Volatility Estimator Analysis

Introduction

This project provides an overview of how volatility is defined, measured, and interpreted in the context of financial assets. Volatility is a central concept in risk management and portfolio construction, as it captures the magnitude of price fluctuations and helps investors assess uncertainty in returns across time.

Motivation

When comparing funds or investment strategies, investors often face difficulty in determining which option offers the most attractive risk–reward trade-off. While many platforms provide volatility metrics for assets and mutual funds, these figures are frequently presented without sufficient context, making them hard to interpret or compare meaningfully. For this project, we have built a tool that computes and compare different volatility measures on the same asset. We first start off with simple historical volatility using log returns and then add rolling windows (20, 60, 120 days) and an EWMA version to capture recent shocks faster. To make it more realistic, we will extend the analysis by comparing realized volatility before and after macro events like CPI or CB meetings.

Scope of Analysis

For our project, we will be analysing volatility through the use of **Simple Rolling Windows, Exponential-Weighted Moving Averages, Realised Volatility**, as well as **standard deviation, correlation, alpha and beta** when comparing our asset portfolio with a benchmark (SPY).

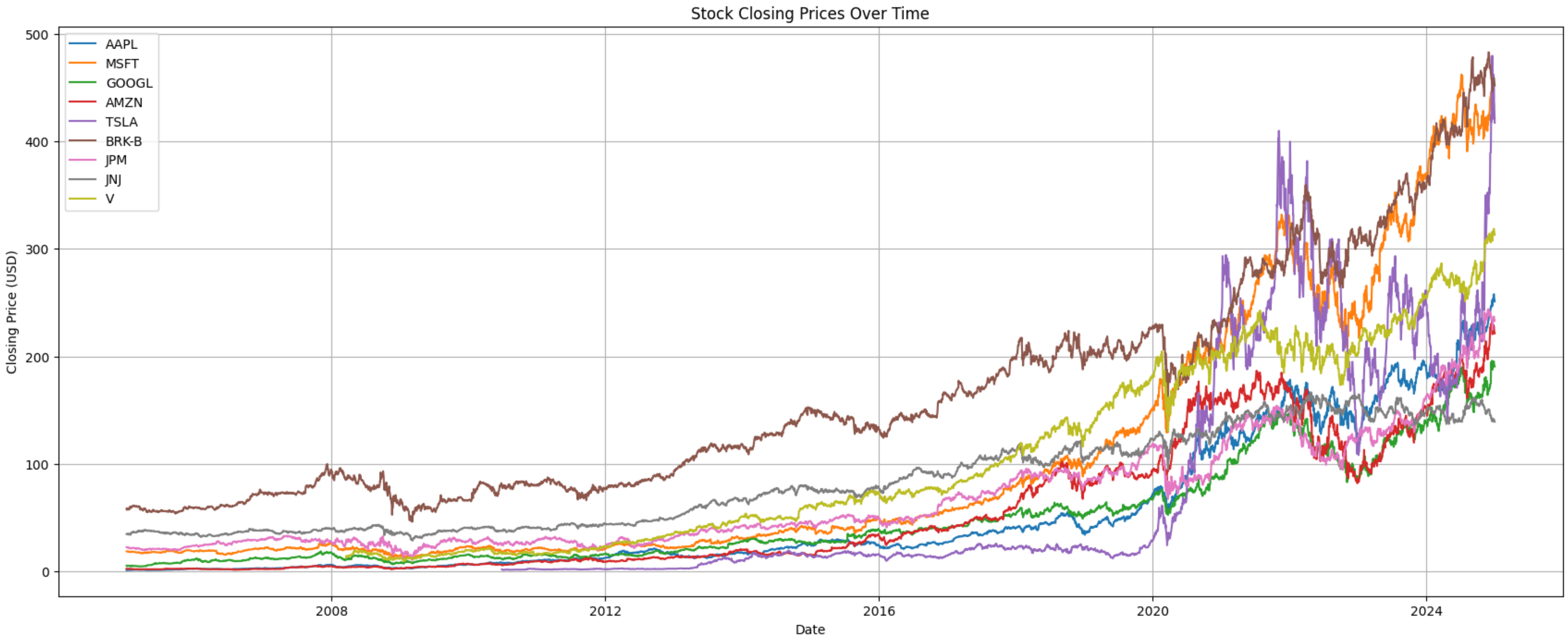
Period of analysis: Up to individual to decide
Dataset: Yahoo Financial data from 2005 to 2025 (Frequency of 1-Day)
Assets in focus (ticker symbols): AAPL, MSFT, GOOGL, AMZN, TSLA, BRK-B, JPM, JNJ, V
Benchmark: SPY

