Interim Report: Change Point Analysis of Brent Oil Prices

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Project: Week 11 Challenge - Birhan Energies

Executive Summary

This interim report presents the foundational work for analyzing how major political and economic events affect Brent oil prices using Bayesian change point detection methods. The analysis aims to identify structural breaks in oil prices and associate them with significant geopolitical events, OPEC policy changes, and economic crises.

1. Analysis Workflow

1.1 Data Acquisition and Preparation

1. Load historical Brent oil price data (May 1987 - November 2022)
2. Handle mixed date formats and data quality issues
3. Compute derived features (log returns, rolling statistics)
4. Merge with major events dataset

1.2 Exploratory Data Analysis

1. Visualize price trends and volatility patterns
2. Test for stationarity (ADF, KPSS tests)
3. Analyze return distributions
4. Identify potential structural breaks visually

1.3 Bayesian Change Point Modeling

1. Define PyMC model with discrete change point prior

2. Specify likelihood function with switch mechanism

3. Run MCMC sampling with convergence checks

4. Extract posterior distributions for change points

1.4 Results Interpretation

1. Identify most probable change point dates

2. Quantify parameter changes (mean, volatility)

3. Associate detected changes with documented events

4. Calculate impact percentages and confidence intervals

1.5 Communication

1. Create interactive dashboard (Flask + React)

2. Generate visualizations for stakeholders

3. Write comprehensive final report

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2. Major Events Dataset

We have compiled 18 major events that potentially impacted Brent oil prices between 1987-2022:

Event	Date	Type	Expected Impact
Gulf War Invasion	1990-08-02	Conflict	Price Increase
Asian Financial Crisis	1997-07-02	Economic Crisis	Price Decrease
OPEC Production Cuts	1999-03-23	OPEC Policy	Price Increase
September 11 Attacks	2001-09-11	Geopolitical	Price Decrease
Iraq War Begins	2003-03-20	Conflict	Price Increase
Global Financial Crisis Peak	2008-07-11	Economic Crisis	Price Decrease
Lehman Brothers Collapse	2008-09-15	Economic Crisis	Price Decrease
Arab Spring Libya	2011-02-15	Conflict	Price Increase
ISIS Captures Mosul	2014-06-20	Conflict	Price Increase

| Event	Date	Type	Expected Impact
OPEC Refuses to Cut	2014-11-27	OPEC Policy	Price Decrease
Iran Nuclear Deal	2015-07-14	Sanctions	Price Decrease
OPEC Production Agreement	2016-11-30	OPEC Policy	Price Increase
US Withdraws Iran Deal	2018-05-08	Sanctions	Price Increase
OPEC+ Price War	2020-03-06	OPEC Policy	Price Decrease
COVID-19 Pandemic	2020-03-11	Economic Crisis	Price Decrease
Negative Oil Prices	2020-04-20	Economic Crisis	Price Decrease
Russia Ukraine Invasion	2022-02-24	Conflict	Price Increase
EU Russian Oil Ban	2022-06-02	Sanctions	Price Increase

3. Initial EDA Findings

3.1 Data Overview

Metric	Value
Total Observations	9,011 daily records
Date Range	May 20, 1987 to November 14, 2022
Trading Days	12,962 calendar days
Missing Values	0

3.2 Price Time Series with Major Events

The figure below shows the complete Brent oil price series from 1987 to 2022, with vertical lines marking major events color-coded by type (Conflict, OPEC Policy, Economic Crisis, Sanctions, Geopolitical).

