Reading Between the Lines: Uncovering Market Regimes with Hidden Markov Models

Jacob Martin

Department of Mathematics
West Chester University of Pennsylvania

Spring 2025

Content

Project Motivation

- Since 2016, I have been an investor and algorithmic trader
- The strategies and indicators often involve advanced applied math concepts
- Roughly 5 years ago, after futile attempts to read about an indicator using hidden markov models, I was motivated to get the degree in Applied & Computational Mathematics

Here we are, five years later, implementing the model.

What is a Markov Chain?

- Discovered in 1906 by Andrey Markov, a **Markov Chain** (MC) is a stochastic (random) model describing a sequence of events
  - The MC incorporates randomness and probability to **predict outcomes**
  - The MC **embraces uncertainty** rather than fighting it
  - The model wants to determine what the future state a given system will be in
    - E.g., Is tomorrows **weather state** going to be sunny or rainy?

The Memoryless Nature of Markov Chains

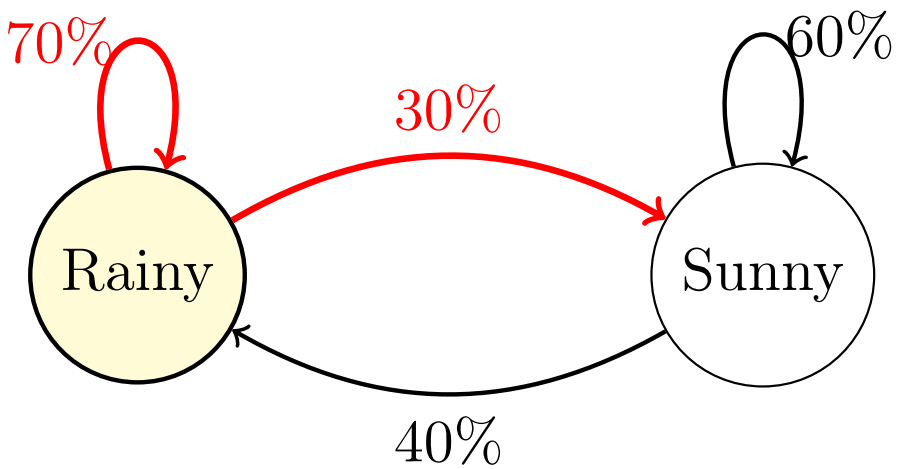
- Markov chains have "no memory" of their past
- Only the **current state** matters for deciding the future
- Previous history is irrelevant once you know the current state

Real-World Example

Think of a weather forecast:

- If it's sunny today, there's a 70% chance it's sunny tomorrow
- A Markov chain only considers "it's sunny today" to predict tomorrow

Markov Chain State Transition Example



Transition Matrix P

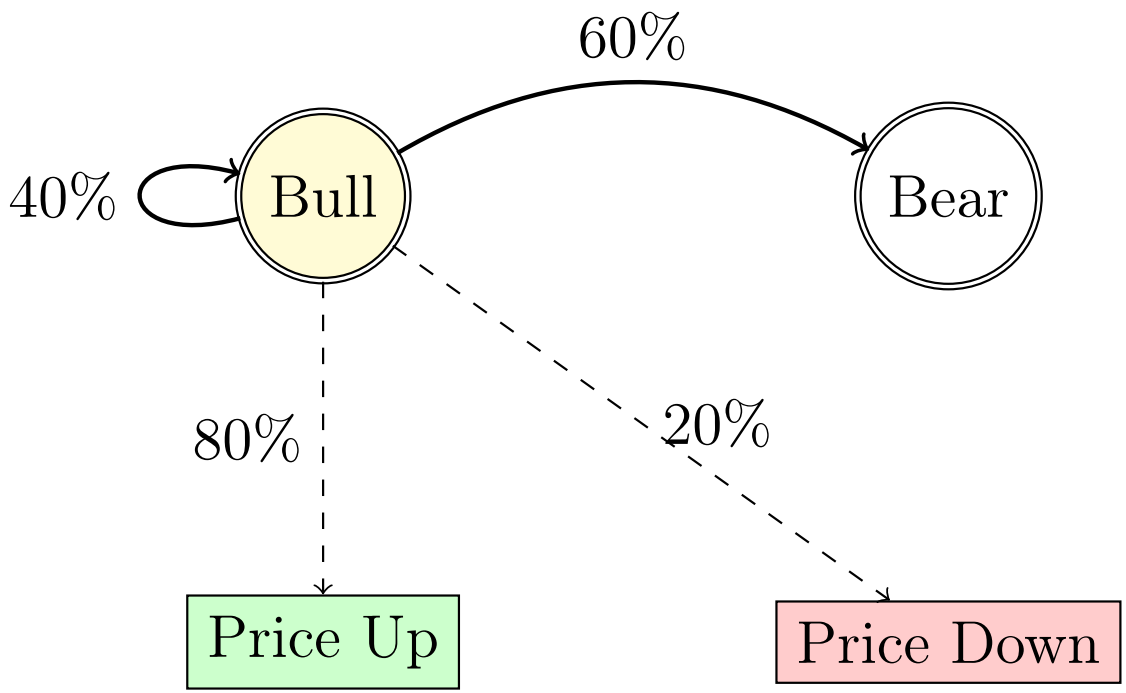
$$P = \begin{array}{c|cc} & \text{Rainy} & \text{Sunny} \\ \hline \text{Rainy} & 0.7 & 0.3 \\ \text{Sunny} & 0.4 & 0.6 \end{array}$$

