Navigating Interest Rate Risk

Project 3

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Contents

1 Executive Summary

1.1 Project Overview

It is May 10, 2022. Sally lose nearly 15 percent of her 20-year Treasury bond portfolio in the first four months of the year, from Jan to April 2022. She wants to preserve capitals for an upcoming acquisition, which make the situation even worse. As the managing director of institutional investments, we have to give a concise overview of the facts, explain what has gone wrong, and provide a timely actionable plan to put things right with the client. we answer the following questions in this report:

1.1.1 What does the historical record tell us about such event?

Analyzing the historical data, we have collected 13 months with a bad return that similar to Sally's loss. Bad return are not only associate with interest rate change, but also associate with duration, which is the reason why we observe a similar loss today.

1.1.2 What is the probability of such an event?

We use AIRG Economic Scenario Generator to predict the probability of loss. The probability of loss that is greater than 15 percent is 0.00126.

1.1.3 Which adjustments to the portfolio strategy do we recommend going forward?

1. For shorter investment time horizons (1 years - 3 years)
    - Moving to the Intermediate Treasury portfolio
2. For intermediate investment time horizons(10 years)
    - Conservative Investor: The intermediate Treasury portfolio
    - Aggressive Investor: The blended portfolio
3. For long term investment time horizons (30 years)

- Conservative Investor: The blended portfolio
- Aggressive Investor : The long term treasury bond portfolio

1.2 Basic Facts about bond market

1. There are several types of risk associate with bonds, including interest rate risk, and prepayment risk.
2. Bonds have different maturity date, short term bond tend to mature within 1 to 3 years,intermediate term bond mature within 5 years, while long term bond generally mature over longer periods of time. In this report, we are operating a long term(20 year) Treasury bond portfolio.
3. Bond Return can be affected be several factors, such as change in interest rate or inflation. When interest rate goes up, bond return would decrease. Likewise, when interest rate falls, bond return would likely to increase.
4. Longer term bond price are much more responsive to changes in interest rate, with an upward sloping yield curve. The income from a long term bond is typically higher than the short term bond. Likewise, long term bond also have a higher interest rate risk because of longer duration.

2 Analysis on Historical Data

We have collected historical data for long term government bond return and bond yield dated from 1926. In order to understand to bond market behave historically, we need to compute the return for different time-frame. First, we compute the 4-month return using the monthly bond return data by setting an index value, and then we use the index value as reference to compute the following 8-month return as well as 12-month return. The rolling return for each period of time and their distribution are shown in the following charts:

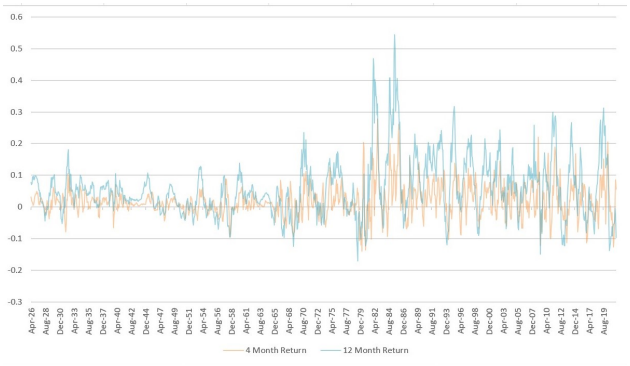

Figure 1: Rolling 4 Month Return and 12 Month Return Since 1926

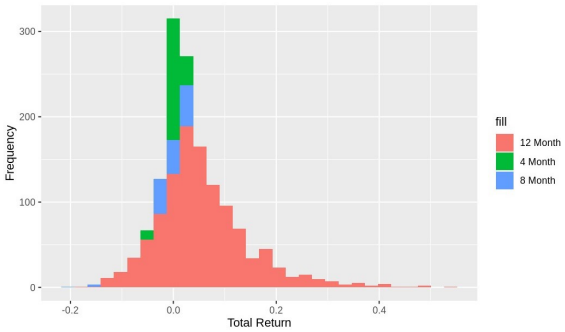

Figure 2: Distribution of Return

Figure 1 has offered us an overview on how the bond market develop over the past 100 years. Notice that the bond market is extremely volatile in the 1980s as we observe some significant shifts in bond return. Figure 2 has shown us the distribution of bond return. All distribution are slightly skew to the right with a mean around 0.05. According to summary statistic, the best 4-month bond return 0.2783 and the worst 4-month bond return is -0.1402.

