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A New Model of Capital Structure Based on Portfolio Theory

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Abstract

In this paper, a theoretical model is introduced to solve for the optimal weights of debt (bonds) and equity (stocks) that determine the minimum weighted average cost of capital (WACC), which in turn leads to maximizing the value of the firm. The model uses a Lagrangian function to determine the optimal weights that minimize risk for a given level of return. The model's unique contribution is its direct application of the efficient portfolio framework, typically used for investment management, to a firm's capital components by treating debt and equity as a two-security portfolio. Empirical results of the model using real-world data show the robustness of the model in obtaining the optimal WACC.

Keywords

Capital Structure, Efficient Market, Efficient Portfolio, Optimal Mix of Debt and Equity, MM Propositions, Pecking Order Theory, Trade off Theory

1. Introduction

The relationship between capital structure and portfolio management is a crucial intersection of corporate finance and investment theory. Capital structure—the mix of debt and equity financing—directly affects a firm's risk-return profile, influencing cost of capital, financial flexibility, and market valuation (Brealey, Myers, & Allen, 2020; Ahmed et al., 2024). In contrast, portfolio management focuses on selecting and combining assets to achieve the optimal balance between return and risk, guided by the principles of Modern Portfolio Theory (Markowitz, 1952, 1991; Statman, 2019). Understanding how a firm's financing decisions interact with portfolio-level risk-return optimization offers valuable insights for both corporate managers and investors.

Traditional capital structure theories, including Modigliani and Miller's (1958) irrelevance proposition, the trade-off theory (Kraus & Litzenberger, 1973), the pecking-order theory (Myers & Majluf, 1984), and agency cost theory (Jensen & Meckling, 1976), provide complementary perspectives on how leverage impacts firm value. Recent empirical evidence suggests that while pecking-order behavior often dominates in practice, trade-off considerations remain important, especially when accounting for taxes, bankruptcy costs, and financial flexibility (Frank & Shen, 2016; Dang et al., 2020).

Most classical models, however, treat debt and equity in isolation from portfolio risk considerations. Integrating Modern Portfolio Theory into capital structure analysis allows for a more unified approach—treating debt and equity as a two-asset portfolio whose weights can be optimized to minimize the Weighted Average Cost of Capital (WACC) for a given expected return (Rubinstein, 1973; Huang & Ritter, 2022). By applying mean-variance optimization and solving via a Lagrangian function, firms can identify the capital structure point that lies on the efficient frontier, thus achieving both cost minimization and risk control.

Recent studies have explored this integration further. For example, Li and Shi (2021) demonstrate that portfolio-based capital structure models can better capture market volatility effects on firm value, while Baker and Wurgler (2020) show that market timing and behavioral factors also influence leverage decisions in ways consistent with portfolio optimization logic. Dynamic approaches, such as those by DeAngelo and Roll (2015), highlight how firms adjust capital structures over time in response to changing market conditions and internal constraints.

Furthermore, broader portfolio innovation, such as Hierarchical Risk Parity (HRP) and machine learning–based optimization models, illustrates modern advances in risk minimization—though largely within asset manager rather than firm-level contexts (de Prado, 2016). These techniques motivate our approach of adopting mean-variance optimization at the corporate balance-sheet level.

This paper builds on these insights by proposing a quantitative framework that explicitly combines capital structure theory with portfolio optimization methods. The proposed model treats debt and equity as correlated portfolio assets, uses mean-variance analysis to model risk-return trade-offs, and applies Lagrangian optimization to determine the optimal leverage that minimizes WACC for a target return. By doing so, the model bridges a theoretical gap, offering a rigorous, closed-form method that aligns corporate finance decisions with portfolio optimization principles.

