Short Rate Prediction Model

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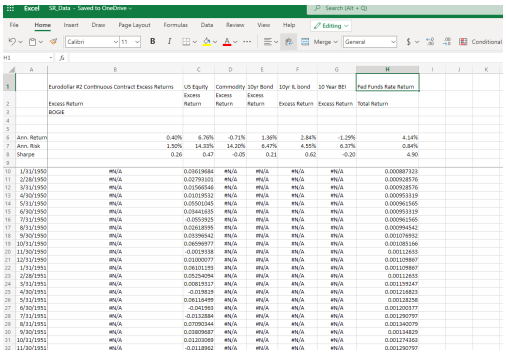
1 Problem and Data

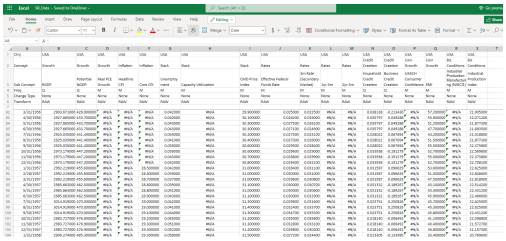
Problem:

> This interview asks you to take a look at historical rate and economy data and use 10 indicators to predict short rates shift 6 months out. You are asked to work on this ahead of your interview and come prepared to discuss your solution.

Data:
I was given an Excel workbook with two worksheet of data.



(a) Market Data



(b) Economic Data

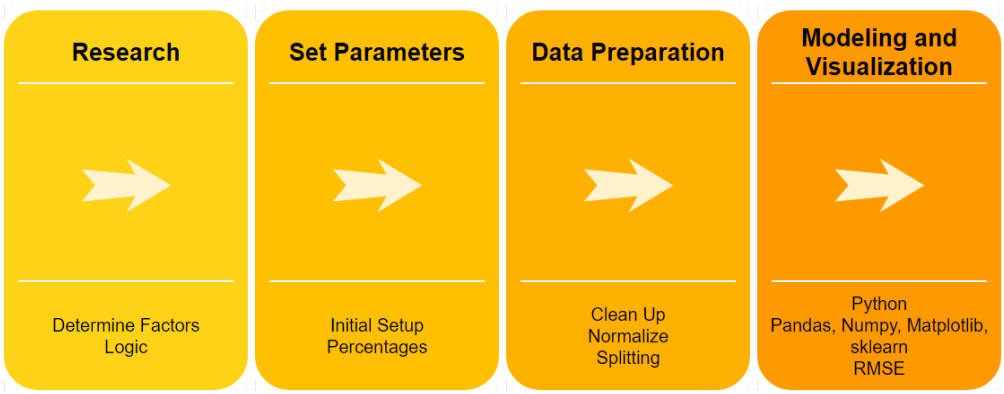
Figure 1: Data

I plotted 78 all of them, so I can better make sense of these data.

From plots, I see that data before 1980 are either missing or very messy. Data so old would not be relevant now so I trimmed data to 1978 where all indicators of my choice are with data(not NULL)

2 Approach

I began with reading research papers and articles about short rates.



Papers didn't really help me tackle the problem. However, they did give me ideas of how to approach the problem.

Eurodollar #2 Excess Returns 10yr Bond Fed Funds Rate Return	US Equity 10yr IL bond	Commodity 10 Year BEI
RGDP Headline CPI Capacity Utiliization 3m Rate (Secondary Market) Household Credit Creation PMI	Potential NGDP Core CPI CMD Price Index 1yr-3m Business Credit Creation Industrial Production (NAICS)	Real PCE Growth Unemployment Effective Federal Funds Rate 2yr-3m UMICH Consumer Confidence Industrial Production Index

Table 1: Given Indicators

Lagging indicators would not be very useful since this is a problem looking to speculate. I am mainly looking for a combination of leading and coincident indicators.

Then everything comes down to supply and demand. Which in this case, it's **Liquidity** ($\tilde{\text{M2}}$) and **Demand for cash flow**. I choose the following 9 indicators according to their characteristics plus the 3 month short rate I would need as benchmark.

