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Master of Science Thesis

Optimizing Global Portfolio Weights using Artificial Intelligence and Macroeconomic Analysis

Master in Artificial Intelligence and Quantum Computing Applied to Financial Markets, 11th edition (mIA-X)

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# Introduction

The pursuit of optimal portfolio diversification and risk-adjusted returns has long been a cornerstone of investment management. Traditional methods often rely on Modern Portfolio Theory (MPT) and historical data analysis. However, these approaches can be limited by static assumptions and the inherent difficulty of accurately forecasting future market behaviour.

This thesis explores the potential of Artificial Intelligence (AI) and macroeconomic analysis to create a more dynamic and data-driven approach to global portfolio weight optimization. By leveraging the power of AI techniques to identify complex patterns and relationships within vast datasets, I aim to develop an investment algorithm that can adapt to evolving market conditions and generate superior portfolio management.

This research will delve into various AI techniques, such as machine learning methods of Random Forest, XG Boost and Learning to Rate as well as different neural network models. It will validate their applicability in the context of portfolio optimization. Moreover, it will examine the role of macroeconomic analysis in shaping investment strategies and how it can be integrated with AI for portfolio management.

The main motivation for this thesis is to evaluate an alternative to passive investing, via index funds and Exchange-Traded Funds (ETFs), which has been rapidly gaining market share for both individual and institutional investors. A desired result for this investment algorithm would be to achieve both superior absolute returns and risk-adjusted returns in comparison to MSCI All Country World Index (ACWI), taken as a benchmark.

This thesis will try to offer a fresh perspective on global portfolio management in the age of AI. It is hoped to provide new insights and practical applications for the world of finance, helping to navigate the complexities of the global investment landscape.

# Background



## Basic portfolio creation with global diversification

Creating a globally diversified portfolio is a strategic approach to investing that can help mitigate risk and potentially enhance returns. The process begins by defining investment goals and constraints. A sound investment plan outlines the investor’s objectives and any significant constraints. Most investment objectives can be viewed in the context of a required rate of return (RRR). This is the return a portfolio would need to generate to bridge the gap between an investor’s current assets, any future cash flows, and the investment goals.

The next step is broad strategic allocation among the primary asset classes such as equities, fixed income, and cash. The allocation should be based on the investor's risk tolerance, investment horizon, and financial goals. This is followed by sub-asset allocation within classes, such as domestic and non-domestic securities or large-, mid- or small-capitalisation equities.

The investor then decides on the allocation to indexed or actively managed funds or both. Depending on the investment strategy, the investor can choose to invest in indexed or actively managed funds, or a combination of both.

The final step in the process is rebalancing. This is the process of realigning the weightings of the portfolio of assets. Rebalancing involves periodically buying or selling assets in a portfolio to maintain an original or desired level of asset allocation. (The power of portfolio diversification | Vanguard UK Professional, n.d.)

The goal of global diversification is not necessarily to boost performance but rather to spread risk across a variety of investments from different countries and sectors. This can potentially smooth out returns over time and help protect the portfolio from the volatility of any single investment or market.

## Global portfolio with index funds and ETFs

In recent years there has been a growing trend of investing through index funds and global ETFs for both individual and institutional investors. Index funds and Exchange-Traded Funds (ETFs) based on the MSCI World and MSCI All Country World Index (ACWI) have become key instruments for achieving global diversification in an investment portfolio.

The MSCI World Index tracks large and mid-cap representation across 23 developed markets countries, covering approximately 85% of the free float-adjusted market capitalization in each country. The MSCI ACWI goes a step further by including both developed and emerging markets, covering large and mid-cap representation across 23 developed and 24 emerging markets countries. This allows investors to gain exposure to a wide range of global equities through a single investment.

Moreover, these indices prioritize diversification by incorporating a broad range of sectors. The top sectors within the MSCI World and MSCI ACWI are information technology, financial services, and healthcare. This sector diversification can help to mitigate risk and potentially enhance returns.

Therefore, investing in index funds and ETFs based on the MSCI World and MSCI ACWI indices can be an effective strategy for achieving global diversification. It allows investors to spread their investments across different countries and sectors, thereby reducing the risk associated with any single investment or market.

