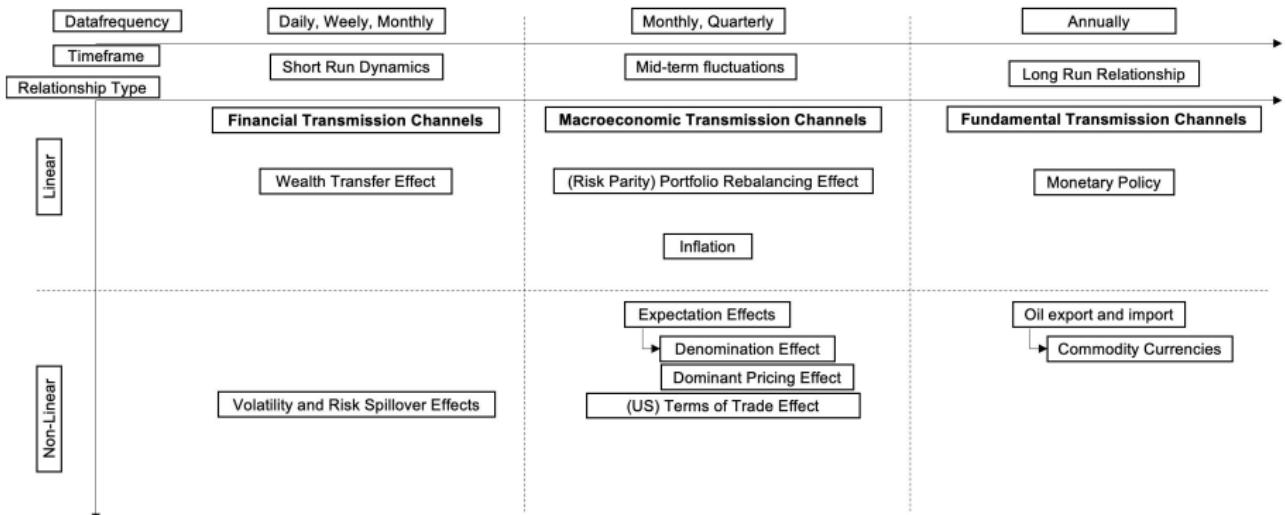


Figure: Systematic Overview about main theoretical approaches.¹²

¹²Own Illustration based on [OUS20], Figure 5, page 5.

Chapter 4)

Theoretical Framework

Definitions - prices and measurements

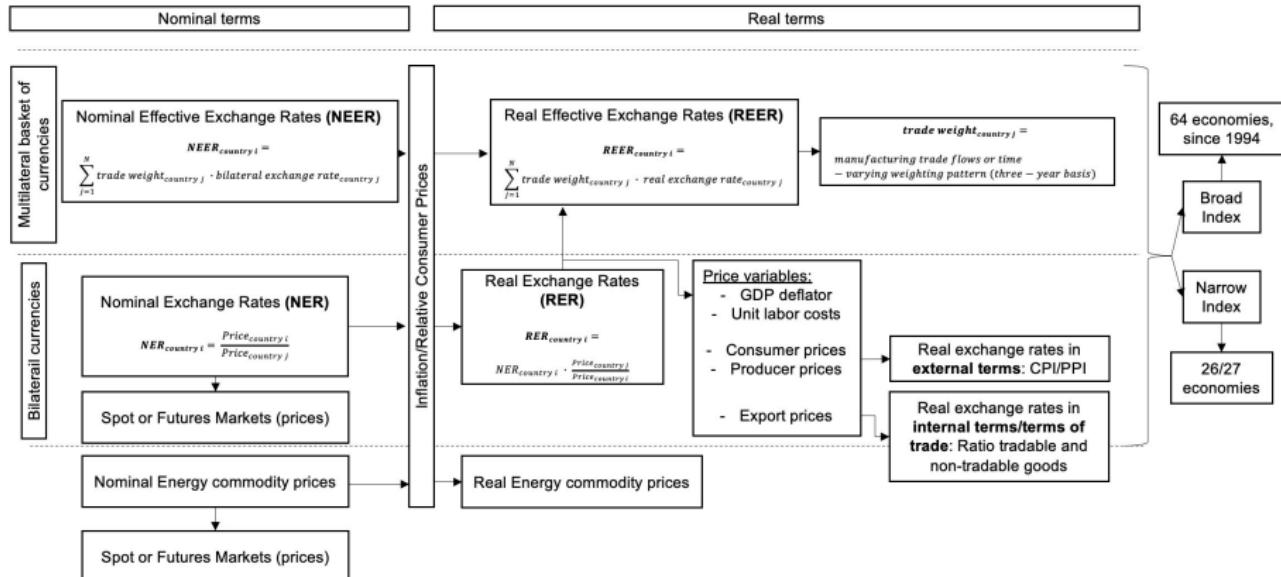


Figure: Schematic overview of prices and measurements of various exchange rate types.¹³

¹³ Own Illustration based on [Ros03], page 8, exchange rates in natural logarithm (geometric averages).