- Liquidity
  - 1yr-2m
  - 2yr-2m
  - Equity Return
  - 10yr Bond
  - Real GDP
- Credit Demands
  - Capacity Utilization
  - Household Credit Creation

- Guide Index

  Purchasing Managers' Index (PMI)

  Consumer Confidence Index (CCI)

Points worth mentioning:

1. Missing Fed Fund Rate
2. Potential use of CPI
3. Use of 10yr Bond instead of Index-linked Bond
4. Choice of Consumer Credit over Business Credit

3 Code Walk through

The given data are separated into two csv files: **EconomicData.csv** and **MarketData.csv**

3.1 getData.py

Github linked to getData.py

1. Separate short rates and dates
2. Drop all unused indicators
3. Normalize Data using MinMaxScaler Method

3.2 analyze.py

Github linked to analyze.py

1. Calculate Liquidity Coefficients for six months
2. Calculate Demand Side factor
3. Validate using MA of short rates, calculate the two guide curves
4. Plot prediction curves with one year window
5. RMSE

Equity	1yr-3m	2yr-3m	RGDP	10yr Bond	Sum
20%	30%	25%	5%	20%	100%

3.2.1 Liquidity

Each indicator is assigned a percentage representing its influence in liquidity. These percentages could be tuned or modeled to find the best set, but right now I assign values to them based on my understanding of the market.

Then define the the Liquidity contribution as follows:

$$L(t) = P_E \times \left(E(t) + E(t+1) + \sum_{i=-1}^{-12} E(t-i) \right) \tag{1}$$

$$+ P_{13} \times (R_{13}(t-5) - R_{13}(t-17)) \tag{2}$$

$$+ P_{23} \times (R_{23}(t-5) - R_{23}(t-17)) \tag{3}$$

$$+ \left. \frac{dG(\tau)}{d\tau} \right|_{\tau=t+3} \times \left(1 + \left. \frac{d^2G(\tau)}{d\tau^2} \right|_{\tau=t+6} \right) \times (1 + P_G) \tag{4}$$

$$+ f(R_B(t)) + \frac{1}{5}(f(R_B(t-1)) + f(-R_B(t-1)) + f(-R_B(t-2)) \tag{5}$$

with

$$f(x) = \begin{cases} x & \text{if } x > 0 \\ 0 & \text{else} \end{cases} \tag{6}$$

where t is in unit of month, P_E is the Equity weight percentage, $E(t)$ is the equity, P_{13}, P_{23} are the 1y-3m and 2y-3m rates weight percentage, $R_{13}(t), R_{23}(t)$ are the 1y-3m and 2y-3m rates, P_G is the GDP weight percentage, $G(t)$ is the GDP, and $R_B(t)$ is the bond rate.

Equity effect: Using sum of previous year's return as the basis. By dividing current year into 6 parts I can incorporate market's speculation to corresponding future month.

Forward interest rate effect: current rate subtracted by previous year/2-year rate can obtain the net effect on liquidity.

RGDP effect: the acceleration of this quarter compared to previous quarter could be a great reflection on economic activities. Negative acceleration would mean slowing activity level. Plus GDP provides the first layer of liquidity.

10-year Bond effect: which I considered the most relevant indicator. I assumed the short rate would follow a pattern similar to retail-wholesale market that is: if the wholesale price (10yr bond in this case) drops, retail price won't drop immediately, it (short rates) will wait for as long as possible before dropping its price. However, the short rate will increase right after the bond price increases.

3.2.2 Demand side

The Total Demand contribution is defined as the following:

$$D(t) = \frac{1}{2} \times \frac{1}{6} \left(\sum_{i=0}^{-5} U(t-i) - \sum_{i=-6}^{-12} U(t-i) \right) + \frac{1}{2} \times \frac{1}{6} \left(\sum_{i=0}^{-5} C(t-i) - \sum_{i=-6}^{-12} C(t-i) \right) \quad (7)$$

where $U(t)$ is the Capacity Utilization, and $C(t)$ is the Credit Creation.

Capacity Utilization effect: if there's an increase in capacity utilization, that means businesses are expanding.

Credit Creation effect: if there's an increase in credit creation, that means consumers are looking to spend more.