Brent Crude Oil Prices (1987-2022) with Major Events
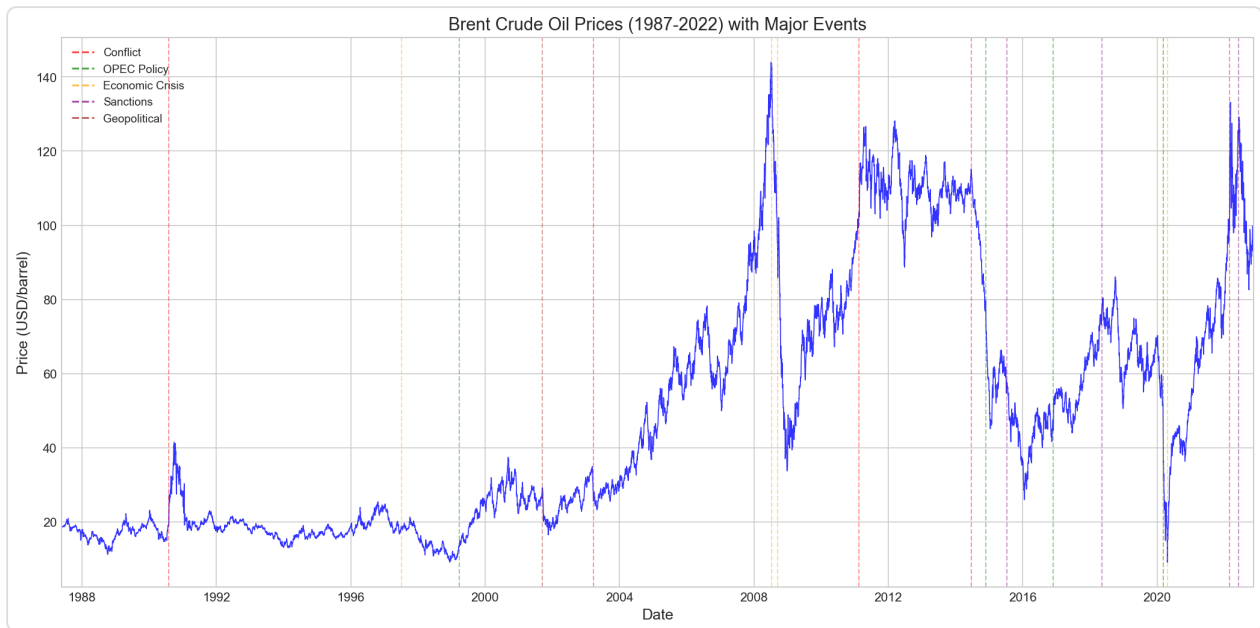
Key Observations:

- Clear structural breaks visible around major events

- Gulf War (1990), 2008 Financial Crisis, 2014 OPEC price war, and COVID-19 (2020) show dramatic price changes

- Long-term upward trend from ~$20 to $100+ with significant volatility

3.3 Price Statistics

| Statistic	Value
Mean Price	$48.42
Median Price	$38.57
Standard Deviation	$32.86
Minimum Price	$9.10 (December 10, 1998)
Maximum Price	$143.95 (July 3, 2008)
Price Range	$134.85