$$P_{ij} = P(X_{t+1} = j \mid X_t = i)$$

Where P_{ij} is the probability of transitioning from state i to state j

Difference in Hidden Markov Chain

The HMM can expose future observations using an **Emissions Matrix**



- **Bear** and **Bull** are the states
- Price data are **observations** within the current state
- **Price up** and **Price down** are additional probabilities which the model outputs

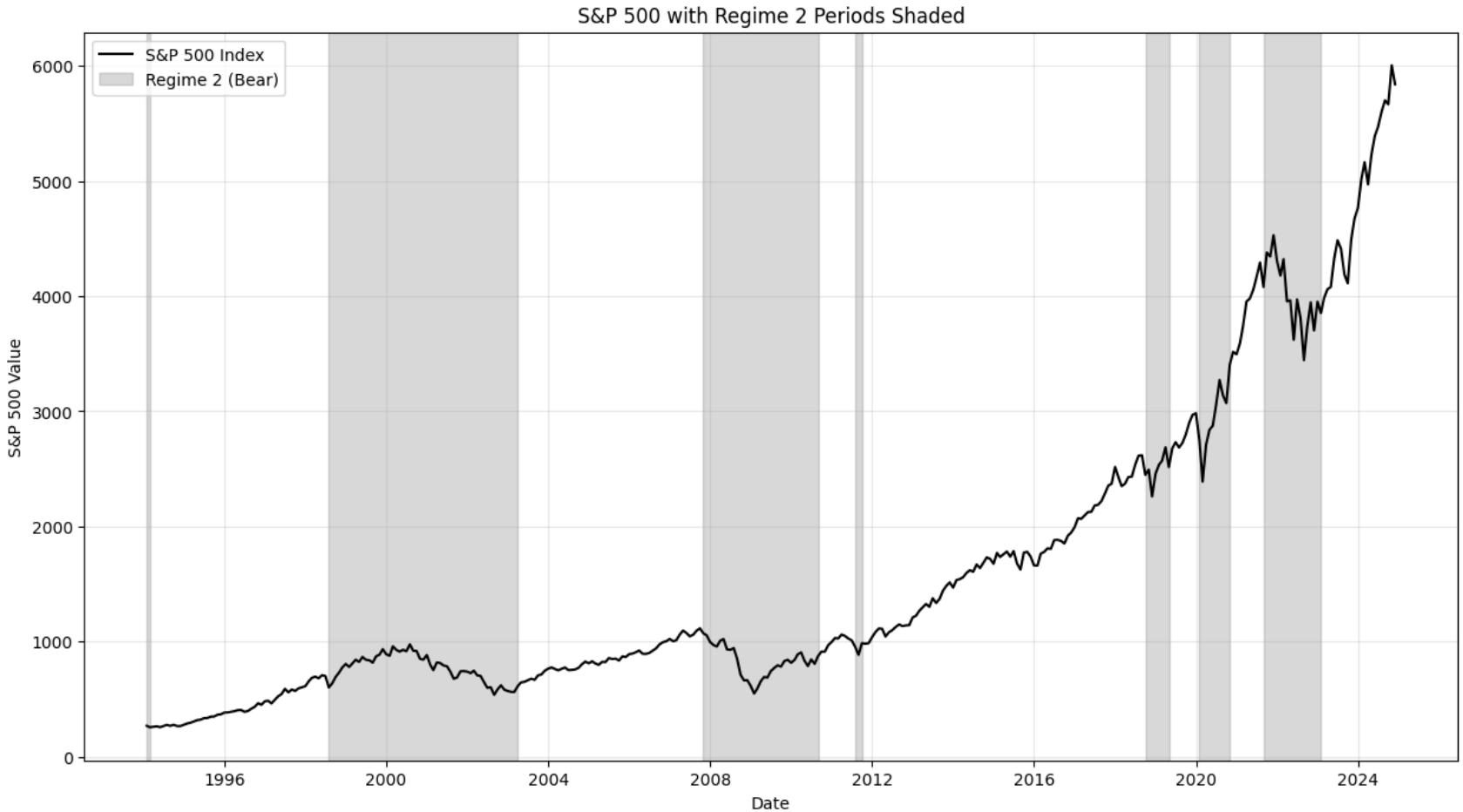
Implementation

- This implementation of the Hidden Markov Model is based on the work by in the white paper called *RISKS* by Nguyen and Nguyen. (1-1).
- The research performed in the paper aimed to implement several HMM's to detect regimes for various macroeconomic variables.
- The authors implemented four algorithms:
  - Forward & Backward Algorithms,
    - Used for parameter estimation
  - Baum-Welch algorithm
    - Maximizes parameter estimation
  - Vertibi algorithm
    - Determines optimal next state to choose

