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Integrating ESG into Factor Pricing Models and Actuarial Risk Estimation: Implications for Venture Capital

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Abstract

This paper reviews how Environmental, Social and Governance (ESG) factors can be incorporated into factor pricing models and actuarial risk estimation methods, and evaluates their implications for venture capital (VC) investment. Traditional asset pricing models, including single-factor and multi-factor models, provide a framework for assessing systematic risk, while actuarial techniques such as Value at Risk (VaR), Conditional Value at Risk (CVaR), and Extreme Value Theory (EVT) are effective in measuring tail risk. Existing literature suggests that ESG performance influences both expected returns and downside risk, with firms exhibiting stronger ESG profiles generally showing lower tail risk and greater resilience during periods of financial stress. In the context of venture capital, ESG serves as a signal of management quality, governance capability, and long-term growth potential, helping investors mitigate information asymmetry and improve investment selection. This review identifies major research findings, ongoing debates, and current gaps, particularly the lack of an integrated framework combining factor pricing and actuarial methods for ESG analysis in private markets. The paper concludes by proposing future research directions for building quantitative ESG assessment tools tailored to venture capital.

Keywords

environmental, social and governance (ESG), factor pricing model, actuarial risk estimation, venture capital, tail risk

1. Introduction

In recent years, Environmental, Social and Governance (ESG) investing has grown rapidly worldwide. According to the Global Sustainable Investment Alliance (GSIA), global sustainable investment assets have exceeded USD 30 trillion, and ESG factors have become an increasingly important component of asset allocation and risk management in capital markets. In this context, venture capital (VC) firms have gradually incorporated ESG considerations into their investment decision-making processes, as start-up companies are highly dependent on external financing in the early stages, and ESG performance is widely regarded as an indicator of long-term growth potential, governance quality, and potential risk exposure [1,2]. Despite the rapid development of ESG investing in practice, traditional quantitative financial models, such as factor pricing models and actuarial risk estimation methods, have not yet been systematically applied to ESG risk analysis.

This methodological gap makes it difficult to accurately capture and measure ESG-related risks, particularly tail risk and systematic risk, thereby limiting the depth of ESG applications in asset pricing and venture capital decision-making. Therefore, it is necessary to develop a systematic modeling framework for ESG risk by integrating financial econometrics and actuarial risk theory [1]. Existing research on factor pricing models, actuarial risk estimation, and ESG finance remains highly fragmented. Factor pricing models provide a fundamental framework for asset pricing and risk decomposition, but they require structural extensions to incorporate ESG factors and account for their nontraditional risk characteristics [3-5]. Meanwhile, actuarial risk estimation methods, including Value at Risk (VaR), Conditional Value at Risk (CVaR), and Extreme Value Theory (EVT), are particularly effective in analyzing low-probability, high-impact events and are therefore well suited to capturing the tail-risk characteristics of ESG-related events. Integrating actuarial methods into ESG risk measurement can improve the identification of extreme risk exposures arising from environmental and social shocks. Against this background, this paper examines the role of ESG in quantitative finance and venture capital, focusing on three key questions: how factor pricing models can incorporate ESG factors to capture systematic risk; how actuarial risk estimation methods can be used to quantify ESG-related tail risk; and how ESG integration influences venture capital performance and the mechanisms through which it operates. Building on these questions, this study integrates financial econometrics, actuarial science, and sustainable finance theory to develop a conceptual framework for quantitative ESG analysis in venture capital and to address the current lack of interdisciplinary integration in the literature. The remainder of this paper is organized as follows. Section 2 introduces the theoretical foundations, including factor pricing theory, actuarial risk estimation methods, and the theoretical perspectives that explain ESG as a risk driver. Section 3 provides a systematic literature review covering ESG in asset pricing models, ESG-related risk measurement, and ESG in venture capital. Section 4 synthesizes the literature and discusses the main areas of consensus, debate, and research gaps. Section 5 concludes and outlines directions for future research.

