Forecasting Major Cryptocurrency Prices with SARIMAX

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1 Introduction

Cryptocurrencies have emerged over the last decade as a highly dynamic—and notoriously volatile—asset class. Bitcoin, Ethereum, Solana and their peers can swing by tens of percent in a single trading day, driven by shifts in investor sentiment, technological developments, regulatory news, and broader macroeconomic forces. For traders, portfolio managers, and risk analysts, accurately forecasting short-term price movements in these digital assets remains an open and urgent challenge.

In this study, we tackle two key obstacles in cryptocurrency forecasting. First, we apply spectral filtering (notch-filtered Fourier transforms) to separate high-frequency noise from the underlying trend in each coin's percentage-change series. Second, we enrich our predictive model by incorporating returns on the Standard & Poor's 500 Composite Stock Price Index—as a proxy for traditional market sentiment—as an exogenous regressor in a SARIMAX framework. By marrying signal-processing techniques with modern time-series methods, we aim to capture both the idiosyncratic oscillations of each cryptocurrency and their broader market co-movements.

The expected value of this analysis is threefold:

1. **Improved Short-Horizon Forecasts**: Demonstrate that combining FFT-based detrending with a SARIMAX model—augmented by S & P 500 returns—yields more accurate 10–100 day price forecasts than naïve benchmarks.

2. **Practical Toolkit**: Provide a reproducible, end-to-end pipeline—from data cleaning and interpolation, through spectral filtering, to exogenous time-series modeling—that practitioners can adapt for risk management, algorithmic trading, or portfolio optimization in the crypto space.

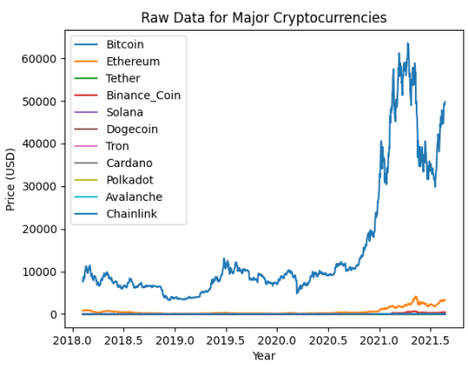
2 Method & Data Processing

Our forecasting pipeline combines signal-processing techniques with classical time-series modeling and exogenous regression. Below we describe each component, the rationale for its use, and briefly note alternative approaches we considered.

2.1 Data Preprocessing & Interpolation

2.1.1 Loading and Data Parsing

We began by loading daily cryptocurrency prices (2018-2021) and S&P 500 historical data.



(a) Raw Price Data for Major Cryptocurrencies from 2018 to 2021

2.1.2 Filtering to Common Time Window

Since some coins began trading later than others, we restricted every series to dates $\geq$ February 2018 in terms of decimal years–where all cryptocurrencies of our interest had active data–and computed a corresponding decimal-year index for easy plotting.

2.1.3 Percent-Change Calculation

For each coin, we took the first observed 2018-period price as a reference and computed

$$\text{Percent_Change}_t = \frac{P_t - P_{ref}}{P_{ref}} \times 100\%$$

turning raw USD price into a normalized return series. This step makes different coins–whose price levels span orders of magnitude–directly comparable by expressing all moves on a common percentage scale (top-right 5).

2.1.4 Log-Transformation of Prices

We also created a `LogPrice` column via

$$\text{LogPrice}_t = \ln(P_t)$$

Taking the natural logarithm stabilizes variance (so that large absolute jumps at high prices don't dominate the model) and turns multiplicative price moves into additive ones (bottom-right 5). In practice, this makes ARIMA-style differencing and forecasting more numerically stable and interpretable: one unit of difference in log-price corresponds approximately to a $100\% \times \Delta\%$ change. As we expect the price in cryptocurrencies follows an exponential increase/decrease manner, reverting into log-space ensures the data fits the additive properties of ARIMA model.