To analyse volatility in greater detail, the analysis is augmented with major macro-economic shocks and market events that occurred during the sample period. These events are used to contextualise spikes in volatility and assess how markets respond to periods of systemic stress. The macro-economic events considered are as follows:

Event	Start Date	End Date
Global Financial Crisis	2008-09-15	2009-03-09
European Debt Crisis	2010-04-23	2012-07-31
US Debt Ceiling Crisis & S&P Downgrade	2011-07-25	2011-10-14
Chinese Stock Market Turbulence	2015-06-12	2015-09-30
Brexit Referendum	2016-06-23	2016-07-11
2018 Stock Market Sell-Off	2018-01-26	2018-02-08
COVID-19 Pandemic	2020-02-20	2020-03-23
Russia–Ukraine War	2022-02-24	2022-03-08
US Regional Banking Crisis (SVB, Signature)	2023-03-08	2023-03-17

Our Data at a glance

Pulling our data from YFinance and plotting the closing prices of our assets over time yielded the following chart. As we can see across all assets, we witness a general upward trend from 2005 to 2025, with fluctuations being more pronounced in the latter stages of the analysis period. Volatility, which measures the fluctuations in asset prices, is more pronounced in 2020 to 2025 for a host of reasons which we shall analyse in greater detail below. The price charts alone only paints a small picture, but breaking it down can reveal a lot about how volatility can be measured and minimized in the eyes of financial institutions.



Analysing Volatility

We subset our data to the range from 2018 to 2025, which also coincided with a series of macro-shocks such as Covid-19, Russia-Ukraine war and the Sub-Regional Banking crisis in the US. Now, different assets have different volatilities which can be attributed to a host of reason (we will not cover them in detail in this report). Volatilities are measured using the standard deviation of the asset's daily returns across time. In Mathematical terms, they are represented as follow:

$$r_t = \frac{P_t - P_{t-1}}{P_{t-1}} \qquad \text{or} \qquad r_t = \log\left(\frac{P_t}{P_{t-1}}\right)$$