3.2.3 Guides and Fine-Tuning

The PMI Guide curve is defined by:

$$\gamma_P(t) = \left(-50 + \frac{1}{6} \sum_{i=0}^{-5} P(t-i) \right) \times \lfloor \log_{10} \left(\left| \frac{dS}{dt} \right| \right) \rfloor + \frac{dS}{dt} \quad (8)$$

where $S(t)$ is the short rate, and $P(t)$ is the PMI.

PMI: by definition of the index: if the index is below 50, it is likely that the economy is in recession. It could be used as a guide line to how the economy is performing and to how should the interest rates behave

The CCI Guide curve is defined recursively:

$$\gamma_C(t) = \gamma_C(t-1) + \frac{1}{6} \left(\sum_{i=0}^{-5} \times I(t-i) - I(t-i-1) \right) \times \lfloor \log_{10} \left(\left| \frac{dC}{dt} \right| \right) \rfloor \times t \quad (9)$$

where $C(t)$ is the CCI.

Consumer Confidence Index: How willingly consumers are to spend more money could be a good indicator for pointing direction the interest rate will head to.

Simple Moving Average: Firstly, I compute Simple MA of 6-month window over 36 months (3 years). Then I use linear regression to fit a linear curve to find where is the short term rates generally heading towards. I can tune my final results by balancing demand side effect and liquidity effect. Right now I'm using a binary function which depends on whether demand side effect is closer to the MA. If it is closer, I assigned an coefficient of 0.7 so it would be the heavier factor when driving the interest rate

The predicted short rate is:

$$S(t+1) = \begin{cases} S(t) \times (1 + 0.7L(t) + 0.3D(t)) & \text{if } |L(t) - SMA(t)| < |D(t) - SMA(t)| \\ S(t) \times (1 + 0.3L(t) + 0.7D(t)) & \text{if } |L(t) - SMA(t)| > |D(t) - SMA(t)| \end{cases} \tag{10}$$

where $SMA(t)$ is the Short Rate moving average.

4 Performance

Because of the noise 1980 economic event brought, the model did not perform very well during that period.