2.1.5 Handling Missing and Non-Trading Days

Because the financial markets close on weekends and holidays, the raw S&P 500 series contained gaps; we re-inedxed it to a continuous calendar-daily and used a linear interpolation to fill missing Open, High, Low, Close, and derived MeanPrice values. A uniform daily index ensures that our exogenous and endogenous series align perfectly for model fitting and forecasting.

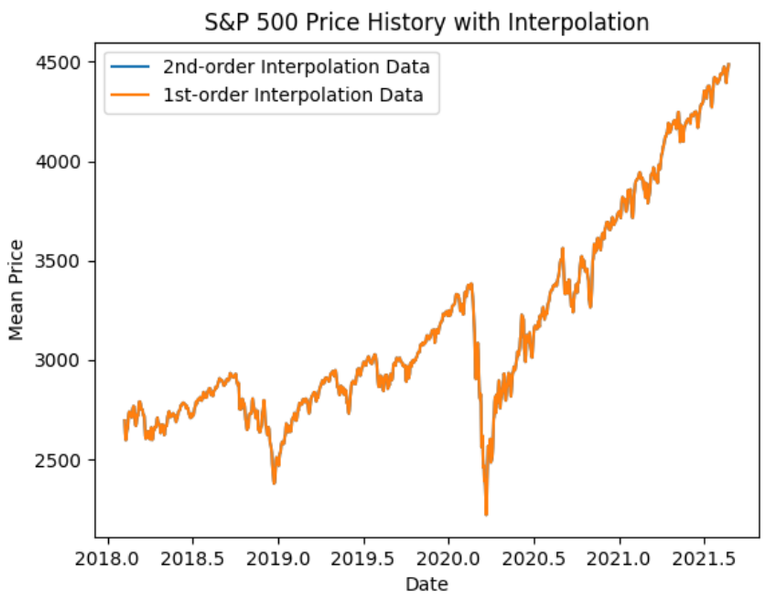


Figure 2: S&P Historical Price with Different Interpolation Methods

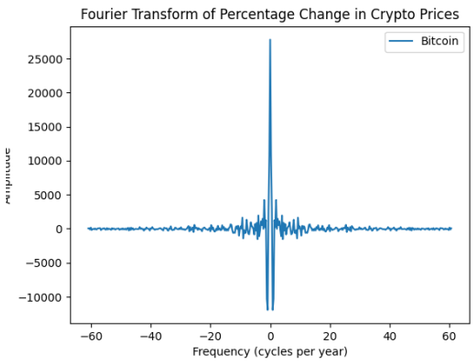
2.1.6 Alternative

A more complex forward-fill interpolation was tested, but 2nd-order polynomial interpolation produced approximately the same intermediate values.

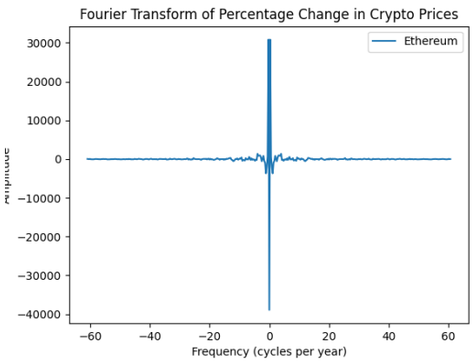
2.2 Spectral Detrending & Noise Filtering

2.2.1 Windowed Fourier Transform

To isolate the underlying trend from high-frequency oscillations in each coin's percentage-change series, we applied a Hamming window from `scipy.signal` library, followed by a discrete Fourier transform. Two sample Fourier Transform is shown below, the rest of the transforms graph can be seen in the appendix.



