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Performance Attribution Analysis

Project Statement

This project applies the Capital Asset Pricing Model (CAPM) to analyze and attribute portfolio performance by decomposing returns into systematic market risk, measured by beta, and abnormal risk-adjusted performance, measured by alpha. Using linear regression techniques introduced in STAT GU4205/GR5205, the analysis examines whether differences in sector-level portfolio returns can be explained solely by exposure to market risk or whether statistically significant alpha remains after controlling for the market.

CAPM regressions are estimated by regressing excess portfolio returns on excess market returns using ordinary least squares (OLS). Formal hypothesis tests are conducted to assess whether the intercept term, alpha, is statistically different from zero. This framework allows us to quantify the extent to which portfolio performance is driven by broad market movements versus sector-specific behavior that may be interpreted as abnormal performance.

In addition to estimation and inference, the project incorporates exploratory data analysis and regression diagnostics to evaluate the validity of the linear regression assumptions underlying the CAPM. By grounding the analysis in OLS estimation, hypothesis testing, and

diagnostic tools, the project directly links theoretical concepts from linear regression models to a widely used financial application in performance attribution.

Data Collection

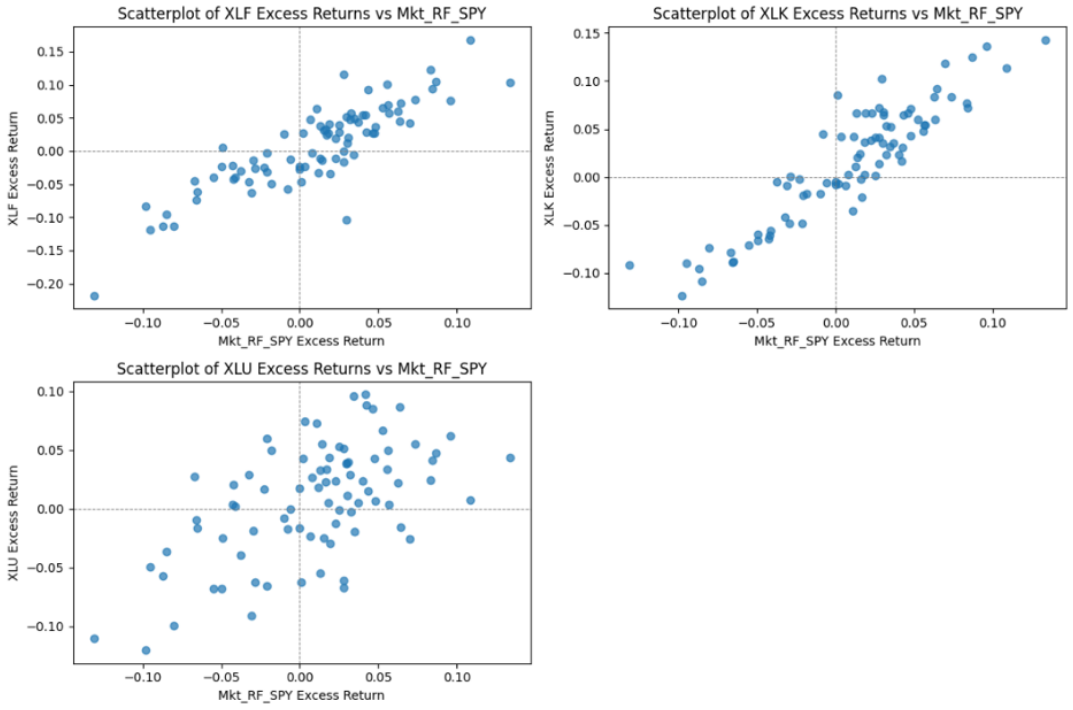
To reduce idiosyncratic, asset-specific risk and focus on systematic behavior, the analysis considers diversified sector portfolios in the form of exchange-traded funds (ETFs). The portfolios examined include the Technology sector ETF (XLK), the Financials sector ETF (XLF), and the Utilities sector ETF (XLU). The S&P 500 ETF (SPY) is used as a proxy for the market portfolio. Using ETFs rather than individual stocks ensures that the analysis reflects sector-level and market-wide dynamics rather than firm-specific noise.