	4 Month TR	Following 8 Month TR	12 Month TR
Min	-0.140	-0.201	-0.171
Max	0.278	0.389	0.544
Mean	0.019	0.039	0.059
SD	0.050	0.073	0.092

Table 1: Summary Statistic for Bond Return

2.1 Worst Four-Month Return

Our goal is to identify and review significant historical losses over four month periods. We sorted our data base on the worst 4-month return, and filtered out any returns less than -10 percent.

	4 Month Returns	Following 8 month TR	12 Month TR
Mar-80	-0.1402	0.085418	-0.06679
Oct-80	-0.1359	0.015323	-0.12264
Apr-22	-0.1355		
Mar-21	-0.1263	0.081985	-0.05467
Apr-09	-0.1218	-0.03098	-0.14903
Jan-80	-0.1205	0.019018	-0.1038
Nov-16	-0.1133	0.035256	-0.08209
Aug-13	-0.1124	0.060735	-0.05848
Oct-79	-0.1061	0.102548	-0.01441
Dec-16	-0.1059	0.071256	-0.04214
May-94	-0.1039	0.030814	-0.0763
Sep-81	-0.1023	0.249922	0.121997
Jan-11	-0.1001	0.270214	0.143081

Table 2: Months with the worst 4-Month Bond Return(>10% loss)

Here, There are 13 months in history that have more than 10 percent loss in four month return. We highlighted the monthly return before 2010. Note that the four month return in 2021 is similar the four month return in 1980.From historical data, we know that the interest rate are much higher in the 1980s. Why both period has similar outcome while the interest rate is totally different? One possible explanation would be the change of duration. The duration now are more higher than the duration in the 80s. Therefore, bond price are more sensitive to the fluctuation of interest rate, which explains the reason why we observe similar loss in 2021.

2.2 Regression Analysis

Since we have computed the return for different month period. We also interested in the relationship like 4 month versus 8 month or 4 month versus 12 month. Does bad return in first four month indicative of bad return for the following 8 month? Does it have an impact on the total return of 12 month period?

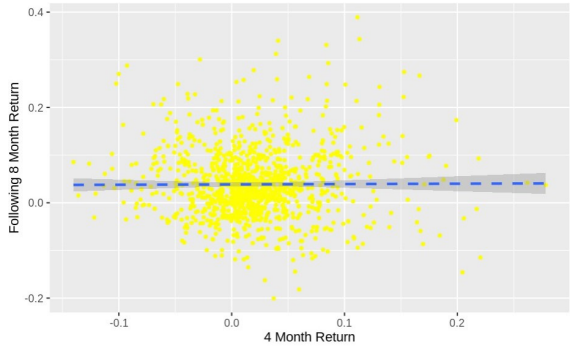

Figure 3: 4 Month versus 8 Month

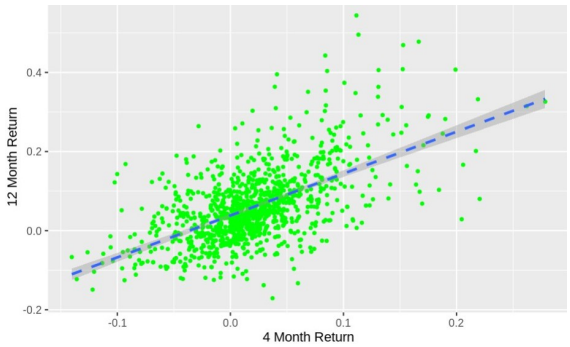

Figure 4: 4 Month versus 12 Month

From the graph shown above, we observe that there is no correlation between 4 month return and the following 8 month return, which means that the bond price in the following 8 month are not affected by the bad return in the previous months, and there are chances of recovery. Nonetheless, poor performance in the first four months has an effect on the annual return, since there is a positive correlation between the 4-month and 12-month returns.

3 ESG Simulation

Economic Scenario Generator

An economic scenario generator(ESG) is a computer-based model of an economic environment that is used to produce simulation of the joint behavior of financial market value and economic variables. It become a powerful tool for solving risk management problems. In this section, we use a calibrated ESG model to generate 1000 scenario that simulates possible outcome of long term treasury bond as of May 2022.