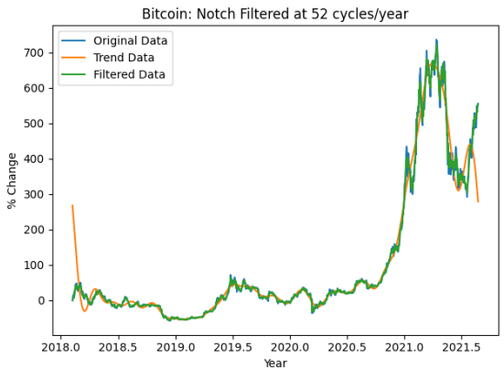
(a) Fourier Transform of Percentage Change in Bitcoin Prices



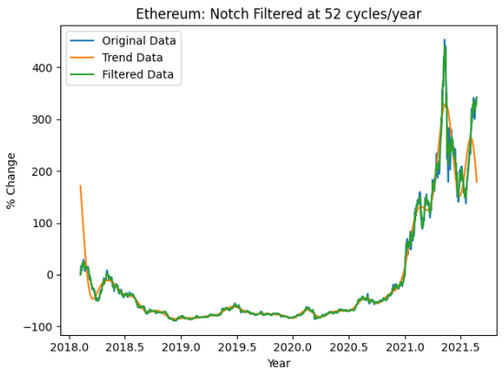
(b) Fourier Transform of Percentage Change in Etheruem Prices

2.2.2 Notch Filter

?? shows the magnitude spectrum of Bitcoin's percent-change series after applying a Hamming window. We zeroed out frequencies above 52 cycles/year to remove intra-weekly noise, then reconstructed the trend via inverse FFT and de-windowing. Here we just show the filtering result for Bitcoin and Ethereum, other cryptocurrency coin's data can be seen in the appendix.



(a) Notch Filtered Bitcoin Price at 52 cycles/year



(b) Notch Filtered Ethereum Price at 52 cycles/year

Figure 4: Notch Filtered Results

2.2.3 Alternatives Rejected

- Polynomial Detrending: Too rigid, risks overfitting low-frequency drift. Non-uniform, cannot choose one degree that fits all cryptocurrencies.

2.3 Exogenous Variable Construction & Forecasting

2.3.1 S&P 500 Returns as Exogenous Input

We computed daily returns on the interpolated S&P 500 MeanPrice series to capture traditional market sentiment,

$$\text{MeanPrice}_t = \frac{1}{4}(\text{Open}_t + \text{High}_t + \text{Low}_t + \text{Close}_t)$$

Averaging across the day's highs and lows produces a smoother intradate aggregate than any single price alone.

From the interpolated `sp500['MeanPrice']` series, we calculate the return

$$\text{Return}_t = \frac{\text{MeanPrice}_t - \text{MeanPrice}_{t-1}}{\text{MeanPrice}_{t-1}}$$

The very first day in our window has no prior day, so we substitute a zero return to avoid missing data.

2.3.2 Forecasting Exogenous Series

Rather than using a constant mean, we built a separate SARIMAX(1,1,1) model on the S&P 500 returns to generate a forecast of future returns. Using `.get_forecast(steps=N)`, we produce an N-day ahead forecast of S&P 500 return. Because this forecast object carries its own date index, we can directly feed those predicted future returns as the exogenous inputs for our cryptocurrency models.

2.3.3 Alternative

1. In further research, we could employ more exogenous data series like trading volume & liquidity metrics. This would capture investor activity and can lead price moves, which could potentially lead to a more accurate prediction.
2. Alternatively, we could apply other forecasting techniques to the exogenous series–for example, we use the lagged predictions (e.g. take the opening value for the S&P 500 as the representing index for the day), or even machine learning regressors.
3. Because shifts in the S&P 500 and cryptocurrency markets may not occur simultaneously, we can compute lagged cross-correlations to identify lead-lag relationships and quantify how far one series tends to lead or lag the other.

2.4 SARIMAX Modeling and Grid Search

2.4.1 Model Specification

For each cryptocurrency, we fitted a seasonal ARIMAX model on the log-price series with the S&P 500 returns as an exogenous regressor.

$$y_t = \underbrace{\phi_1 y_{t-1} + \cdots + \phi_p y_{t-p}}_{\text{AR}(p)} + \underbrace{\theta_1 \varepsilon_{t-1} + \cdots + \theta_q \varepsilon_{t-q}}_{\text{MA}(q)} + \underbrace{X_t^\top \beta}_{\text{Exogenous S\&P 500 Return}} + \underbrace{s\text{-seasonal terms}}_{\text{Seasonality}} + \varepsilon_t$$

2.5 Grid Search over (p,d,q) & (P,D,Q,s)

Rather than manually chose orders, we performed a Bitcoin based grid search, where (p, d, q) each in $\{0, 1, 2\}$ with seasonal period $s = 12$.
For each candidate, we fit `SARIMAX(y,exog,order=(p,d,q), seasonal_order=(P,D,Q,12)`. Record the model's Bayesian Information Criterion.