The analysis uses monthly data from January 2018 through December 2024. Monthly frequency is appropriate for CAPM analysis, as it smooths short-term fluctuations while preserving economically meaningful variation in returns. Monthly adjusted closing prices for all ETFs are obtained from Yahoo Finance to ensure that dividends and stock splits are incorporated into returns. The risk-free rate is taken from the Kenneth French Data Library and measured using the three-month U.S. Treasury bill. Monthly excess returns are constructed by subtracting the risk-free rate from both portfolio and market returns. Portfolio excess returns are defined as $r_{i,t} = R_{i,t} - R_{f,t}$, while market excess returns are defined as $r_{m,t} = R_{m,t} - R_{f,t}$, where $R_{i,t}$ denotes the return on portfolio i at time t, $R_{m,t}$ is the market return proxied by SPY, and $R_{f,t}$ is the risk-free rate. All series are aligned by date and cleaned of missing observations to produce an analysis-ready dataset.

Exploratory Data Analysis

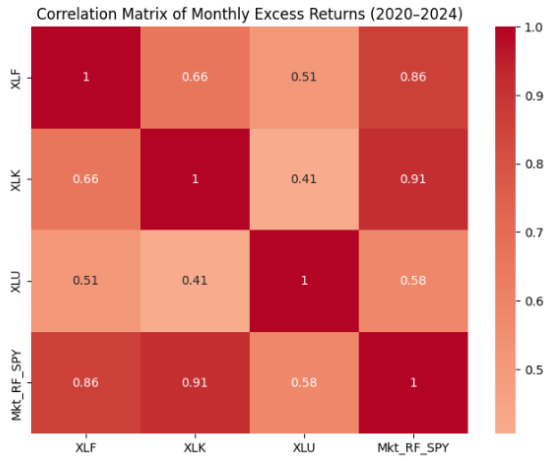
The exploratory data analysis examines the behavior of monthly excess returns for each sector portfolio relative to the market in order to develop intuition about risk, dependence, and potential CAPM relationships prior to formal model estimation. The analysis focuses on descriptive statistics and visualizations that highlight differences in average performance, volatility, correlation with the market, and distributional characteristics.

Descriptive statistics reveal clear heterogeneity across sectors. The Technology sector (XLK) exhibits the highest average excess returns in expansionary periods, but also the greatest volatility, particularly during episodes of market stress. The Financials sector (XLF) displays similarly elevated volatility and experiences pronounced losses during downturns such as the 2020 market crash, suggesting strong exposure to systematic risk. In contrast, Utilities (XLU) shows lower volatility and more stable excess returns, consistent with its classification as a defensive sector. These patterns align with CAPM intuition, where higher volatility portfolios tend to exhibit higher market betas.

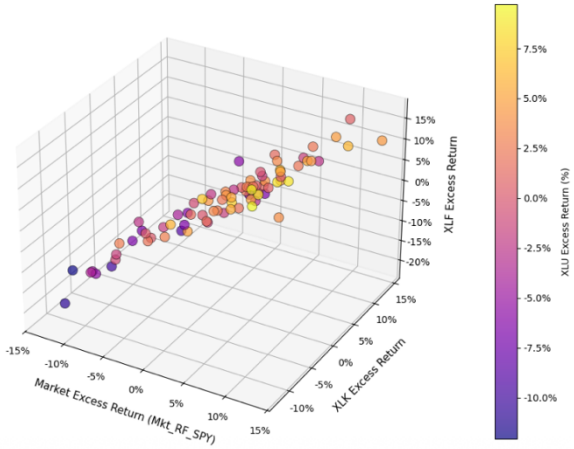


Extreme return behavior further differentiates the sectors. Minimum and maximum monthly excess returns indicate that XLK and XLF experience larger negative tail events than XLU, particularly during periods of sharp market declines. Utilities exhibit smaller drawdowns and fewer extreme observations, suggesting reduced sensitivity to adverse market conditions.

