

**Portfolio Optimization and**

**Efficient Frontier in R programming**

In Partial Fulfillment

Of the Requirements for

Trading Software and Programming

MCF320M-G01

For the Degree in

Master of Science in Computational Finance

*A Case study by:*

Richard Justin Gan

*Submitted to:*

Dioscoro P. Jr Baylon

July 26, 2024

# Table of Contents

[Table of Contents 2](#_Toc172706369)

[**1** **Chapter 1: Introduction** 5](#_Toc172706370)

[1.1 Overview of Portfolio Optimization 5](#_Toc172706371)

[1.2 Importance of Efficient Frontier in Investment Decision-Making 5](#_Toc172706372)

[1.3 Objectives of the Case Study 5](#_Toc172706373)

[**2** **Chapter 2: Review of Related Literature** 7](#_Toc172706374)

[Markowitz Portfolio Theory (1952): Harry Markowitz’s foundational work on mean-variance optimization. 7](#_Toc172706375)

[Capital Asset Pricing Model (CAPM): William Sharpe’s model relating systematic risk and expected return. 7](#_Toc172706376)

[Black-Litterman Model: An advanced model incorporating investor views and market equilibrium. 7](#_Toc172706377)

[Fama-French Three-Factor Model: Expansion of CAPM including size and value factors. 8](#_Toc172706378)

[Recent Advances: Articles on machine learning in portfolio optimization, and the impact of big data on investment strategies. 8](#_Toc172706379)

[**3** **Chapter 3: Exploratory Data Analysis** 10](#_Toc172706380)

[Portfolio 1 10](#_Toc172706381)

[3.1 Descriptive Statistics - mean, std dev, skewness and kurtosis of asset returns 10](#_Toc172706382)

[3.2 Correlation matrix of asset returns 10](#_Toc172706383)

[3.3 Visualization 11](#_Toc172706384)

[3.3.1 Time series plots 11](#_Toc172706385)

[3.3.2 Histograms 11](#_Toc172706386)

[3.3.3 Density plots of asset returns 11](#_Toc172706387)

[3.3.4 HEATMAP of the correlation Matrix 12](#_Toc172706388)

[Portfolio 2 12](#_Toc172706389)

[3.3.5 Descriptive Statistics - mean, std dev, skewness and kurtosis of asset returns 12](#_Toc172706390)

[3.3.6 Correlation matrix of asset returns 13](#_Toc172706391)

[3.3.7 Visualization 13](#_Toc172706392)

[3.3.8 Time series plots 13](#_Toc172706393)

[3.3.9 Histograms 13](#_Toc172706394)

[3.3.10 Density plots of asset returns 14](#_Toc172706395)

[3.3.11 HEATMAP of the correlation Matrix 14](#_Toc172706396)

[**4** **Chapter 4: Results and Discussions** 16](#_Toc172706397)

[Introduction 16](#_Toc172706398)

[Model 1 16](#_Toc172706399)

[Model 2 16](#_Toc172706400)

[**5** **Chapter 5: Optimized Portfolios comparison and Discussion** 17](#_Toc172706401)

[Model 1 17](#_Toc172706402)

[Model 2 17](#_Toc172706403)

[**6** **Chapter 6: Efficient Frontier for both Cases** 18](#_Toc172706404)

[Model 1 Efficient Frontier 18](#_Toc172706405)

[Model 2 Efficient Frontier 18](#_Toc172706406)

[**7** **Chapter 7: Analysis and Discussion** 19](#_Toc172706407)

[**8** **Chapter 8: Conclusion** 20](#_Toc172706408)

[References 21](#_Toc172706409)

# **Chapter 1: Introduction**

## Overview of Portfolio Optimization

In the first quarter of 2023, the global debt stock increased by $8.3 trillion to a near-record $305 trillion. The combination of high debt levels and increasing interest rates has increased debt servicing expenses, raising worries about the use of leverage in the financial system (*Global Debt Monitors*, 2023). The global debt of 305 trillion dollars has consequences for future generations. The expenditures connected with the impending generational storm, as predicted by Kotlikoff C, (2023) would bankrupt the governments of most affluent nations unless large and painful changes are made now in the form of hiking interest rates and lowering the federal balance sheet.

The study will include inflation rate as a factor and include the period of years post 2016, as well as previous years for the calculation of default risk and hence provide an accurate representation for fiscal sustainability in the Philippines.

## Importance of Efficient Frontier in Investment Decision-Making

Fiscal sustainability depends on the ability of a country to control debt. Therefore, the study aims to ask whether inflation rate and debt to GDP has an impact on sovereign risk premium which is measured through the EMBI?