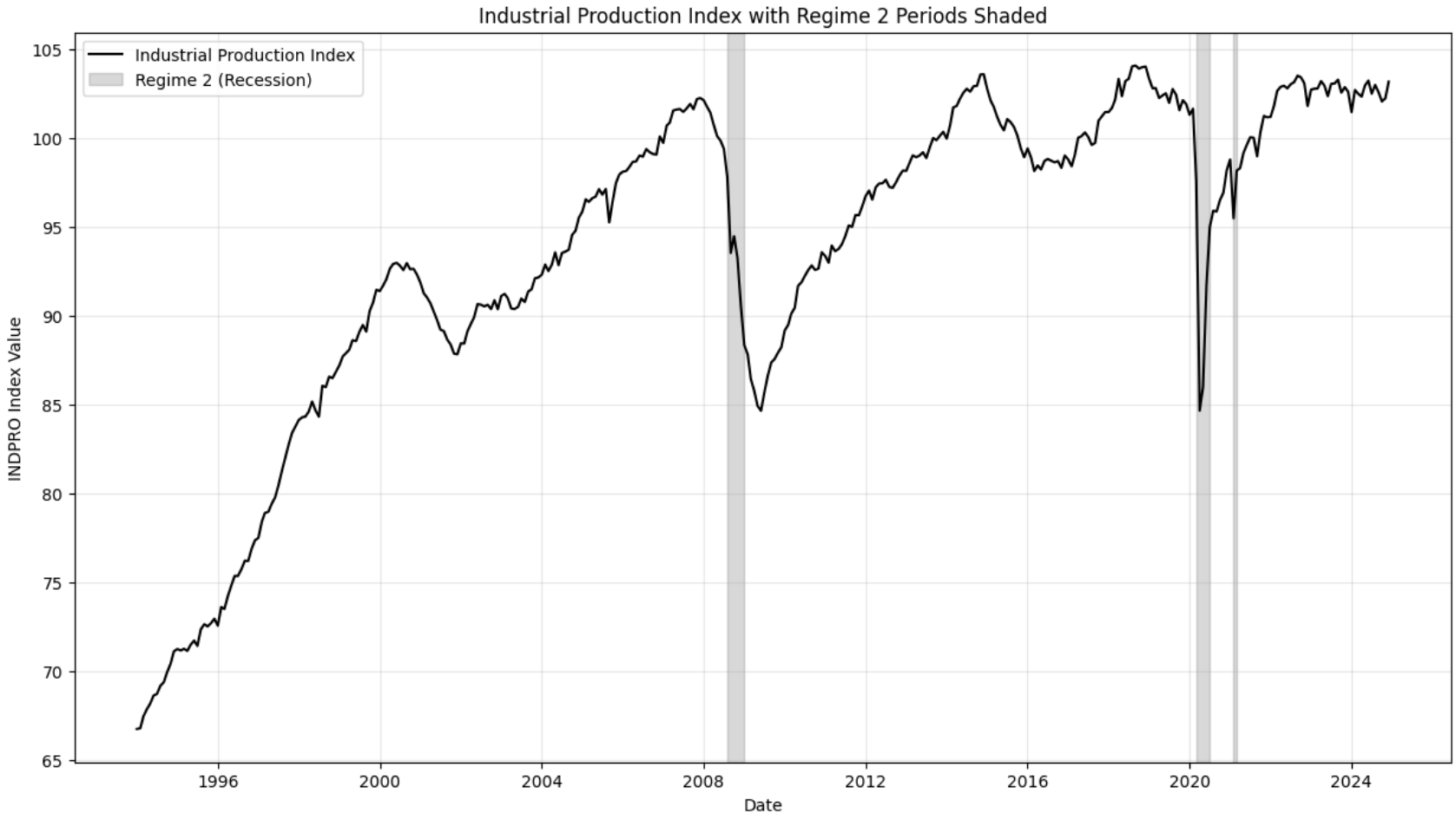
Macroeconomic Variables Overview

Variable	**Data Description**	**State 1**	**State 2**
S&P 500 (total market index)	MoM % change	bull	bear
INDPRO (industrial production index)	MoM % change	growth	recession
VIX (volatility index)	MoM % change	low volatility	high volatility
CPI (total urban consumer index)	YoY % change	inflation	deflation