3.1 Probability of Loss

After we run the ESG simulator, it generates a folder that contains multiple CSV files. For the simulated long term treasury data, each row represent a scenario(path), and each column represent a month, each cell of data represents the wealth factor, which indicates how much the bank account worth if we invest our money in long term treasury bond. To calculate the 4-month return, we take the wealth factor at the fourth month, and divide it by the wealth

factor at the first month, then subtract one. Using this formula, we computed the 4-month return for 1000 Scenarios.

Our ultimate goal is to calculate the probability of loss that is greater than 15 percent. To calculate the probability, we begin by setting -0.15 as our threshold, then we apply a conditional argument to each cell of our spreadsheet. If the data is less than -0.15 , we change the data in that cell to 1, otherwise it would be 0. After that, we count how many cells in the spreadsheet that equal to one, and then divide it by the total number of observation. In our case, the number of simulated data that below the -0.15 threshold is 450, and the total number of observation is 357000. Therefore, the probability of loss that is greater than 15 percent is $\frac{450}{357000} = 0.00126$. The graph below is a bar chart that shows the frequency of bad 4-month return, the height of each bar represent the number of bad return($>$ 15 percent loss) in each month. Notice that the frequency of bad return are high at around 250 months.

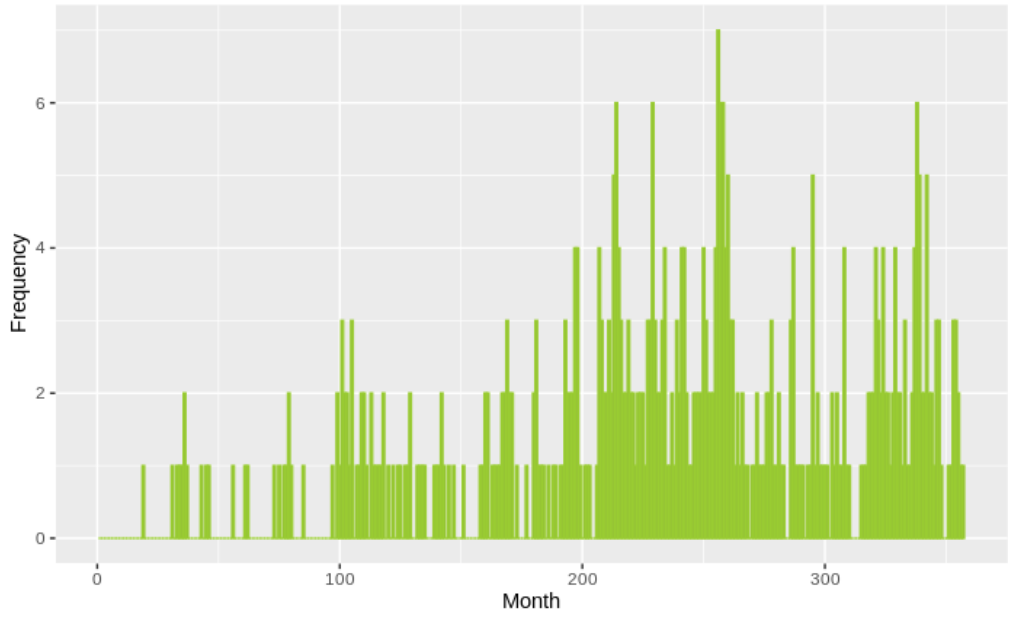

Figure 5: Frequency of Bad Return in ESG Simulated Data

4 Investment Plan

In general, the higher a bond's duration, the more sensitive the bond price react to interest rate, which makes the bond much more volatile. Hence, for Risk-averse client like Sally who is concerned about fluctuations in the principal value of bond holding, We should consider a bond investment plan with a respectable yield and comparatively reduced risk. We have

to decide whether we should recommend shorting the duration of Sally's portfolio, which will cost return but should reduce interest rate risk. To quick way to reduce the duration of the portfolio is shifting from long-term treasury bond to intermediate-term treasury bond. Using AIRG Economic Scenario Generator, we will evaluate the following three options:

- Status Quo: maintain a 20 year Treasury bond portfolio.
- Move to an intermediate Treasury portfolio.
- Change to a 50-50 blend of intermediate Treasury bonds and 20 year Treasury Bonds.