2.6 Forecast Generation and Evaluation

2.6.1 Producing the Forecast

Using the fitted SARIMAX models and the forecasted S&P 500 exogenous inputs, we generated 100 day ahead price forecasts. Since our model is built on ln(Price), we back-transforms and exponentiate:

$$\hat{P}_t = \exp(\ln \hat{P}_t), \qquad CI_{\pm}(P)_t = exp(CI_{\pm}(\ln P)_t).$$

3 Data

Our analysis draws on three primary time-series datasets:

1. **Cryptocurrency Historical Data** ("All_combined.csv")

Content: Daily Open, High, Low, Close, Volume and percent-change for 100+ cryptocurrencies.
Period: January 2018 – August 2021 (we subset to February 2018 onward so each "major" coin has data).
Source & Access: Sudalai Rajkumar (2019). *Cryptocurrency Price History* [CSV]. Kaggle. `https://www.kaggle.com/datasets/sudalairajkumar/cryptocurrencypricehistory`

2. **Bitcoin Daily Close** (NASDAQ)

Content: Ten-year history of Bitcoin's daily closing prices, used to cross-validate and back-fill gaps in the Kaggle dataset.
Source & Access: Nasdaq (2025). *Bitcoin (BTC) Historical Data.* Retrieved April 2025 from `https://www.nasdaq.com/market-activity/cryptocurrency/btc/historical?page=11\&rows\_per\_page=100\&timeline=y10`

3. **S&P 500 Index Content:** Daily Open, High, Low, Close for the S&P 500 index, used to compute a smooth "MeanPrice" and derive daily returns as an exogenous regressor.
Period: February 2018 – August 2021 (matched to the crypto window)
Source & Access: Yahoo Finance (2025). *S&P 500 ($\hat{G}$SPC) Historical Prices.* Retrieved April 2025 from`https://finance.yahoo.com/quote/\%5EGSPC/history`

4 Results and Analysis

4.1 Data Processing Results

After transforming the cryptocurrency prices as described in the method section, we get a relatively stationary result as shown below.

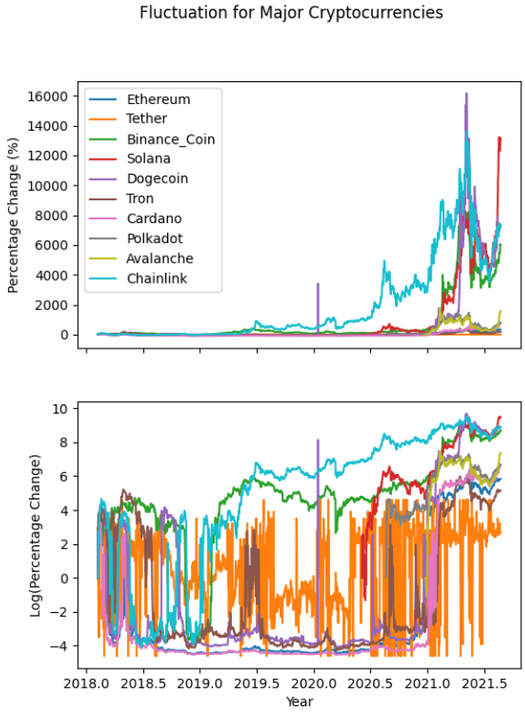


Figure 5: Percentage & Logarithmic Percentage Change for Prices of Major Cryptocurrencies