## MSCI ACWI

The MSCI All Country World Index (ACWI) is a stock index designed to provide a broad measure of equity-market performance throughout the world. It is maintained by Morgan Stanley Capital International (MSCI) and comprises the stocks of nearly 3,000 companies from 23 developed countries and 24 emerging markets. (Investopedia, n.d.)

The MSCI ACWI captures large and mid-cap representation across these countries, covering approximately 85% of the global investable equity opportunity set. The index is used as a benchmark for global equity funds and as a guide to asset allocation. Approximately $4.6 trillion in assets are benchmarked to the index as of December 31, 2023.

Along with MSCI World and FTSE All World Index it is the most selected index for global portfolios. As of March 2024, it covers following markets:

A table with different countries/regions

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Figure 1. Countries included in MSCI AWCI index. Source: MSCI

TODO:

* Describe Modern Portfolio Theory
* Describe Risk-Parity and Hierarchical Risk Parity
* Other more advanced methods?

# Methodology



## Data sources

In the course of conducting research for my master’s thesis, I have exclusively utilized open databases accessible via the internet. While these sources may not match the quality of paid data providers such as the Bloomberg Terminal, which is considered the gold standard, they nonetheless provide adequate data coverage to facilitate a detailed macroeconomic analysis.

There are various international organizations collecting broad range of macroeconomic statistics which are publicly available. Main organizations with open datasets are World Bank (WB), Organisation for Economic Co-operation and Development (OECD), International Monetary Fund (IMF), United Nations (UN) and Bank for International Settlements (BIS).

Additionally, there are multiple financial websites that offer a variety of resources for investors and traders. The most popular portals providing market data and economic indicators are Investing.com, Yahoo Finance, Trading Economics and FX Empire.

After extensive analysis of all available data sources, I have selected those with the highest data coverage for all countries selected for global portfolio. In the subsequent sections, I will provide a detailed description of all the data sources utilized in my algorithm.

### Organisation for Economic Co-operation and Development (OECD)

The Organisation for Economic Co-operation and Development (OECD) compiles a comprehensive collection of economic, social, and environmental datasets encompassing member countries and selected non-member economies. These datasets include:

* National accounts, trade, labour, and productivity statistics
* Science and technology innovation indicators
* Entrepreneurship and formation data
* Environmental-economic accounting information
* Development resource flows and official development assistance (ODA) data

In my macroeconomic analysis, I have used a wide range of monthly and quarterly economic indicators. It has the best data coverage for most countries included in MSCI ACWI index. Data can be downloaded using csv exports or developer’s API. In my algorithm, I have managed to use multiple indicators from OECD.Stat website reaching back to 1999.

### World Bank (WB)

World Bank Data is a comprehensive resource for global development data. It offers data by country or indicator, databases, pre-formatted tables, reports, and other resources. It includes tools for data analysis and visualization, access to microdata, international debt statistics, and development indicators. It also provides information on World Bank’s finances and lending projects.

For my analysis, it includes even more countries than OECD. Unfortunately, it provides mainly yearly data with significant delay. That limits its use in terms of monthly portfolio rebalancing. Data can be exported using csv files or third-party python libraries providing an easy access to all indicators formatted automatically to pandas’ data frames.

### Bank of International Settlements (BIS)

The BIS Data Portal provides global financial statistics. It includes data on international banking activity, debt securities, credit to non-financial sectors, credit-to-GDP gaps, debt service ratios, global liquidity indicators, exchange-traded derivatives, OTC derivatives, triennial survey data, and residential property prices. All data can be downloaded in CSV or SDMX format. Moreover, databases can be accessed via REST API providing data in XML format.

In my work I have used its data for central bank rates. I haven’t found any other place with such a complete daily data for interest rates for almost all central banks in both developed and emerging economies. Data is updated weekly what provided very precise and up to date information.

### Yahoo Finance

Yahoo Finance is a financial website that provides investors with:

* Market Data: Real-time stock quotes, news, and analysis.
* Investment Tools: Portfolio management tools and research resources.
* Financial News: Up-to-date headlines and insights on global markets.