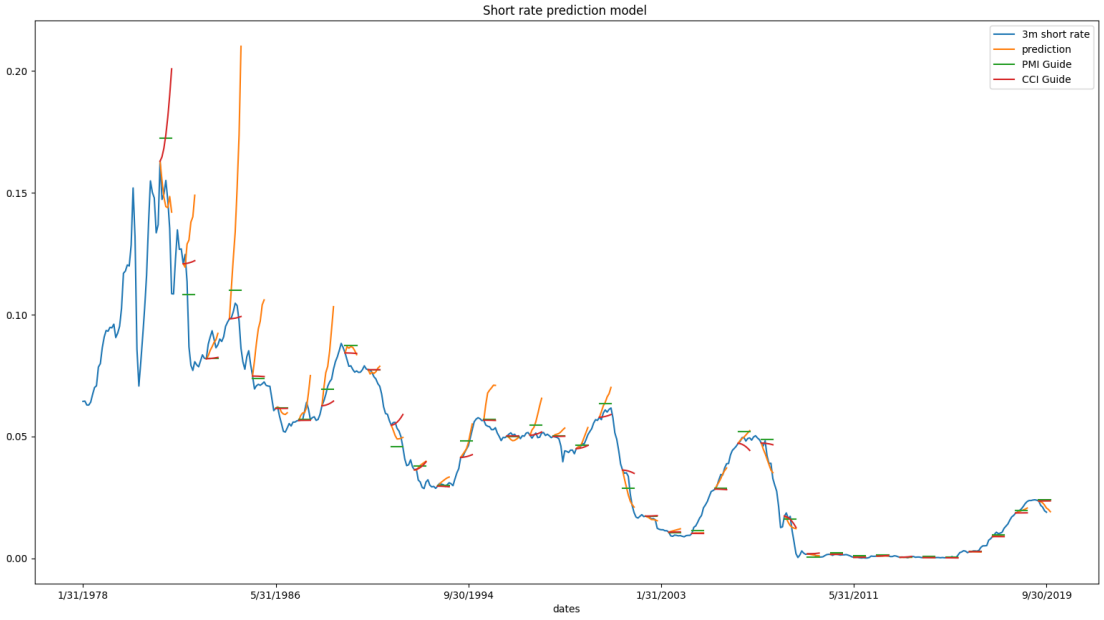


Figure 2: Full Range Prediction

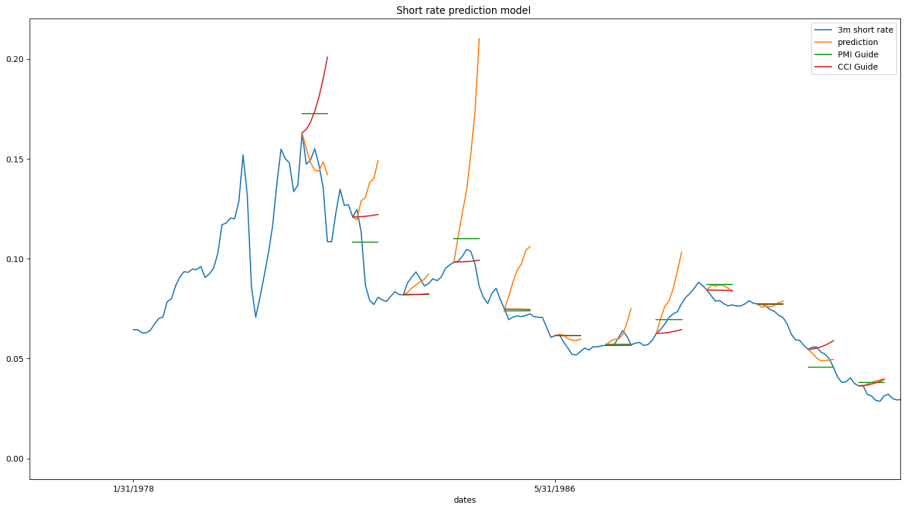


Figure 3: 1980 Deep Recession (1978-1994)

If looking at predictions after 1994 when the influence from previous shock mostly has settled, the model begin to perform well. It also produced quite good result during the 2008 melt-down.

