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Predictability of Treasury Yield via ARMA and VAR Approach —-Evidence from United States

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Abstract

Yield rate of sovereign bonds, as an important indicator of a country's business cycle, and cost and ability of local governments to raise funds, has also been a policy target for governments and central banks for long. My long-term interest in financial market and monetary policy inspired me to think further about the factors determining the yield rates of sovereign bonds and the predictability of yield rate based on historical data. This paper will focus on the yield rates of 3-month, 5-year and 10-year U.S treasuries. It aims to shed a light on how different economic variables would affect the course of short-term, mid-term and long-term treasury yield rates. Based on the analysis of the interaction between yield rates and those economics variables, it also makes the attempts to predict the forementioned yield rates by constructing ARMA (auto-regressive and moving average) and VAR (vector auto-regressive) model, and reach a conclusion on its predictability.

Key Word: Yield Rate, ARMA, VAR, Predictability

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Chapter 1

Introduction

The main focus of this paper are different determinants of yield rate of U.S treasuries, including 3-month, 5-year and 10-year treasuries. Based on analysis on these determinants, predictions will be conducted with two approaches, the ARMA (auto-regreesive and moving average) approach and VAR (vector auto-regressive) approach.

To construct the VAR model for the prediction of yield rates of 3-month, 5-year and 10-year treasuries, the paper will first research on the interactions between yield rates of 3-month, 5-year and 10-year treasuries and other economics factors, including party of president, Debt-to-GDP ratio, returns of stock market, oil price, consumption price level, residential price level, unemployment rate, trade balance, labor participation rate, target fed funds rate, and gold price. The main method used is to explore the correlation coefficient of different combinations of the aforementioned time-series data. And based on the result of the analysis on factor, the predictive VAR model will be constructed and used to be compared with the ARMA model obtained. And thus the optimal model can be selected for the treasury yield rate of each type of U.S treasury. And comment on the performance of the prediction with this optimal model can be made and thus the

conclusion about predictability of U.S treasury yield can be attained.

Overall, this goal of this paper is to explore the determinants of yield rates of U.S treasuries and find out how they played a role on the formation and change of the rates. More of interest, how we can construct a predictive model and to what extent can this model capture the future course of the yield rates of U.S treasuries.

The rest of the paper will be organized in this way: Chapter 2 will include the related literature review. Chapter 3 will introduce the data and relevant background used in this paper. Chapter 4 will be factor analysis, which will include the analysis on the interaction between yield rates of 3-month, 5-year and 10-year treasuries and political factor, debt-to-GDP ratio, returns of stock market, oil price, consumption price level, and residential price. Chapter 5 will introduce 2 models, ARMA model and VAR model, in attempting to predict the future course of yield rates of 3-month, 5-year and 10-year treasuries respectively. In addition, some comparsions will be done to reach a conclusion about the predictability of the yield rates of different treasuries. Chapter 6 is the conclusion part that summarizes and comments on the results obtained in this paper.

Chapter 2

Literature Review

In this papers the main focus is on different determinants of yield rates of sovereign bonds, especially on U.S treasuries. Since it has been a heated topic in Euro Zone for long, lots of related papers are working papers of ECB (European Central Bank) and IMF (International Monetary Fund) and most of them based their analysis on the european circumstances. However, due to the similarities shared by U.S treasuries and sovereign bonds of Euro Zone countries, it is worth exploring these papers and providing evidence and sheding a light on the research of this paper. Besides, some literatures that specifically focus on the situation in United States and some that cover all type of sovereign bonds are included.

There are some papers researching the relationship between yield rate of sovereign bonds and political factors, among which the latest one is written by Stephan Eichler (2014). By the conclusion of his paper [1], among different political factors, political system and quality of governance played a significant role while the degree of democracy and elections didnt have lots of impact on the yield rate. In his analysis, the ability and determination of governments to conduct austerity policy is a deciding factor in the determination of yield rate and a more stable and powerful

government usually resulted in a low yield rate in sovereign bonds. Though it may not completely apply to the situation of United States. The same logic can be used to analyze the politics in United States, since the key point of the analysis is that how determined and capable a government is to conduct tight fiscal policy, which is different between the Republican party and Democratic party.

In Tygran Poghosyans IMF working paper (2012), he separated the analysis on behaviors of long run and short run yield rate of sovereign bonds and conducted empirical research [2]. And he found that the debt-to-GDP ratio is an important factor in the change of yield rates of sovereign bonds. He analyzed data from 22 advanced economy over the 1980-2010 and drew the conclusion that for every one percent increase in debt-to-GDP ratio, the yield rates will increase by 2 basis point, which indicated a positive relation between debt-to-GDP and sovereign bonds yield. Tygrans work mainly focused on advanced economies, especially countries in Euro zone. And to the emerging economies, Emanuele Baldacci and Manmohan S. Kumar (2010) did the research and drew similar conclusions, that if the fiscal deficit increase by 5 points of GDP, long-term interest rates could rise by 100 basis points [3]. This is intuitive since with a higher debt-to-GDP usually comes higher default risk. However, the risk premium should be different across countries and this paper mainly focused on countries of Euro zone. And another question of interest is that whether the two factors, debt-to- GDP ratio and yield rates will interact continuously. Nevertheless, there are few papers researching the interaction of debt-to-GDP ratio and yield rates of sovereign bonds. Bernardin Akitoby and Thomas Stratmann (2012) also drew the similar conclusion on the other direction though [4]. They proved that for emerging markets, reduction in public expenditure is a more powerful in dragging down the yield rate of sovereign bonds. To be specified, cuts in current spending is more useful than cut in investment spending.

As an alternative of government bond, the returns of stock market seem to be closely related to the yield rates of U.S treasuries. Lieven Baele, Geert Bekaert and Koen Inghelbrecht (2010) indicated the relationship between stock market and bond market when taking factors like risk aversion, uncertainty into consideration [5]. However, they also claimed that macroeconomics fundamentals contribute few to this relationship, which is under doubt.

There are also some papers indicating the influence on yield rates brought by exchange rate. Blaise Gadanecz, Ken Miyajima and Chang Shu (2014), pointed out in their BIS working paper that the exchange rate, especially expectations and uncertainty of exchange rate could have an influence on the yield rates of sovereign bonds, and it has become more important since mid-2013 [6]. And his analysis accords with the analysis of risk premium. As the volatility of value of local currency increases, investors would demand a higher compensation for holding them thus the yield rate would be higher. Also, if the expectation of a currency to be devalued is strong, investors would ask for a higher yield rate to compensate for that as well. All these factors are included in the calculation of value of sovereign bonds by market.

And with recent developments, the factors proposed previously seemed to be minor in the determination of yield rate of sovereign bonds. Instead, with the development of behavioral finance and application of game theory, there are more papers focusing on the behavior of investors and other agents. In Duccio Martelli and David Aristeis paper (2014), by conducting empirical research, they found proxies of consumer and market sentiment and expectations strongly affected the course of yield rate of sovereign bonds, especially during financial crisis [7]. The research focused on behaviors of yield rate in countries in Euro Zone, especially during European Debt Crisis. From my point of view, this conclusion also applies to the circumstances in United States as weve seen how forward guidance worked in the aftermath of financial crisis. They noted that market sentiment seemed to be minor in the previous analysis, however, once we introduced them into the analysis during debt crisis, they become much more significant. It seems that markets expectation are more easily to be altered in a volatile economy. However, in my opinion, we should also take the behavior of central banks into consideration, that whether the central bank of a country is transparent and consistent in actions, since its highly correlated with market sentiment.

Different from other sovereign bonds, U.S treasury has a unique position in the financial market, since it's mostly widely held sovereign bonds. And in the past several decades, the foreign holding of U.S treasuries has been increased at a large scale. According to Daniel Betran, Maxwell Kritchmere, Jaime Marquez and Charles Thomas (2013), such a huge amount of foreign holding

has a huge affect on the yield rate of long-term treasuries [8]. And those countries are usually important partners in international trade. Take China as example, due to its trade surplus with U.S, China is holding more and more U.S debt and affect the yield curve of it.(M. Andre & L. Radhames, 2011)[9].

There's also an improrant opinion decmosing the yield rate into expected inflation rate and risk premia (P. Monika & C.John, 2005). By this opinion [10], it's important to include the expected price level when analyzing the yield rates of treasuries.

Another important but easily ignored factor of the yield rates of U.S treasury is liquidity. By Yakov Amihud and Haim Mendelson (1991), the liquidity of treasuries is always included into the price when investors are making their decision of purchase or sale. [11] However, the paper was written in 1991 and the situations of the financial market has changed greatly. Due to the invention and application of financial derivatives, the importance of liquidity issue are questioned.

About the predictive model, there's an argument arguing using state variable, such as CPI growth, Fed Funds rate and unemployment rate [12], may perform better than using latent variables. It further proposed to use expected value in the future analysis (H. Cristian, 2010).

Overall, we can see lots of previous papers, mainly focused on empirical facts from advanced economy. Due to European debt crisis and rich available data, lots of papers are related to the problems in Europe. Different factors are proposed by different papers, including political situation, financial market, inflation rate, etc. The evidence are not from a long time ago, though, also not latest. The latest situation in United States, seemed to be missed. Therefore, it remains interesting to explore how things will develop in United States in the recent future.

Chapter 3

Data and Background

Yield of sovereign bond, to some extent, measures the credibility and ability to raise fund of a country's central government, and the markets expectation on the future course of a countrys economy and currency. Therefore, the yield of sovereign bond, fluctuated along with the changes of a set of economics variables.

In United States, the treasuries, long-term or short-term, has always been thought to be a risk free and highly liquid asset, with huge volume of them traded around the world. Considering the openness and influence on the world of United States, and the indispensable function of it. To analyze the fluctuation of U.S treasury bill, we need to take a large set of economic variables into consideration, including political factor, debt-to-GDP ratio, returns of stock market, oil market, comsumption price level, residential price level, unemployment rate, trade balance, etc.

The yield rate of treasury that the paper is about to research includes short-term, mid-term and long-term treasury bills. For the short-term rate, 3-month treasury bill is going to be used, the rate is daily second market rate, not seasonally adjusted, form Jan 4th, 1954 to present. For the mid-term rate, 5-year constant maturity rate of treasury bill is going to be used, the rate is daily market

rate, not seasonally adjusted, from Jan 2nd, 1962 to present. For the long-term rate, the 10-year treasury with constant maturity date, daily data that is not seasonally adjusted, will be used, from Jan 2nd, 1962 to present. All these data are retrieved from website of Federal Reserve Electronic Data of Federal Reserve Bank of St. Louis.

