version 1:

Over the course of this summer, I built a quantitative research framework to study option pricing, risk management, and systematic trading strategies. My starting point was the Black–Scholes–Merton model, which I used not only for theoretical pricing but also as a foundation for experiments on return optimization, volatility effects, and risk profile analysis.

I structured the project around several key questions: how do option returns behave when implied volatility is held constant versus when it rises around major events? Which combinations of strike, time-to-expiration, and underlying price movement yield the highest percentage returns, and which lead to the steepest losses? To answer these, I ran thousands of simulations across different scenarios, visualizing profit-and-loss distributions and quantifying how far out-of-the-money options provide lottery-like outcomes, while deep in-the-money trades expose investors to persistent decay and large downside risk.

As the project evolved, I expanded beyond Black–Scholes to incorporate statistical research methods. I developed tools for detecting local extrema in stock prices, ran rolling regressions to estimate time-varying beta and momentum relative to the market, analyzed stock correlation structures, and applied Differential Evolution optimization to identify clusters of highly interrelated assets. I also explored seasonality in stock returns and tested the predictive value of macroeconomic indicators such as TSA passenger volumes.

The result is a body of work that blends financial theory, data science, and optimization into a unified research effort. More than just coding simulations, the project deepened my understanding of how derivatives function as both speculative instruments and hedging tools, and how market dynamics like volatility, correlation, and momentum can be quantified and harnessed. This project not only gave me hands-on experience in quantitative finance research but also reinforced my drive to pursue a career applying mathematics, programming, and statistical inference to real-world trading problems.

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v2

This project presents a comprehensive study into the pricing, risk dynamics, and trading strategies of financial derivatives, with a primary focus on equity options. Using the Black–Scholes–Merton model as a foundation, the research examined both theoretical and practical aspects of option valuation, including risk profiles, sensitivity measures (Greeks), and optimization of returns under varying market conditions.

The work investigated option return distributions under two distinct regimes: fixed implied volatility and increasing implied volatility. Thousands of simulated trades across a broad range of strikes, maturities, and underlying price paths revealed how extreme gains arise from far out-of-the-money contracts in favorable markets, while substantial losses are concentrated in deep in-the-money positions exposed to adverse movements. These findings validated well-known intuitions about leverage, convexity, and time decay, while quantifying the magnitude of potential returns and risks.

Beyond option pricing, the project incorporated advanced quantitative methods including rolling regression analysis for beta and momentum estimation, local extrema detection for trend analysis, correlation mapping across equities, and portfolio selection using Differential Evolution optimization. Supplementary studies applied kernel density estimation to seasonal stock returns and examined macroeconomic indicators, further connecting derivative pricing with broader market behavior.

Overall, the results underscore how volatility dynamics, strike selection, and timing interact to shape return distributions. By combining financial theory with statistical modeling and algorithmic optimization, this work demonstrates a multi-disciplinary approach to systematic trading and risk management, bridging the gap between abstract models and practical market application.

The following document represents what I spent a large fraction of the summer (June - September 2025) after my first year of college at University of California, Davis working on.

It is a write up of independent research in quantitative finance.

This research presents a quantitative framework developed to analyze equity option pricing, risk dynamics, and systematic trading strategies. Grounded in the Black-Scholes-Merton model, the framework was utilized to conduct large-scale simulations of option return distributions under both static and dynamic implied volatility regimes. The study systematically evaluated thousands of trade scenarios across varying strikes, maturities, and underlying price paths to quantify the drivers of extreme profit and loss, validating the lottery-like payoff structures of out-of-the-money contracts while measuring the impact of time decay on in-the-money positions.

The project extends beyond classical option theory by integrating advanced quantitative methods. These include the implementation of rolling regression models to estimate time-varying beta and momentum factors, correlation matrix analysis to map market structure, and the application of Differential Evolution—a stochastic optimization algorithm—to identify highly correlated asset clusters. Further analyses explored seasonality in equity returns using Kernel Density Estimation and incorporated alternative macroeconomic data, such as TSA passenger volumes, to contextualize market behavior.

Key findings empirically demonstrate the amplifying effect of implied volatility expansion on returns and successfully identified persistent, economically intuitive stock groupings (e.g., financials and REITs) via optimization. This body of work establishes a rigorous, multi-disciplinary approach to quantitative research by bridging financial theory with statistical modeling and computational optimization.