Data can be easily downloaded using open-source Python library which reads real time market data from publicly available APIs. I have used this library to read historical prices for ETFs, stock indices and currency rates.

### Investing.com

Investing.com is a leading financial website and platform that offers a variety of tools and resources for investors and traders. It offers:

* Real-time market data: Stocks, bonds, commodities, currencies, futures, options across 70+ exchanges.
* Analysis & news: Articles on market trends, company performance, and economic events.
* Investment tools: Economic calendar, earnings calendar, technical analysis tools, portfolio tracker.

In my work, its economic calendar has provided a great value. While it has slightly worse data coverage than OECD dataset, it does provide report date time for all indicators. That is immensely important for proper back testing because we know exactly what data was available at a certain point in time. While other databases only hold final revision for given indicators like GDP values, with exact investing calendar we can read all values for subsequent revisions and know on which days they were released. Economic calendar cannot be easily downloaded, so I have used techniques of web scrapping using Selenium library. I have managed to download over 320 thousand data points for 50 countries in MSCI ACWI index dating back to 1999.

Apart from economic calendar, I have also downloaded csv data for missing currency rates and selected stock indices that aren’t available on Yahoo Finance. Moreover, it has complete historical data for Manufacturing PMI indicators, hard to find anywhere else, which are very useful to calculate economic cycles.

### Morgan Stanley Capital International (MSCI)

Morgan Stanley Capital International maintains a family of stock market indexes which are widely followed by investors around the world. MSCI indexes are widely used benchmarks for global stock markets. They track different segments (like developed, emerging or country-specific) and by market cap (where bigger companies influence more). This allows investors to see how their portfolios perform compared to a specific market segment.

In my algorithm, I have used MSCI indexes to both obtain MSCI ACWI benchmark and also fill missing returns on selected exchange traded funds where Yahoo Finance doesn’t have complete data.

### Other sources

Apart from data sources listed above, I have explored other datasets and web portals:

* **The International Monetary Fund (IMF)** Data provides comprehensive economic, financial, and socio-demographic statistics. It includes data on direct investment, climate transition, greenhouse gas emissions, world economic outlook, international finance, global financial stability, fiscal monitor, and exchange rates. It covers many similar indicators to OECD. However, it has worse historical data coverage and more missing values for old data. In the end I opted to use OECD datasets instead.
* **Trading Economics** is a platform that provides similar features to Investing.com but is better protected against automatic web scrapping and offers paid subscriptions to access its data.
* **FX Empire** is another data provider resembling Investing.com and Trading Economics. Unfortunately, its interactive website makes it very difficult to download data using web scrapping.
* **FRED** (Federal Reserve Economic Data) is a trusted source for economic data since 1991. It provides access to over 824,000 US and international time series. It does provide an excellent coverage for US economy, but lacks international indicators, referencing data from OECD and other public database.
* **EBS Statistics** provide comprehensive data that supports all aspects of the ECB’s work, including monetary policy, financial stability, and banking supervision. It covers European economies in great details but covers few international indicators required to optimise global portfolio.

## Macroeconomic Data

To perform macroeconomic analysis, we need to collect a wide range of economic indicators. In my research I have downloaded 70 indicators and divided them into 9 distinct categories of related measures. That has made it easier to get an overall view and select the best indicators for an investment algorithm.

Each of these categories provides a different perspective on the health of the economy and can be used together to get a comprehensive understanding of economic conditions. Below I provide a brief description of each category:

1. ***Stock Market***: This refers to the collection of markets and exchanges data. Moreover, provides an overview of stock market for each country with its relevant metrics.
2. ***GDP***: It refers to various measures of Gross Domestic Product when it comes to total value, growth rate or value per capita.
3. ***Labour***: Labour market indicators provide an overview of the economic health of the employment sector. They include metrics such as the unemployment rate, employment rate and population.
4. ***Prices***: This provides various measures of price changes over time. For example, an indicator like CPI examines the weighted average of prices of a basket of consumer goods and services, such as transportation, food, and medical care.
5. ***Money***: This refers to various indicators like money supply, interest rates, and credit availability. These indicators can influence spending and investment activities in an economy.
6. ***Trade***: Trade indicators include metrics related to imports, exports, trade balance, and terms of trade. They provide insights into a country's competitiveness, the demand for its goods and services, and its economic ties with other countries.
7. ***Government***: Government indicators include government spending, budget deficits, and public debt. These indicators can show how government policy is affecting the economy.
8. ***Business***: Business indicators include measures of business confidence, industrial production, and manufacturing output. They provide insights into the health of the business sector and can be leading indicators for the overall economy.
9. ***Customer***: This refers to measures of consumer confidence, which provide an indication of consumers' attitudes about the health of the economy and their willingness to spend.

### Full list of economic indicators

Full list of economic indicators downloaded for analysis is included in the table below. There are 5 columns to describe each indicator:

* Indicator – full name of the indicator.
* Source – data source from which the indicator has been downloaded.
* Freq – frequency of the data. Can be D-daily, M-monthly, Q-quarterly, or Y-yearly.
* Measure – additional description of applied measure.
* Data coverage – a percentage of available data for 50 countries for years 1999 to 2024.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Indicator** | **Source** | **Freq** | **Measure** | **Data Coverage** |
| **1. Stock Market** | | | | |
| Stock Indices | Yahoo Finance, Investing.com | D | Index |  |
| Currency Rates | Yahoo Finance, Investing.com | D | Exchange rates |  |
| ETFs in USD | Yahoo Finance | D | US Dollars |  |
| ETFs in EUR | Yahoo Finance | D | EUR |  |
| MSCI Indices | MSCI | D | Index |  |
| Stock Market Cap | World Bank | Y | Current US Dollars | 76.2 |
| Stock Market Cap Pct of GDP | World Bank | Y | Pct of GDP | 76.2 |
| Listed Domestic Companies Total | World Bank | Y | Count | 80.5 |
| Stocks Traded Total Value | World Bank | Y | Current US Dollars | 78.2 |
| Stocks Traded Total Value Pct of GDP | World Bank | Y | Pct of GDP | 78.2 |
| **2. GDP** | | | | |
| GDP Annual Growth Rate | OECD | Q | Growth YoY | 73.9 |
| GDP Growth Rate | OECD | Q | Growth QoQ | 73.1 |
| GDP Per Capita | OECD | Q | Per Head, US dollars (2015) | 60.1 |
| GDP Current Prices US Dollars | OECD | Y | Current US Dollar | 77 |
| GDP Current Prices PPP | OECD | Y | Current US Dollar | 77 |
| GDP | World Bank | Y | Current US Dollar | 98 |
| GDP Per Capita | World Bank | Y | Current US Dollar | 98 |
