

MSDS 451: Financial Machine Learning

Portfolio Optimization via Monte Carlo

Programming Assignment 2

Blade Hunter Robelly
7-30-2025

Introduction and Problem Statement

Portfolio optimization plays a central role in financial decision-making, particularly when an investor seeks to maximize expected returns within a tolerable level of risk. This project explores the comparative benefits of two investment strategies: (1) portfolios constrained to long positions only, and (2) portfolios allowing short positions. Specifically, we examine these strategies using historical monthly return data for four technology-oriented assets: NVIDIA (NVDA), Meta Platforms (META), Microsoft (MSFT), and Amazon (AMZN), from 2015 to mid-2025. The core objective is to illustrate how short-selling expands the opportunity set and alters the Sharpe-optimal set of portfolios. We use Monte Carlo simulation to generate 700 random portfolios under each strategy and evaluate their risk-return profiles.

Research Design and Modeling Methods

I employed a stochastic programming approach using Monte Carlo simulation to generate portfolios. The methodology includes the following steps:

- **Data Acquisition:** Monthly adjusted closing prices were obtained using Yahoo Finance's API via the *yfinance* library.
- **Preprocessing:** Logarithmic monthly returns were computed to approximate continuously compounded returns.
- **Portfolio Simulation:**

- 700 portfolios were generated for each strategy.
- Long-only portfolios were constrained to weights ≥ 0 , summing to 1.
- Shorts-allowed portfolios had weights in $[-1, 1]$, normalized to sum to 1.
- **Performance Metrics:** For each portfolio, the following metrics were computed:
 - Expected return (mean of log returns)
 - Risk (standard deviation of log returns)
 - Sharpe Ratio (excess return over a 3% annual risk-free rate, divided by standard deviation)

Results

In Figure 1, there are two side-by-side plots depicting the simulated portfolios:

- **Left Panel:** Short Positions Allowed
 - Portfolios span a much broader range of returns, with several exceeding 0.04 but no returns exceeding anything greater than 0.05.
 - All of NVIDIA's portfolios can be found above a return of 0.03 meanwhile the other assets have a wide range of returns. Some portfolios even return negative.
 - Amazon has the greatest range in terms of returns and standard deviation of risk.

- Sharpe Ratios increase as the returns increase.
- **Right Panel: Long Positions Only**
 - Few risk-return combinations cluster below a 0.20 monthly return.
 - Sharpe Ratios are moderate and concentrated.
 - Returns are capped at lower levels compared to portfolios with shorting.
 - NVIDIA seems to yield the most returns in this position.

Analysis and Interpretation

This simulation clearly shows that:

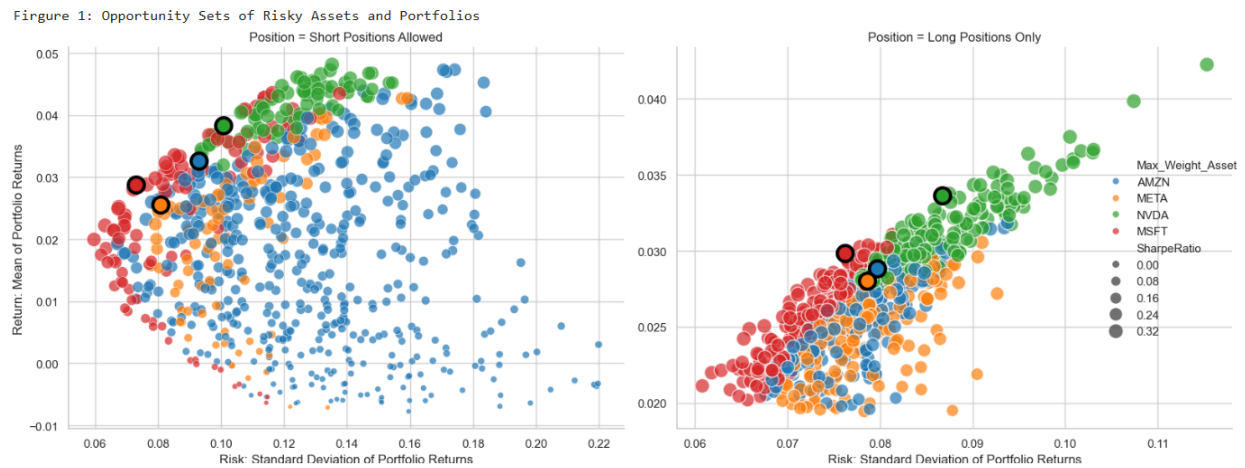
- Short selling expands the opportunity set. Without shorting, investors are confined to portfolios with lower expected return, especially when seeking to minimize risk.
- Sharpe-optimal portfolios are more accessible when shorts are allowed. The best Sharpe Ratios in the simulation arise in the shorts-allowed panel.
- Portfolio efficiency is constrained by position rules. Long-only portfolios form a smaller and more limited region of return-risk trade-offs.

These results support the general understanding that constrained optimization restricts portfolio flexibility and efficiency. While short positions introduce more risk, they also unlock access to returns otherwise inaccessible.

Conclusions

The Monte Carlo analysis illustrates a key lesson in portfolio management: to maximize risk-adjusted returns, especially in environments of moderate risk tolerance, investors should consider incorporating short positions into their strategies. By removing the non-negativity constraint on asset weights, the feasible set of portfolios is enlarged, allowing greater flexibility in reaching risk-return goals. This project demonstrates the power of Monte Carlo methods to visualize and quantify the trade-offs inherent in portfolio construction under constraints. It also bridges theoretical concepts with applied financial modeling.

Appendix



Note: Figure 1 shows Risk vs Returns for assets and their portfolios. The black circled points are each asset's highest sharpe ratio.

Table 1: Highest Sharpe Ratios for Each Asset under Portfolio Constraints

Asset	SharpeRatio_ShortAllowed	SharpeRatio_LongOnly
AMZN	0.3517	0.3620
META	0.3168	0.3567
NVDA	0.3809	0.3883
MSFT	0.3952	0.3919

Note: Table 1 shows the highest sharpe ratio for each asset in the two positions.