3.4 Price Distribution Analysis
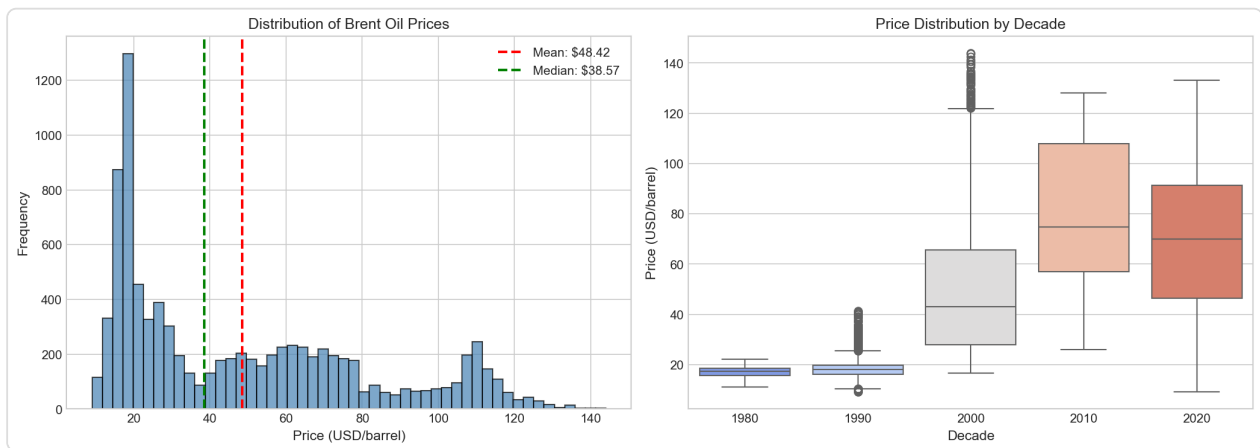
Key Observations:

- Right-skewed distribution with most prices below $60
- Mean ($48.42) higher than median ($38.57) indicates positive skew
- Significant evolution across decades: 1980s-1990s concentrated below $30, 2000s-2010s spread to $100+