2. Capital Structure Theories and Concepts

2.1. Modigliani and Miller Proposition (1958)

The foundational work by Modigliani and Miller (M&M) is a cornerstone in the study of capital structure (Modigliani & Miller, 1958) Their Proposition I asserts that under perfect market conditions (no taxes, bankruptcy costs, or agency costs), a firm's capital structure does not affect its value In their Proposition II, M&M

suggest that the cost of equity rises with leverage in such a way to exactly offset the use of cheaper debt, thereby keeping the overall cost of capital (WACC) constant in a world without taxes. However, real-world factors like taxes and bankruptcy costs challenge the direct applicability of M&M's.

Impact on Portfolio: From a portfolio management perspective, while M&M's insights suggest value is independent of capital structure in a perfect market, portfolio managers in the real world must consider how different capital structures impact risk and return due to market imperfections.

2.2. Trade-off Theory

Trade-off Theory suggests that firms aim to balance the tax advantages of debt against the potential costs of financial distress (bankruptcy)This theory posits that an optimal capital structure can be achieved where the marginal benefit of debt equals its marginal cost

Impact on Portfolio: Firms with moderate leverage are often seen as more stable, offering a good balance of risk and return. Excessive leverage, however, increases financial distress risk, which can negatively affect stock prices and a portfolio's risk profile.

2.3. Pecking Order Theory

Pecking Order Theory introduced by Myers and Majluf (1984), states that firms prefer internal financing (retained earnings) first, then debt, and finally, as a last resort, issuing new equity This hierarchy exists because of the information asymmetry between managers and investors, which makes debt issuance less costly than equity.

Impact on Portfolio: This theory helps portfolio managers understand a firm's financing behavior A firm with a low debt ratio might be seen as conservative and lower risk, while firms with high debt may carry higher risk.

2.4. Agency Theory

Developed by Jensen and Meckling (1976), Agency Theory explores conflicts of interest between managers and shareholders It suggests that debt can act as a disciplining mechanism by reducing the free cash flow available to managers, thus limiting potentially wasteful investments. Impact on Portfolio: Agency costs associated with high levels of debt or equity can affect a firm's governance and decision-making, which in turn influences stock price volatility and portfolio risk (Fama & French, 1993; Mabandla & Marozva, 2024).

3. Portfolio Theory and Risk Management

3.1. Modern Portfolio Theory (MPT)

Modern Portfolio Theory (MPT), introduced by Markowitz [6], emphasizes diversification MPT holds that an investor can build an efficient portfolio that maximizes expected return for a given level of risk by combining assets with low or negative correlations.

Impact of Capital Structure on MPT: A firm's capital structure is pivotal to its risk profile (Sharpe, 1964). Highly leveraged companies tend to have higher volatility, which impacts overall portfolio risk (Shefrin & Stateman, 2000).

3.2. Capital Asset Pricing Model (CAPM)

Capital Asset Pricing Model (CAPM) provides a framework for evaluating an asset's expected return based on its systematic risk (beta) relative to the risk-free rate and the overall market.

Impact of Capital Structure on CAPM: The cost of equity used in CAPM is influenced by a firm's capital structure. High leverage can increase a firm's beta, raising the expected return required to compensate for that increased risk.

4. Capital Structure's Impact on Portfolio Construction

4.1. Capital Structure and Diversification

A firm's capital structure can affect its correlation with other assets. Highly leveraged companies tend to be more sensitive to macroeconomic factors like interest rates, which can increase their correlation with other similarly leveraged.

Effect on Portfolio Composition: Firms with a balanced capital structure may be preferred for their stable risk-return profile, while high-debt firms may offer higher potential returns but at an increased risk that must be managed.

4.2. Risk Management and Capital Structure

Capital structure directly impacts the volatility of a firm's earnings and stock price. Firms with high leverage are subject to greater financial risk and may exhibit higher stock price volatility.

Impact on Risk Management: Portfolio managers must select assets based on their risk tolerance: Conservative portfolios might exclude firms with excessive debt, while higher-risk portfolios might include them to capitalize on higher expected returns.