For the political factor part, the paper will mainly focus on two types of data. The first is the specific date with presidential elections, with the result coming out on the same day. The other is the time period of president from different parties taking offices in Washington. The paper will focus on the movement of yield rate of treasuries in these two time scale. When conducting the empirical research, this data will be represented as a binary variable, with 1 representing democratic party and 0 representing republican party.

Total public debt as a percent of gross domestic product will be used as debt-to-GDP ratio. The data collected is quarterly and seasonally adjusted. Its recorded from quarter 1 of 1966 to quarter 3 of 2015. The data are retrieved from the website of Federal Reserve Electronic Data of Federal Reserve Bank of St. Louis. And since the debt-to-GDP are quarterly data, we simulated the data between each data with a constant changing rate and use the simulated data to test its relationship with yield rates of U.S treasuries and fit in the predictive model.

The return of stock market will be measured with two important indexes, the first is Dow Jones Industrial Average and the second is SP 500 index. The Dow Jones Industrial Average data is retrieved form Yahoo Finance, the daily data from Jan 29th, 1985 to present. The SP 500 will be retrieved from Yahoo Finance, daily data from Jan 3rd, 1950 to present.

For the oil market, the paper will focus on international crude oil price. Two representative prices will be West Texas Intermediate and Brent Oil Price. The former one will be daily data from Jan 2nd, 1986 to present, not seasonally adjusted. The Brent Oil Price will be daily data from May 20th, 1987 to present. Both of them are in dollar amount and retrieved from website of Federal Reserve Electronic Data of Federal Reserve Bank of St. Louis.

The price level of consumption will be measured by consumer price index for all urban: all items and personal consumption expenditure. The consumer price index is recorded from Jan 1st,

1947 to present, monthly data and seasonally adjusted. The personal consumption expenditure is collected from Jan 1st, 1959, monthly data and seasonally adjusted. Both of them are retrieved from website of Federal Reserve Electronic Data of Federal Reserve Bank of St. Louis. And since CPI and PCE are monthly data, we simulated the data between each data with a constant changing rate and use the simulated data to test its relationship with yield rates of U.S treasuries and fit in the predictive model.

For the residential price level, the real residential property prices for United States will be used. The data is quarterly, not seasonally adjusted and from the 4th quarter of 1975 to the second quarter of 2015, retrieved from website of Federal Reserve Electronic Data of Federal Reserve Bank of St. Louis. Again, we simulated the data between each data with a constant changing rate and use the simulated data for the empirical research.

The unemployment rate data is seasonlly adjusted monthly data, from January, 1948 to March 2016. And we simulated the data between each two monthly data with constant changing rate and thus generate the daily data. This paper used the simulated data to test its interaction with U.S treasuries yield and fit in the data. It's retrieved from website of Federal Reserve Electronic Data of Federal Reserve Bank of St. Louis. Similarly, we simulated the data between each data with a constant changing rate and use the simulated data for the empirical research.

Trade Balance is yearly data from 1960 to 2015. And we simulated the data between each two monthly data with constant changing rate and thus generate the daily data. This paper used the simulated data to test its interaction with U.S treasuries yield and fit in the data. It's retrived from the website of U.S Census Bereau. Again, we simulated the data between each data with a constant changing rate and use the simulated data for the empirical research.

Labor Participation Rate is seasonally adjusted monthly data from January 1, 1948 to March 1,2016. And we simulated the data between each two monthly data with constant changing rate and thus generate the daily data. This paper used the simulated data to test its interaction with U.S treasuries yield and fit in the data. It's retrieved from website of Federal Reserve Electronic Data of Federal Reserve Bank of St. Louis. Similarly, we simulated the data between each data with a

constant changing rate and use the simulated data for the empirical research.

Target Federal Funds Rate is the federal funds rate that the federal reserve intend to achieve with open market operations. We generate the target rate for each time period based on the public statement made by the federal reserve.

Gold Price is Gold Fixing Price at 10:30 A.M. (London time) in London Bullion Market, based in U.S. Dollars. The data is daily, not seasonally adjusted, from April 1, 1968 to March 20, 2016. It's retrieved from website of Federal Reserve Electronic Data of Federal Reserve Bank of St. Louis.

For the discrete data, we simulate the daily data only for those that are usually recognized as steadily changing in a short time period. When conducting empirical research, we used a set of 9,378 observations with 14 variables measured for each observation, from January 3rd, 1997 to Jaly 1st, 2015.

Chapter 4

Factor Analysis

4.1 Political Factor

In this paper, the political factors involved in the changes of yields of sovereign bond mainly refer to the policies conducted by president. President from different parties may have different influences on yield rate.

In accordance with Stephan Eichlers theory, the yield rate of sovereign bonds somehow depends on a governments ability and willingness to conduct tight fiscal policies. In this regard, during the time with a president from Republican Party, the yield rate of bonds should go down while go up when the Democratic Partys president takes office. Since the republicans tend to decrease the influence of the federal government and thus cut the expenditure and deficit while the democrats do the opposite. Reflected on the movement during the day of election, the yield rate should increase on the day when a president from Democratic Party was elected and decrease while the opposite happened.

However, by investigation, the movement of the yield rate on the election data are negligible. Considering the process of election, its likely that the results of elections accord with the prediction and poll before the day of election and thus have minor influence on market on that specific date.

Date	Winning Party	3-month treasury	5-year treasury	10-year treasury
1976.11.2	**Democratic**	$-0.03(-0.04\%)$	$+0.09(1.3\%)$	$+0.06(+0.81\%)$
1980.11.4	**Republican**	$+0.23(+1.7\%)$	$+0.21(+1.6\%)$	$+0.15(+1.2\%)$
1984.11.6	**Republican**	$-0.12(-1.4\%)$	$+0.05(+0.44\%)$	$-0.88(-7.0\%)$
1988.11.8	**Republican**	$+0.08(+1.1\%))$	$0(0\%)$	$0(0\%)$
1992.11.3	**Democratic**	$+0.02(+0.66\%)$	$-0.02(-0.34\%)$	$-0.01(-0.15\%)$
1996.11.5	**Democratic**	$+0.01(+0.20\%)$	$-0.07(-1.1\%)$	$-0.08(-1.3\%)$
2000.11.7	**Republican**	$0(0\%))$	$-0.07(-1.2\%)$	$0(0\%)$
2004.11.2	**Republican**	$-0.02(-1.2\%)$	$-0.02(-0.60\%)$	$-0.01(-0.24\%)$
2008.11.4	**Democratic**	$-0.01(-2.0\%)$	$-0.15(-5.5\%)$	$-0.15(-3.8\%)$
2012.11.6	**Democratic**	$+0.01(+6.7\%)$	$+0.05(+0.71\%)$	$+0.06(+3.5\%)$

Table 4.1: Change Rate of Treasury Yield in General Elections

By looking at the movement of yield rate during the presidency of the presidents in the last 40 years, it seems to be the case that the yield rates tend to increase when a Democratic hold the office and decrease when a Republican hold the office, which accords with Stephan Eichlers theory.

President & Party	**Date**	**3-month treasury**	**5-year treasury**	**10-year treasury**
Carter Democratic	1977.1.20	4.63	6.64	7.26
		$+10.69(230.88\%)$	$+6.13(92.32\%)$	$+5.24(72.18\%)$
Reagon Republican	1981.1.20	15.32	12.77	12.5
		$-7.08(-46.21\%)$	$-3.66(-28.67\%)$	$-3.47(-27.76\%)$
G.Bush Republican	1989.1.20	8.24	9.11	9.03
		$-5.23(-63.47\%)$	$-3.26(-35.78\%)$	$-2.42(-26.80\%)$
Clinton Democratic	1993.1.20	3.01	5.85	6.61
		$+2.09(+69.44\%)$	$-1.01(-17.26\%)$	$-1.42(-21.48\%)$
G.W.Bush Republican	2001.1.20	5.1	4.84	5.19
		$-4.97(-97.45\%)$	$-3.36(-69.43\%)$	$-2.79(-52.76\%)$
Obama Democratic	2009.1.20	0.13	1.48	2.4
		$+0.16(123.08\%)$	$-0.23(-15.54\%)$	$-0.53(-22.08\%)$
	2016.1.20	0.29	1.25	1.87

Table 4.2: Change Rate of Treasury Yield during Presidency

In summary, it may be rather hard to capture the news related to the results of election.

4.2 Debt-to-GDP Ratio

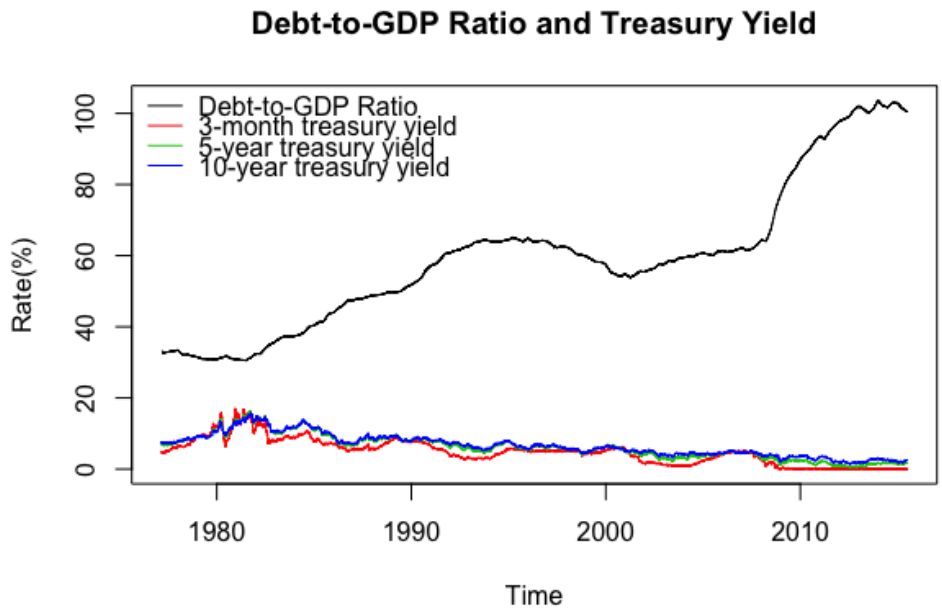

Figure 4.1: Debt-to-GDP Ratio abd Treasury Yield

By Tygran Poghosyans's discovery(2012), Debt-to-GDP ratio should be positively related to yield rate of treasuries. Because Debt-to-GDP ratio somehow measures the ability of a government to pay his debt without default. If a Debt-to-GDP ratio is high, then buying sovereign bonds issued by the government will be risky since it's more possible that the government will default on its bonds. To attract buyers, a higher yield rate should be offered.