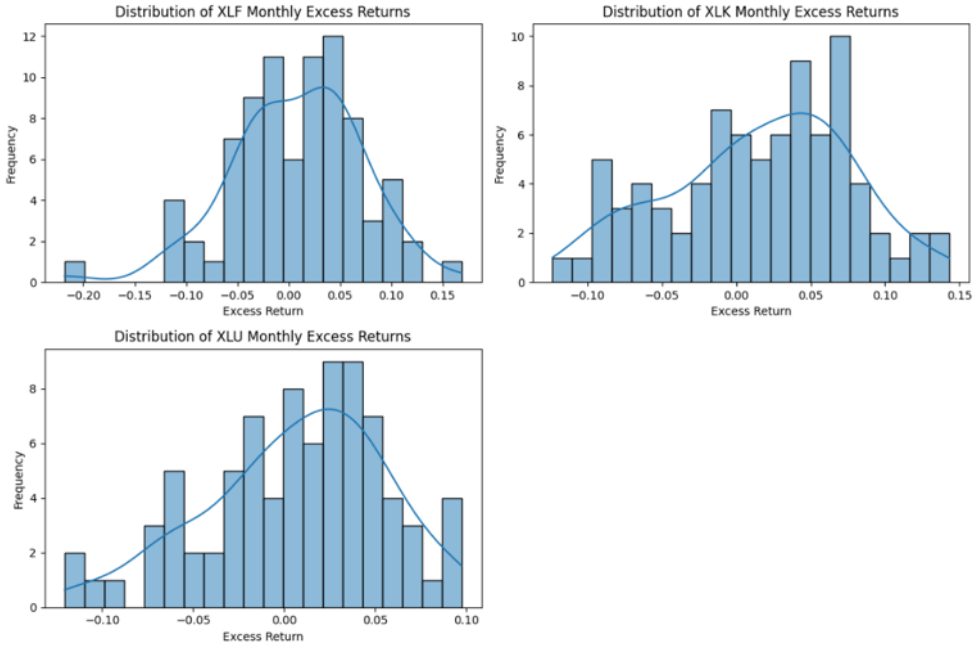
Correlation analysis reinforces these findings. Both XLK and XLF display strong positive correlations with the market excess return, indicating that these sectors move closely with overall market conditions. XLU shows a more moderate correlation with the market, implying lower systematic exposure and potential diversification benefits. Correlations across sector portfolios also suggest that growth-oriented sectors tend to move together more closely than with defensive sectors.



Visualizations provide additional insight. Time series plots show that XLK and XLF closely track market movements, especially during volatile periods, while XLU deviates more frequently from the market path. Scatterplots of portfolio excess returns against market excess returns reveal strong linear relationships for XLK and XLF, consistent with high beta exposure, while XLU exhibits a flatter slope and greater dispersion.



Distributional plots show approximately bell-shaped return distributions centered near zero, with XLK displaying the widest spread and XLU the tightest. A three-dimensional visualization further highlights the strong co-movement between Technology and Financials relative to Utilities.



Overall, the exploratory analysis suggests substantial differences in sector behavior with respect to market movements, motivating the use of CAPM regressions to formally quantify market exposure and test for abnormal performance.