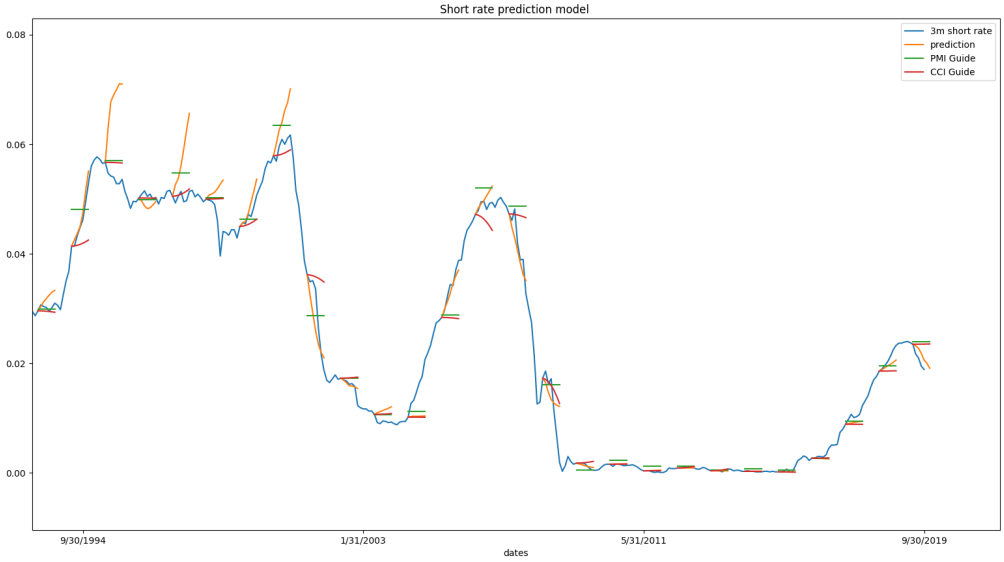


Figure 4: Starting 1994

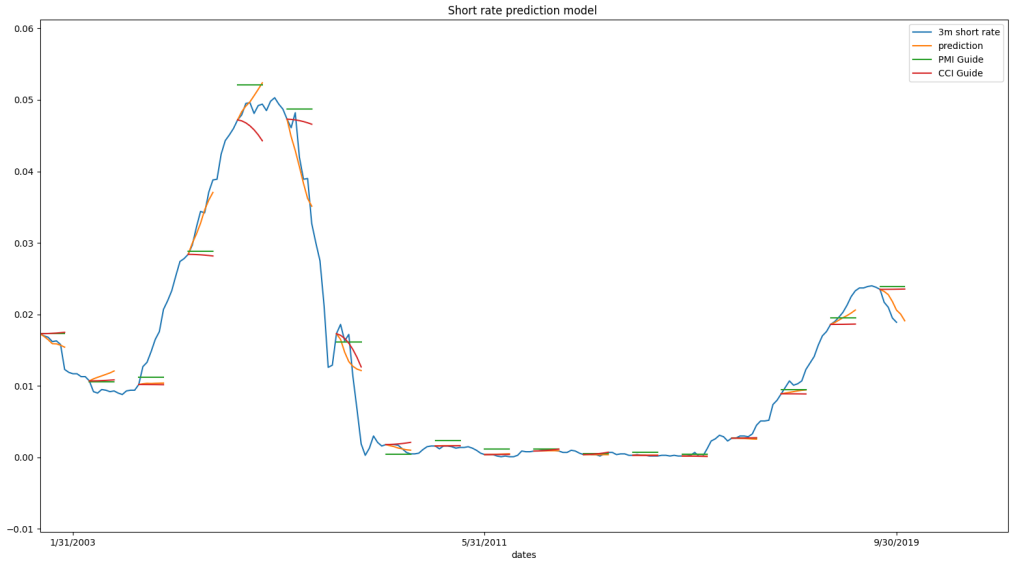


Figure 5: Starting 2003

Finally the last prediction which is a peak into unknown short rates.

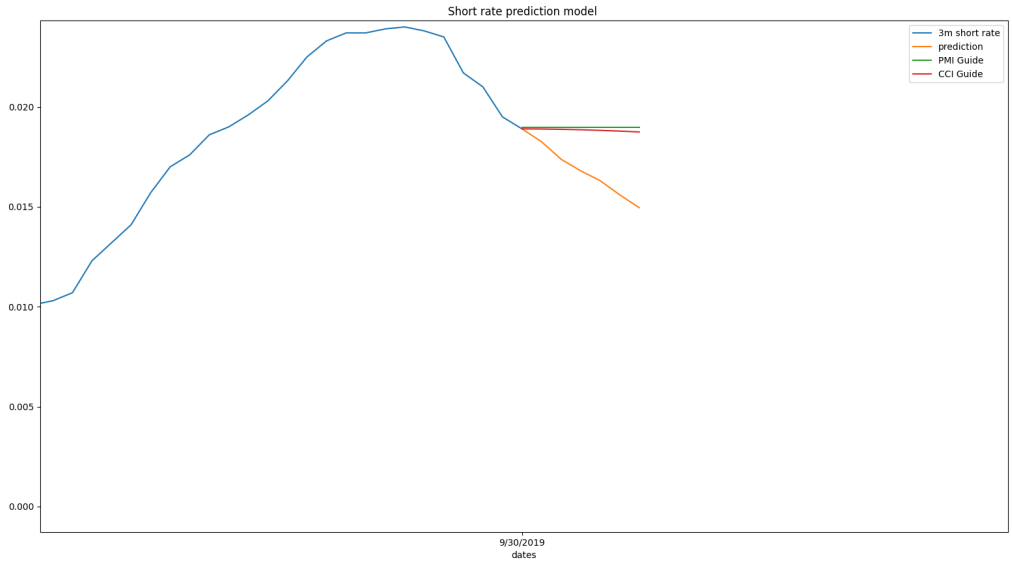


Figure 6: Last Prediction

5 Evaluation

$$RMSE = \sqrt{\frac{\Sigma_{i=1}^{n}(p_i - a_i)^2}{n}}$$

RMSE (root mean square error) is used to evaluate the model. The number is to be the smaller the better. If it is between 0.2 and 0.5, it means the model can mostly accurately match the desired results