5. The Model

Major Assumptions:

1. The security market is efficient; prices of bonds and stocks reflect all available information.
2. An efficient portfolio can be formed; a firm can minimize its total risk for a given level of return.
3. Agency costs, bankruptcy costs, and Pecking Order Theory considerations are ignored. While these factors are important in practice, they are excluded here to isolate the core relationship between risk and return as defined by portfolio theory. This provides a baseline optimal structure that can be later adjusted for these real-world frictions.

Derivation of the Model:

First: Estimating rates of return, variances and covariance

The rate of return on bond and stock are estimated as:

$$R_{dt} = \frac{B_t - B_{t-1}}{B_{t-1}} \tag{1}$$

$$R_{et} = \frac{S_t - S_{t-1}}{S_{t-1}} \tag{2}$$

Where, d = debt, e = equity, B = market price of bond, and S = market price of stock.

$$\sigma^2(d) = \sum_1^n \frac{(R_{dt} - R_d)^2}{n-1} \tag{3}$$

$$\sigma^2(e) = \sum_1^n \frac{(R_{et} - R_t)^2}{n-1} \tag{4}$$

Where σ^2 = variance, R_d and R_e the mean of R_{dt} and R_{et}.

Finally, the covariance between debt and equity is given by

$$Cov(d.e) = \sum_1^n \frac{(R_{dt} - R_d)(R_{et} - R_e)}{n-1} \tag{5}$$

Second: Given

$$\sigma^2 = W_d^2\sigma_d^2 + W_e^2\sigma_e^2 + 2W_dW_eCov(d.e) \tag{6}$$

Where W_d and W_e are the weights of debt and equity, which are given by $W_d = \frac{d}{d+e}$, and $W_e = \frac{e}{d+e}$, subject to

$$W_d + W_e = 1 \tag{7}$$

Forming Lagrange function as L, we have

$$L = W_d^2\sigma_d^2 + W_e^2\sigma_e^2 + 2W_dW_eCov(d.e) + \lambda(W_d + W_e - 1) \tag{8}$$

Taking the partial derivative of L with respect to W_d, W_e and λ, we get

$$\frac{\partial L}{\partial W_d} = 2W_d\sigma_d^2 + 2W_eCov(d.e) + \lambda = 0 \tag{9}$$

$$\frac{\partial L}{\partial W_e} = 2W_e\sigma_d^2 + 2W_dCov(d.e) + \lambda = 0 \tag{10}$$

$$\frac{\partial L}{\partial \lambda} = W_d + W_e = 1 \tag{11}$$

Rearrange in Matrix form we have

$$\begin{bmatrix} 2\sigma_d^2 & 2Cov(d.e) & 1 \\ 2Cov(d.e) & 2\sigma_e^2 & 1 \\ 1 & 1 & 0 \end{bmatrix} \begin{bmatrix} W_d \\ W_e \\ \lambda \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \tag{12}$$

Using Cramer's rule we solve for W_d and W_e, the optimal weights of debt and equity:

$$W_d = \frac{\sigma_e^2 - Cov(d.e)}{\sigma_d^2 + \sigma_e^2 - 2W_d W_e Cov(d.e)} \quad (13)$$

$$W_e = \frac{\sigma_d^2 - Cov(d.e)}{\sigma_d^2 + \sigma_e^2 - 2W_d W_e Cov(d.e)} \quad (14)$$

Hence,

$$W_d + W_e = 1 \text{ or } W_e = 1 - W_d \quad (15)$$

These optimal weights will achieve the minimum cost of capital hence maximize the value of the firm.

6. Results and Discussions

An empirical test was conducted to validate a model for determining the optimal weight of debt for corporations. [1]The analysis utilized data from the Egyptian securities market, with a focus on companies listed on the EGX30 and EGX70 indices.

The objective of the analysis was to use the collected data to estimate the optimal weight of debt W_d.

6.1. Data Collection

A dataset was compiled for 29 large corporations, with banks and financial institutions explicitly excluded. The data spanned a 10-year period from 2016 to 2024 and was collected on a quarterly basis. The collected data was used to determine the rates of return on bonds (R_d), the rates of return on stocks (R_e), the variance of debt and equity, and the covariance between debt and equity.