A simple model of exchange rates and commodity prices

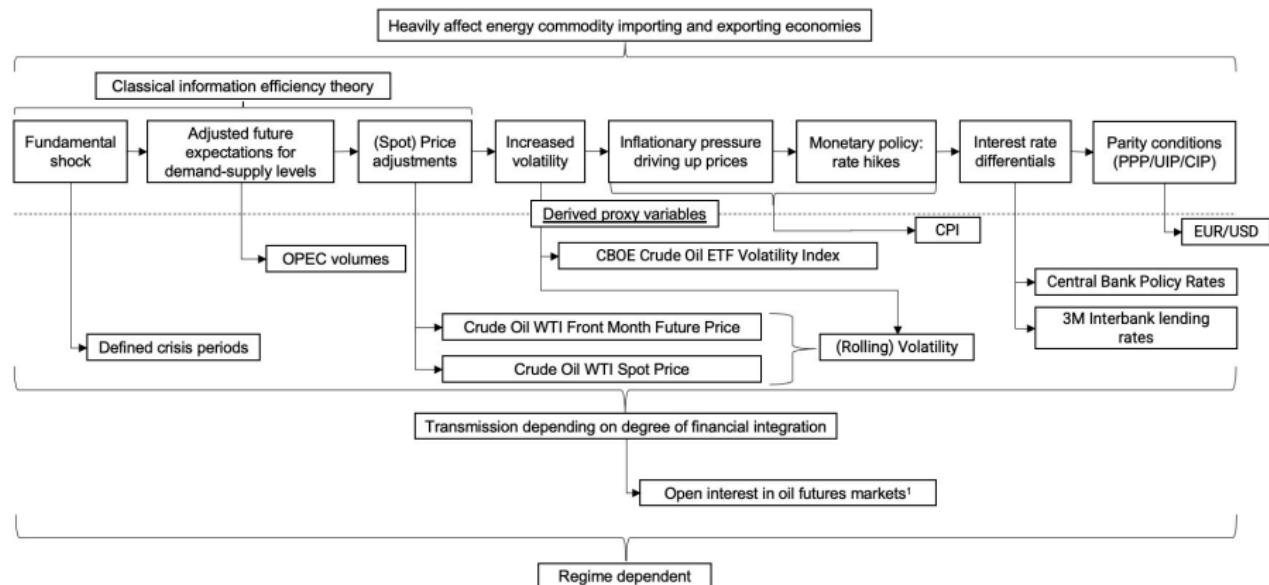


Figure: Main theoretical framework for the seminar project analysis, inflation pass-through effect of energy commodity prices.¹⁴

¹⁴ Own Illustration based on [OUS20], Figure 3, page 3.

Theoretical Framework (I)