CAPM Regression Analysis

The core empirical analysis is based on the Capital Asset Pricing Model, estimated separately for each sector ETF using ordinary least squares. The regression model is given by $r_{i,t} = \alpha_i + \beta_i r_{m,t} + \varepsilon_{i,t}$, where α_i represents Jensen's alpha, β_i measures systematic market

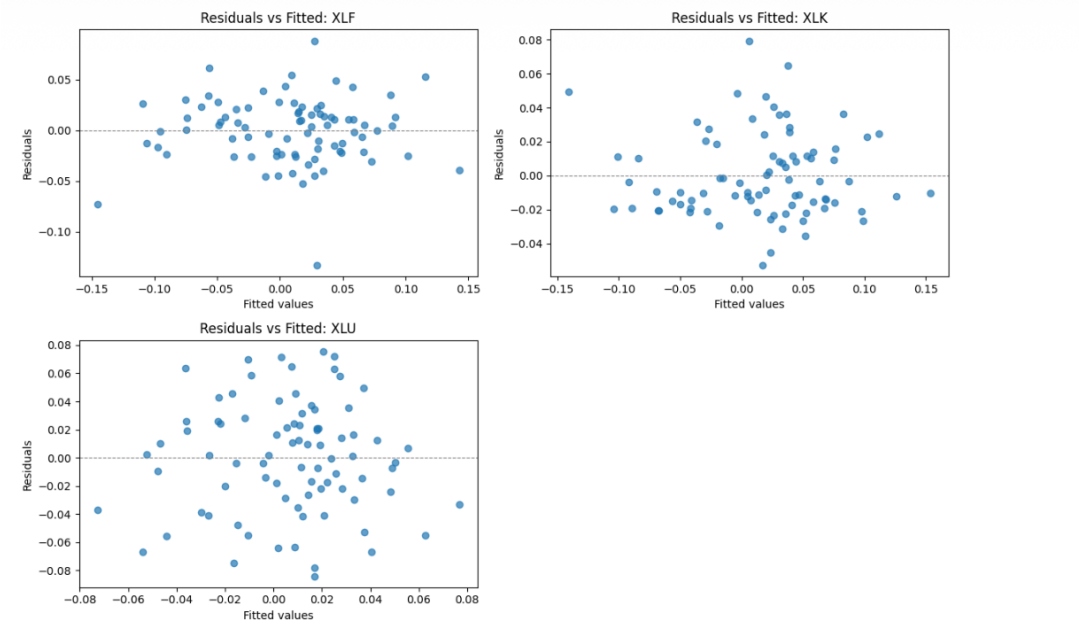
exposure, and $\varepsilon_{i,t}$ is the error term. Regression results indicate that all three ETFs exhibit statistically significant exposure to market risk.

ETF	alpha	beta	t_alpha	p_alpha	t_beta	p_beta	R2
XLF	-0.002788	1.088478	-0.771356	0.442740	15.368990	0.000000e+00	0.744645
XLK	0.005032	1.112624	1.802637	0.075165	20.342982	0.000000e+00	0.836310
XLU	0.001276	0.564296	0.286430	0.775280	6.463882	7.153663e-09	0.340293