## Objectives of the Case Study

1. To determine the effect of debt to GDP and inflation rate on sovereign risk premium measured by EMBI.
2. Identify which of the two variables has a greater effect on sovereign risk premium.

Examine whether Inflation rate has a significant impact on sovereign risk premium.

# **Chapter 2: Review of Related Literature**

## Markowitz Portfolio Theory (1952): Harry Markowitz’s foundational work on mean-variance optimization.

This Chapter will focus on previous literature and topics such as sovereign risk premium, inflation rate, debt to GDP and other key components of these topics; it will also delve on how they are interconnected with fiscal sustainability, and lastly the purpose of each of them in the research paper.

To summarize, debt and inflation are key factors in fiscal sustainability. To further expound on the key topics, the study will discuss the following: Fiscal Sustainability, debt-GDP, inflation, and debt threshold.

### Capital Asset Pricing Model (CAPM): William Sharpe’s model relating systematic risk and expected return.

Propose that sovereign nations possessing the ability to control their own currency issuance are immune to bankruptcy since they can effectively generate additional fiat currency to fulfill debt obligations.

### Black-Litterman Model: An advanced model incorporating investor views and market equilibrium.

There has been considerable theoretical interest in understanding how rational lenders make decisions when they don't have all the information about borrowers. Some studies suggest that when lenders limit the amount of credit they give to borrowers, it can be seen as a failure in the market. However, there is another perspective that argues default penalties and credit limits can actually help keep irresponsible borrowers, like governments, in check. This positive view is known as the Market Discipline Hypothesis and has been an important factor in discussions on how to prevent risky fiscal policies.

The market discipline hypothesis, introduced by Bayoumi et al., (1995), explores the non-linear connection between government debt and sovereign risk premium. According to this hypothesis, borrowers face penalties for accumulating debt in order to discourage excessive borrowing and provide creditors with higher compensation for taking on additional risk. The risk premium gradually increases at an accelerating rate as the debt level rises until the credit market reaches a point where it can no longer tolerate higher risk and refuses to lend to participants with low creditworthiness.

### Fama-French Three-Factor Model: Expansion of CAPM including size and value factors.

Extensive research provides substantial evidence supporting the notion that government debt, as a proportion of GDP, has a positive impact on sovereign risk premium. To illustrate, (Park & Sung, 2020; Tran, 2018) investigate the influence of gross public debt on fluctuations in sovereign risk premium by analyzing Emerging Market Bond Index (EMBI) Global spreads across a broad sample of emerging economies. The findings reveal that a 1% increase in the external debt-to-GDP ratio leads to a significant rise in EMBI spreads, typically ranging from 1 to 3 basis points. The empirical study predominantly employs a linear regression model, indicating a consistent positive relationship between the debt-to-GDP ratio and default risks.

### Recent Advances: Articles on machine learning in portfolio optimization, and the impact of big data on investment strategies.

Fiscal sustainability refers to the ability of a government to maintain its fiscal policies and meet its financial obligations over the long term(*Fiscal Sustainability*, 2013).

Debt and inflation play crucial roles in determining fiscal sustainability. High levels of public debt can undermine fiscal sustainability. When a government accumulates significant debt, it may face challenges in servicing that debt, especially if the interest payments consume a large portion of its revenue. If debt levels become unsustainable, it can lead to concerns about default or difficulties in accessing affordable financing. This can create fiscal instability and jeopardize the government's ability to fund essential services and investments (Kotlikoff C, 2023).

# **Chapter 3: Exploratory Data Analysis**

## Portfolio 1

This chapter discusses the research design to be used, sampling design, the source of the data gathered, data analysis procedures, and the statistical tools implemented to examine the data and acquire results.

## Descriptive Statistics - mean, std dev, skewness and kurtosis of asset returns

The paper would use multiple linear regression with the independent variables as debt to GDP and inflation rate. Further, EMBI is used as the dependent variable, this is because it accurately mirrors the return performance of international government bonds from emerging economies. Hence, EMBI spreads are extensively employed in previous empirical research, making the analysis comparable to prior studies (Tran, 2018).

**Linear Model:**

Where: = Intercept, = Inflation rate, = EMBI, = error term

## Correlation matrix of asset returns

The sampling method used is purposive non-probability sampling due to the limited data for the three variables.

## Visualization

three variables.

Where: = Intercept, = Inflation rate, = EMBI, = error term

### Time series plots

three variables.

Where: = Intercept, = Inflation rate, = EMBI, = error term

### Histograms

three variables.

Where: = Intercept, = Inflation rate, = EMBI, = error term

### Density plots of asset returns

three variables.