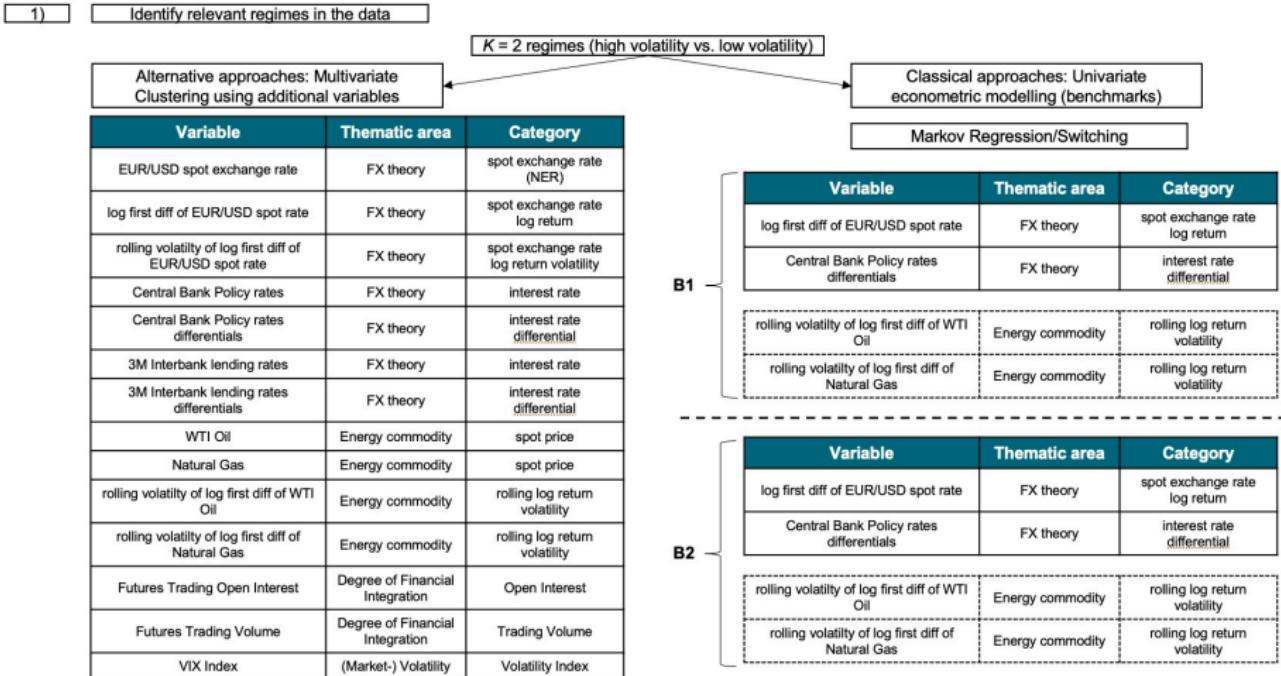


Figure: Main theoretical framework for the seminar project analysis, main variables and benchmark models used.¹⁵

¹⁵Own Illustration.

Theoretical Framework (II)

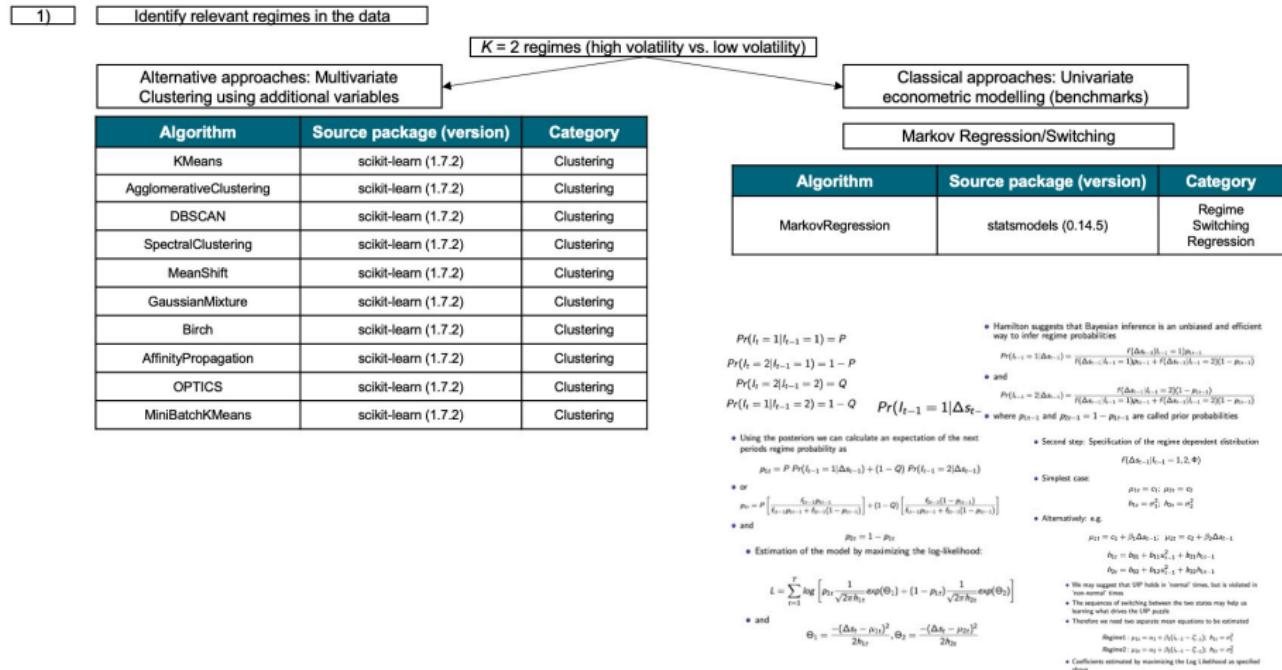


Figure: Main theoretical framework for the seminar project analysis, main algorithms used.¹⁶

¹⁶ Own Illustration based on formulas taken from [Rei25], section "Modeling Nonlinearities I: Markov-Switching", page 7-15.

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: Main theoretical framework for the seminar project analysis, main evaluation metrics and crisis periods used.¹⁷

¹⁷ Own Illustration based on data taken from [St 25], last accessed 24.10.25

Methodology Overview

Systematic Methodology Overview: Linear vs. Non-linear approaches

Data Characteristics and Stylized Facts

Interest Rate Benchmarks

Main variables distributions (raw data - normalized)