4.1 Short-term Investment Horizon

We have collected 1000 paths of intermediate treasury data and long-term treasury data from the previous ESG simulation. We compute the monthly return for each type of bond, then we multiply the monthly return with the weighted combination that reflects our investment choice, which generates the weighted monthly return of our portfolio. We calculate the wealth factor and geometric annual return based on the weighted monthly return. Since our client has an upcoming acquisition,we might consider a short term investment horizon because we have to preserve some of our capitals. Here, we will examine the bond performance at Year 1 and Year 3.

Wealth Factor at Year 1			
Max	1.1909	1.132476	1.09637
Min	0.82185	0.878743	0.93869
Geometric Annual Return			
	All LTGOV	Blended	All INTGOV
Stdev	0.042609	0.030366	0.02077116
Mean	0.026016	0.025435	0.02486198

Figure 6: Wealth Factor at Year 1

Wealth Factor at Year 3			
Max	1.33758	1.255205	1.24707
Min	0.71847	0.825491	0.93813
Geometric Annual Return			
	All LTGOV	Blended	All INTGOV
Stdev	0.023643	0.016039	0.010237
Mean	0.027006	0.026267	0.02538294

Figure 7: Wealth Factor at Year 3

We also create scatter plot and box plot showing the relations between the mean and standard deviation of geometric annual return of our portfolio at Year 1 and Year 3:

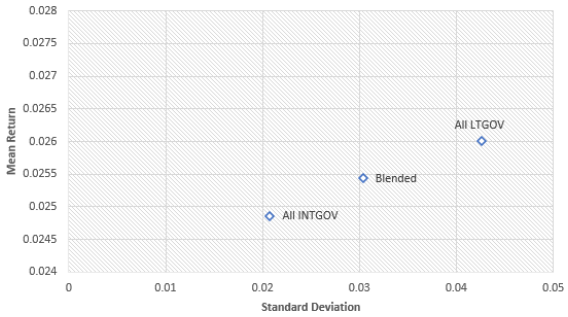

Figure 8: Geo Annual Return at Year 1

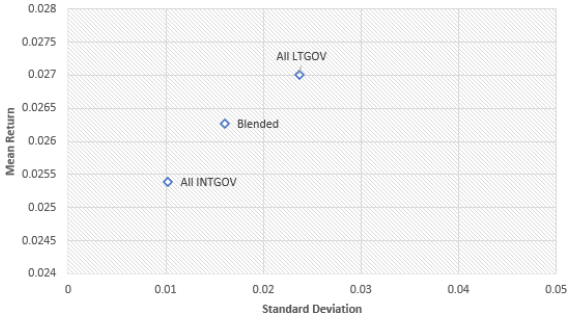

Figure 9: Geo Annual Return at Year 3

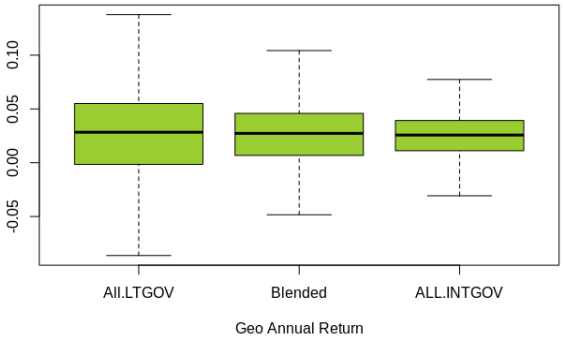

Figure 10: Box Plot at Year 1

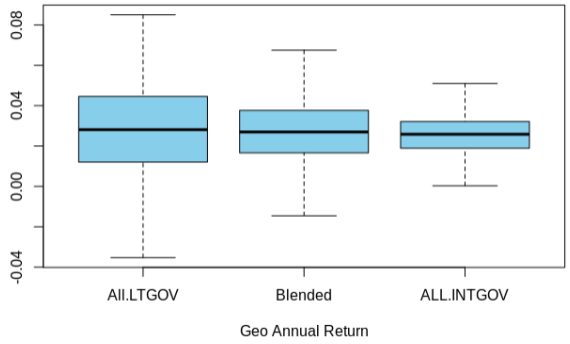

Figure 11: Box Plot at Year 3

The scatter plot and box plot shown above give us an overview for different investment options. The portfolio will all intermediate government bond has the lowest mean and standard deviation for both Year 1 and Year 3. All investment option have higher mean return and lower standard deviation at Year 3 compared to Year 1. The box plot also show the percentile of bond return. According to the box plot, the median return, which is the horizontal line segment inside each rectangular box, are nearly the same for all investment options. The spread of returns, on the other hand, varies greatly amongst investment plans. Let take the long government bond at Year 1 as an example, the interquartile range(IQR) is between -0.0015 to 0.0551, while the interquartile range for "All INTGOV" is between 0.0112 to 0.03927.