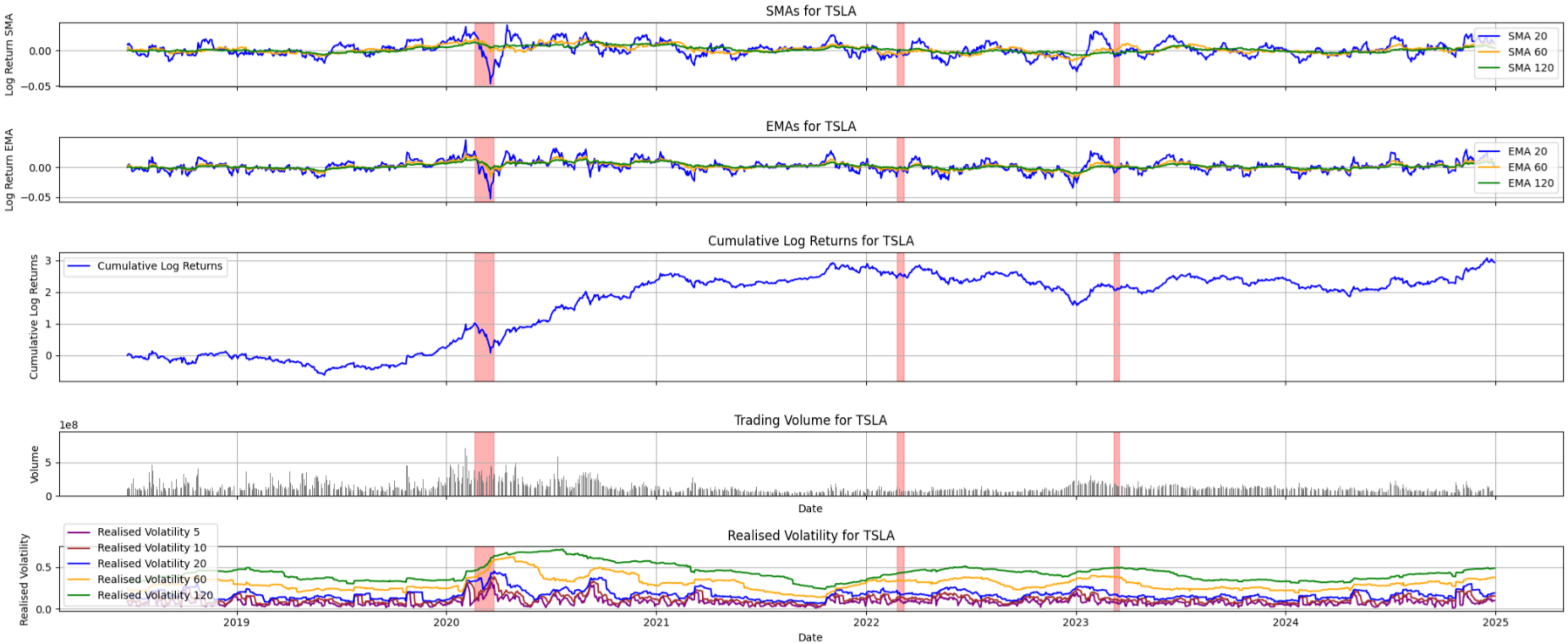
Each asset has different volatilities, and when we benchmark it against an index's volatility, we get a measurement called the Beta β. **Beta** measures an asset's **systematic risk** — how sensitive its returns are to movements in the broader market.