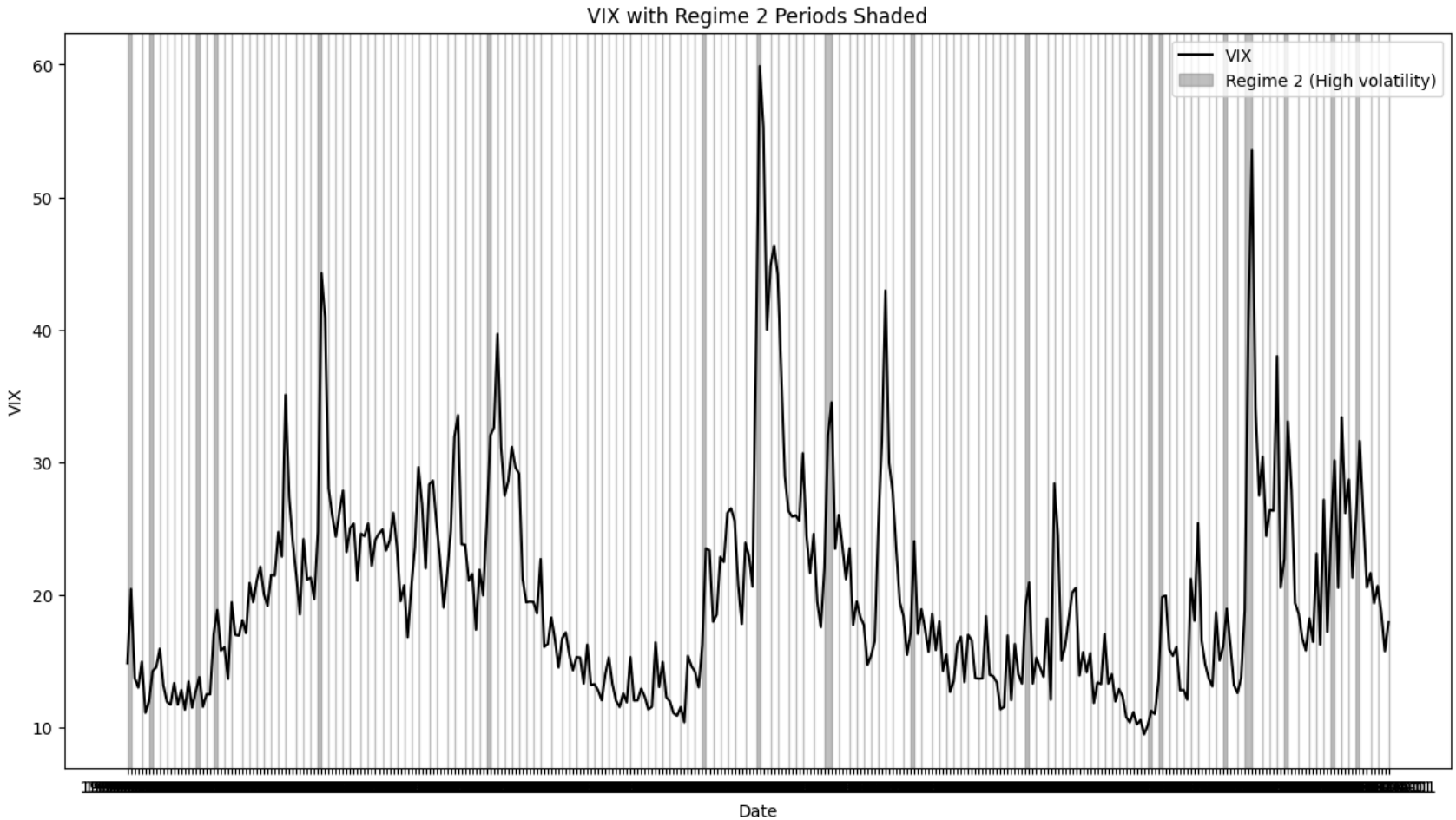
S&P 500 Results



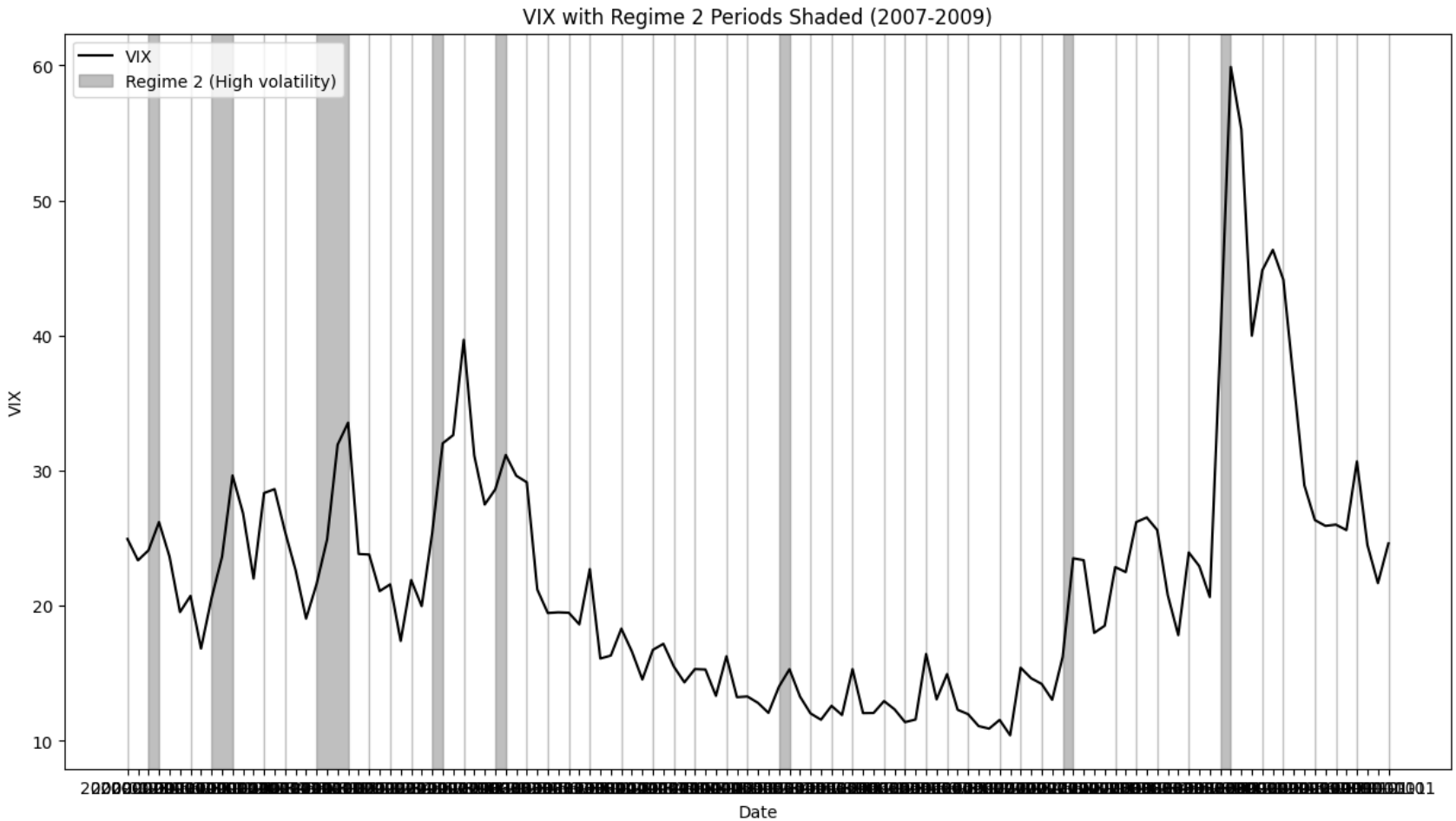
INDPRO Results



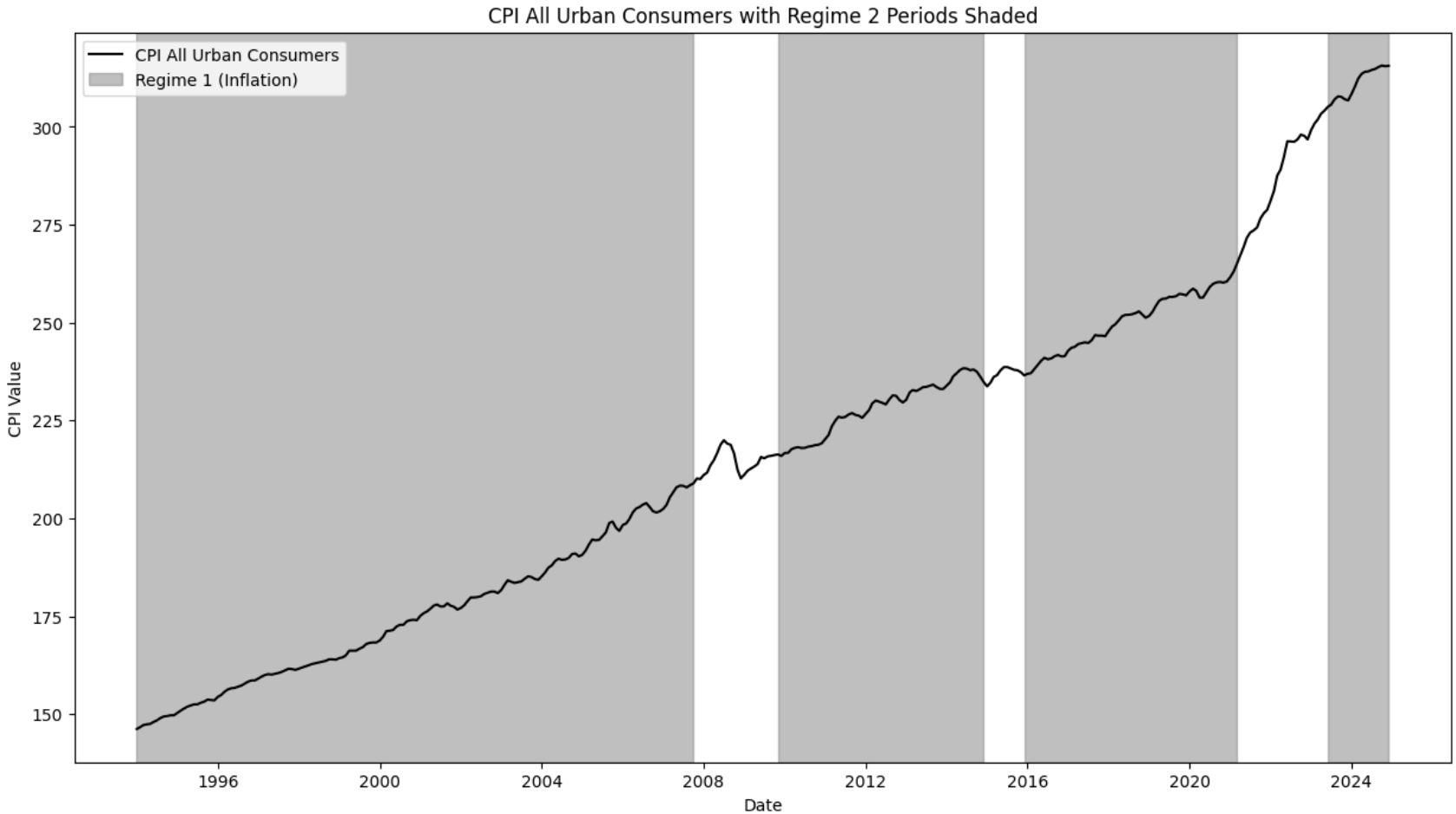
VIX Results


VIX with Regime 2 Periods Shaded
VIX
Regime 2 (High volatility)
60
50
40
30
20
10
VIX