3.5 Yearly Average Prices
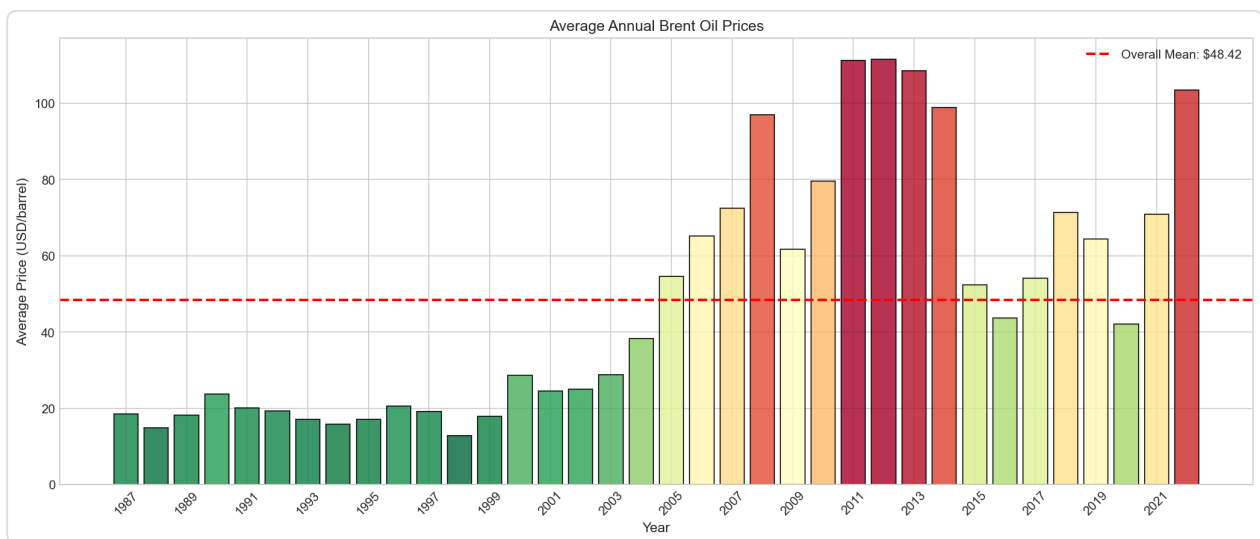
Key Observations:

- Dramatic price increase from 2003-2008 (Iraq War, economic growth)
- Peak in 2008, 2011-2013 period with prices above $100
- Sharp decline in 2014-2016 (OPEC price war)
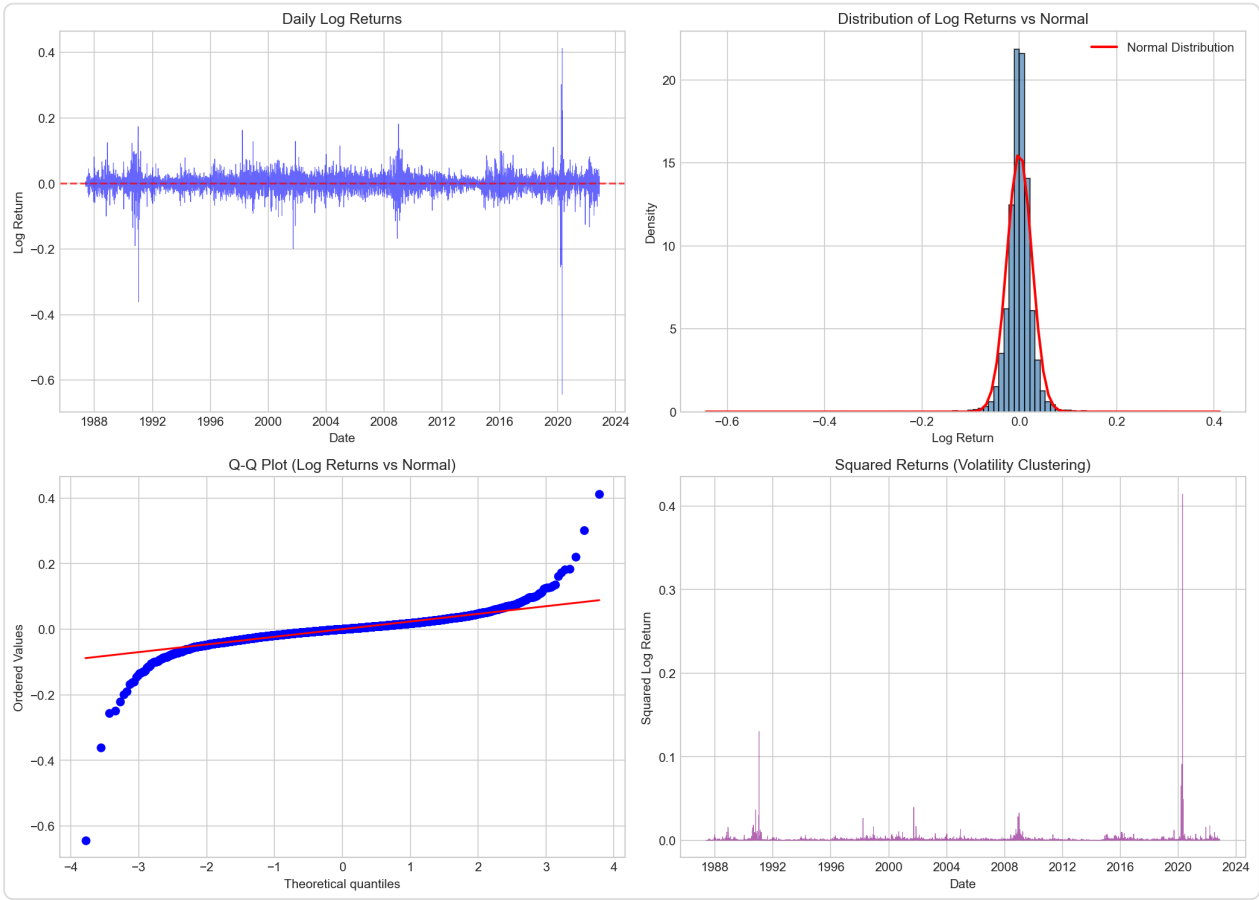- COVID-19 impact visible in 2020 low