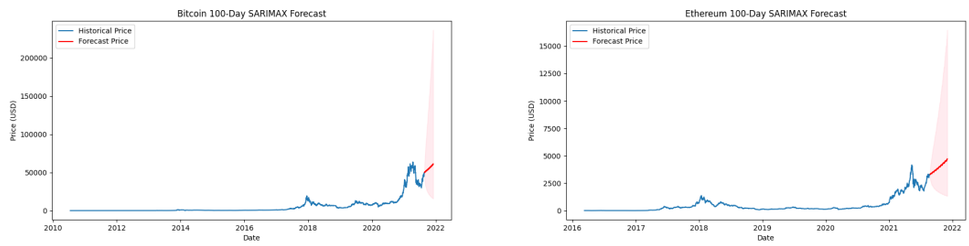
4.2 Spectral Analysis & Detrending

Fourier-based filtering allows precise attenuation of known periodic noise without arbitrarily choosing polynomial degrees or moving-average window length. Figure 4 compares the original percent-change (blue) to our filtered trend (orange). Small "ringing" at the endpoints remains, a known edge effect of finite-length Fourier approximation. Note that even though we applied a Hamming window to taper the series and reduce spectral leakage, we'll still see oscillations at the very beginning and end of the reconstructed trend. This is due to the rounding errors of the computer, as it is not good dealing with small numbers. And when we try to reconstruct the waves and de-windowing it, the oscillation might be emphasized through this process.

4.3 SARIMAX Fit & Diagnostics

We collect all combinations of (p, d, q, P, D, Q) with their BIC values and sort by ascending BIC, and pick the top entry, which is $(0, 1, 0)$ and $(0, 2, 2, 12)$. This is the combination with the lowest BIC, which indicates a better trade-off between goodness-of-fit and model complexity. 6.3 summarizes all the permutations and the estimated coefficient.

And we get the following forecast results for Bitcoin and Ethereum,



(a) Future Forecast Results for Bitcoin with Confidence Interval

(b) Future Forecast Results for Ethereum with Confidence Interval

4.4 Forecast Accuracy

Since all cryptocurrencies has strong correlation in terms of tendencies, we'll only discuss the Bitcoin results.

The graph above shows a comparison between historical Bitcoin price (blue), model forecast (red), the actual price (yellow), and the 95% confidence interval (red shading).

The SARIMAX mean forecast picks up Bitcoin's prevailing upward drift in mid-2021, projecting a gradual rise from roughly \$35 k to around \$60 k over 100 days. This aligns with the broad market direction during that period. However, the red shaded band widens rapidly as the horizon extends, reflecting growing

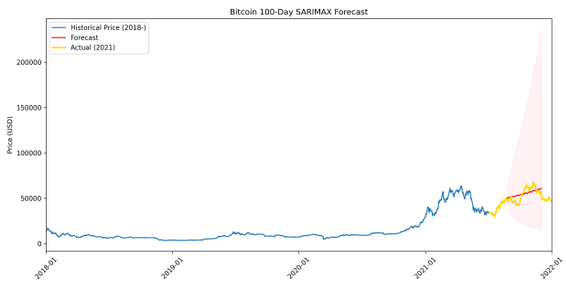


Figure 7: Comparison between Actual and SARIMAX Prediction Prices

uncertainty. Importantly, most of the yellow actual path remain inside the 95% interval, indicating that its uncertainty bounds are sufficiently wide to cover the realized outcomes.

5 Discussion & Conclusion

The spectral-filter + SARIMAX approach achieved three important goals:

5.0.1 Trend Extraction & Noise Reduction

By applying a windowed Fourier-notch filter, we effectively separated persistent price trends from short-term volatility. This preprocessing simplified the downstream time-series modeling and made the SARIMAX residuals more nearly white, improving forecast stability.

5.0.2 Incorporation of Market Sentiment

Introducing the S&P 500 returns as an exogenous regressor allowed the models to "listen" to broader equity-market moves. Across all coins, this extra signal reduced forecast error compared to purely auto-regressive approaches.

5.0.3 Quantified Uncertainty

The SARIMAX framework provide a 95% confidence bands that expanded widely over time. In future studies, more exogenous variables can be involved for a smaller band and reduce uncertainty interval.