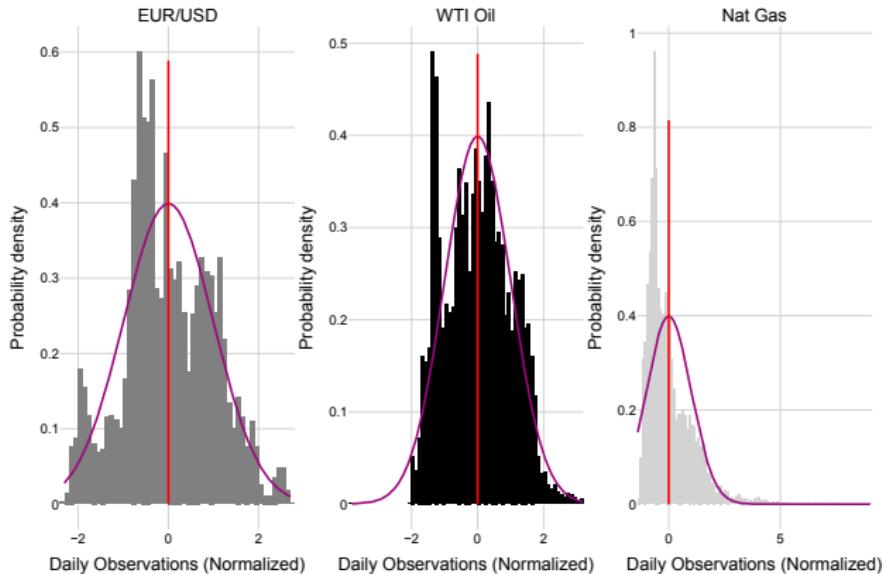


Figure: Normalized daily EUR/USD spot exchange rate, oil and gas over the time range: 1999 - 2025.¹⁸

¹⁸Own Illustration based on [CPT24], page X and data taken from [St 25], last accessed 24.10.25.

Main variables distributions (log first differences)

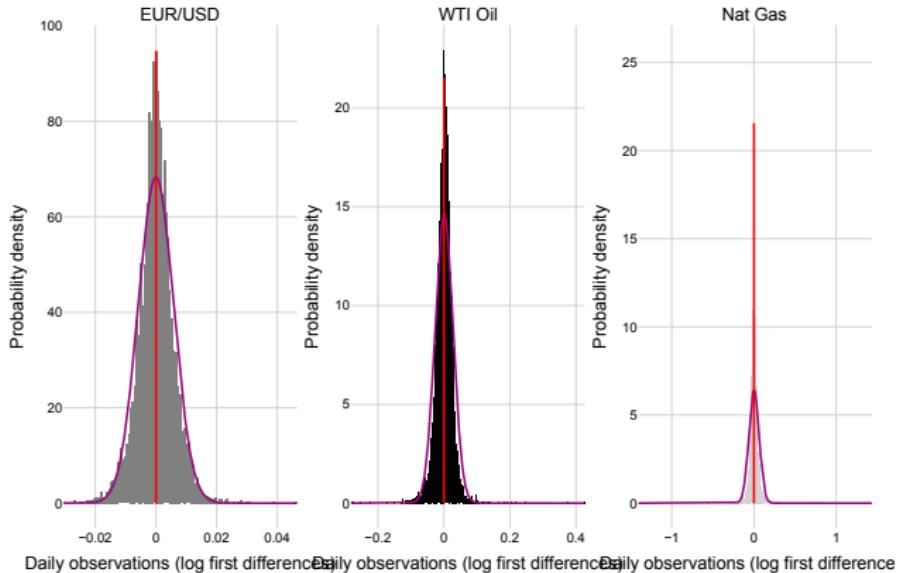


Figure: Log first differences of daily EUR/USD spot exchange rate, oil and gas over the time range: 1999 - 2025.¹⁹

¹⁹ Own Illustration based on [CPT24], page X and data taken from [St 25], last accessed 24.10.25.

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 Own Illustration based on XX, page X, tests used from: [Vir+25] and data taken from: [St 25], last accessed 24.10.25.



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 Own Illustration based on XX, page X, tests used from: [SP10] and data taken from [St 25], last accessed 24.10.25.

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

²²Own Illustration based on XX, page X, tests used from: [SP10] and data taken from [St 25], last accessed 24.10.25.



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

²³ Own Illustration based on XX, page X, tests used from: [SP10] and data taken from [St 25], last accessed 24.10.25.

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

²⁴ Own Illustration based on XX, page X, tests used from: [SP10] and data taken from [St 25], last accessed 24.10.25.

Tests for Autocorrelation (raw data)