3.6 Rolling Statistics (Mean and Volatility)
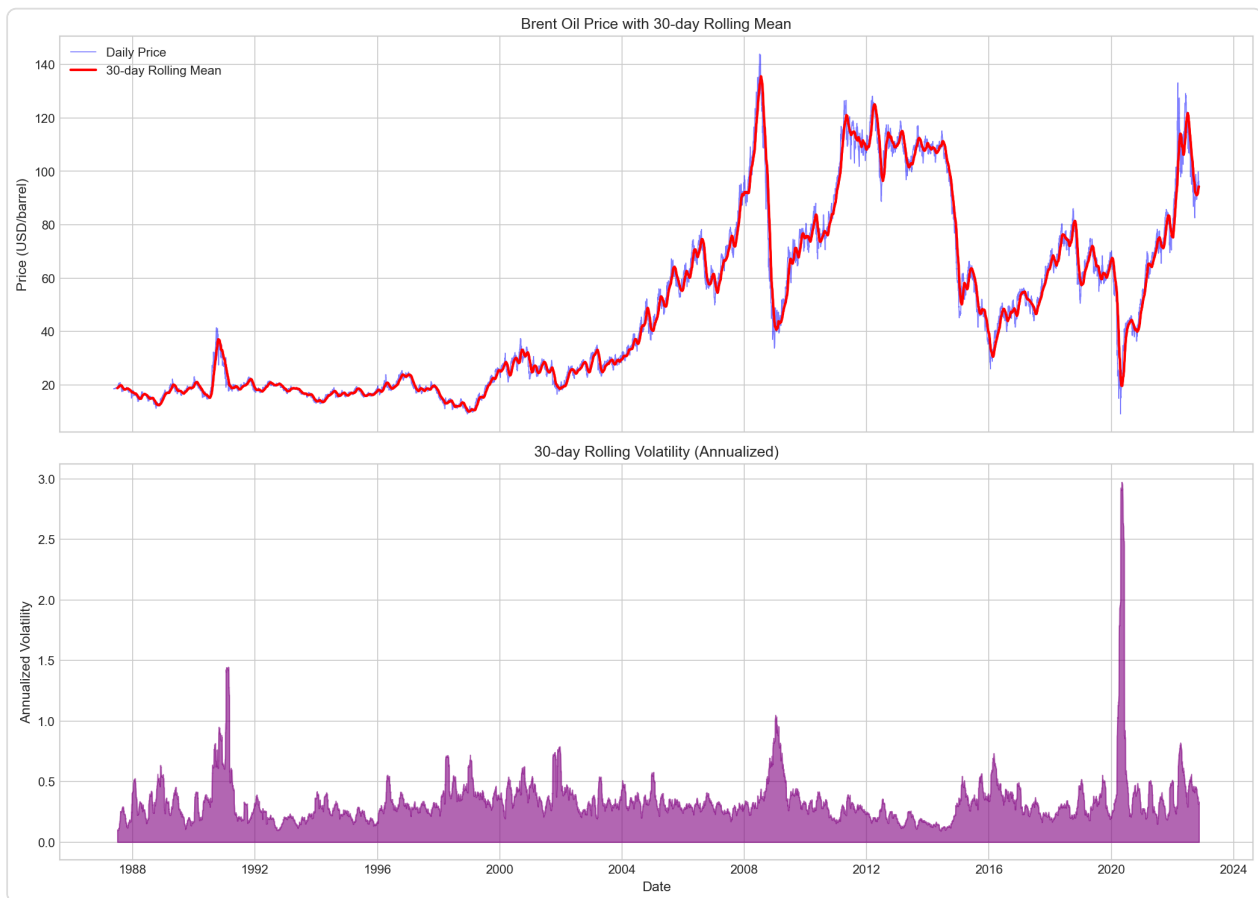
Key Observations:

- Rolling mean tracks price trends smoothly
- Volatility spikes correspond to major events
- 2008 and 2020 show extreme volatility periods
- Volatility tends to cluster (high volatility followed by high volatility)

3.7 Log Returns Analysis

Key Statistical Properties:

Statistic	Value
Mean Daily Log Return	0.0179%
Standard Deviation	2.5532%
Annualized Volatility	40.53%
Skewness	-1.7444
Kurtosis	65.9047

Key Observations:

- **Negative Skewness**: Large negative price shocks more common than positive ones
- **Extreme Kurtosis (65.9)**: Fat tails - much higher probability of extreme events than normal distribution
- **Q-Q Plot**: Clear deviation from normality in tails
- **Volatility Clustering**: Squared returns show periods of high/low activity

## 3.8 Stationarity Test Results

Raw Prices (Non-Stationary)

Test	Statistic	P-Value	Conclusion
ADF	-1.9939	0.2893	Non-stationary
KPSS	9.5588	0.0100	Non-stationary

Log Returns (Stationary)

Test	Statistic	P-Value	Conclusion
ADF	-16.4271	0.0000	Stationary
KPSS	0.0343	0.1000	Stationary

Implication: Change point models should be applied to log returns or prices within specific time windows for valid statistical inference.