By testing the correlation coefficient between Debt-to-GDP ratio and yield rates of treasuries, we can have a basic idea about their correlation. It turns out the correlation between Debt-to-GDP ratio and yield rate of 3-month, 5-year and 10-year treasury bill are -0.8365094, -0.8539935 and -0.8400708, respectively. A fairly significant negative correlation is observed.

Such an observation seems to contradicts Tygran Poghosyans's discovery(2012). And by investigation, the special role and position of U.S treasury differ it from other sovereign bonds in the aforementioned regard. And such a phenomenon is more likely due to two simultaneous trends, the

increase of Debt-to-GDP ration and decrease of treasury yield in the last four decades. Therefore, although presenting a high correlation, the Debt-to-GDP doesn't appear to be a good predictor of treasury yield.

4.3 Returns of Stock Market

We measure returns of stock market mainly by two index, the Dow Jones Idustrial Average (DJIA) and Standard & Poor's 500 (SP 500). According to Lieveen Baele, Geert Beckhaert and Koen Inghelbrecht(2010), the yield rates and returns of stock market are usually positively related, since investors hold treasuries as an alternative of stocks and other assets. When the returns of stock market is high, people may be more willing to take risk and hold stocks instead of treasuries. Consequently, demand of treasuries falls and price of treasuries will decrease and the yield rate will increase, and vice versa. However, in terms of this paper's view, it's also likely that people's decision are made based on the changes of stock market returns. The volatility of stock returns, which is measured by the absolute value of change rate, will be negatively rated to yield rate of treasuries, since when the market is volatile, investors tend to hold more treasuries to control risk.

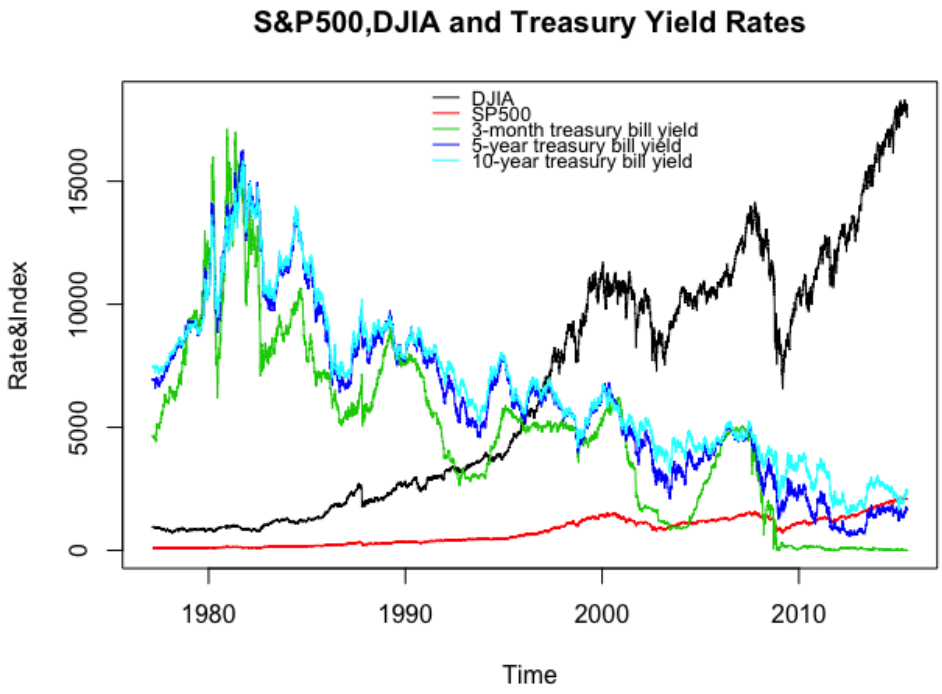

Figure 4.2: SP500,DJIA and Treasury Yield

By testing the correlation of them, we find the correlation coeffcient between DJIA and yield rates of 3-month, 5-year and 10-year treasuries are -0.7664443,-0.8400844 and -0.8557568, respectively, while the correlation coefficient between SP500 are -0.7353452, -0.8132904 and -0.8347104, respectively. The correlation coeffcients demostrate a negative correlation between the sotck market returns and yield rates of treasuries.

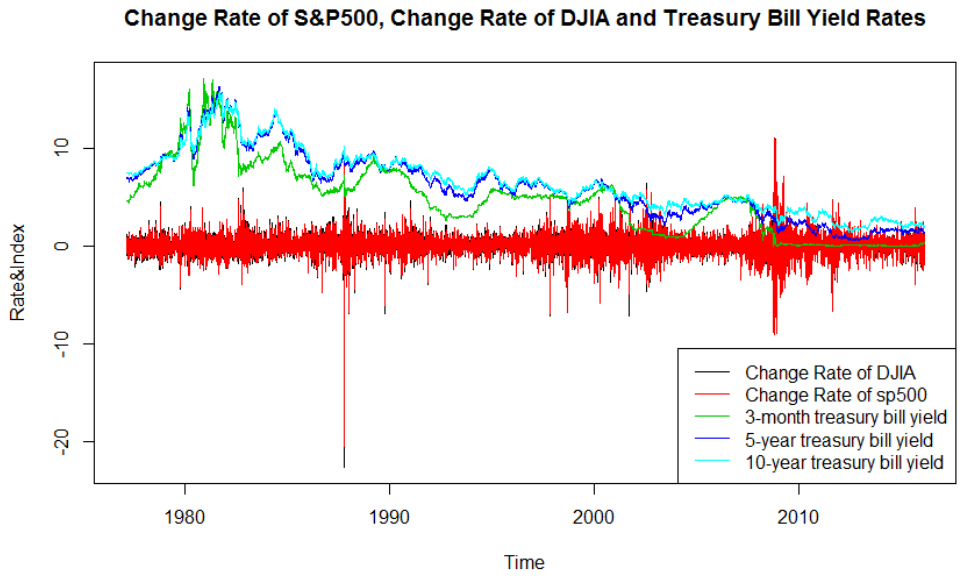

Figure 4.3: Volatility of SP500, DJIA and Treasury Yield

The change rate and absolute change rate of stock market returns demonstrate a slight negative relationship with yield rate of treasuries. The correlation between absolute change rate of DJIA and 3-month, 5-year, and 10-year treasuries are -0.04747019, 0.04309507 and -0.03991927, respectively, while the correlation between absolute change rate of SP 500 is -0.07792544, -0.07789792 and -0.07434431, respectively. The correlation between change rate, instead of absolute change rate, and yield rates of treasuries are even minor.

4.4 Oil Market

We usually measure returns of stock market mainly by two prices, the West Texas Intermediate price (WTI) and Brent Crude Oil price (Brent). Due to the availability of historical data, only the WTI will be used to represent the price of oil.

When the price of oil are increased, the cost of production goes up and thus the investment will be produced to maximize the profit. In this regard, investors may be pesimistic about the market and substitute their asset investment with risk-free treasuries. Thus, the price of treasuries will increase and lower the yield rates of treasuries.

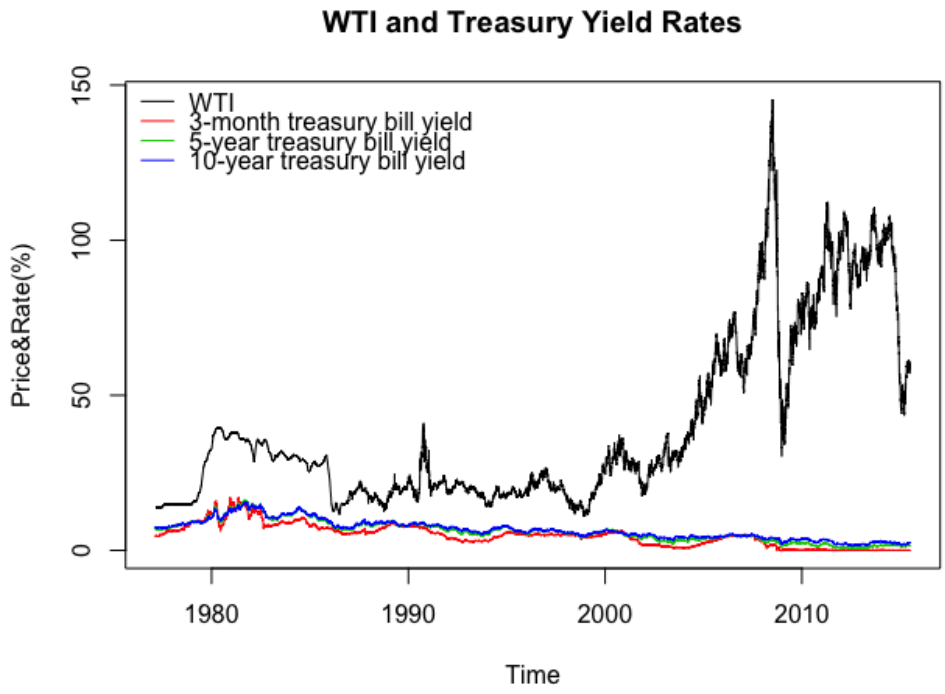

Figure 4.4: WTI and Treasury Yield

By looking at the correlation, we found a fairly significant negative relationship between the WTI and yield rates of treasuries. The correlation between WTI and 3-month, 5-year and 10-year treasuries are -0.5256436, -0.576039 and -0.5571986 repectively. Such a result accords with our aforementioned analysis.

4.5 Price Level

We measure price level mainly by Consumer Price Index (CPI) and Personal Consumption Expediture (PCE).

The inflation price level, can be either positively or negatively related to yield rate of treasuries. When the price level is increasing, treasuries with low yield rate will no longer be attractive for investors. Consequently, people will substitute their treasuries with other assets or consumption. Consequently, the prices of treasuries will fall and yield rates go up. This analysis also accords with the opinion that decomposes the yield rate of treasuries into expected inflation rate and risk

premium. However, it might also be the case that the government lower the yield rates of treasuries by open market operations, to increase the total demand, and thus the price level.