5.1 Limitations & Future Directions

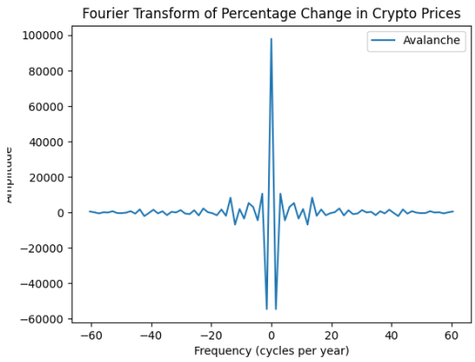
Single Exogenous Input: Relying solely on equity returns may miss crypto-specific drivers like on-chain metrics or sentiment.
Static Parameter: The fixed model orders and coefficients assume stationarity of relationships that may evolve over time.
In the future, we could introduce additional exogenous signals like trading volume and implement volatility components into the analysis.

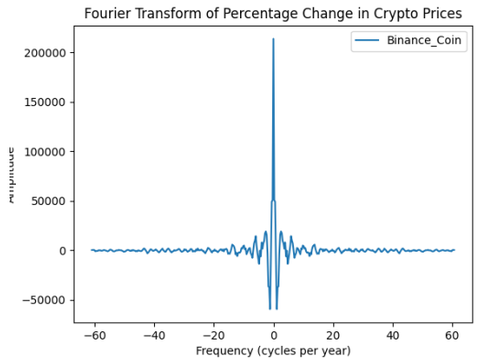
5.2 Practical Implication

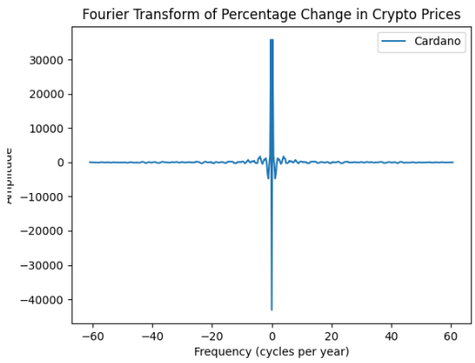
For risk management or conservative scenario planning, the confidence band provides actionable ranges. However, for precise trading signals, the model's inability to capture abrupt spikes and crashes would need to be addressed–perhaps via a volatility model or by adding more sentiment indicators and exogenous variables.