| GDP (QoQ) | Investing.com | Q | Growth QoQ | 36.2 |
| GDP (YoY) | Investing.com | Q | Growth YoY | 39.6 |
| **3. Labour** | | | | |
| Unemployment Rate | OECD | M | Level | 53.6 |
| Unemployment Rate | OECD | Q | Level | 58.2 |
| Population | World Bank | Y | Count | 98 |
| Unemployment Rate | Investing.com | M | Level | 53.8 |
| **4. Prices** | | | | |
| Inflation Rate | OECD | M | Growth YoY | 70.6 |
| Inflation Rate | OECD | Q | Growth YoY | 74.2 |
| Inflation Rate MoM | OECD | M | Growth MoM | 70 |
| CPI | OECD | M | Index 2015 = 100 | 69.5 |
| PPI Manufacture of food products | OECD | M | Index 2015 = 100 | 36.8 |
| PPI Manufacturing | OECD | M | Index 2015 = 100 | 47.7 |
| CPI (MoM) - Inflation Rate MoM | Investing.com | M | Growth MoM | 61.8 |
| CPI (YoY) - Inflation Rate | Investing.com | M | Growth YoY | 80 |
| PPI (MoM) | Investing.com | M | Growth MoM | 26.2 |
| PPI (YoY) | Investing.com | M | Growth YoY | 35.6 |
| **5. Money** | | | | |
| Central Bank Rates | BIS | D | Level |  |
| Overnight Interbank Rate | OECD | M | Level | 73.7 |
| Short Term Interest Rate | OECD | M | Level | 68.4 |
| Long Term Interest Rate | OECD | M | Level | 66.4 |
| Narrow Money M1 | OECD | M | National Currency | 49.5 |
| Broad Money M3 | OECD | M | National Currency | 49.5 |
| **6. Trade** | | | | |
| Current Account to GDP | OECD | Q | Pct of GDP | 70 |
| Export of goods and services | OECD | Q | Growth YoY | 70.3 |
| Import of goods and services | OECD | Q | Growth YoY | 70.3 |
| Export - Value (goods) | OECD | M | US Dollars, monthly level | 74.2 |
| Import - Value (goods) | OECD | M | US Dollars, monthly level | 74.4 |
| Net Trade - Value (goods) | OECD | M | US Dollars, monthly level | 74.2 |
| Current Account Pct of GDP | World Bank | Y | Pct of GDP | 91.4 |
| Current Account | World Bank | Y | Current US Dollars | 93.3 |
| Trade Balance | Investing.com | M | Local Currency, monthly level | 64.7 |
| **7. Government** | | | | |
| Government Debt to GDP | OECD | Y | Pct of GDP | 54.8 |
| Total Government Expenditure | OECD | Y | Current prices, local currency | 61.9 |
| Total Government Revenue | OECD | Y | Current prices, local currency | 61.9 |
| Government Budget | OECD | Y | Pct of GDP | 77 |
| Government Expense | World Bank | Y | Pct of GDP | 77.8 |
| **8. Business** | | | | |
| OECD Business Confidence Indicator | OECD | M | Index, Amplitude adjusted | 72.7 |
| OECD Composite Leading Indicators | OECD | M | Index, Amplitude adjusted | 34 |
| Industrial Production | OECD | M | Growth YoY | 60.6 |
| Total Manufacturing | OECD | M | Index 2015=100, s.a. | 66.7 |
| Total Industry ex Construction | OECD | M | Index 2015=100, s.a. | 60.3 |
| Total Construction | OECD | M | Index 2015=100, s.a. | 44.7 |
| Changes in Inventories | OECD | Q | Current prices, local currency | 62.3 |
| Manufacturing PMI | Investing.com | M | Index | 31.9 |
| Services PMI | Investing.com | M | Index | 13.8 |
| Industrial Production | Investing.com | M | Growth YoY | 42.3 |
| **9. Consumer** | | | | |
| OECD Consumer Confidence Indicator | OECD | M | Index, Amplitude adjusted | 66.1 |
| Private Consumption | OECD | Q | Growth YoY | 67.7 |
| Total Retail Sales Value | OECD | M | Index 2015=100, s.a. | 52.7 |
| Passenger Car Registration | OECD | M | Index 2015=100, s.a. | 48.4 |
| Permits Issued (Residential Buildings) | OECD | M | Index 2015=100, s.a. | 42.6 |
| Retail Sales | Investing.com | M | Growth YoY | 46.8 |
| Consumer Confidence | Investing.com | M | Index | 33.9 |