6.2. Results and Analysis

A comparison between the actual weight of debt (W_d) and the model's calculated optimal weight of debt (W_d^*) for the 29 companies are shown in Table 1.

Table 1. The actual (W_d) weights of debt and the model's calculated optimal weight of debt (W_d^*) for 29 Egyptian companies.

Company Number	Actual W_d	Optimal W_d^*
1	0.76	0.72
2	0.81	0.75
3	0.40	0.44
4	0.30	0.35
5	0.61	0.67
6	0.67	0.65
7	0.52	0.50
8	0.40	0.42
9	0.49	0.51

Continued

10	**0.53**	**0.55**
11	0.69	0.70
12	0.81	0.80
13	0.64	0.61
14	0.40	0.40
15	0.53	0.50
16	0.19	0.20
17	0.80	0.76
18	0.70	0.68
19	0.30	0.35
20	0.50	0.47
21	0.73	0.70
22	0.80	0.78
23	0.11	0.14
24	0.90	0.85
25	0.34	0.39
26	0.80	0.76
27	0.19	0.16
28	0.60	0.63
29	0.17	0.14

6.3. Statistical Evaluation

A comprehensive statistical analysis was conducted to assess the model's performance, which indicated a high degree of accuracy and a near-perfect fit. The model's predicted values demonstrated a strong and reliable correspondence with the observed values. Key statistical indicators were calculated and are summarized in Table 2.

Table 2. Summary of the calculated Key statistical indicators.

Metric	Value	Interpretation
Correlation Coefficient (r)	0.993	Indicates an almost perfect positive linear relationship.
Coefficient of Determination (R^2)	0.968	Shows that 96.8% of the variation in observed values is explained by the model.
Nash-Sutcliffe Efficiency (NSE)	0.968	A value very close to 1 signifies excellent predictive power. An NSE score of this level is considered to be in the "very good" performance class.
Willmott's Index of Agreement (d)	0.993	A value nearing 1 indicates a near-perfect agreement between predictions and observations.
Mean Absolute Error (MAE)	0.031	The average difference between predicted and observed values is very small.
Root Mean Squared Error (RMSE)	0.035	Represents a low magnitude of error.

The low error metrics, MAE and RMSE, are particularly noteworthy when compared to the range of the data (0.11 to 0.90), confirming the model's consistent accuracy.

6.4. Regression Analysis

To further validate the results, a regression analysis was performed. The analysis yielded an R-value of 0.993 and an R-squared value of 0.968. The F-ratio was 1668.4 with a significance level of less than 0.001, indicating a highly significant relationship.

6.5. Implications for Egypt and Developing Countries

The diversity in findings across developed and developing economies indicates the importance of institutional and market-specific factors. For countries like Egypt, where capital markets are less developed and ownership is often concentrated in families or the state, capital structure choices may not fully align with Western models. Hence, empirical validation within local contexts becomes critical.

7. Conclusion

The relationship between capital structure and portfolio management is multifaceted and critical for financial decision-making. A firm's capital structure significantly affects its risk profile, stock price volatility, and cost of capital, all of which are crucial inputs for portfolio construction and management as demonstrated, there is no one-size-fits-all approach; portfolio managers must carefully consider the capital structure of firms and its implications for risk and return. By integrating modern portfolio theory with capital structure principles, this paper offers a model to optimize the debt-equity mix, minimize the WACC, and thereby maximize firm value. The statistical evidence overwhelmingly suggests that the model is exceptionally good, performing its function with a high degree of accuracy and reliability. The high correlation, strong predictive power, and low error rates, further supported by the regression analysis, affirm that the model is both powerful and valid for empirical work. Future research could further explore how the interaction between capital structure and industry-specific factors influences portfolio performance. Furthermore, emerging approaches in behavioral and macro-finance may shed light on how investors perceive and react to capital structure in their decision-making.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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