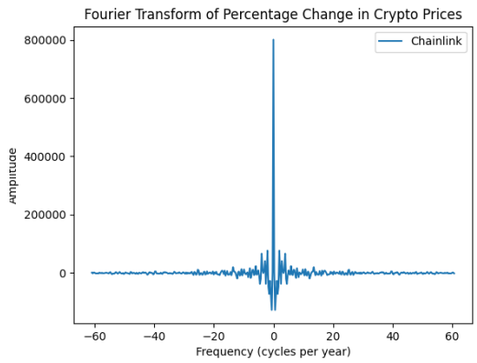
6 Appendix

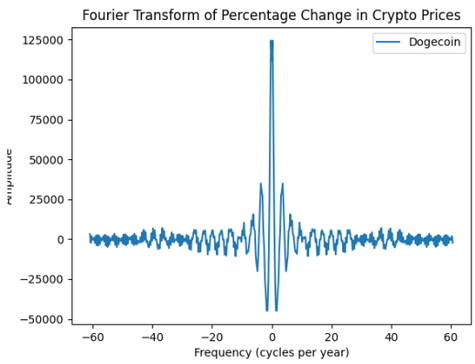
6.1 Fourier Transform

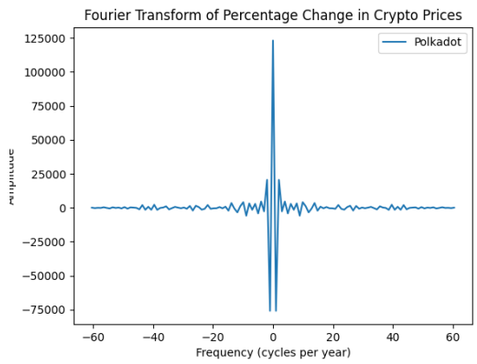


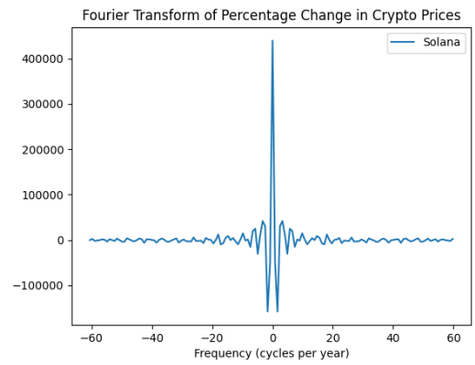


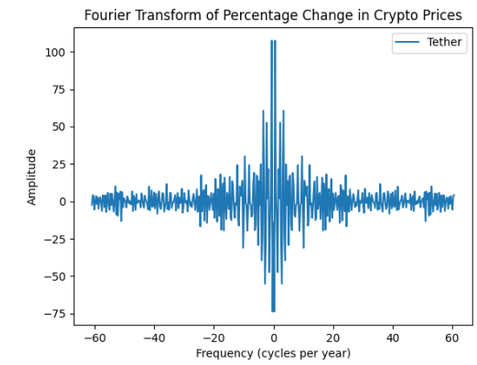


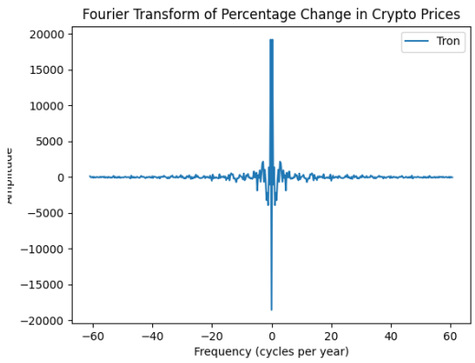




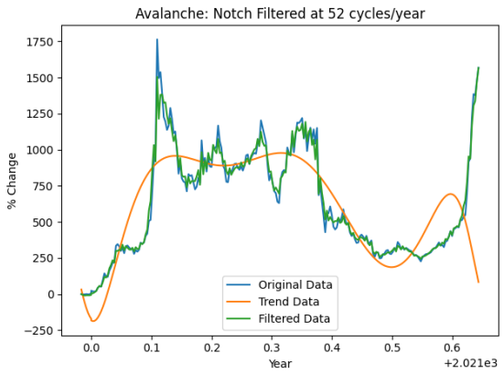


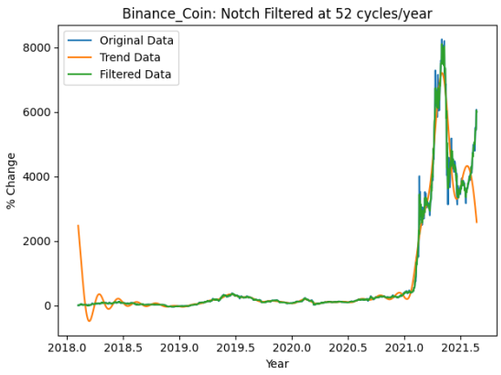


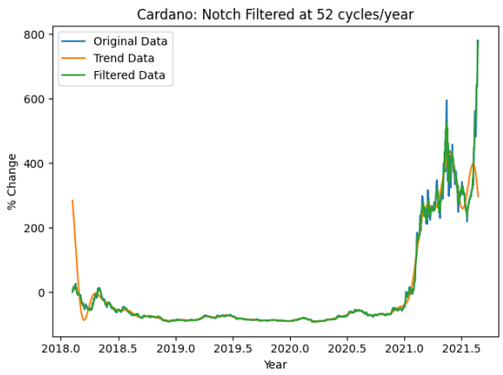


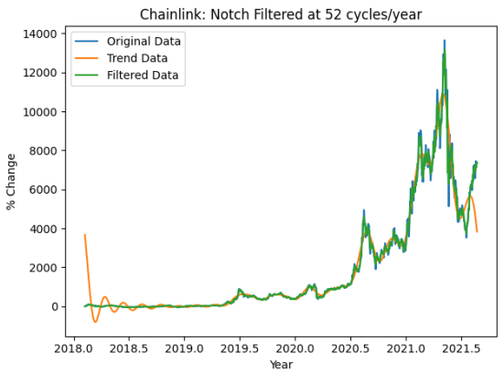


