

Online Portfolio Optimization: S&P 500 vs IPO 180-Day Index

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Problem Statement

- **Objective:** Optimize daily portfolio weights between two asset classes
 - S&P 500 (SPY ETF) – Established large-cap US equities
 - IPO 180-Day Index – Market-cap weighted index of recent IPOs
- **Goal:** Maximize risk-adjusted fitness score
 - Balance returns vs volatility, drawdown, and transaction costs
- **Constraints:**
 - Long-only: $w_i \geq 0$ for all i
 - Fully invested: $\sum_i w_i = 1$ (simplex constraint)
 - Daily rebalancing

Why This Problem Matters

IPO Characteristics

- **High volatility:** 3–4× the volatility of S&P 500
- **Mean reversion:** Significant price changes in first 6 months
- **Information asymmetry:** Early price discovery creates alpha opportunities

Opportunity

Systematic allocation between stable market exposure (SPY) and high-risk/high-reward IPO exposure could capture upside while managing downside risk.

Success Metrics

Metric	Target	Rationale
Sharpe Ratio	> 1.0	Risk-adjusted return above market
Max Drawdown	< 30%	Capital preservation
Annualized Return	> 15%	Beat SPY baseline
Calmar Ratio	> 0.8	Return per unit drawdown

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Mathematical Formulation

Objective Function (Fitness Score)

$$F(w) = \mu_p - \lambda_1 \sigma_p^2 + \lambda_2 \cdot \text{MDD}_p - \lambda_3 \|w_t - w_{t-1}\|_1$$

where:

- $w \in \mathbb{R}^2$ = portfolio weights [SPY, IPO_INDEX]
- μ_p = mean portfolio return over window
- σ_p^2 = portfolio variance
- MDD_p = maximum drawdown
- $\lambda_1 = 20.0$ (risk aversion), $\lambda_2 = 8.0$ (drawdown penalty), $\lambda_3 = 0.15$ (turnover penalty)

Constraints

$$w_i \geq 0, \quad \sum_i w_i = 1 \quad (\text{probability simplex})$$

Algorithm: Online Gradient Descent (OGD)

Walk-Forward Optimization

For each day t :

- ① Extract trailing 126-day window of returns $R[t - W : t]$
- ② Compute fitness gradient via PyTorch autograd
- ③ Gradient ascent: $w_{\text{new}} = w + \text{lr} \cdot \nabla F(w)$
- ④ Project onto simplex: $w = \text{proj}_{\text{simplex}}(w_{\text{new}})$
- ⑤ Apply weights to next day's returns (walk-forward, no look-ahead)
- ⑥ Decay learning rate: $\text{lr} \leftarrow \text{lr} \times 0.999$

Why OGD?

- Online learning adapts to regime changes (bull/bear markets)
- No assumptions about return distributions
- Differentiable objective enables PyTorch autograd

Simplex Projection

Euclidean Projection onto Probability Simplex

Ensures weights satisfy:

- Non-negativity: $w_i \geq 0$
- Sum constraint: $\sum_i w_i = 1$

IPO Index Construction

- **Universe:** ~80 IPOs from 2020–2024
 - Major US IPOs (Snowflake, Airbnb, Coinbase, etc.)
- **Holding period:** 180 trading days per stock
 - Captures “IPO pop” while avoiding long-term underperformance
- **Weighting:** Market-cap weighted
 - Price \times shares outstanding
 - Average ~8.5 constituents at any given time
- **Data source:** Yahoo Finance (yfinance API)

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Performance Metrics (2020–2025 Backtest)

Strategy	Total Return	Ann. Return	Ann. Vol	Sharpe Ratio	Max DD	Calmar Ratio
OGD Portfolio	193.5%	28.5%	20.1%	1.42	-26.2%	1.09
Equal Weight	577.7%	56.2%	35.0%	1.60	-51.3%	1.09
S&P 500 Only	86.1%	15.6%	16.1%	0.97	-24.5%	0.64
IPO Index Only	1699.3%	96.0%	61.4%	1.56	-73.1%	1.31

Key Finding

OGD achieves a **Sharpe ratio of 1.42** with only **-26% max drawdown**, significantly improving risk control compared to IPO-only exposure (-73% drawdown).

Performance Analysis

Strengths

- Sharpe ratio: 1.42 (beats SPY: 0.97)
- Max drawdown: -26.2% (vs IPO-only: -73.1%)
- Calmar ratio: 1.09
- Annual return: 28.5% (beats SPY: 15.6%)

Trade-offs

- Lower total return than equal-weight (193.5% vs 577.7%)
- Much lower volatility (20.1% vs 35.0%)
- Better risk-adjusted performance
- More stable drawdown profile

Implementation Details

- **Time horizon:** 2020-01-01 to 2025-01-14 ($\sim 1,200$ trading days)
- **Lookback window:** 126 days (6 months)
- **Initial learning rate:** 0.10
- **Learning rate decay:** 0.999 per step
- **Runtime:** ~ 3 minutes for full backtest
- **Memory:** $< 1\text{GB}$

Validation

- Walk-forward testing (no look-ahead bias)
- 21 unit tests covering core functionality
- Simplex constraint satisfied at all times

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Current Limitations

① Look-ahead bias in market caps

- Uses current shares outstanding for all historical dates
- Should use quarterly SEC filings

② Survivorship bias

- Only includes "significant" IPOs that still trade using unclear selection filter
- Excludes delisted/acquired companies

③ No real transaction costs

- Turnover penalty is a proxy, not actual bid-ask spreads

④ Heuristic hyperparameters

- Penalty coefficients not yet systematically optimized

Future Work

Immediate Improvements

- Expand IPO universe: Scrape comprehensive IPO data from using WRDS
- Historical shares outstanding: Use historical sharecount data via WRDS for accurate market cap calculation to determine portfolio weights
- Add transaction costs: Model bid-ask spreads and market impact
- Hyperparameter optimization: Grid search or Bayesian optimization

Alternative Approaches

- Factor-based IPO selection: Use momentum/value/quality factors
- Dynamic holding period: Optimize exit timing instead of fixed 180 days, tune hyperparameters like look-back period and loss function weights

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Key Takeaways

What We Learned

- IPOs are extremely volatile ($3\text{--}4 \times \text{SPY}$) but offer high returns in aggregate
- Market-cap weighting reduces impact of small, illiquid names
- OGD effectively shifts to defensive (SPY) during IPO drawdowns
- The 180-day holding period captures most of the “IPO pop” while avoiding long-term underperformance (also through IPO selection, creating limitations for future extrapolation)

Main Contribution

Online Gradient Descent balances risk and return, achieving superior risk-adjusted performance (Sharpe 1.42) with controlled drawdowns (-26%) compared to naive strategies.

Thank You

Questions?