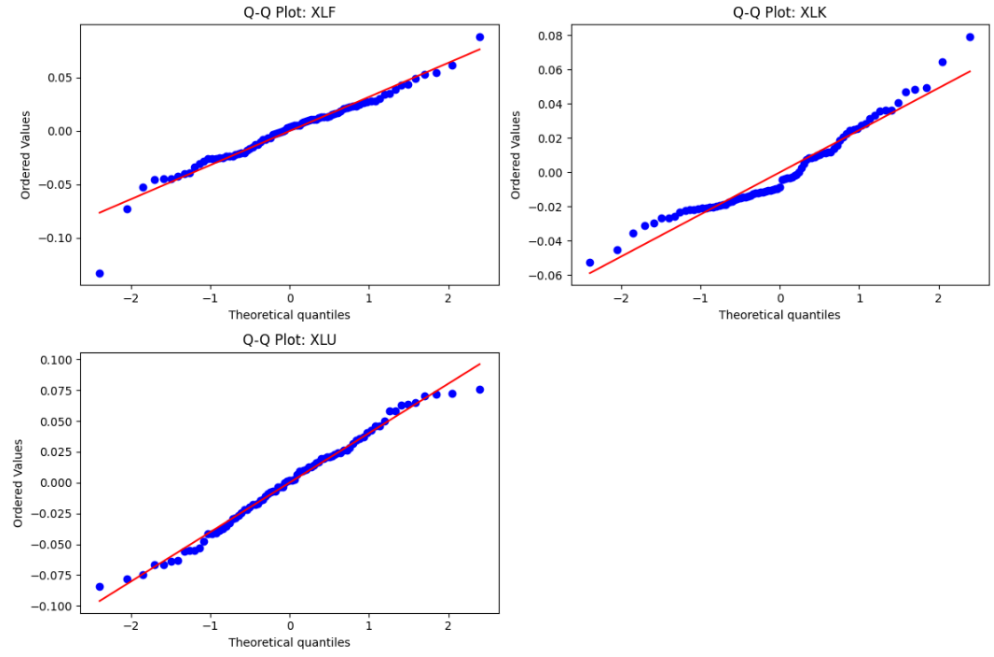
The Technology (XLK) and Financials (XLF) sectors have beta estimates greater than one, indicating that these sectors amplify market movements and are more volatile than the market. In contrast, Utilities (XLU) has a beta well below one, consistent with its defensive characteristics. Estimated alpha values are small in magnitude and statistically insignificant at conventional significance levels for all three sectors. Although XLK exhibits a positive alpha estimate and XLF a slightly negative one, hypothesis tests indicate that these estimates are not statistically distinguishable from zero. This suggests that differences in average sector performance are largely explained by differences in market exposure rather than persistent abnormal returns. The CAPM explains a substantial portion of return variation for XLK and XLF, as reflected in high R^2 values, while the lower R^2 for XLU indicates weaker co-movement with the market and a greater role for idiosyncratic factors.

Model Diagnostics

Regression diagnostics support the validity of the CAPM specification. Residuals plotted against fitted values show no strong evidence of heteroskedasticity or nonlinear patterns, suggesting that the assumptions of linearity and constant variance are reasonably satisfied.



Q–Q plots indicate that residuals are approximately normally distributed, with mild tail deviations typical of financial return data.