4.2 Long-Term Investment Horizon

If our client want to get back the money she lost in the first four month, she might consider a long term investment horizon. What will happen if we extend the investment horizon to

10 year or even 30 years? Now, we have change the investment horizon to 10 years and 30 years. The summary statistic and the corresponding scatter plot are shown as follows:

Wealth Factor at Year 10			
Max	1.8083	1.743698	2.06263
Min	0.69031	0.833834	0.99415
Geometric Annual Return			
	All LTGOV	Blended	All INTGOV
Stdev	0.012191297	0.008458	0.007170242
Mean	0.029632665	0.02975	0.029616393

Figure 12: Wealth Factor at Year 10

Wealth Factor at Year 30			
Max	10.32706	10.57422	10.30945
Min	1.33377	1.774976	1.69672
Geometric Annual Return			
	All LTGOV	Blended	All INTGOV
Stdev	0.009237694	0.008892	0.009533893
Mean	0.039253434	0.038462	0.037283418

Figure 13: Wealth Factor at Year 30

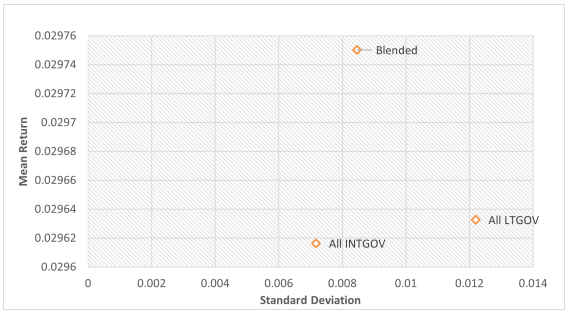

Figure 14: Geo Annual Return at Year 10

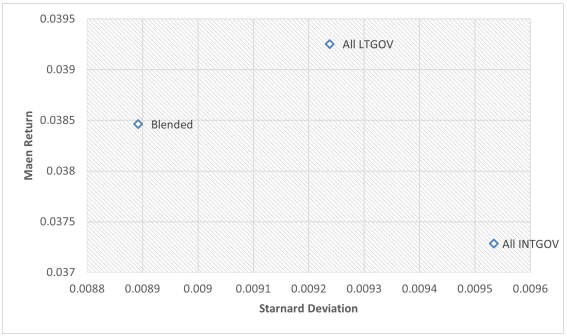

Figure 15: Geo Annual Return at Year 30

Looking at the summary statistic. For 10 years investment horizon, the intermediate treasury portfolio still has the lowest mean return and standard deviation, which means that investing in intermediate treasury portfolio is still the safest option. However, for 30 years investment horizon, intermediate treasury bond is no longest the safest choice because it has highest risk(standard deviation). If we take a look at the scatter plot, for 10 year investment horizon, blended has the highest mean return yet it only cost a little more risk than the intermediate treasury portfolio, so blended would be the best choice for aggressive investors. For 30 years investment horizon, We can see that Long Term Treasury portfolio have the highest yield. Intermediate treasury portfolio is no longer favorable because it has the highest risk and the lowest yield. Blended portfolio has less return than Long Term Treasury Portfolio, but it is also less risky. Hence, we can choose either portfolio, but it really depends on the preference of our client. For aggressive investor who wants to have more return, we would recommend the blend portfolio. For conservative investor who wants to have lower risk, we would recommend the intermediate treasury portfolio.

We want to explore the distribution of bond return for long term investment horizon, so we created the following box plot. Note that the box plot for 10 year investment horizon looks very similar from the box plot for short term investment, where the intermediate treasury portfolio has the lowest spread, whereas the spread for all portfolio in 30 years investment horizon are almost the same because of similar interquartile range. Hence, the risks associated with each bond are similar over a long horizon.