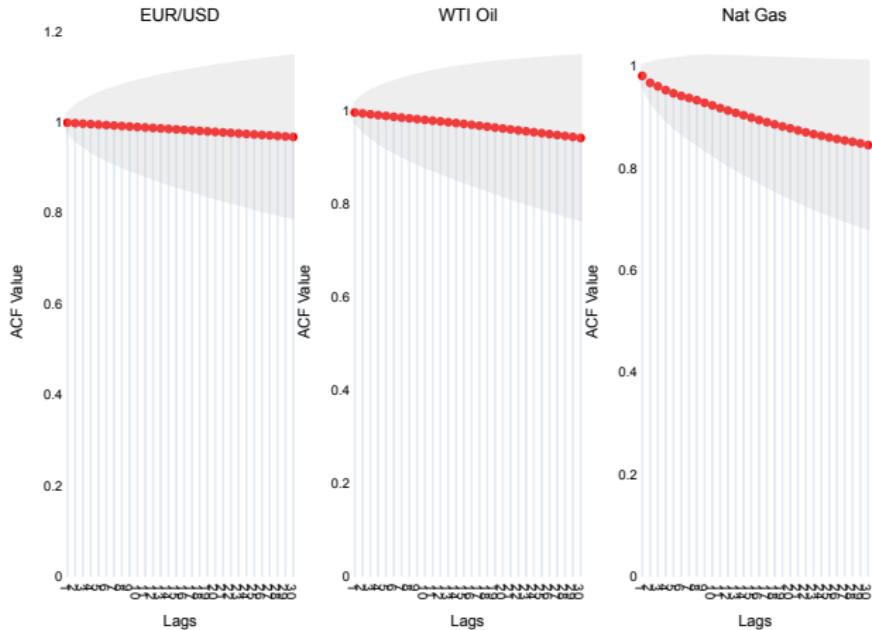


Figure: ACF values for daily observations of the EUR/USD spot exchange rate, oil and gas over the time: 1999 - 2025.²⁵

²⁵Own Illustration based on XX, page X, tests used from: [SP10] and data taken from [St 25], last accessed 24.10.25.

Tests for Autocorrelation (log first differences)

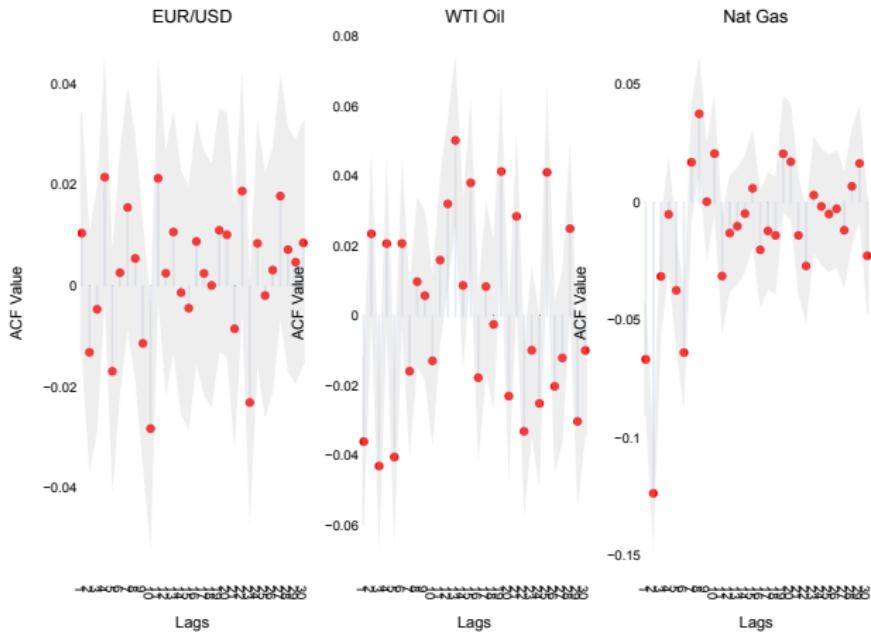


Figure: ACF values for daily observations (log first differences) of the EUR/USD spot exchange rate, WTI Oil and Natural Gas over the time: 1999 - 2025.²⁶

²⁶Own Illustration based on XX, page X, tests used from: [SP10] and data taken from [St 25], last accessed 24.10.25.

Tests for Partial Autocorrelation (raw data)

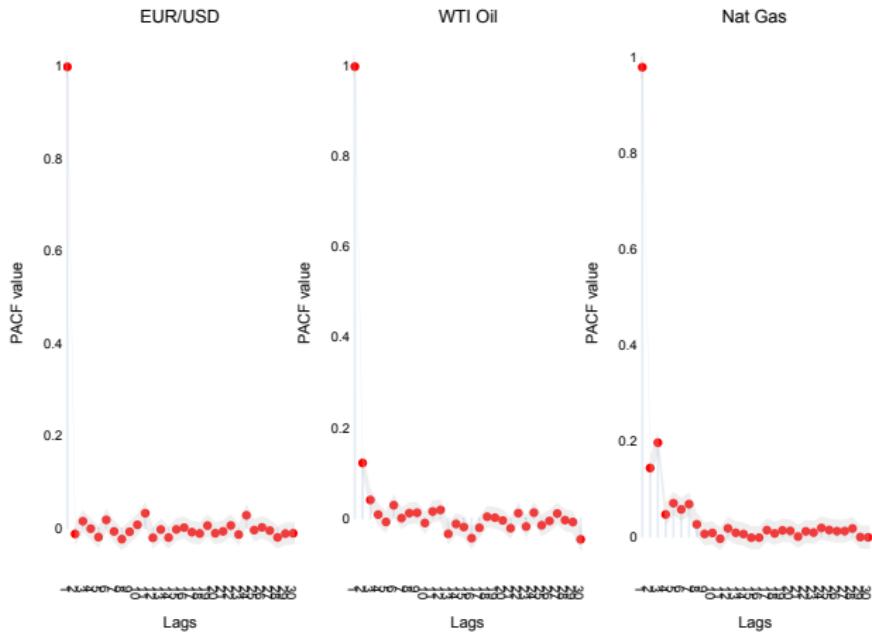


Figure: PACF values for daily observations of the EUR/USD spot exchange rate, WTI Oil and Natural Gas over the time: 1999 - 2025.²⁷

²⁷ Own Illustration based on XX, page X, tests used from: [SP10] and data taken from [St 25], last accessed 24.10.25.