Starting 1981	Starting 1993	Starting 2000
0.737	0.401	0.351

6 Figures

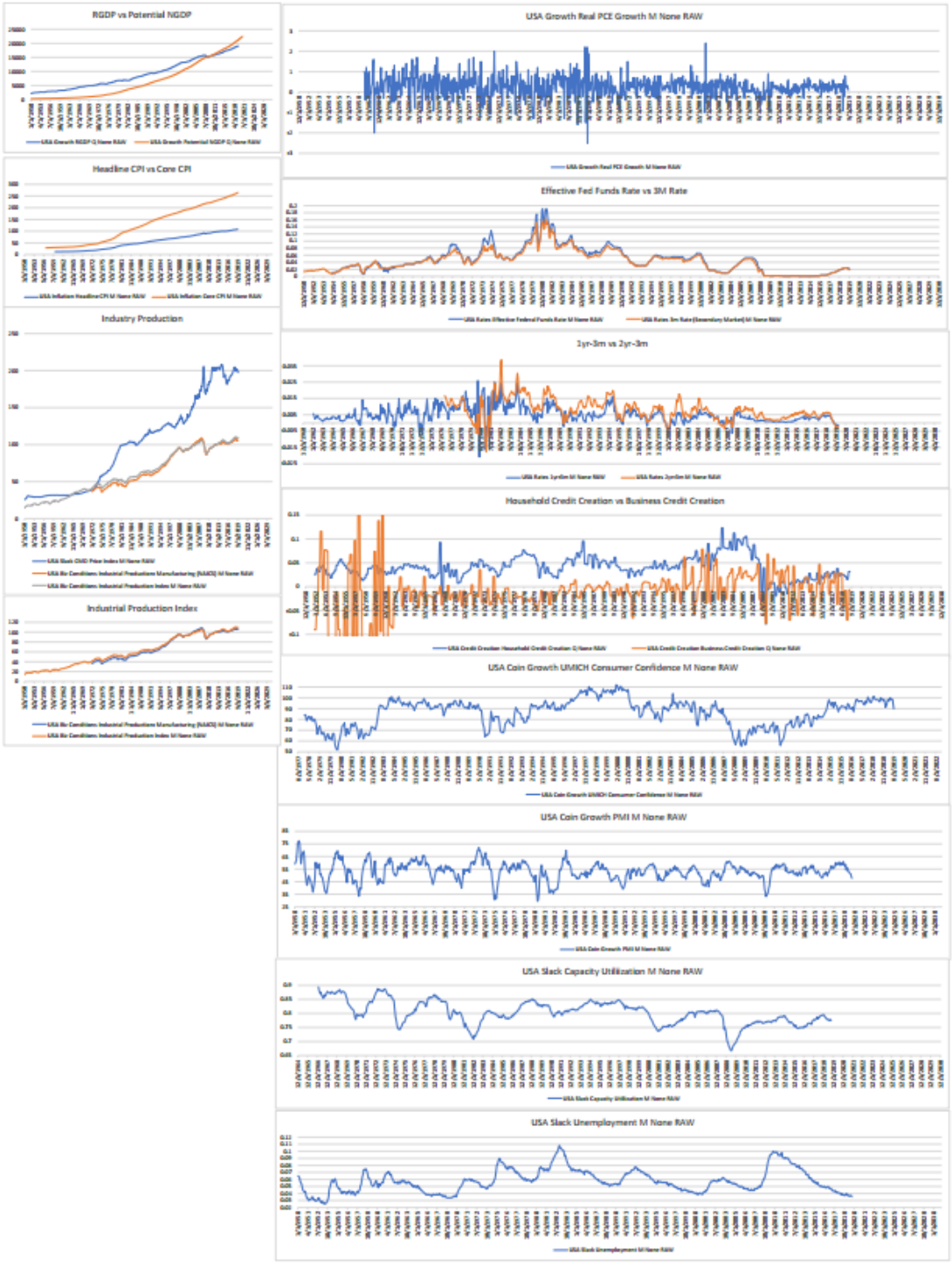