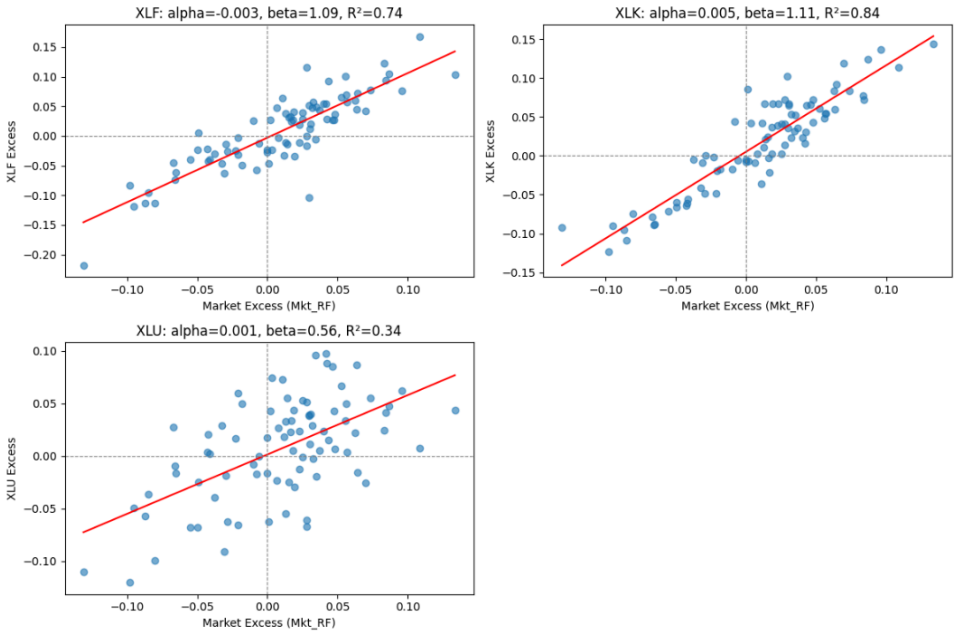


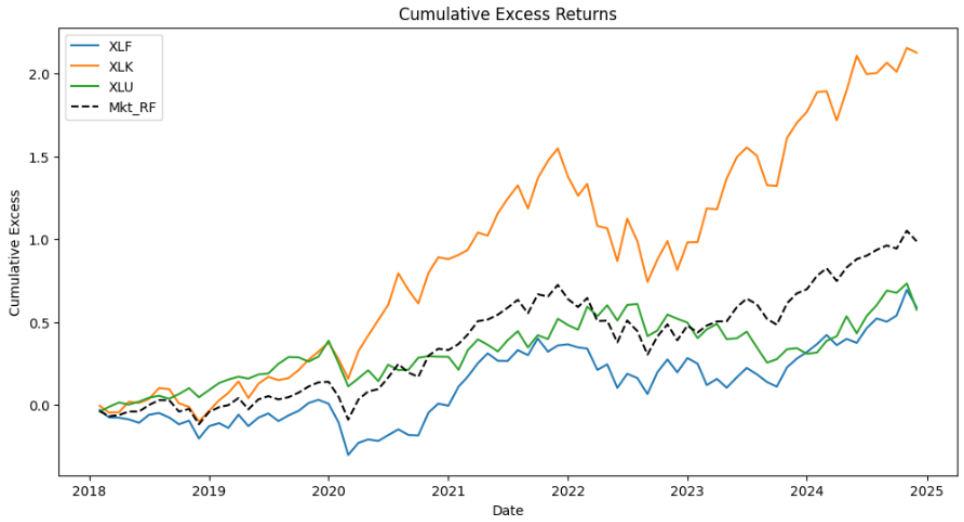
Formal normality tests yield mixed results, with Utilities failing to reject normality and Technology and Financials showing modest departures. Given the sample size and the robustness

of OLS inference to mild non-normality, these deviations are not considered problematic. Influential observations identified using leverage and Cook's distance largely correspond to periods of extreme market stress, particularly during early 2020, and do not materially affect the estimated coefficients (more on the notebook).

Final Visualizations

This section presents publication-quality visualizations that summarize and reinforce the empirical findings of the CAPM analysis. Scatterplots of portfolio excess returns against market excess returns illustrate the strength and linearity of the CAPM relationship across sectors, while cumulative excess return plots provide a time-series perspective on relative performance over the sample period. Together, these figures visually confirm the regression results and highlight differences in market exposure and return dynamics across sectors.





Conclusion

This project applied the CAPM to attribute the performance of sector-based ETF portfolios by decomposing returns into systematic market exposure and abnormal performance. Using monthly data from 2018 to 2024, the analysis finds that sector-level differences in returns are primarily driven by differences in market exposure rather than statistically significant alpha. Technology and Financials exhibit high sensitivity to market movements, while Utilities behave as a defensive sector with lower beta and weaker market dependence. Across all sectors, alpha estimates are small and statistically insignificant, consistent with the CAPM's central implication that expected excess returns are driven by systematic risk. Overall, the results demonstrate how the CAPM, combined with standard linear regression techniques, provides a coherent and interpretable framework for performance attribution. The analysis highlights both the explanatory power and the limitations of the CAPM when applied to sector-level portfolios, reinforcing its role as a foundational model in empirical finance.

Work cited

John C. Hull. “Capital Asset Pricing Model.” Options, Futures, and Other Derivatives, 11th ed., Pearson, 2023, Appendix to Chapter 3, pp. 96–97.