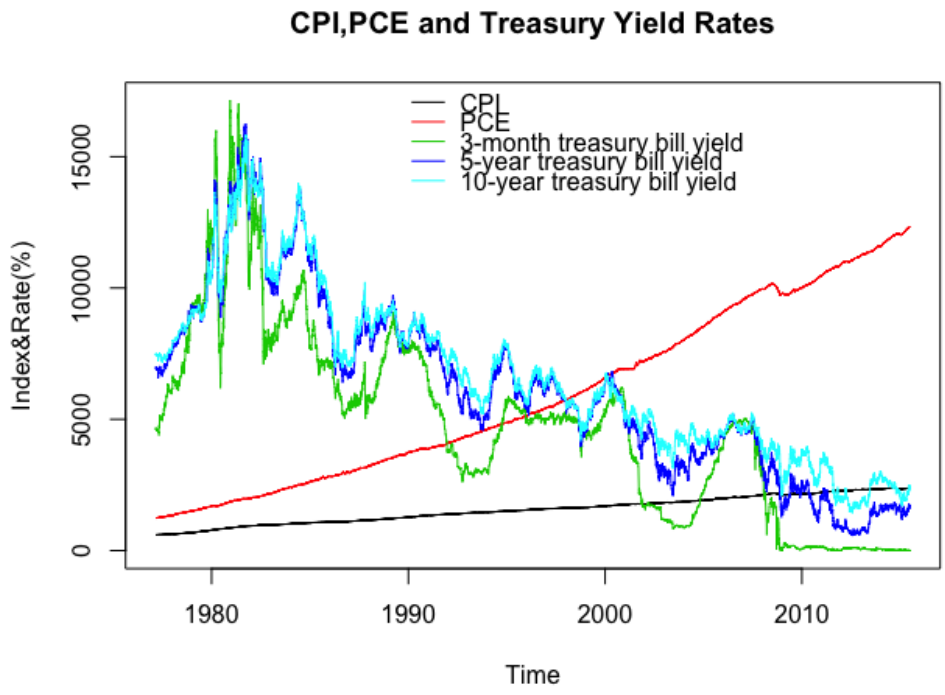

Figure 4.5: CPI, PCE and Treasury Yield

By observing the correlation between change rate of CPI and treasuries yield and correlation between change rate of PCE and treasuries yield, we do find a strong negative relations. The correlation coefficient between change rate of CPI and yield rate of 3-month, 5-year, and 10-year are -0.8335258, -0.8747231 and -0.8753155, respectively. In comparison, the correlation coefficient between change rate of PCE and yield rate of 3-month, 5-year, and 10-year are -0.8306337, -0.8838008 and -0.8847003, respectively. These results show that the latter opinion might be the case, in which the government played an important role.

4.6 Residential Price

We measure the residential price with real residential property prices for united states. It's a index with the price in 2010 as 100. As to the relationship between residential price and yield rate of treasuries, there are two completely different possibilities. The first is that that housing market is in the shortage of supply, the residential property is appreciating and expected to appreciate. Investors may substitute their treasuries with residential property. Housing prices fall and yield rates go up. Under this circumstance, the yield rate and residential prices are positively related. However, on the opposite, it also may be the case that the residential prices are negatively related to the yield rates of treasuries. In this regard, the government conducts open market operations to lower the yield rates of treasuries. As expected, investors will substitute their treasuries with residential property. The demand of residential property goes up and so does the prices.

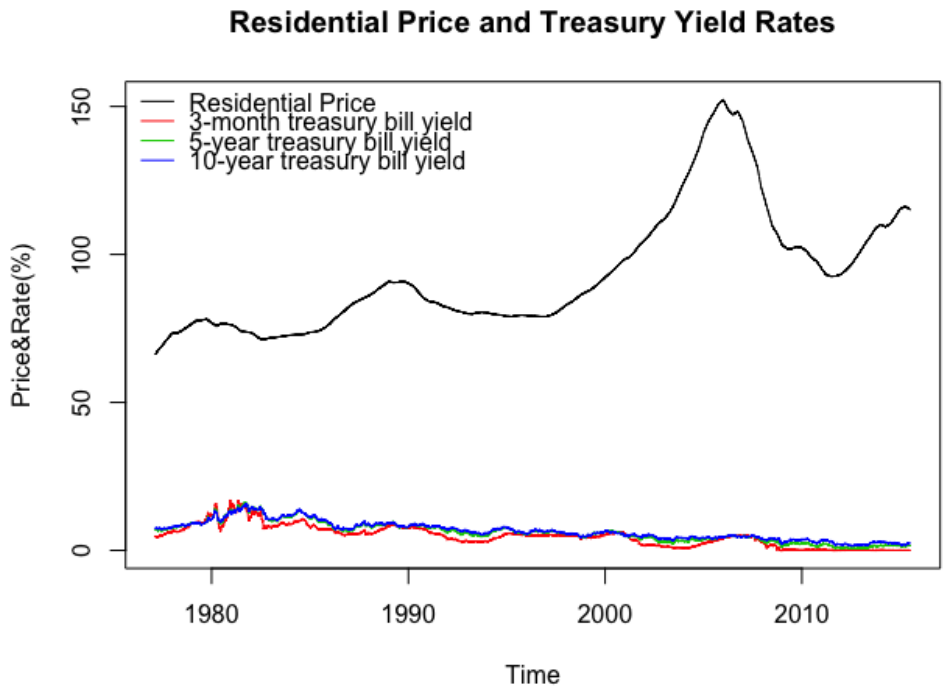

Figure 4.6: Residential Price and Treasury Yield

By investigating their correlation, the correlation coefficient between residential prices and

yield rates of 3-month, 5-year and 10-year treasuries are -0.5406558, -0.6160448 and -0.639162. By this result, it seems it's more likely that people's choice of purchasing residential property are influenced by the yield rate of treasuries instead of the opposite. Also, their decision depends more on the yield rate of long-term treasuries.

4.7 Unemployment Rate

The umemployment, which indicates the situation of labor market, also reflects the wellness of the economy. When the unemployment is low, people are substituting risk-free treasuries with other asset investment. In this regard, the price of treasuries will decrease and yield rates thus will increase. They are positively related.

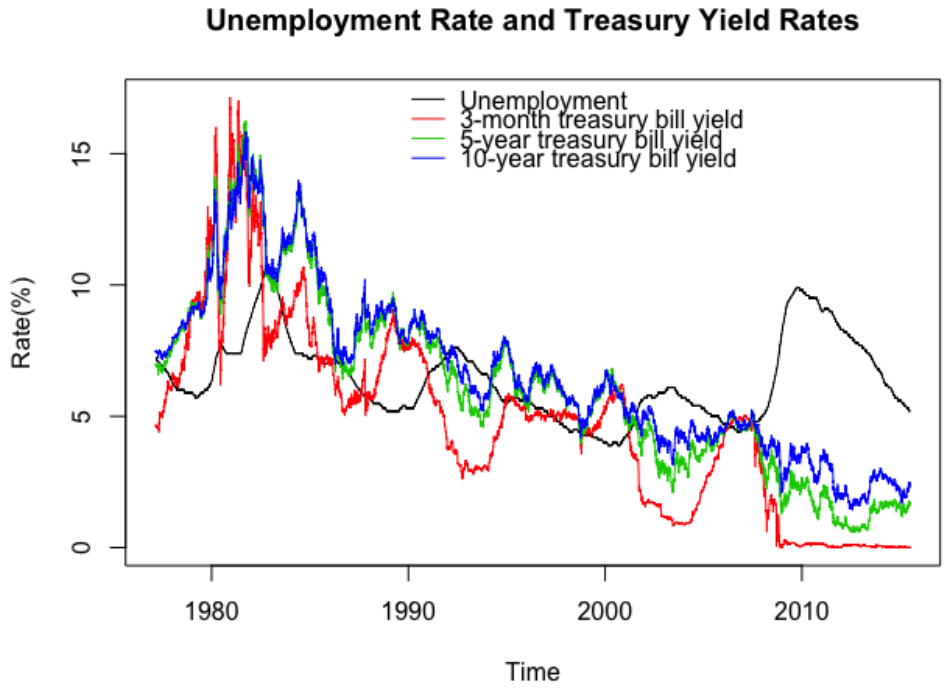

Figure 4.7: Unemployment Rate and Treasury Yield

By testing their correlation, the correlation coefficient between unemployment rate and yield rates of 3-month, 5-year and 10-year treasuries are 0.009742432, 0.1264822 and 0.195862. It

seems the correlation are not significant and even minor for the yield rate of short-term treasury, while there's still a weak positive correlation between the unemployment rate and 5-year and 10-year treasuries. Thus, it seems that the unemployment rate may not be a good indicator.

4.8 Trade Balance

The trade balance is the change of the current account of a country. When the trade balance is negative then there's a dificit while there's a surplus when it's positive. Usually when there's a deficit, investor from foreign countries will have a gain in dollar cash and tend to substitute them with U.S treasuries. Consequently, the price of treasuries will increase and the yield rates will decrease. Thus, there's a positive relationship between the trade balance and the yield rates of treasuries.

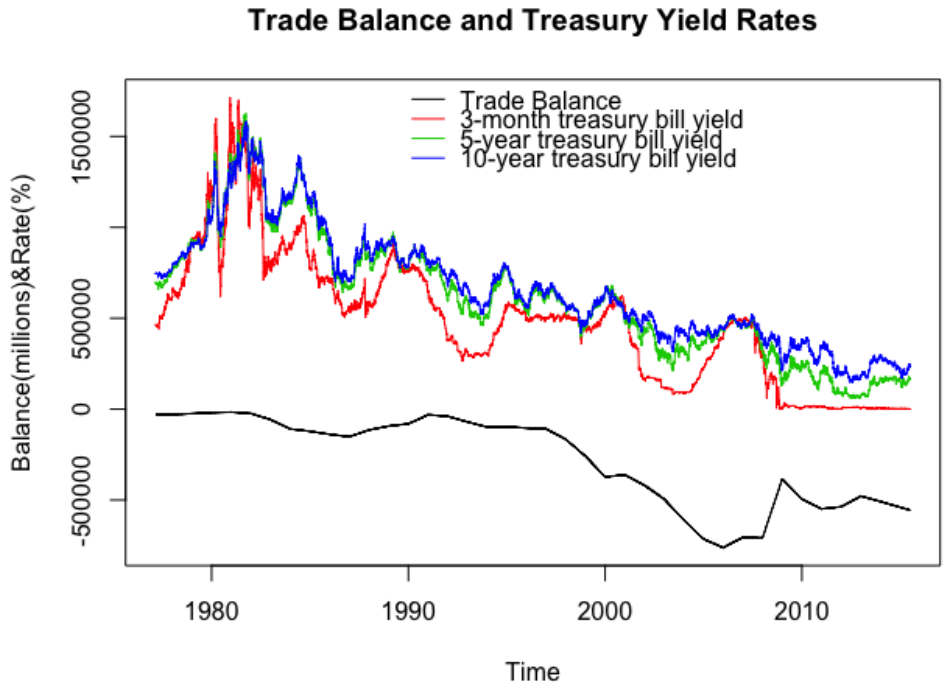

Figure 4.8: Trade Balance and Treasury Yield

By investigating the correlation, the correlation coefficient between trade balance and 3-month,

5-year and 10-year treasuries are 0.6929095, 0.7523292 and 0.7609948, respectively. This correlation is pretty strong and accords with our theory.