Date

VIX Results 07 - 08 zoomed

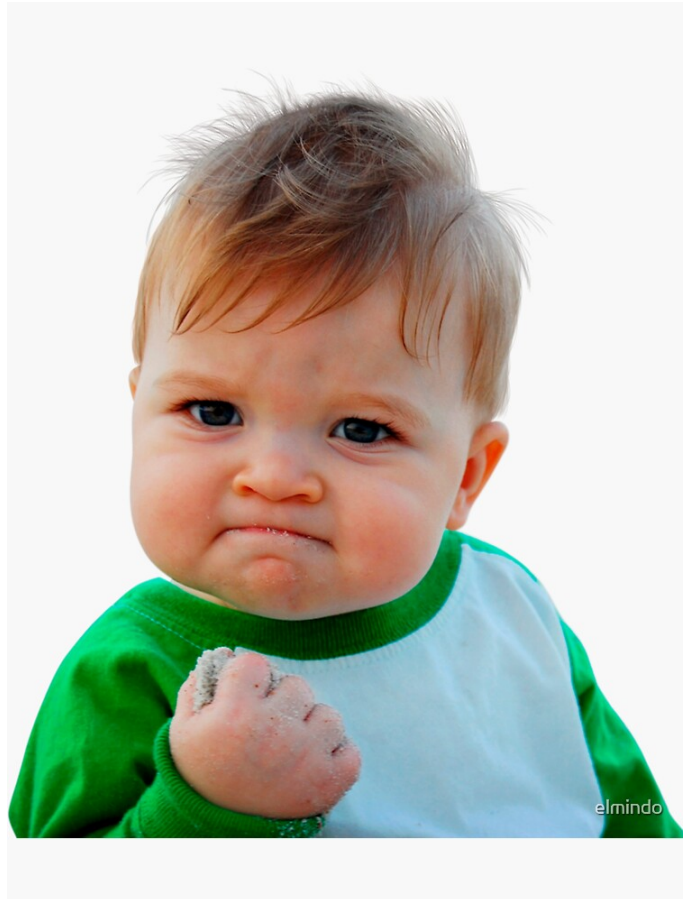


CPI Results


CPI All Urban Consumers with Regime 2 Periods Shaded
CPI All Urban Consumers
Regime 1 (Inflation)
CPI Value
300
275
250
225
200
175
150
1996
2000
2004
2008
2012
2016
2020
2024
Date

Conclusion

This project included learning about the inner workings of a hidden markov model enough to fully understand and implement it. It is quite satisfying to achieve this goal with quantifiable, valid results.



Next Steps

- Finer granularity models (hour-by-hour)
- Implement a trading strategy on top of this indicator

References

1 Nguyen, N., & Nguyen, D. (2015). Hidden Markov Model for Stock Selection. *Risks*, 3(4), 455-473. Published: 29 October 2015 ISSN 2227-9091 www.mdpi.com/journal/risks