Tests for Partial Autocorrelation (log first differences)

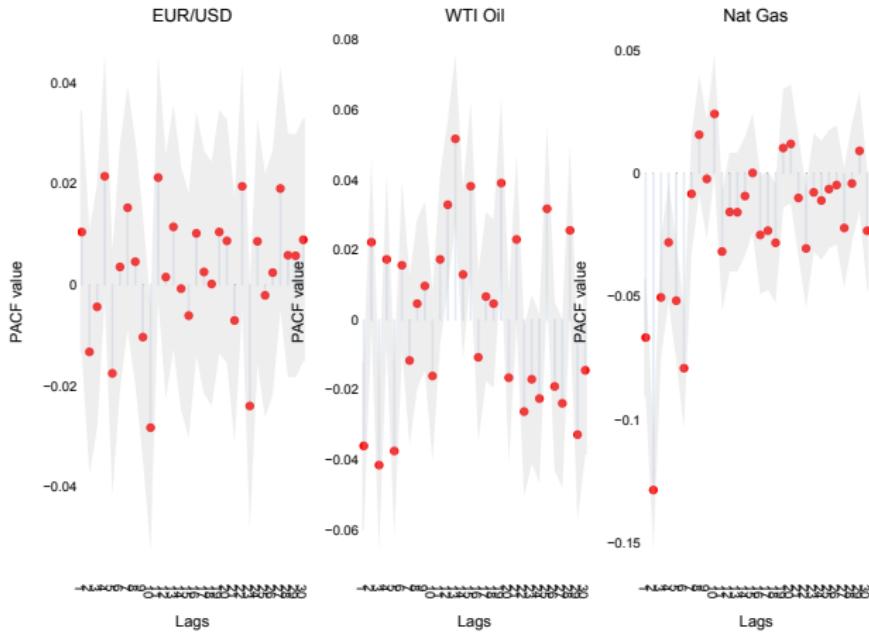


Figure: PACF values for daily observations (log first differences) of the EUR/USD spot exchange rate, WTI Oil and Natural Gas over the time: 1999 - 2025.²⁸

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

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

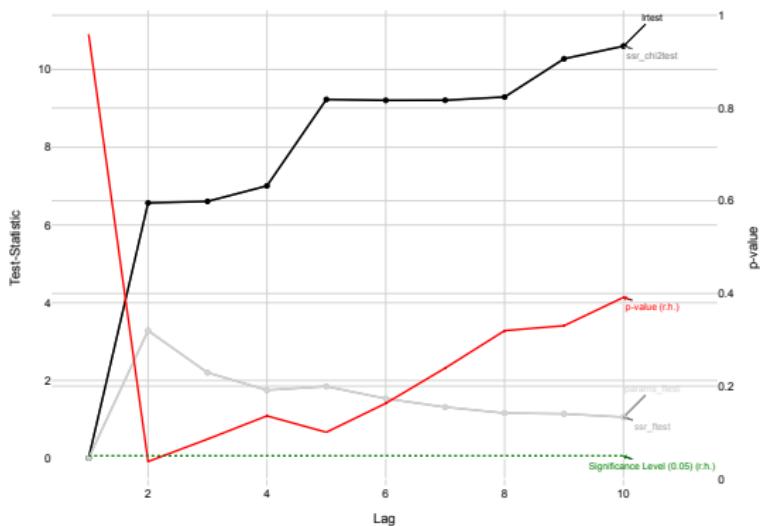


Figure: Granger causality test results testing granger causality of daily observations of oil for EUR/USD spot exchange rate over the time: 1999 - 2025.²⁹

²⁹ Own Illustration based on XX, page X, tests used from: [SP10] and data taken from [St 25], last accessed 24.10.25.

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

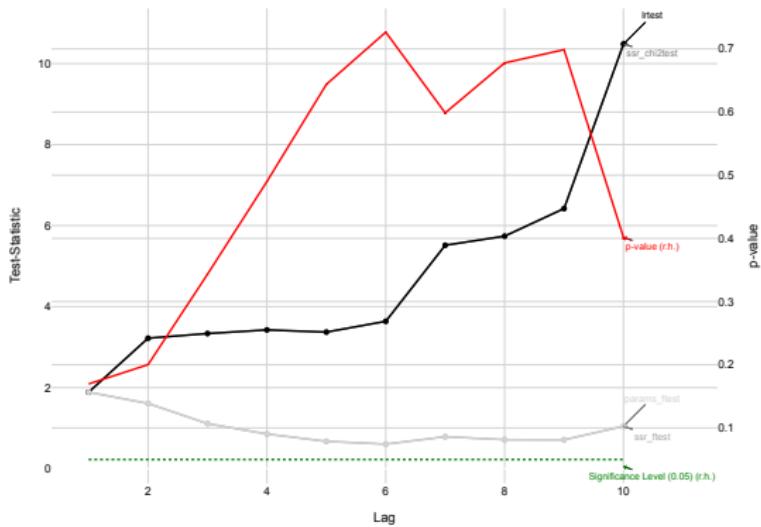


Figure: Granger causality test results testing granger causality of daily observations of gas for EUR/USD over the time: 1999 - 2025.³⁰