4.9 Labor Participatetion Rate

Labor participation rate is also a potential factor that could influence the yield rates of treasuries. Basically, we may expect a positive relationship between the labor participation rate and yield rates of treasuries. Since when the labor participation rate is low, the pension fund will play a more important role in asset market, which also has a preference for the risk-free U.S treasuries. The price of treasuries will increase and the yield rates decrease.

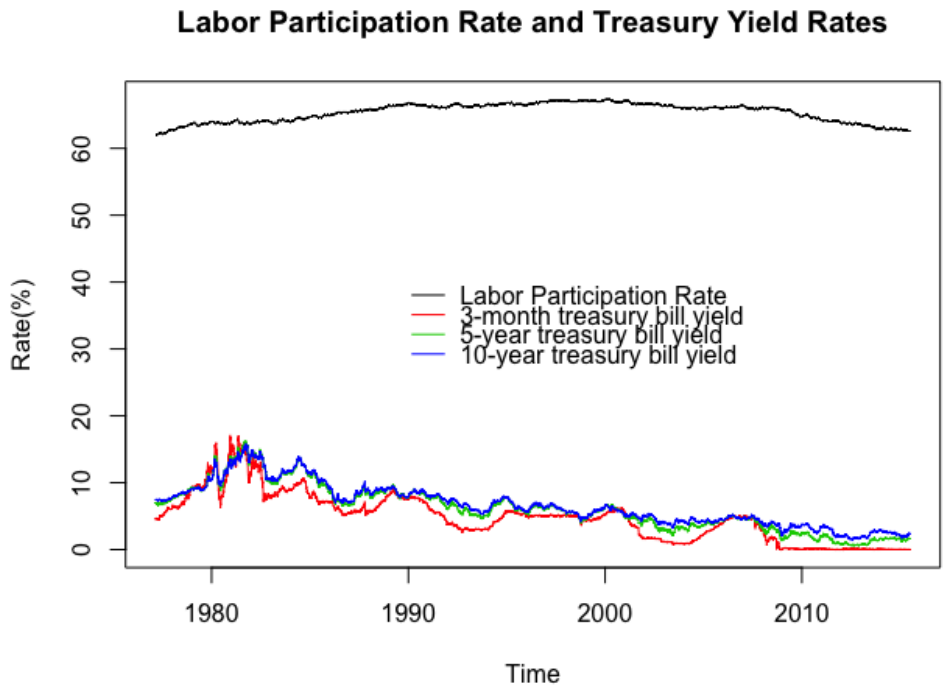

Figure 4.9: Labor Participation Rate and Treasury Yield

It turns out the correlation coefficient between labor participation rate and 3-month, 5-year and 10-year treasuries are -0.1042757, -0.1129234 and -0.1458473, respectively. This correlation seems minor and contradicts our aforementioned theory. Thus, it may not be a good indicator for

our VAR model.

4.10 Target Federal Funds Rate

The target federal fund rate, is an important policy target of the monetary policies made by federal reserve. It's strongly positively correlated with federal funds rate and thus yield rates of treasuries.

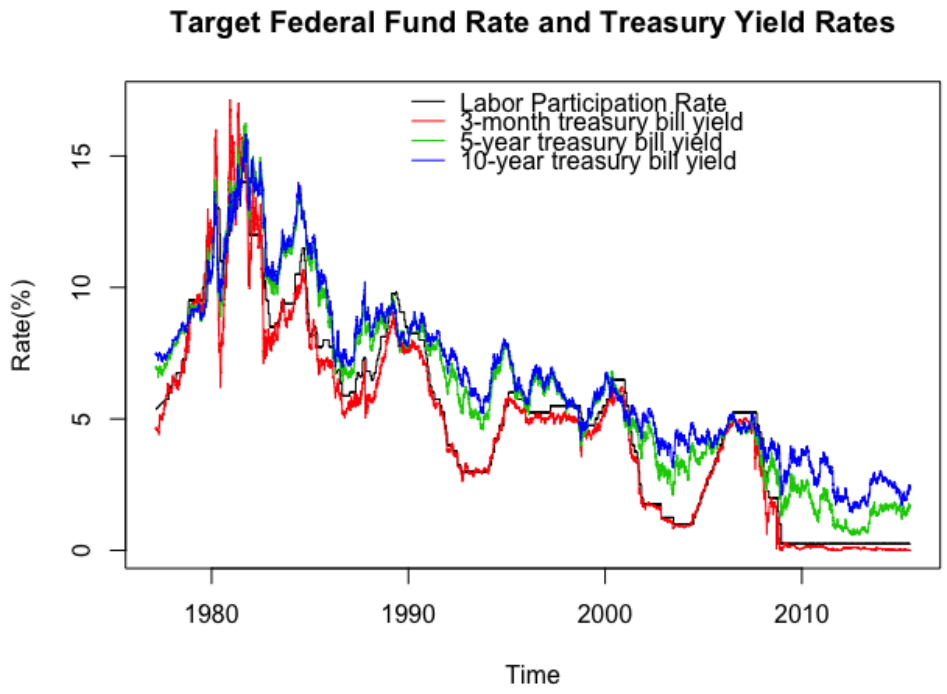

Figure 4.10: Target Fed Funds Rate and Treasury Yield

The correlation coefficient between target funds rate and 3-month, 5-year and 10-year treasuries are 0.9855456, 0.9558638 and 0.9345317, respectively. It's a pretty strong correlation.

4.11 Gold Price

The gold, as a substitute asset of U.S treasuries. Since they have the similar anti-risk property, investors might hold more U.S treasuries while they hold more gold. Thus, the price of them should

be positively related. And as the price and yield rates of treasuries are negative, the correlation between gold price and yield rates are supposed to be negative.

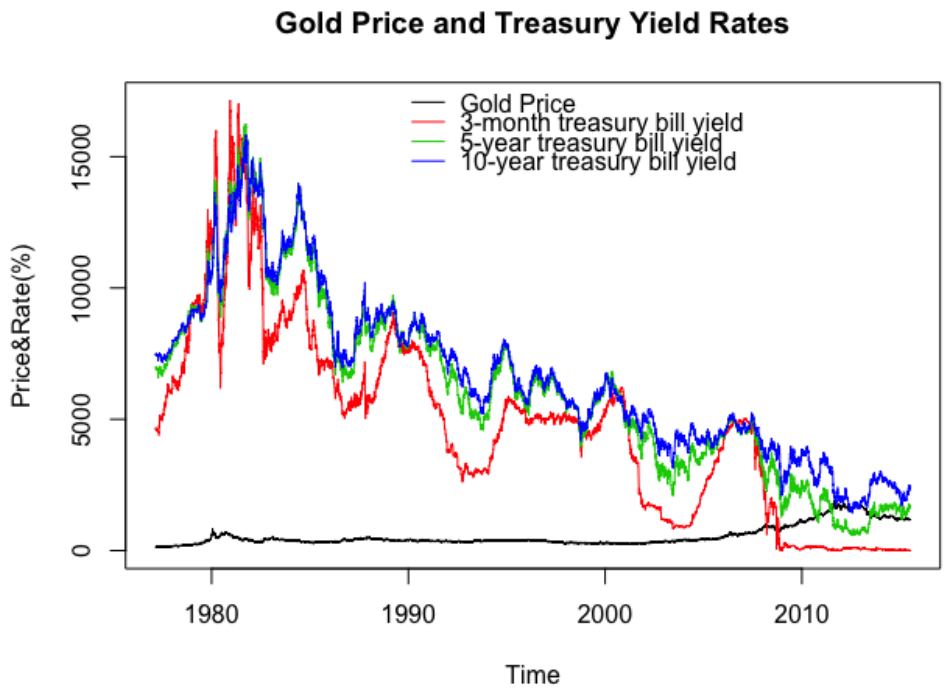

Figure 4.11: Gold Price and Treasury Yield

By looking at the correlation between gold price and treasury yield rates. The correlation coefficient between gold price and 3-month, 5-year and 10-year treasuries are -0.5604163, -0.6008714 and -0.5725364, respectively. This result is fairly significant and accords with the aforementioned argument.

Chapter 5

The Model

5.1 ARMA Model

We conduct prediction on yield rate of treasury bill mainly via two approaches, ARMA approach and VAR approach, which presents two directions, one is to predict yield rate based on its historical data and the other is to predict yield rate through related economics variables.

A ARMA(p,q) model is in the form of the following [13]

$$\phi(B)X_t = \theta(B)\omega_t$$

where

$$\phi(B) = 1 - \sum_{i=1}^{p} \phi_i B^i$$

$$\theta(B) = 1 + \sum_{i=1}^{q} \theta_i B^i$$

It follows that

$$X_t = \phi_1 X_{t-1} + ... + \phi_p X_{t-p} + \omega_t + \theta_1 \omega_{t-1} + ... + \theta_q \omega_{t-q}$$

It's noted that X_t is the value of the variable of interest at time t while ω_t is the white noise at time t. It's noted that sometimes we may see seasonal trend in time series data, thus a seasonal lag can also be of interest.

Based on this construction, we evaluate the parameters and get the optimal models for yield rate of 3-month treasury, 5-year treasury and 10-year treasury.