Where: = Intercept, = Inflation rate, = EMBI, = error term

### HEATMAP of the correlation Matrix

The sampling method used is purposive non-probability sampling due to the limited data for the three variables.

Where: = Intercept, = Inflation rate, = EMBI, = error term

The data which is contained within the csv file is imported into R software and the necessary packages are then executed to begin the data processing. R software will use pooled OLS stepwise regression which will regress the model until there is no more variables left that have lower than 0.05 p value score. This will show that whichever variable left is significant and will test the hypothesis.

Further, the study will also perform multiple linear regression and take the p-value from the model itself to validate if the p-values are in fact less than 0.05 instead of relying solely on the stepwise regression in R programming.

## Portfolio 2

This chapter discusses the research design to be used, sampling design, the source of the data gathered, data analysis procedures, and the statistical tools implemented to examine the data and acquire results.

### Descriptive Statistics - mean, std dev, skewness and kurtosis of asset returns

The paper would use multiple linear regression with the independent variables as debt to GDP and inflation rate. Further, EMBI is used as the dependent variable, this is because it accurately mirrors the return performance of international government bonds from emerging economies. Hence, EMBI spreads are extensively employed in previous empirical research, making the analysis comparable to prior studies (Tran, 2018).

**Linear Model:**

Where: = Intercept, = Inflation rate, = EMBI, = error term

### Correlation matrix of asset returns

The sampling method used is purposive non-probability sampling due to the limited data for the three variables.

### Visualization

three variables.

Where: = Intercept, = Inflation rate, = EMBI, = error term

### Time series plots

three variables.

Where: = Intercept, = Inflation rate, = EMBI, = error term

### Histograms

three variables.

Where: = Intercept, = Inflation rate, = EMBI, = error term

### Density plots of asset returns

three variables.

Where: = Intercept, = Inflation rate, = EMBI, = error term

### HEATMAP of the correlation Matrix

The sampling method used is purposive non-probability sampling due to the limited data for the three variables.

Where: = Intercept, = Inflation rate, = EMBI, = error term

The data which is contained within the csv file is imported into R software and the necessary packages are then executed to begin the data processing. R software will use pooled OLS stepwise regression which will regress the model until there is no more variables left that have lower than 0.05 p value score. This will show that whichever variable left is significant and will test the hypothesis.

Further, the study will also perform multiple linear regression and take the p-value from the model itself to validate if the p-values are in fact less than 0.05 instead of relying solely on the stepwise regression in R programming.

# **Chapter 4: Results and Discussions**

## Introduction

This chapter delved into the data analysis portion of the study, such as assumptions of multiple linear regression model, significance testing, and discussion of results. The data was represented in

Model 2: EMBI = β0 + β(Inflation rate) + e is the second model and hypothesis tested, which excludes Debt to GDP to test if there is any relationship between inflation rate and the riskiness of a country. Therefore, Descriptive Statistics and Correlation Coefficient Matrix

## Model 1

Model 1 is the primary model that is tested in the study and includes all variables in the equation; EMBI = β0 + (Debt/GDP) + β(Inflation rate) + e. It includes Debt to GDP, Inflation rate, and EMBI. The P value is 0.83 and F statistic of 0.187 which indicates that both Debt to GDP and Inflation rate does not have any impact on the EMBI variable and that the alternative hypothesis is rejected. In the previous research by Tran, (2018) the market discipline hypothesis was further divided into three different forms: the weak, the strong, and the ugly. The weak version refers to a linear relationship which is the focus of this study and is used as the main model. However, the

## Model 2

Model 2: *EMBI = β0 + β(Inflation rate) + e* is the second model and hypothesis tested, which excludes Debt to GDP to test if there is any relationship between inflation rate and the riskiness of a country. Therefore,

# **Chapter 5: Optimized Portfolios comparison and Discussion**

## Model 1

Model 2: *EMBI = β0 + β(Inflation rate) + e* is the second model and hypothesis tested, which excludes Debt to GDP to test if there is any relationship between inflation rate and the riskiness of a country.

## Model 2

Model 2: *EMBI = β0 + β(Inflation rate) + e* is the second model and hypothesis tested, which excludes Debt to GDP to test if there is any relationship between inflation rate and the riskin

# **Chapter 6: Efficient Frontier for both Cases**

## Model 1 Efficient Frontier

Model 2: *EMBI = β0 + β(Inflation rate) + e* is the second model and hypothesis tested, which excludes Debt to GDP to test if there is any relationship between inflation rate and the riskiness of a country.