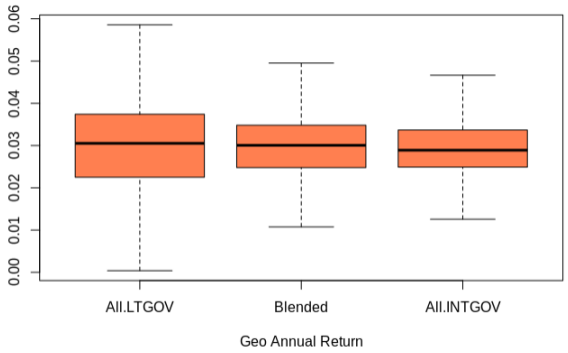

Figure 16: Box Plot at Year 10

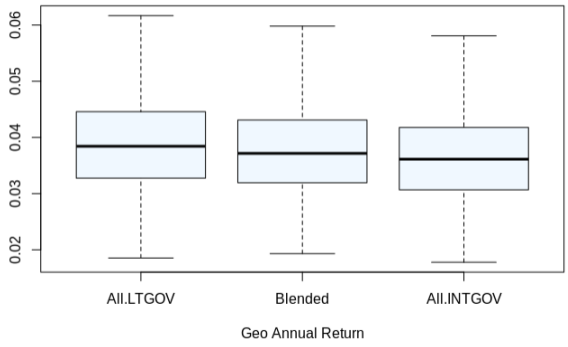

Figure 17: Box Plot at Year 30

Moreover, if we compare the long term investment box plot with short term investment box plot, we will notice an interesting fact. Let's compare the box plot at Year 3 with the box plot Year 30. Take Long Term Treasury portfolio as an example, The median bond return after 3 years of investment is around 0.32, whereas the median return after 30 year of investment will increase to 0.39. To measure the spread of data, we can take a look at the range of IQR between different investment horizon. The interquartile range for the Long Term Treasury portfolio after three years of investment is between 0.01206 and 0.044577, while the same portfolio after thirty years of investment is between 0.032746 and 0.044577. Therefore, if we retain our bond for a longer period of time, the spread will narrow and the median bond return will rise. The longer we keep a bond, we will have lower risk and higher return for our investment.

4.3 Sharpe Ratio

Assuming the investment returns are normally distributed, we can calculate the Sharpe Ratio to evaluate the performance of a portfolio. By definition, Sharpe Ratio is the average return earned in excess of the risk-free rate per unit of volatility or total risk.It measures how the bond performs compared to risk-free investment(such as US Treasury bond and Treasury

note) The formula for Sharpe Ratio is shown as follows:

$$\text{Sharpe Ratio} = \frac{R_p - R_f}{\sigma_p}$$

where:
R_p = return of portfolio
R_f = risk-free rate
σ_p = standard deviation of the portfolio's excess return

First, we have to compute the risk free rate. Risk-Free Rate can be easily computed by averaging annual bond return of a risk-free portfolio and modifying the investment horizon. To calculate the Sharpe ratio, investors subtract the risk free rate from the portfolio's mean return rate, then divide the result by the standard deviation of the portfolio's excess return. The Sharpe Ratio and Risk-Free Rate are shown below:

Risk-Free Factor	
Year 1	0.0123
Year 3	0.0167
Year 10	0.0223
Year 30	0.0284

Figure 18: Risk-Free Rate

Sharpe Ratio		
All LTGOV	Blended	All INTGOV
Year 1		
0.321	0.431	0.603
Year 3		
0.437	0.597	0.850
Year 10		
0.601	0.880	1.019
Year 30		
1.178	1.135	0.935

Figure 19: Sharpe Ratio

Here, we computed the Sharpe ratio for our portfolio in different investment horizons. Practically, the higher the Sharpe ratio, the better investment portfolio we have. Intermediate treasury portfolio has the highest Sharpe ratio for short term and intermediate term investment. For long term investment, Long term treasury and blended is more favorable because they outperforms the intermediate treasury in terms of shape ratio. It corresponds to our observation in the previous section.

5 Recommendations

A risk-reward comparison of the three portfolio allocation considered:

1. For shorter investment time horizons (1 years - 3 years)
    - Moving to the Intermediate Treasury portfolio is the best option because it has the lowest risk
2. For intermediate investment time horizons(10 years)
    - The intermediate Treasury portfolio is still the best option
    - A blended allocation is also a good option only if our client is aggressive
3. For long term investment time horizons (30 years)
    - The long term treasury bond portfolio start to become a better option
    - For risk-averse client, blended is better because it significant reduce the risk even though it cost some return.