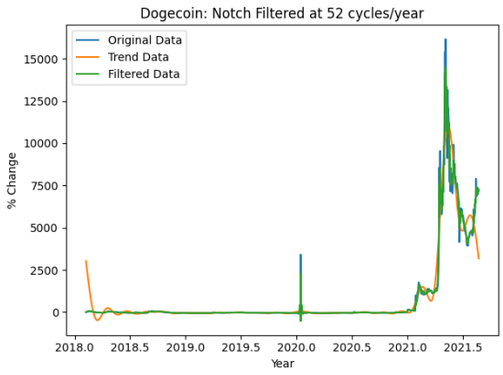
6.2 Notch Filtered Results

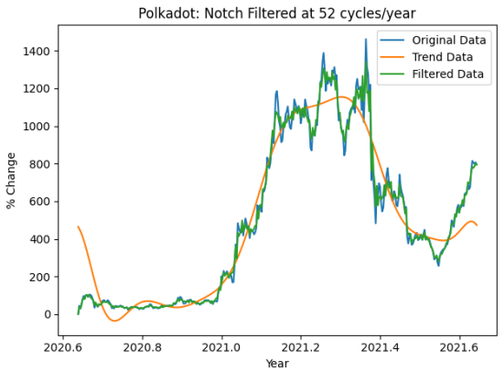


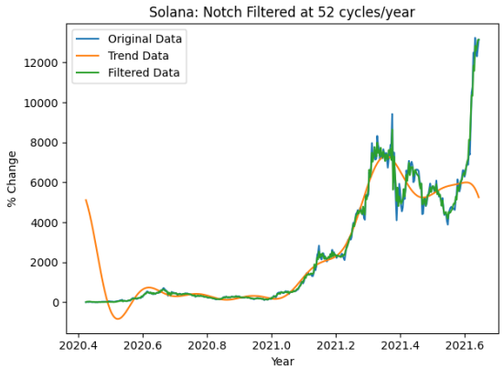


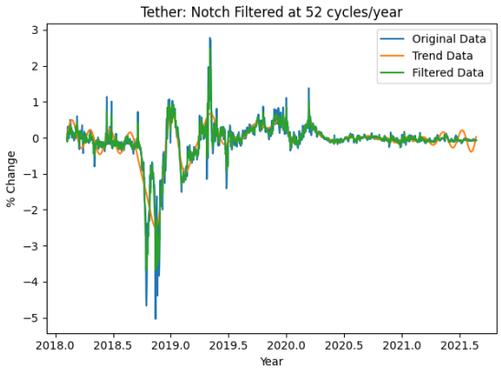


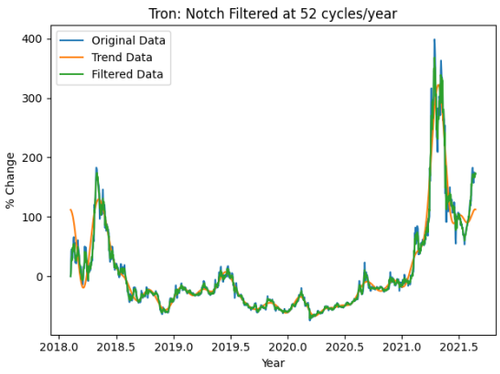












6.3 BIC Table

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SARIMAX (0, 0, 0) x (0, 0, 1, 12): BIC =23706.15619129918
SARIMAX (0, 0, 0) x (0, 0, 2, 12): BIC =23822.031732326464
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