³⁰ Own Illustration based on XX, page X, tests used from: [SP10] and data taken from [St 25], last accessed 24.10.25.

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

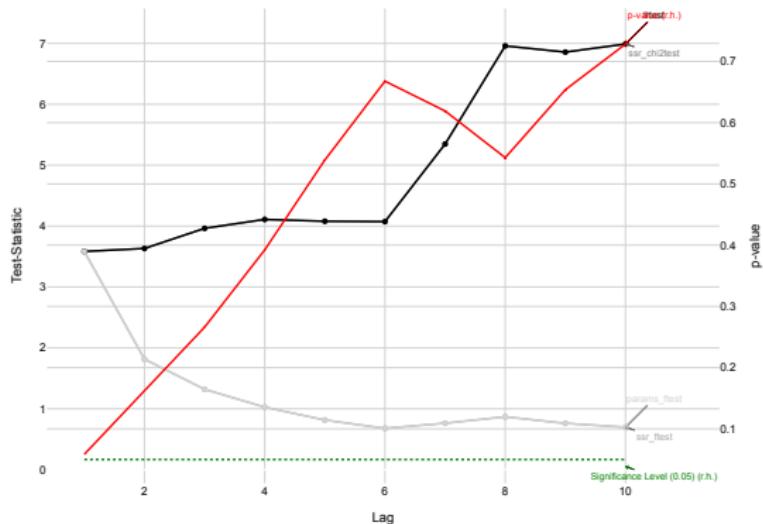


Figure: Granger causality test results testing granger causality of daily observations (log first differences) of WTI Oil for EUR/USD over the time: 1999 - 2025.³¹

³¹ Own Illustration based on XX, page X, tests used from: [SP10] and data taken from [St 25], last accessed 24.10.25.

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

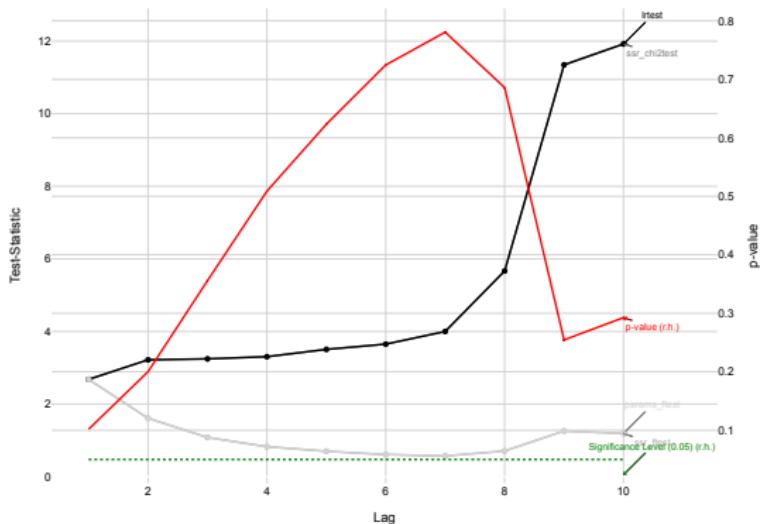


Figure: Granger causality test results testing granger causality of daily observations (log first differences) of Natural Gas for EUR/USD over the time: 1999 - 2025.³²

³²Own Illustration based on XX, page X, tests used from: [SP10] and data taken from [St 25], last accessed 24.10.25.