Introduction & Author Background

The following document is a report outlining independent data analysis and research in quantitative finance that I conducted over a large portion of the summer (June – September 2025), after completing my first year of undergraduate studies at the University of California, Davis. Entering my sophomore year, I currently have junior standing and am majoring in Mathematics and Scientific Computation, with plans to either double major in Computer Science and Engineering or complement my degree with double minors in Computer Science and Economics and/or a physical science. All work presented here, from coding and data analysis to writing, was completed independently by me.

My interest in quantitative finance, mathematical finance, and data analysis has developed over the past three years, guided by my father, a self-taught trader with a background in computer science, and through conversations with family friends. Together, all of us regularly discuss topics spanning finance, machine learning, artificial intelligence, data analysis, and algorithms all of which are applied to fields such as finance, healthcare, and computer vision. This early exposure provided me with practical experience, including familiarity with the Thinkorswim trading platform and its associated programming language Thinkscript. This project represented an important step in moving from informal discussions to formally applying concepts in finance and analyzing data.

Through the process of completing this research and writing this report, I developed important skills in Python programming, data analysis, and quantitative/statistical modeling. Equally important, producing this document of more than fifty pages gave me practice in technical writing and communication, an area I have not always been confident in but one where I made substantial progress through this project.

All analyses were conducted in Python, and unless otherwise specified, market data was scraped from Yahoo Finance. For this project, all referenced code and data files can be found in the *code/* and *results/* folders within the main GitHub repository. This work reflects my long-term interest in learning and applying mathematical methods to various domains, and my ongoing effort to build the technical and analytical skills needed for a career. My technical experience also includes building machine learning models using scikit-learn for data mining applications across various domains. One such project, an analysis of health data for a Kaggle contest, achieved a strong result and the accompanying report is available for review on my GitHub.

This document is free to read and share for academic or professional discussion purposes. However, as it represents my original independent work, please contact me at the email address listed on the title page if you would like to reference, cite, or make use of any part of it. Feel free to contact me also for any questions!

### Abstract

This research presents a quantitative framework developed to analyze equities, option pricing, risk dynamics, systematic trading strategies, and algorithms. The initial report is based on the Black-Scholes-Merton model, which was utilized to conduct large-scale simulations of option return distributions under both static and dynamic implied volatility regimes. The initial studies systematically evaluated thousands of trade scenarios across varying strikes, maturities, and underlying price paths to quantify the drivers of extreme profit and loss.

The project extends beyond classical options by integrating advanced quantitative methods. These include the implementation of rolling regression models to estimate time-varying beta and momentum factors, correlation matrix analysis to map market structure, and the application of Differential Evolution, a stochastic optimization algorithm, to identify highly correlated asset clusters. Further analyses explored seasonality in equity returns using Kernel Density Estimation and incorporated alternative macroeconomic data, such as TSA passenger volumes, to contextualize market behavior.

This report and code is meant to establish a rigorous, multi-disciplinary approach to quantitative research by bridging financial data analysis with statistical modeling and computational optimization.

Statistical modeling, backtesting, and coding-driven experiments in **derivatives pricing, volatility, and stock dynamics**

Built a **Python based options pricing & trading simulation framework** using the **Black–Scholes model**, regressions, and **stochastic optimization algorithms**

Applied **time-series regression, correlation matrices, and Differential Evolution** to identify correlated equity clusters for **portfolio construction and risk factor modeling**

Ran **20,000+ simulated option trades** across fixed and variable **parameters to** analyze optimal conditions for returns

Researched **volatility–return tradeoffs, seasonal stock return distributions (Kernel Density Estimation)**, and **macroeconomic indicators (TSA passenger volumes)** into equity market analysis

Produced time-varying beta and momentum factors through rolling CAPM analysis

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* Conducted statistical modeling, backtesting, and code-driven experiments in derivatives pricing and stock dynamics.
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* Ran 20,000+ simulated option trades across variable parameters to analyze optimal return conditions.
* Researched volatility–return tradeoffs, seasonal stock return distributions (Kernel Density Estimation), and macroeconomic indicators (TSA passenger volumes) for equity market analysis.
* Produced time-varying beta and momentum factors via rolling CAPM analysis.
* Authored a 50-page research report detailing methodology, analysis, and findings.