3.9 Volatility by Decade

Market Volatility by Decade
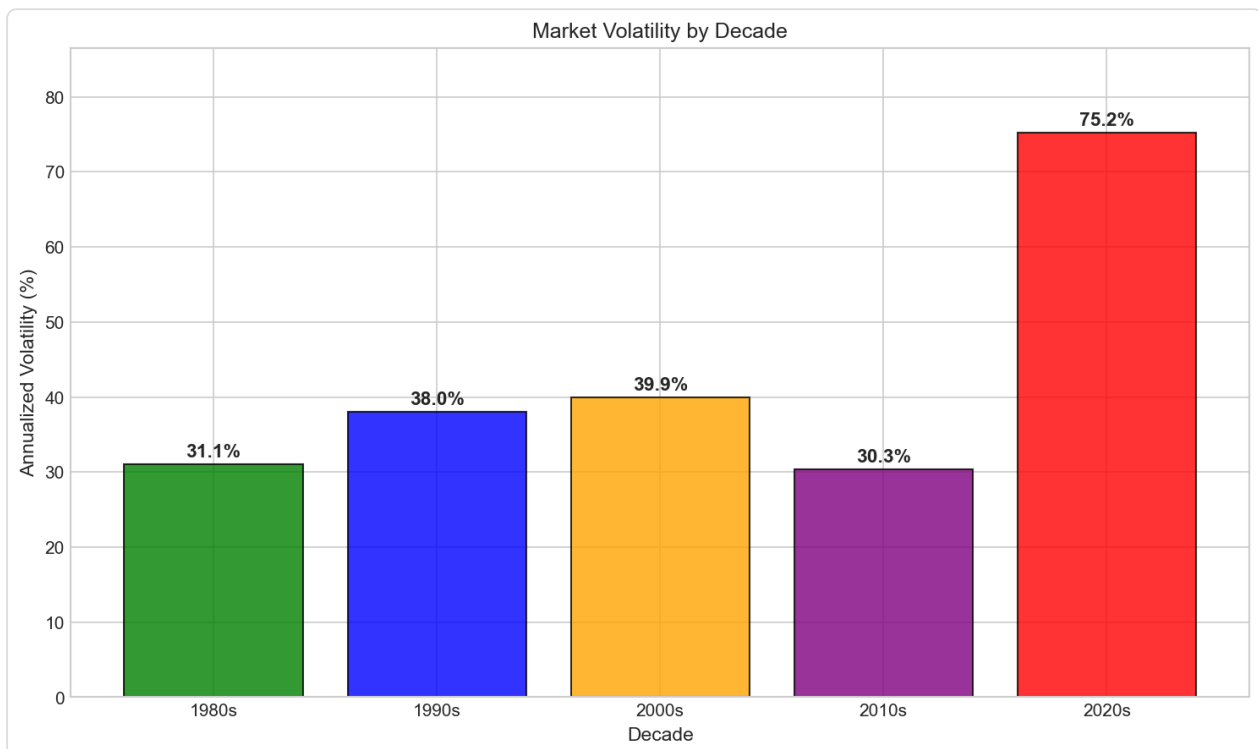
Decade	Annualized Volatility
1980s	31.05%
1990s	37.99%
2000s	39.90%
2010s	30.31%
2020s	**75.23%**

Key Finding: The 2020s show dramatically higher volatility (75.23%) due to the COVID-19 pandemic and subsequent market disruptions - more than double any other decade.