Figure 7: Economic Plots

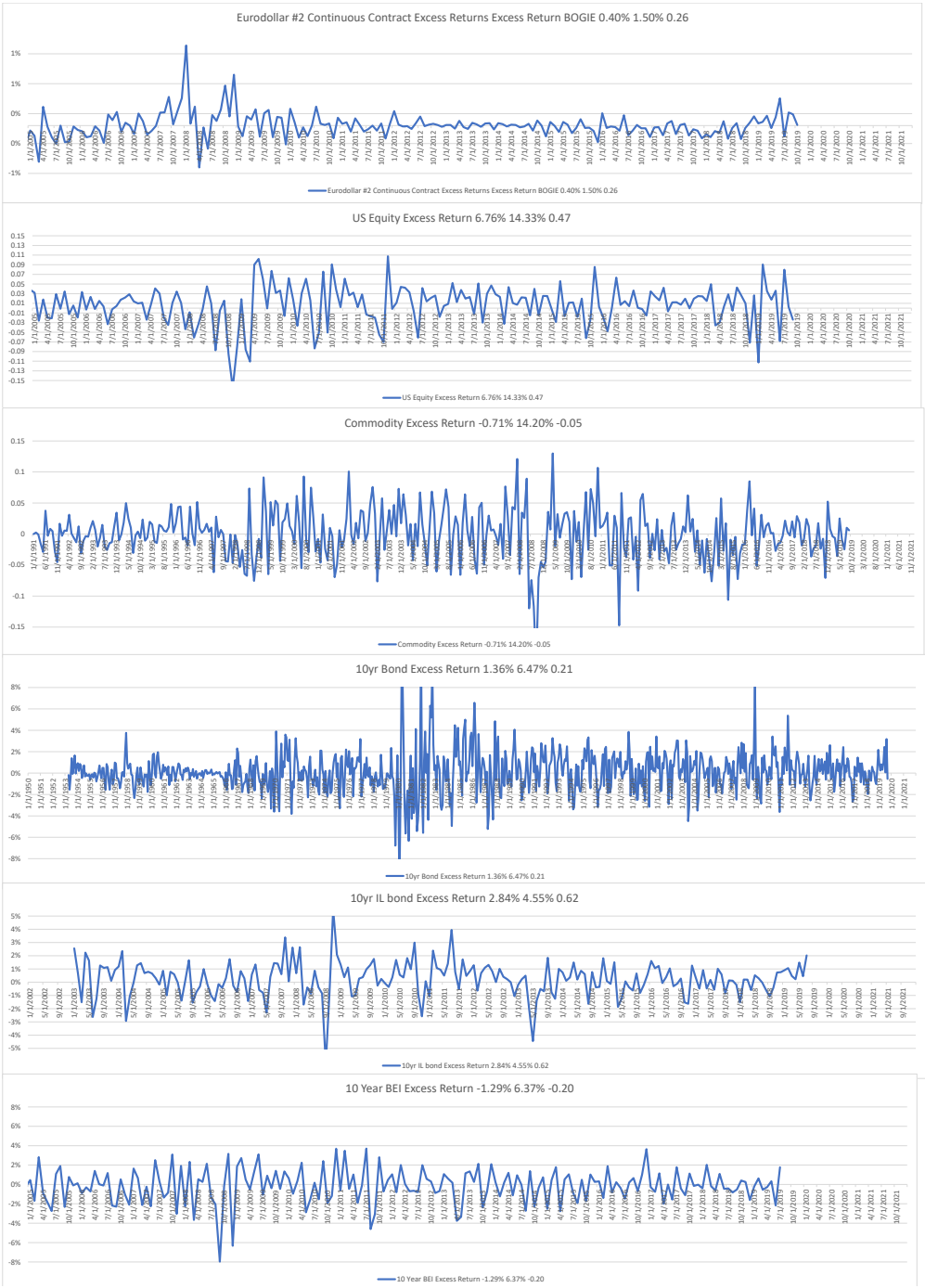


Figure 8: Market Data Plots