### Key Economic Indicators

Out of all indicators I have selected 6 most relevant measures to include in all models. Each of these indicators provides a different perspective on the health of the economy and can be used together to get a comprehensive understanding of economic conditions. Moreover, they are widely commented in both economic and general press after each release and are closely followed by traders and investors alike. Below are brief descriptions of each economic indicator:

1. ***GDP Annual Growth Rate***: This measures the percentage change in a country's Gross Domestic Product (GDP) over a year. It indicates whether an economy is expanding or contracting, serving as a critical indicator of its performance.
2. ***GDP Growth Rate****:* Like the annual growth rate, the GDP Growth Rate measures economic growth by comparing GDP from one period to the next, in my study over following quarters. It's an indicator of the health of an economy and helps policymakers adjust fiscal and monetary policy to achieve economic objectives.
3. ***Unemployment Rate***: This is the percentage of unemployed individuals in an economy among individuals currently in the labour force. It's calculated as the number of unemployed individuals divided by the total labour force, multiplied by 100. It's a key economic indicator as it signals the ability (or inability) of workers to obtain gainful work and contribute to the productive output of the economy.
4. ***Inflation Rate***: The Inflation Rate is the percentage increase in price for a basket of goods and services for a particular period. It's used to measure the general increase in the cost of goods and services. It's contrasted by deflation, which refers to the appreciation of the currency and leads to decreased prices of commodities.
5. ***Inflation Rate MoM (Month over Month)***: This measures the change in the Inflation Rate from one month to the next. It provides a more granular view of inflation trends and can be useful for identifying short-term changes in the rate of inflation.
6. ***Manufacturing PMI (Purchasing Managers' Index):*** The PMI is an index of the prevailing direction of economic trends in the manufacturing sector. It consists of a diffusion index that summarizes whether market conditions are expanding, staying the same, or contracting as viewed by purchasing managers. It's based on five major survey areas—each of which is weighted equally: New Orders, Inventory Levels, Production, Supplier Deliveries, and Employment.

### Additional Economic Indicators

For a more comprehensive macroeconomic analysis, I have selected additional nine indicators that predominantly exhibit high data coverage and a monthly data frequency.

Firstly, I have excluded yearly indicators. Indicators with an annual frequency tend to offer limited value for an investment algorithm that operates with monthly rebalancing. This is primarily due to the substantial delay, often up to two years, in their release. Consequently, when these are combined with monthly indicators, they frequently retain the same value over a six to eight-month rolling window.

Secondly, indicators with low data coverage, their utility is inherently restricted. The incorporation of such indicators would necessitate a significant amount of estimated or interpolated data, which could potentially introduce considerable noise into the model. Thus, their use is generally not recommended for precision-oriented tasks such as this.

Additional indicators selected for extra analysis are:

1. ***Producer Price Index (PPI):*** This is a measure of the average change over time in the selling prices received by domestic producers for their output. It is a measure of inflation at the wholesale level.
2. ***Central Bank Rate:*** This is the interest rate set by the central bank of a country that commercial banks are charged to borrow money. It is a key tool used by central banks to implement monetary policy and control inflation.
3. ***Short Term Interest Rate:*** This refers to the interest rates on financial instruments that mature in less than one year. They are generally averages of daily rates and are based on three-month money market rates where available.
4. ***Long Term Interest Rate:*** This refers to the interest rates on financial instruments that mature in ten years or more. These rates are mainly determined by the price charged by the lender, the risk from the borrower, and the fall in the capital value.
5. ***Current Account to GDP***: This ratio provides an indication of a country's level of international competitiveness. A positive current account balance indicates that the nation is a net lender to the rest of the world, while a negative current account balance indicates that it is a net borrower.
6. ***Total Manufacturing:*** This refers to the total output of the manufacturing sector in an economy. It includes the production of goods and services across all manufacturing industries.
7. ***Industrial Production:*** This is a measure of the real output of the manufacturing, mining, electric, and gas industries. It is a key economic indicator that measures the level of production in the industrial sector of an economy.
8. ***OECD Consumer Confidence Indicator (CCI):*** This indicator provides an indication of future developments of households’ consumption and saving, based upon answers regarding their expected financial situation, their sentiment about the general economic situation, unemployment, and capability of savings.
9. ***Retail Sales***: Retail sales refer to the total amount of goods and services sold by retailers to consumers within a specific period¹. They are a vital economic indicator as they reflect consumer spending patterns, which account for a significant portion of overall economic activity. As a leading macroeconomic indicator, healthy retail sales figures typically elicit positive movements in equity markets.

TODO:

* ETFs selection process
  + generation of the synthetic values for missing periods
* Benchmark description,
  + changing weights over time,
  + inclusion of new countries
* Preparation of input data,
  + selecting the most recent indicators values available,
  + formatting input data
  + using PCA
* Using optimal portfolio as a target

# Presentation of work

TODO:

* Describe all models and results they achieved.

# Conclusions

TODO:

* Summary of results
* Recommendations: generalize conclusions to appropriate design decisions, practices and/or procedures
* Implications for further study
* Future Work

# References

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