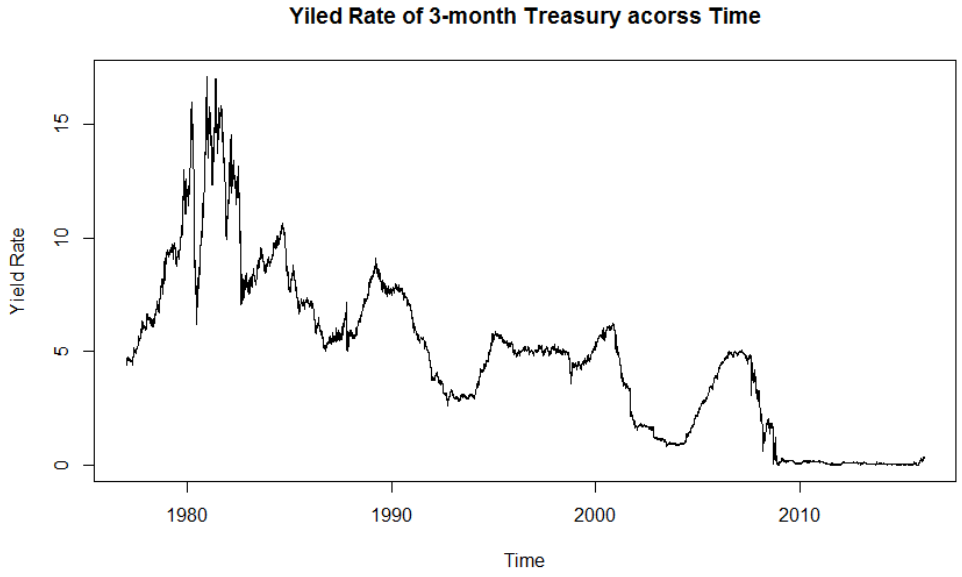

Figure 5.1: Yield Rate of 3-month Treasury

For the 3-month treasury, we made attempts to construct ARMA model according to its auto-correlation and partial auto-correlation. By testing different models, dropping the insignificant term and comparing the AIC and BIC value [14], we found the most suitable model for it is ARMA(5,0)*(0,0) Model,namely, AR(5) Models. The model is specified as follows:

$$X_t = 1.1132X_{t-1} - 0.0956X_{t-2} - 0.0614X_{t-3} + 0.0924X_{t-4} - 0.0488X_{t-5} + \omega_t$$

The standard deviation of the coefficients of the five lag terms are 0.0103, 0.0154, 0.0154,

0.0154 and 0.0103, respectively.

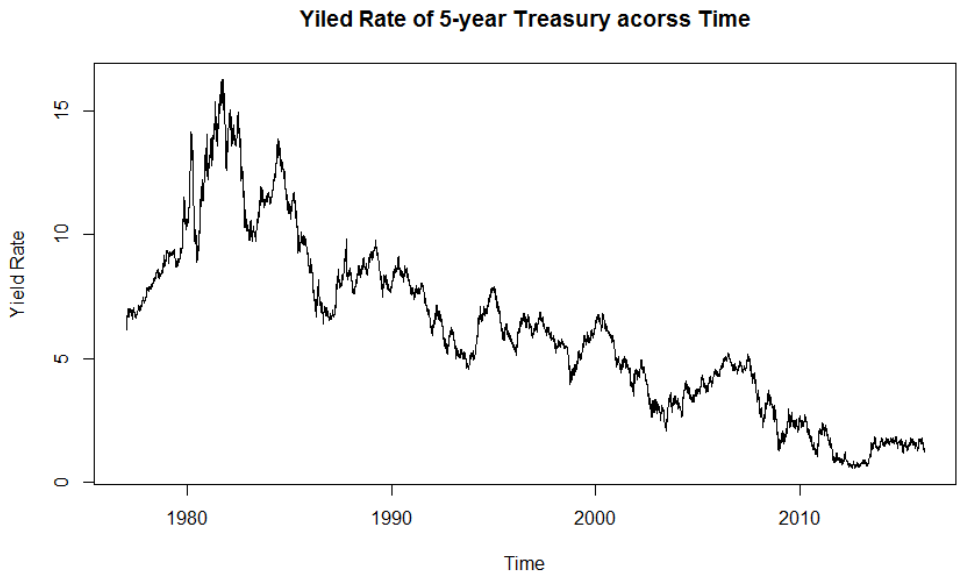

Figure 5.2: Yield Rate of 5-year Treasury

Similarly, we constructed various ARMA models according to its auto-correlation and partial auto-correlation. By testing different models, and comparing term signifance, AIC and BIC value, we found the most suitable model for it is ARMA(2,0)*(0,0), namely, AR(2) model. The model is specified as follows:

$$X_t = 1.0714X_{t-1} - 0.0715X_{t-2} + \omega_t$$

The standard deviation for the coefficient of the first lag term and for second lag term are 0.0103 and 0.0103, respectively.

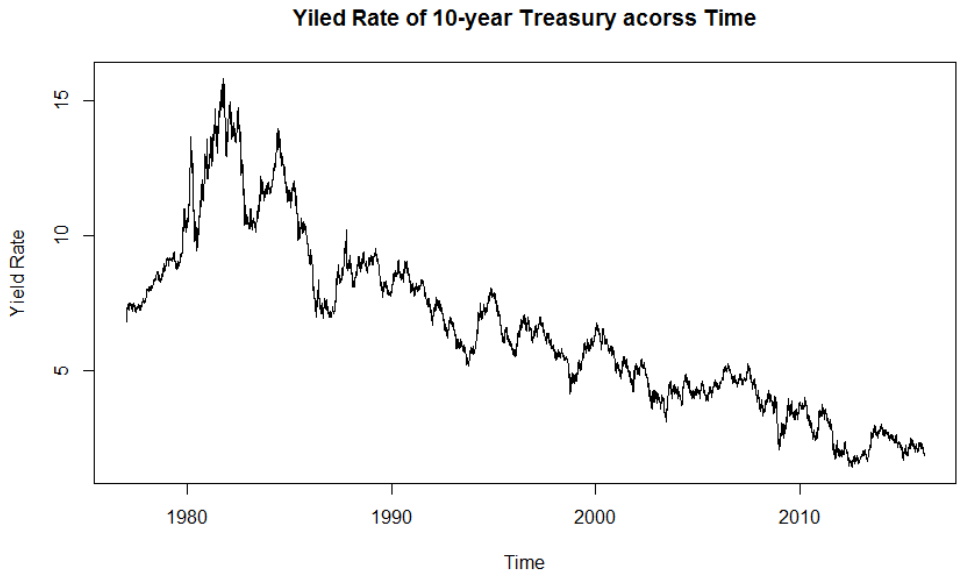

Figure 5.3: Yield Rate of 10-year Treasury

Finally, we also constructed the ARMA models for 10-year treasury in the same way. By tests we find the most suitable is ARMA(2,0)*(0,0), which can be also thought as a AR(2) model. The model is specified as follows:

$$X_t = 1.0590X_{t-1} - 0.0591X_{t-2} + \omega_t$$

The standard deviation of coefficent for the first lag term and for second lag term are 0.0103 and 0.0103, respectively.

The ARMA model for predicting the yield rates of 3-month, 5-year and 10-year treasuries are thus obtained.

5.2 VAR Model

Instead of predicting the yield rates of the U.S treasuries using their historical data, a VAR (vector auto-regressive) can also be considered due to the reasons included in the factor analysis chapter.

The formula of a VAR(p) model can be concluded as

$$X_t = \beta_{t-1}X_{t-1} + \beta_{t-2}X_{t-2} + ... + \beta_{t-p}X_{t-p} + \omega_{t-1}Y_{t-1} + \omega_{t-2}Y_{t-2} + ...\omega_{t-p}Y_{t-p}$$

We define political factor as a dummy equal to 1 if the democats hold the office while 0 if the republican hold the office. We denote this variable at time t with P_t

For the continuous variables, we denote the Debt-to-GDP ratio at time t with S_t,denote DJIA at time t with D_t, denote the WTI at time t with W_t, denote the CPI with C_t and PCE at time t with T_t, denote the residential price index at time t with R_t, denote trade balance at time t with B_t, denote target federal funds rate at time t with F_t and denote gold price at time t with G_t

By checking the significance for each term and each lag, and comparing AIC and BIC of different models. we obtained optimal vector-autoregressive model for yield rates of 3-month, 5-year and 10-year treasuries.

For the yield rate of 3-month treasuries, we have the following result:

Variable	lag1	p-value	lag2	p-value
3-month treasury yield	1.10161	$2e-16$	-0.10801	$2e-16$
Political Factor	-0.07256	0.0773	0.07910	0.0541
Target Fed Funds Rate	0.08543	$1.89e-06$	-0.07947	$7.79e-06$
CPI	0.05706	0.1803	-0.05709	0.1801

Table 5.1: Coefficient of VAR(2) Model for 3-month Treasury Yield

The model is thus specified as

$$X_t = 1.10161X_{t-1} - 0.10801Xt - 2 - 0.07256P_{t-1} + 0.07910P_{t-2} + 0.08543F_{t-1} - 0.07947F_{t-2}$$
$$+ 0.05706C_{t-1} - 0.05709C_{t-2}$$

The table above shows the coefficient for each term for each variable in the model and the corresponding p-values, which measures how unlikely they don't have a effect in the predictive

model.

From the result we can see that the 3-month treasury rate has a negative effect on the yield rate of 3-month treasury on 2 days after and a positive effect on the rate on the next day. While for the political factor, we can see a negative coefficient on the 1 lag term and postive 2 lag term and sum up to be positive, which means that during the presidency of a democratic president, for each 2 day period, there's a overall increasing tread in the 3-month treasury. The target federal funds rate has a positive effect on the yield rate of 3-month treasury on the next day while negative effect on the yield rate of 3-month treasury on the rate on 2 days later. And they sum up to be positive, which means in a longer period thay are positively related to 3-month yield. For the CPI, it has a positive effect on the 3-month yield on the next day and negative effect on the 3-month yield on two days after and they sum up to be negative, which means that they are negatively related to the 3-month yield in a long run. By the p-value of these variables, we can see that the 3-month treasury terms and target fed funds rate are extremely significant in predicting the 3-month treasury. The political factor is fairy significant, while the CPI terms are not so significant, but still with a approximately 82% chance to be significant. All these results accords with our factor analysis. And the adjusted R^2 is 0.9997, which indicates that this model is pretty good at explaining the past fluctuation of 3-month treasury yield.