$$\beta_i = \frac{\text{Cov}(r_i, r_m)}{\text{Var}(r_m)}$$

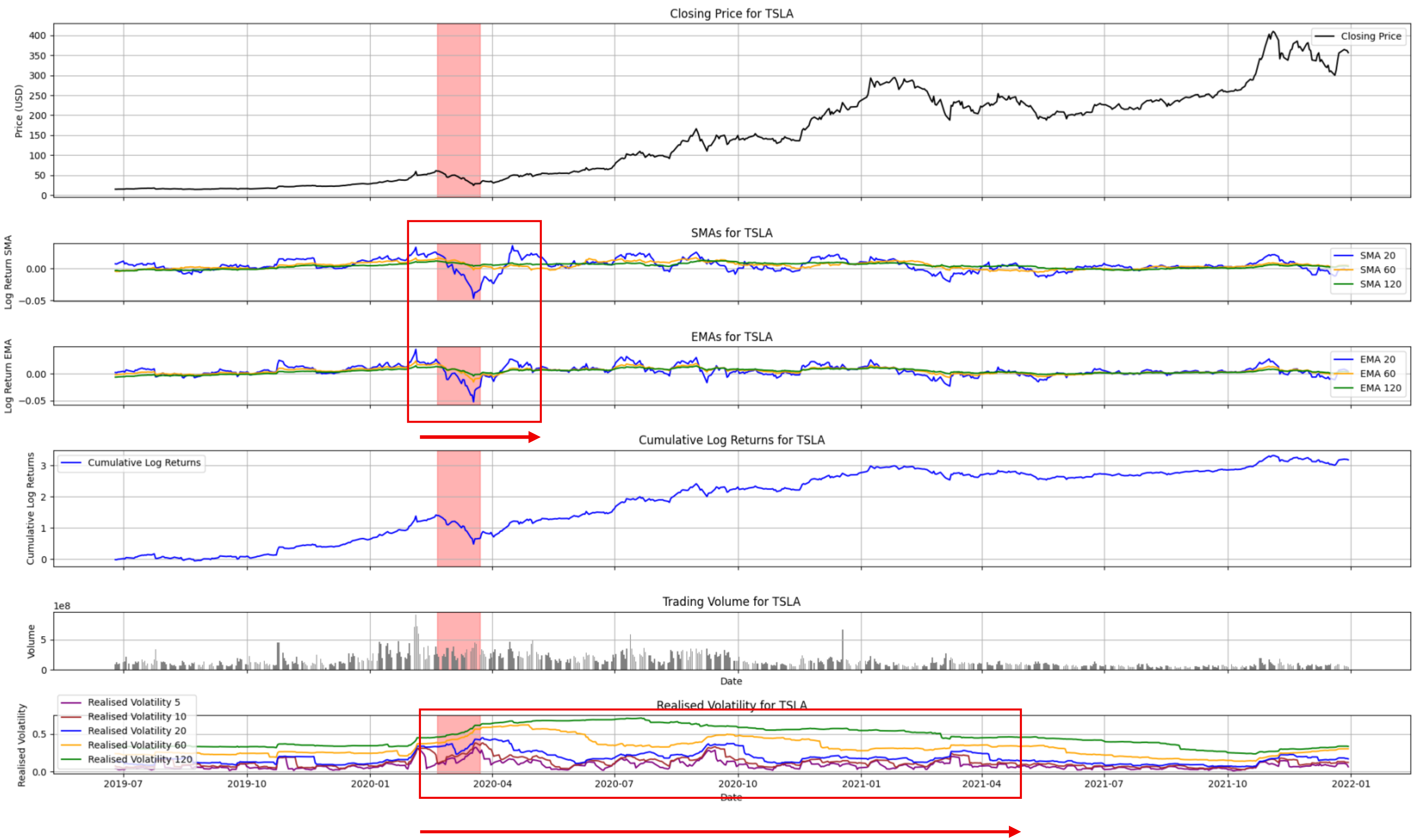
Focusing on one asset

We took a sample asset - TSLA, which is known for its high beta and volatility, and computed the relevant estimators using the daily log-returns over the period from 2018 to 2025.

The vertical red lines represent periods of economic shocks on the macro-scale which has the capacity to cause seismic shifts in the price movements. Notice how for all our charts plotted below, regions with red bars show heightened volatility in the form of sharper MA swings and realized volatility.



If we zoom in on just one macro-shock, we can witness how the measures swing in comparison to other periods. The following chart shows the period from 2019 to 2022, during which Covid-19 sent the entire global economy into a recession. One thing to note is that despite our SMAs and EMAs reverting quickly after a major event, realized volatility continued to persist for some time into the future.



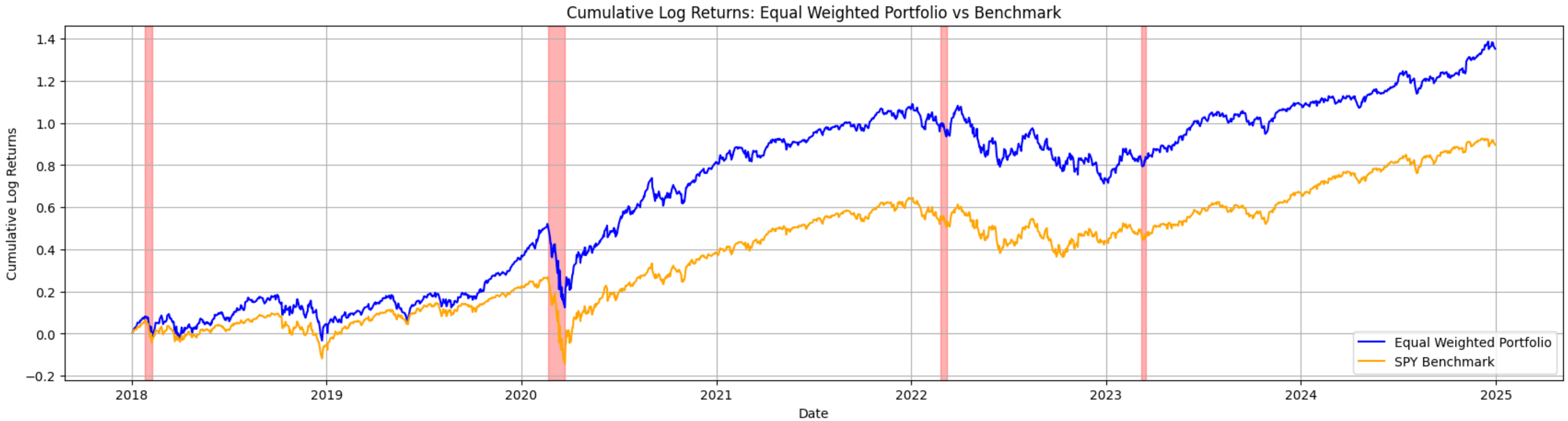
Closing Price for TSLA
Price (USD)
Closing Price
SMAs for TSLA
Log Return SMA
SMA 20
SMA 60
SMA 120
EMAs for TSLA
Log Return EMA
EMA 20
EMA 60
EMA 120
Cumulative Log Returns for TSLA
Cumulative Log Returns
Trading Volume for TSLA
Volume
1e8
Date
Realised Volatility for TSLA
Realised Volatility
Realised Volatility 5
Realised Volatility 10
Realised Volatility 20
Realised Volatility 60
Realised Volatility 120
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01
2021-04
2021-07
2021-10
2022-01
Date