## Model 2 Efficient Frontier

Model 2: *EMBI = β0 + β(Inflation rate) + e* is the second model and hypothesis tested, which excludes Debt to GDP to test if there is any relationship between inflation rate and the riskiness of a country.

# **Chapter 7: Analysis and Discussion**

Model 2: *EMBI = β0 + β(Inflation rate) + e* is the second model and hypothesis tested, which excludes Debt to GDP to test if there is any relationship between inflation rate and the riskiness of a country.

# **Chapter 8: Conclusion**

Model 2: *EMBI = β0 + β(Inflation rate) + e* is the second model and hypothesis tested, which excludes Debt to GDP to test if there is any relationship between inflation rate and the riskiness of a country.

The study concludes with

# References

Allado, A. P., Lim, L. N., Tulauan, N. A., Abreu, M. K., Agabin, P. L., & Regio, J. C. (2022). *Construction of an Index Tracker for Debt Sustainability Assessment in the Philippines*. https://doi.org/10.56506/LPBC3497

Bayoumi, T., Goldstein, M., & Woglom, G. (1995). Do Credit Markets Discipline Sovereign Borrowers? Evidence from U.S. States. *Journal of Money, Credit and Banking*, *27*(4), 1046. https://doi.org/10.2307/2077788

*Databank World Development Indicators*. (2022). The World Bank Group. https://databank.worldbank.org/source/world-development-indicators?l=en#

*Fiscal sustainability* (pp. 48–49). (2013). https://doi.org/10.1787/gov\_glance-2013-11-en

Flandreau, M., Le Cacheux, J., & Zumer, F. (1998a). Stability without a pact? Lessons from the European gold standard, 1880-1914. *Economic Policy*, *13*(26), 115–162. https://doi.org/10.1111/1468-0327.00030

Flandreau, M., Le Cacheux, J., & Zumer, F. (1998b). Stability without a pact? Lessons from the European gold standard, 1880-1914. *Economic Policy*, *13*(26), 115–162. https://doi.org/10.1111/1468-0327.00030

*Global Debt Monitors*. (2023). Institute of International Finance.

Grennes, T., Caner, M., & Koehler-Geib, F. (2010). *“Finding The Tipping Point -- When Sovereign Debt Turns Bad.”* The World Bank. https://doi.org/10.1596/1813-9450-5391

Hayes A. (2020). *Emerging Market Bond Index*. Investopedia. https://www.investopedia.com/terms/e/emerging-markets-bond-index.asp

Kotlikoff C. (2023). *Fiscal Sustainability*.

Michel, P. (1982). On the Transversality Condition in Infinite Horizon Optimal Problems. *Econometrica*, *50*(4), 975. https://doi.org/10.2307/1912772

*Multiple regression*. (2022). California State University Long Beach. https://home.csulb.edu/~msaintg/ppa696/696regmx.htm#:~:text=Regression%20with%20only%20one%20dependent,variable%20added%20to%20the%20equation.

OECD. (2022). *The OECD and Southeast Asia*.

Palacio-Vera, A. (2012). Debt monetization, inflation, and the ‘neutral’ interest rate. *International Review of Applied Economics*, *26*(2), 267–285. https://doi.org/10.1080/02692171.2011.624497

Paleta, T. (2012). Maastricht Criteria of…Divergence? *Review of Economic Perspectives*, *12*(2). https://doi.org/10.2478/v10135-012-0005-7

Park, D., & Sung, T. (2020). Foreign debt, global liquidity, and fiscal sustainability. *Japan and the World Economy*, *54*, 101008. https://doi.org/10.1016/J.JAPWOR.2020.101008

*Philippines Government Debt to GDP*. (2022). TRADING ECONOMICS. https://tradingeconomics.com/philippines/government-debt-to-gdp

Prinz, A. L., & Beck, H. (2021). Modern Monetary Theory: A Solid Theoretical Foundation of Economic Policy? *Atlantic Economic Journal*, *49*(2), 173–186. https://doi.org/10.1007/s11293-021-09713-6

Tran, N. (2018). Debt threshold for fiscal sustainability assessment in emerging economies. *Journal of Policy Modeling*, *40*(2), 375–394. https://doi.org/10.1016/j.jpolmod.2018.01.011

Vitor Gaspar, Paulo Medas, & Roberto Perrelli. (2021). *Global Debt Reaches a Record $226 Trillion*. IMF.

*Yahoo Finance*. (2022). Yahoo Finance. https://finance.yahoo.com/quote/EMB/performance/

Zulauf. (2022, October). *Update on US Interest Rates and Inflation*. Department of Agricultural, Environmental and Development Economics Ohio State University.

Appendix

Appendix 1:

Multiple Linear Model - All variables (Ho1)