For the yield rate of 5-year treasuries, we have the following results:

Variable	**lag1**	**p-value**	**lag2**	**p-value**
5-year treasury yield	1.06618	$2e-16$	-0.06735	$8.41e-11$
Political Factor	-0.06140	0.069451	0.06408	0.058161
Target Fed Funds Rate	0.05272	0.000274	-0.05175	0.000345
CPI	0.09473	0.006598	-0.09474	0.006596

Table 5.2: Coefficient of VAR(2) Model for 5-year Treasury Yield

Thus the resulted model is specified as

$$X_t = 1.06618X_{t-1} - 0.06735Xt - 2 - 0.06140P_{t-1} + 0.06408P_{t-2} + 0.05272F_{t-1} - 0.05175F_{t-2}$$
$$+ 0.09473C_{t-1} - 0.09474C_{t-2}$$

The table above shows the coefficient for each term for each variable in the model and the corresponding p-values, which measures how unlikely they don't have a effect in the predictive model.

By the result we can conclude that the yield rate of 5-year treasury on a specific day has a positive effect on the 5-year treasury on the next day and negative effect on the 5-year treasury 2 days after. The political factor has a negative effect on the 5-year treasury on the next day while a positive effect on the 5-year treasury on 2 days after, and sum up to be positive, which indicates a long-term increasing treand during a democratics president's presidency. The target fed funds rate on a specific day has a positive effect on the 5-year treasury on the next day while negative effect on the -year treasury 2 days after. And they sum up to be positive, which indicates a positive relationship in the long-term. And CPI on a specific day has a positive effect on the 5-year treasury yield on the next day while a negative effect on the 5-year treasury on 2 days after. And they sum up to be negative, which indicates a negative relationship in the long run. Similar to the 3-month VAR model, the 5-year treasury yield term and target federal funds rate term are extremely significant. But differently, both CPI and political factor are quite significant, especially the CPI. This indeicates that the consumption price level may have a greater effect on the yield rates of mid-term and long-term treasury than that of short-term treasury. Also, the adjusted R^2 is 0.9999, indicating that the model is pretty good at explainning the past fluctuation of the yield rates of 5-year treasury.

For the yield rate of 10-year treasuries

Variable	lag1	p-value	lag2	p-value
10-year treasury yield	1.054	$2e-16$	$-5.486e-02$	$1.11e-07$
Political Factor	$-3.815e-02$	0.22204	$3.979e-02$	0.20279
Target Fed Funds Rate	$7.245e-02$	$5.70e-08$	$-7.152e-02$	$8.12e-08$
CPI	$8.543e-02$	0.00809	$-8.544e-02$	0.00809
Gold Price	$1.259e-04$	0.15277	$-1.241e-04$	0.15870

Table 5.3: Coefficient of VAR(2) Model for 10-year Treasury Yield

Thus the resulted model is specified as

$$X_t = 1.054X_{t-1} - 0.05486Xt - 2 - 0.03815P_{t-1} + 0.03979P_{t-2} + 0.07245F_{t-1} - 0.07152F_{t-2}$$
$$+ 0.08543C_{t-1} - 0.08544C_{t-2} + 0.0001259G_{t-1} - 0.0001241G_{t-2}$$

The table above shows the coefficient for each term for each variable in the model and the corresponding p-values, which measures how unlikely they don't have a effect in the predictive model.

By the result we can see that the 10-year treasury yield on a specific day has a positive effect on the 10-year treasury yield on the next day while a negative effect on the 10-year treasury 2 days after. The political factor has a negative effect on the 10-year treasury on the next day while a positive effect on the 10-year treasury 2 days after. And they sum up to be positive, which indicates a increasing treand during the presidency of a democratic president. The target fed funds rate on a specific day has a positive effect on the 10-year treasury on the next day while a negative effect on the 10-year treasury on 2 days after, which indicates a positive relationship. The CPI on a specific day has a positive effect on the 10-year treasury on the next day while a negative effect on the 10-year treasury on 2 days after. And they sum up to be negative, which indicates a negative relationship in the long run. The gold price on a specific day has a postive effect on the 10-year treasury on the next day, while a negative effect on the 10-year treasury on 2 days after.And they sum up to be positve, which indicates a positive relationship. Looking at the p-value, the 10-year treasury yield and target funds rate are extremely significant, while the CPI, as in 5-year treasury

VAR model, is quite significant and the political factor and gold price are not quite significant. Also, the adjusted R^2 is 0.9999, which means the model is pretty good at exlaining the historical fluctuation of 10-year treasury yield.

In summary, we can see that the yield rate's historical data and target fed funds rate are most important in the predictive model, while political factor tends to have effect on the short-term and mid-term treasury instead of long-term treasury. Different from that, the CPI seems to have a minor effect on the short-term treasury yield but fairly strong effect on the mid-term and long-term treasury yield. The three models all have done a pretty good job in exlaining the historical fluctuations.

5.3 Predictability of Treasury Yield

Using the model acquired before, we would compare the prediction using different models for different treasury yield.

The paper attempts to predict the yield rate of 3-month, 5-year and 10-year treasuries in 100 trading days after July 1st, 2016, based on all available data between January 7th,2016 and July 1th,2016. We apply the models abtained before and make the predictions and comparisons.

We denote predicted yield rate of 3-month treasury at time t with $\hat{X_t^t}$, denote predicted yield rate of 5-year treasury at time t with $\hat{X_t^f}$, denote predicted yield rate of 10-year treasury at time t with $\hat{X_t^d}$. Meanwhile, we denote the real data of yield rate of 3-month, 5-year and 10-year treasury at time t with X_t^t, X_t^f and X_t^d, respectively. Further, we define

$$\epsilon_t^t = X_t^t - \hat{X_t^t}$$

$$\epsilon_t^f = X_t^f - \hat{X_t^f}$$

$$\epsilon_t^d = X_t^d - \hat{X_t^d}$$

$$D_n^t = \sum_{t=1}^{n} |\epsilon_t^t|$$

$$D_n^f = \sum_{t=1}^{n} |\epsilon_t^f|$$

$$D_n^d = \sum_{t=1}^{n} |\epsilon_t^d|$$

Then we can get the following result:

D_n^t, D_n^f, D_n^d	**n=30**	**n=60**	**n=100**
3-month ARMA	1.077526	2.195285	3.823977
3-month VAR	0.4041243	1.981744	6.188965
5-year ARMA	2.60894	8.077337	16.69183
5-year VAR	2.771091	8.742196	18.23179
10-year ARMA	4.220744	11.75725	22.53006
10-year VAR	4.480913	12.8033	25.45413

Table 5.4: Perfomance of Prediction for Models Measured by Variation

By the result it seems for the prediction of yield rate of 3-month treasury, ARMA model works better for the prediction with length equals 30 and 60 days while the VAR model works better for the longer period of prediction. For the prediction of yield rates of 5-year and 10-year treasuries, the ARMA model works better for the prediction of treasury yield of 5-year and 10-year treasuries for all time periods.

Based on the results obtained above, we would further examine the performance of prediction with the ARMA model.

Firstly, we would obtain the standard deviation for the past 100 trading days for each treasurt yield and construct the interval for prediction of each day with width equal to 2 standard deviation, and see how much real data would be captured. Then we can get the following results

no. of days-data within the interval	Length=10 days	Length=30 days	Length=100 days
3-month model	9	10	32
5-year model	7	23	41
10-year model	9	20	31

Table 5.5: Perfomance of Prediction for Models Measured by Count Captured

Then, we would like to examine how much does the predicted data deviates from the real data. We measure this by with 1 standard deviation of the 100 real data as one unit, and calculate the number of units for the deviation of each predicted data. And we get the following results:

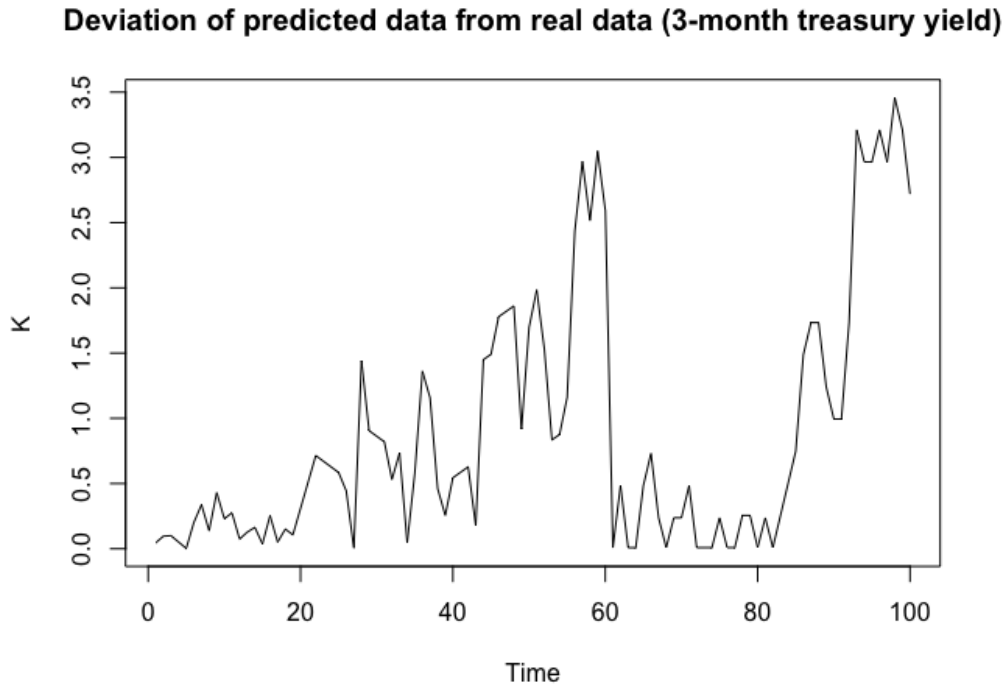

Figure 5.4: Deviation of Predicted Data from Real Data: 3-month Treasury Yield

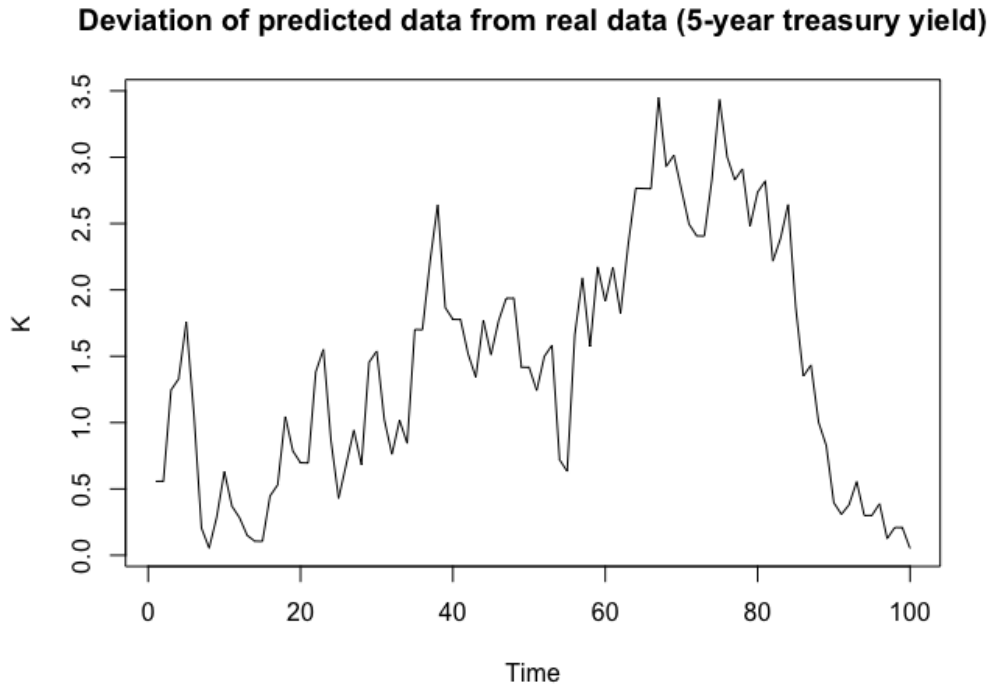

Figure 5.5: Deviation of Predicted Data from Real Data: 5-year Treasury Yieldl

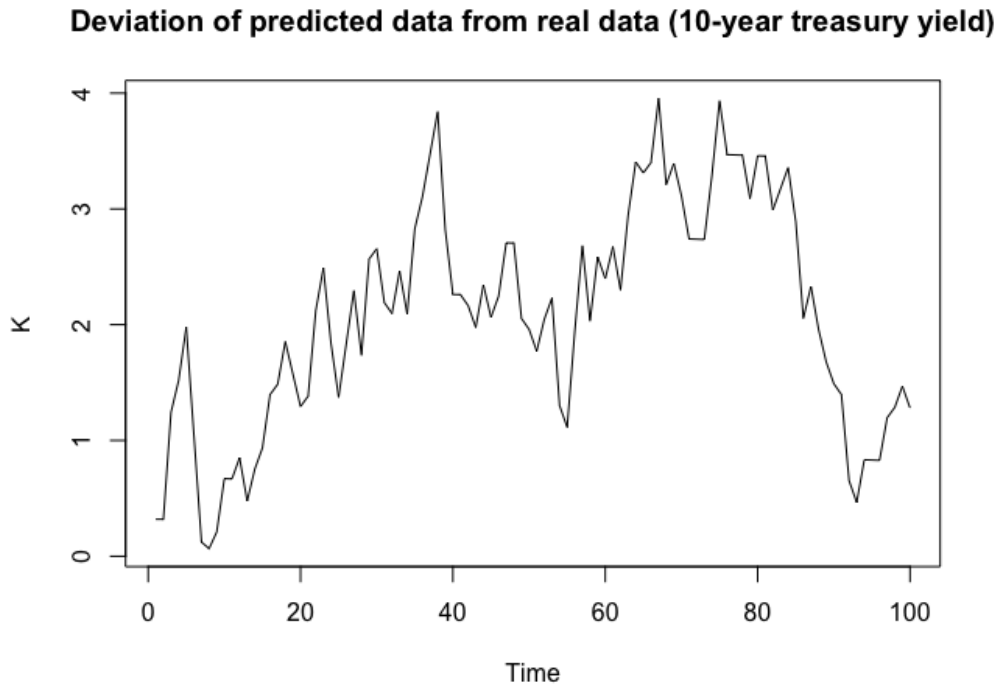

Figure 5.6: Deviation of Predicted Data from Real Data: 10-year Treasury Yieldl

By the plots we can see that the most of the data has a deviation from the real data greater than one standard deviation, with some of predicted data reaching three or four standard deviation away from the real data. And for the treasuries with longer term, the deviation seems to be larger.

Chapter 6

Conclusion

To predict the yield rates of 3-month, 5-year and 10-year treasuires, two methods, ARMA approach and VAR approach are applied.

For the ARMA approach, it turns out the optimal model for yield rate of 3-month treausy is AR(5), while AR(2) is the optimal model for yield rate of 5-year and 10-year treasuries. Using the ARMA model as predictive model in a 100-day period prediction, it works much better for yield rate of 3-month treasury than those of 5-year and 10-year treasury, and it works slightly better for the yield rate of 5-year treasury than that of 10-year treasury, which might be due to the character of ARMA model in capturing the short term effect.

For the VAR approach, after reviewing political factor, Debt-to-GDP ratio, returns of stock market, oil price, consumption price level, residential price, unemployment rate, trade balance, labor participation rate, target federal funds rate and gold price, we found political factor, target fed funds rate, and CPI to be significant predictor of the future course of yield rate of 3-month and 5-year treasuries. While political factor, target fed funds rate, CPI and gold price tend to be significant predictor of the yield rate of 10-year treasuries. The result also shows that political

factor tends to become less and less important from predicting the yield rate of short-term treasury to the long-term treasury, which might be due to the uncertainty of this variable in a long term. And the CPI is much important in predicting the yield rates of mid-term and long-term treasuries than that of short-term treasury. Also, the VAR model works much better for the yield rate of treasuries with shorter period to maturity. This might be due to the uncertainty and risk in a long term, which are hard to be included in this model.

Comparing two models in a 100-day period prediction, the performance of prediction of ARMA model works slightly better than the VAR model, which results in less deviation from the real data when used to predict the yield rate of 3-month, 5-year and 10-year treasuries in the 100 days fowllowing July 1st,2016. It's also noted that within a 30-day period, the VAR model works much better than ARMA model; however, as the period gets longer, its performance becomes much worse than ARMA model. Thus by comparison, the optimal model used to make the prediction of yield rates of 3-mont, 5-year and 10-year treasuries should be ARMA model.

Using the optimal model for each to predict the future course of yield rates of 3-month, 5-year and 10-year treasuries, we found that the performance of predictions tends to be better in the short term, especially in first 10 days of prediction. As the period of prediction gets longer, the predictions are not able to capture the real rate in a reasonable interval. This applies to the yield rates of 3-month, 5-year and 10-year treasuries. Also, it turns out that the yield rate of 3-month treasury is more predictable than that of 5-year and 10-year treasuriesl, since the predicted data of 5-year and 10-year treasury yields deviate much more from the real data than the yield rate of 3-month treasury does. This might be due to more fluctuation and uncertainty in the long run.

Overall the performances in prediction of the models can be further improved. This can be done by checking the model in several ways, one is that the construction of model may be inappropriate. For the ARMA model, the seasonal trend may be considered. And for the VAR model, some more relevant variables should also be included. Another one reason might be that the models are inappropriate, that the ARMA and VAR model might have flaws in capturing and predicting the future course of yield rates of U.S treasuries. All of these remain to be researched on.

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Academic Vitae
Huguang Zheng

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EDUCATION BACKGROUND

Pennsylvania State University, University Park **8/2014-5/2016(Expected)**
B.S in Mathematics, B.S in Statistics and B.S in Economics(With Honors)
Schreyer Honors Scholar, Dean's List for all semesters
Relevant Courses Include: Time Series Analysis, Stochastic Process and Monte Carlo Method, Fourier Series and Partial Differential Equations, C++ Programming, Numerical Computation, MATLAB Programming, Econometrics, Money and Banking, Financial Engineering and Risk Management(Coursera), Processing Data with Python(Coursera)

Central South University **9/2012- 7/2014**
Candidate of Bachelor Degree

PROFESSIONAL EXPERIENCE

Haitong Securities **Shanghai**
Investment Banking Intern **6/2015-8/2015**

- Assisted nationwide National Equities Exchange and Quotations(NEEQ) Listing work.
- Joined a cross-functional team. Worked closely with other staff to accomplish Due Diligence Investigations and Draft of Prospectus of 2 corporations, and made presentations in representative of the team.
- Supported writing of industry analysis report, worked as a co-writer of 2 reports and an assistant of 4 reports.
- Accessed and analyzed data from Wind terminal and researched potential IPO deals among 200+ corporations.
- Helped Coordinate roadshows for 30+ companies, connecting PE/VCs to High-tech Enterprises.

ZheShang Securities **Wenzhou**
Wealth Management Intern **7/2014-8/2014**

- Assisted managers to accomplish weekly analysis on macroeconomics, government policy and market, implemented analysis of the implication on the selection of recommended portfolios to clients.
- Offered advice on financial products to 20+ clients based on client's specified needs.
- Conducted risk analysis of 30+ clients and made suggestions on adjusting portfolio accordingly.

Industrial and Commercial Bank of China **Wenzhou**
Manager Assistant **12/2013-1/2014**

- Participated in CRM work, consulted with 5+ corporate client and draft proposals on improvement.
- Got involved in work of Credit Management and Sales department, learnt about commercial banking business.

RESEARCHES AND PROJECTS

Research Assistant in Economics Department, funded by Bates White Economic Consulting **9/2015-Present**

- Assisted researches on international trade and education in developing countries, responsible for information searching and data cleaning in Stata and R, and involved in pattern recognition and interpretation.

Honors Thesis, *Predictability of Treasury Bill Yield via ARMA and SVAR Approach* **9/2015-Present**

- Conducted researches based on Transaction Cost Based Monetary Model. Performed empirical tests involving treasury yield rate, Federal Funds Rate, Exchange Rate, etc. Constructed ARIMA and SVAR models in R and attempted to make predictions on future course of yield rates of treasury bill. Processed 50,000+ collected data.

LEADERSHIP INVOLVEMENT

Undergraduate Teaching Assistant **1/2015-5/2015**

- Graded homework and exams for Intermediate Economics course with 150+ students and coordinated exams.

Kangteng Business Case Analysis Contest **4/2013-5/2013**

- Team Leader of a group of 5 members, ranked second among 100+ teams in Hunan Province.

ADDITIONAL

Language: Chinese Cantonese (Native); Chinese Mandarin (Native); English (Proficient)
Skills: C++, Python, MATLAB, Mathematica, R/RStudio, SAS, Stata, LaTeX, Excel, Word, PowerPoint
Interest: Soccer, Reading, Hiking, Chess, Badminton, Table Tennis