Volatility Comparison with Benchmark

After analysing the volatility measures for a single asset, we extend the analysis by comparing its volatility against an appropriate benchmark, such as a broad market index or sector-specific index. This comparison is important because absolute volatility in isolation provides limited insight into risk; the same level of volatility can be interpreted very differently depending on overall market conditions. By placing the asset's volatility in a relative context, we can assess whether the asset is riskier or more defensive than the market and determine whether observed volatility is driven by systematic market-wide factors or by asset-specific dynamics.

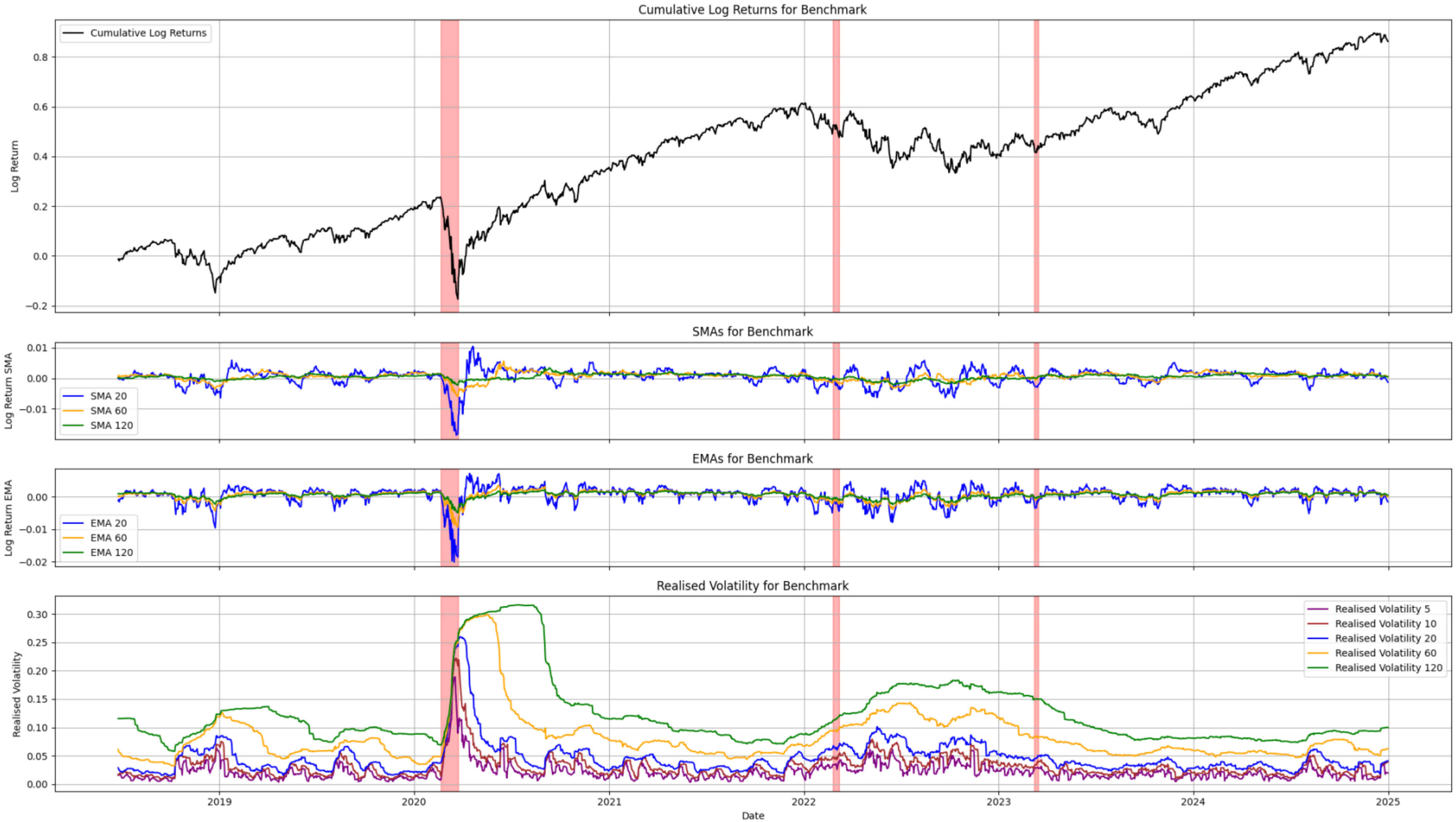
The comparison is conducted using a consistent methodology for both the asset and the benchmark, ensuring that volatility is estimated from log returns, over identical rolling windows, and annualised using the same scaling factors. Relative risk is then evaluated through direct time-series comparison and summary measures such beta, which captures how the asset's volatility is relative to the benchmark over time. Analysing such relationships on a rolling basis allows us to identify periods of divergence, particularly during macroeconomic shocks or market stress events, and to observe how the asset's risk profile changes across different market regimes.