3.10 COVID-19 Period Analysis (2020)

Brent Oil Prices During COVID-19 (2020) - Extreme Volatility Period
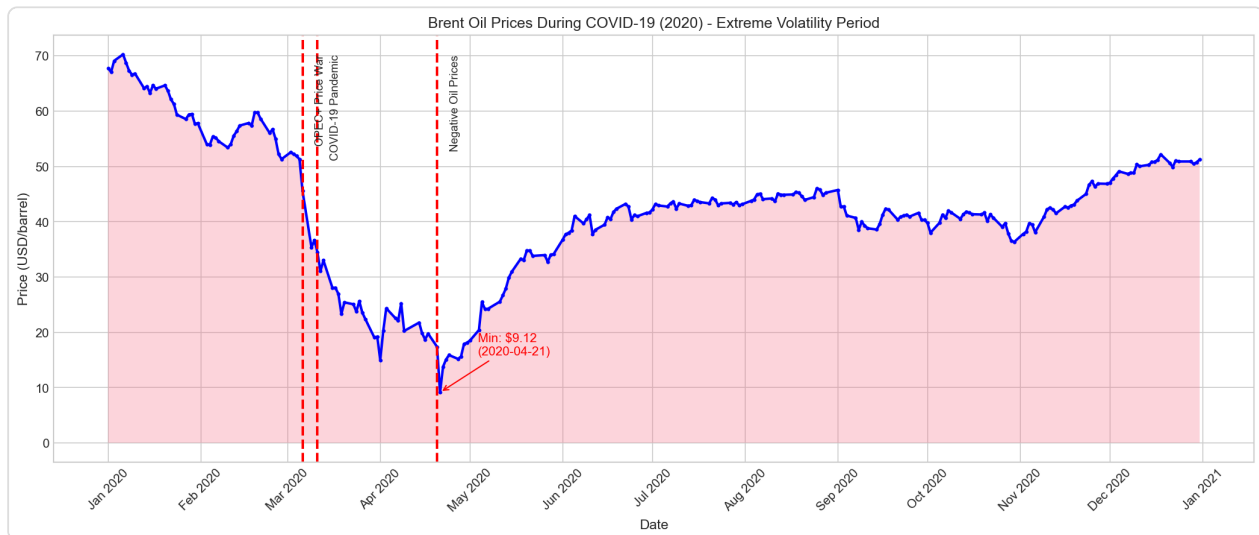
Extreme Events During COVID-19:

Date	Event	Impact
March 6, 2020	OPEC+ Price War	-25% weekly
March 11, 2020	WHO Pandemic Declaration	Continued decline
April 20, 2020	Negative WTI Prices	Historic low
April 21, 2020	**Largest Single-Day Drop**	**-64.37%**
April 22, 2020	**Largest Single-Day Gain**	**+41.20%**

3.11 2008 Financial Crisis Analysis

Brent Oil Prices During 2008 Financial Crisis
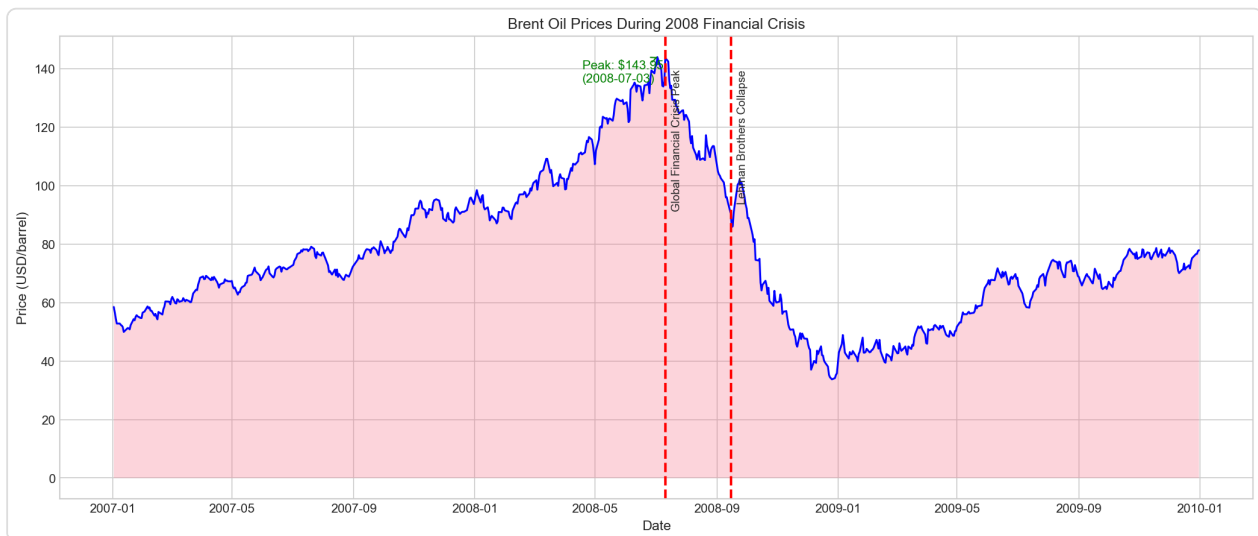
Key Observations:

- Price peaked at $143.95 on July 3, 2008 (all-time high)

- Lehman Brothers collapse (September 15, 2008) triggered rapid decline

- Price dropped from ~$140 to ~$34 in 5 months (76% decline)

- Recovery began in early 2009

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4. Assumptions and Limitations

4.1 Assumptions

1. **Data Quality**: Brent oil price data is accurate and reliable

2. **Event Dating**: Event dates represent the announcement/occurrence timing

3. **Market Efficiency**: Prices reflect available information with some delay

4. **Model Structure**: Simple change point models capture key dynamics

4.2 Limitations

Correlation vs. Causation

Critical Disclaimer: Detecting a statistical change point coinciding temporally with an event does NOT prove that the event caused the change. Multiple factors influence oil prices simultaneously, and:
- Events may be anticipated by markets before official dates

- Multiple events may occur in close proximity
- Confounding factors may not be captured in the model
- Reverse causality or third-variable explanations are possible

Model Constraints

- Single change point models may miss multiple concurrent breaks
- Simple mean-shift models may not capture volatility changes
- Daily data may mask intra-day dynamics
- Historical relationships may not hold for future predictions

Data Constraints

- Limited to publicly available price data
- Market microstructure effects not captured
- Sentiment and expectation effects not directly modeled

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5. Repository Structure

```
week11/
├── data/
│   ├── raw/
│   │   └── BrentOilPrices.csv    # Raw price data (9,011 records)
│   └── processed/
│       └── brent_oil_processed.csv  # Processed with derived features
├── notebooks/
│   ├── 01_eda.ipynb              # Exploratory analysis notebook
│   └── 02_change_point_analysis.ipynb  # Bayesian modeling
├── src/
│   ├── __init__.py
│   ├── data_loader.py            # Data loading utilities
│   └── analysis.py               # Analysis functions
├── events/
│   └── major_events.csv          # 18 key events dataset
├── reports/
│   ├── interim_report.md         # This report
│   ├── figures/                  # EDA visualizations
│   └── final_report.md           # Final submission
├── scripts/
│   ├── download_data.py          # Data preparation
│   ├── run_eda.py                # EDA statistics
│   └── generate_eda_plots.py     # Visualization generation
```

```
├── docs/
│   └── analysis_workflow.md        # Workflow documentation
└── dashboard/
    ├── backend/                    # Flask API (Task 3)
    └── frontend/                   # React frontend (Task 3)
```

6. Next Steps

1. ~~Complete EDA~~: ✅ Finalized exploratory analysis with visualizations

2. **Implement PyMC Model**: Build and validate Bayesian change point detection

3. **Run Analysis**: Apply model to multiple time periods around key events

4. **Quantify Impacts**: Generate probabilistic statements about price changes

5. **Build Dashboard**: Develop Flask backend and React frontend

6. **Final Report**: Compile comprehensive findings and recommendations

7. References

1. PyMC Documentation: https://www.pymc.io/

2. Bayesian Changepoint Detection: https://docs.pymc.io/

3. Change Point Detection Methods: https://forecastegy.com/posts/change-point-detection-time-series-python/

4. MCMC Methods: https://towardsdatascience.com/monte-carlo-markov-chain-mcmc-explained-94e3a6c8de11

5. U.S. Energy Information Administration: https://www.eia.gov/

Submitted for 10 Academy Week 11 Challenge - Interim Deadline