Model Results

Model comparison and selection

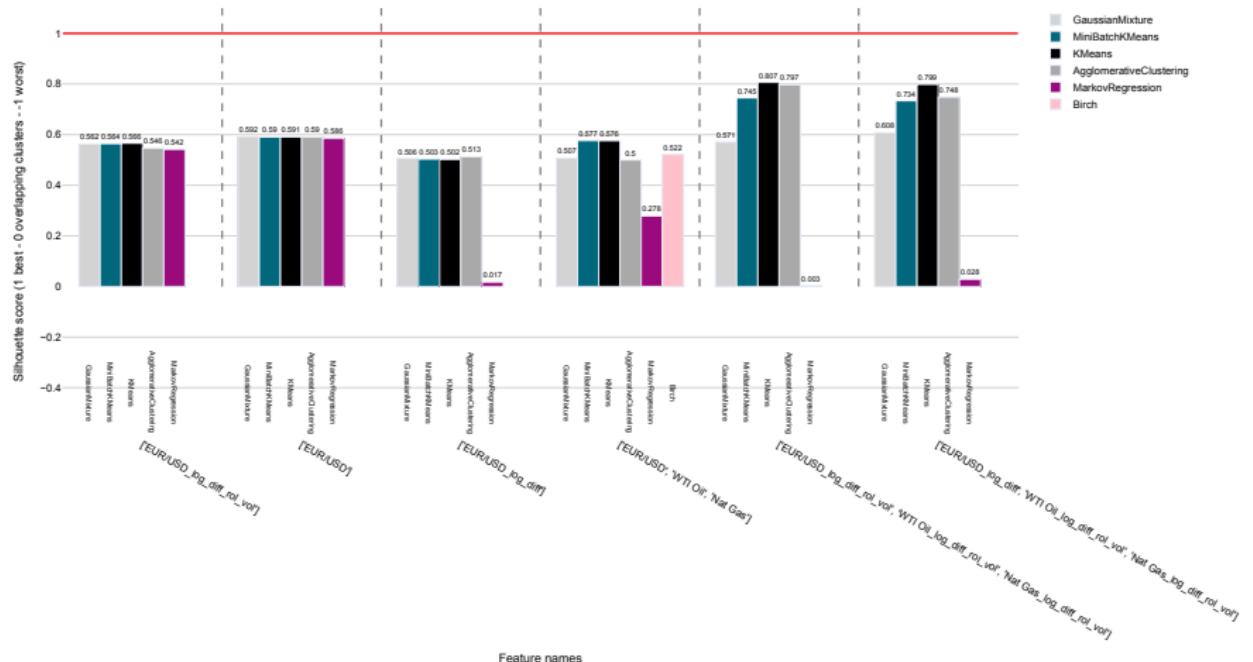


Figure: Model comparison using the silhouette score for various regime identification model configurations.³³

³³ Own Illustration based on XYZ (2000), page 7 and data taken from [St 25], last accessed 24.10.25.

Predicted Regimes - Evolution over time with highlighted Crisis Periods

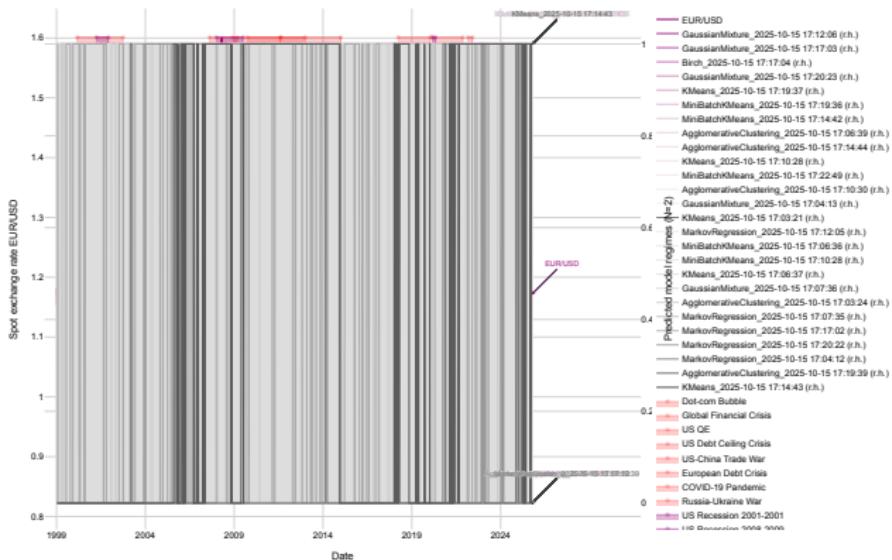


Figure: Predicted regimes over time with highlighted crisis periods.³⁴

³⁴ Own Illustration based on XYZ (2000), page 7 and data taken from [St 25], last accessed 24.10.25.

Conclusion and Discussion

Seminar Project Summary

Seminar Project Limitations

Evaluation Metrics

Only used one metric for clustering (Silhouette Score).

Future Research - Possible Extensions

Other Spot rate pairs

Extend the Analysis to other Spot Exchange Rate Pairs (focus on the Commodity Currencies with a strong Commodity Linkage)

Other commodities

Extend the Analysis to also include other Commodities (e.g. Natural Gas, Brent Oil, Gold, etc.)

Other macroeconomic/external variables

Extend the Analysis by incorporating other Macroeconomic Variables (e.g. Interest Rates, Inflation Rates, etc.)

Other data frequencies

Extend the Analysis by using intraday data to capture more granular dynamics

Appendix

Appendix - Figures and Tables

Appendix - Figures and Tables

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.³⁵

³⁵ See: XXX

Appendix - Data and Definitions

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 caption³⁶

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: [oecd 2025 purchasing power parities]

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 Definition taken from [Int25].

³⁸ Definition taken from [Int25].

³⁹ Definition taken from [CR18], page 5.

⁴⁰ Definition taken from [CR18], page 5.

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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