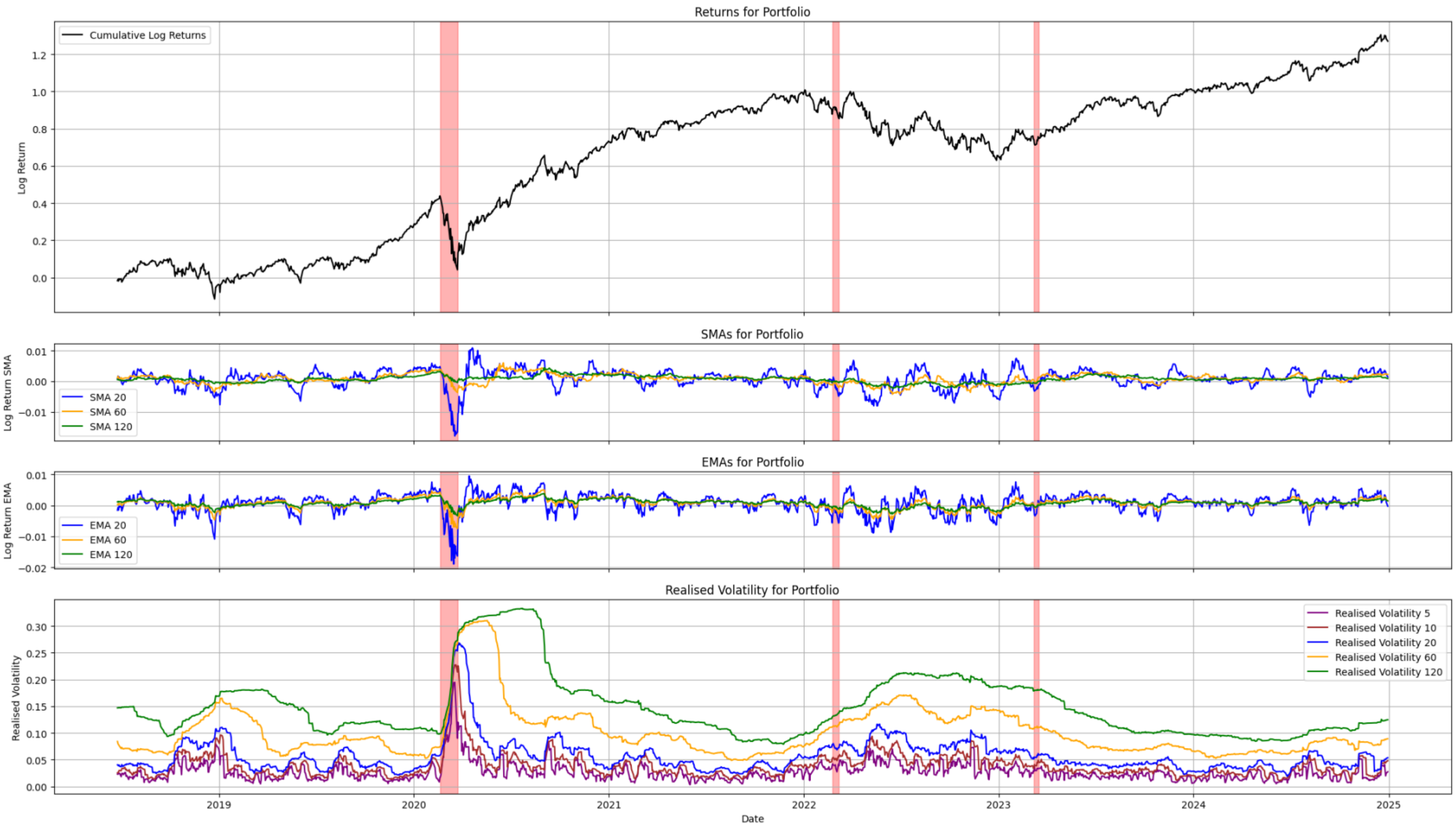
The following chart shows the cumulative log returns of a buy-and-hold equal weighted portfolio against our benchmark (SPY) for the period from 2018 to 2025



Interpreting volatility relative to a benchmark provides valuable insights for portfolio construction and performance evaluation. Persistently higher volatility than the benchmark may warrant smaller position sizes, volatility targeting, or hedging, while lower relative volatility may indicate defensive characteristics or diversification benefits. Overall, benchmark-based volatility comparison enables a more meaningful assessment of risk by embedding asset-level volatility within the broader market context.

We conducted the same analysis of volatility estimate for our SPY benchmark (removing trading volume and price for ease of visualization) and our portfolio over the period from 2018 to 2025, to capture 3 economic macro-shocks. This yielded the charts below.





Returns for Portfolio
Cumulative Log Returns
Log Return
SMAs for Portfolio
Log Return SMA
SMA 20
SMA 60
SMA 120
EMAs for Portfolio
Log Return EMA
EMA 20
EMA 60
EMA 120
Realised Volatility for Portfolio
Realised Volatility
Realised Volatility 5
Realised Volatility 10
Realised Volatility 20
Realised Volatility 60
Realised Volatility 120
Date

Notice the similarity between our portfolio and our benchmark volatility measure? One possible reason could be that the portfolio has **significant exposure to systematic (market) risk**, causing its returns to move closely with overall market fluctuations. If the portfolio is constructed from assets that closely track the benchmark—either through similar sector weights, factor exposures, or high aggregate beta—its volatility will naturally mirror that of the benchmark.

We encourage users to play around with the asset composition and witness the difference in results.

Portfolio Outperformance Relative to Benchmark

To evaluate portfolio outperformance relative to the benchmark, we use a combination of risk and performance measures, including cumulative return, standard deviation, alpha, beta, R-squared, and the Sharpe ratio. Together, these metrics allow us to assess not only whether the portfolio delivers higher returns than the benchmark, but also whether those returns are achieved efficiently and independently of market movements. Cumulative return captures absolute performance over the investment horizon, while standard deviation quantifies the total risk undertaken. Alpha and beta decompose performance into asset-specific excess returns and systematic market exposure, respectively, with beta and R-squared indicating how closely the portfolio's returns track the benchmark. Finally, the Sharpe ratio evaluates risk-adjusted performance by scaling excess returns by volatility, enabling a consistent comparison across different volatility regimes.

	Portfolio	Benchmark
Cumulative Return	1.346598	0.892843
Standard Deviation	0.014451	0.012306
Beta	1.096866	1.0
Sharpe Ratio	0.838748	0.65441
Alpha	0.000209	0.0
R-Squared	0.868851	1.0

By analysing how these metrics vary under different volatility conditions, we gain insight into the robustness of the portfolio's outperformance and its sensitivity to changing market risk.