2. Theoretical Foundations

2.1 Factor Pricing Models

Factor pricing models are central tools in modern financial economics. The single-index model developed by Sharpe decomposes asset returns into systematic market risk and idiosyncratic risk [3]. Subsequently, multifactor models such as the Fama-French three-factor model and the Carhart four-factor model introduced additional factors including size, value, and momentum to explain cross-sectional differences in returns [4,5]. These models distinguish between systematic risk and idiosyncratic risk, where the former is driven by common macroeconomic factors and the latter can be diversified away. This framework provides a natural foundation for ESG analysis. If ESG characteristics influence the return patterns of a broad set of firms, ESG may be interpreted as a systematic factor and incorporated into traditional pricing models [1].

2.2 Actuarial Risk Estimation

The core objective of actuarial risk estimation is to quantify extreme losses. Value at Risk (VaR) measures the maximum expected loss at a given confidence level, while Conditional Value at Risk (CVaR), also known as Expected Shortfall, estimates the average loss beyond the VaR threshold. Because actuarial science focuses on low-probability, high-severity events, it is particularly well suited to analyzing ESG risks such as environmental disasters, labor controversies, and governance scandals. CVaR and Extreme Value Theory (EVT) provide effective tools for assessing tail risks associated with ESG events.

2.3 ESG as a Risk Driver

From a theoretical perspective, ESG can be interpreted as a risk driver through several complementary lenses. Stakeholder theory argues that firms must create value not only for shareholders but also for employees, customers, suppliers, and communities, and that effective stakeholder management reduces operational and reputational risk [1]. Signaling theory suggests that ESG performance functions as a signal of management quality and long-term orientation, allowing firms to communicate stronger governance and risk-control capabilities to investors [1,2]. Legitimacy theory further posits that firms require societal approval to maintain operations, and ESG practices help firms align with social norms, thereby reducing regulatory, reputational, and consumer-related risks [1].

3. Literature Review

3.1 How ESG Enters Asset Pricing

A large body of empirical evidence indicates that ESG performance is positively associated with corporate financial performance. Friede et al. conducted a meta-analysis covering more than 2,000 empirical studies and found that approximately 90% reported a non-negative relationship between ESG and corporate financial performance [6]. Gillan et al. further argue that ESG affects firm value through improved cash flows, lower financing costs, reduced regulatory and reputational risks, and stronger investor demand [7]. In addition, Bolton and Kacperczyk find that firms with higher carbon emissions tend to earn higher expected returns, suggesting that climate-related risk is priced in capital markets [8]. Overall, ESG enters asset pricing through both firm fundamental channels and investor preference channels.

3.2 How ESG Affects Risk Distribution

Beyond expected returns, ESG also influences the distribution of returns, particularly downside and tail risk. Broadstock et al. show that firms with stronger ESG performance exhibit lower downside risk and greater resilience during financial stress periods [9]. Ding et al. further find that firms with higher ESG scores experienced smaller stock price declines during the COVID-19 pandemic and more stable operating performance [10]. These results indicate that ESG reduces left-tail risk and enhances financial resilience. Tail risk analysis further suggests that firms with strong ESG performance are less exposed to extreme negative outcomes due to reduced environmental controversies, governance failures, and social conflicts. In addition, stakeholder relationships formed through ESG practices can act as a stabilizing mechanism during market stress [1,9]. In methodological terms, Extreme Value Theory (EVT) is widely used to model rare but severe ESG-related losses, as it better captures fat-tailed distributions than normality-based models.

3.3 ESG in Venture Capital

In venture capital markets, ESG is particularly relevant due to high uncertainty and information asymmetry. Startups typically face higher failure rates and lack stable financial histories, making traditional financial indicators insufficient for evaluation. Kaplan and Strömberg show that venture capital investing relies heavily on governance structures, control rights, and founder quality to mitigate information asymmetry [11]. Gompers et al. further demonstrate that venture capitalists systematically evaluate management quality and governance characteristics, which significantly affect investment decisions and exit outcomes [12]. Within this context, ESG can be interpreted as an extension of soft information indicators. It provides a multidimensional assessment of governance quality, social responsibility, and environmental sustainability. Dimson et al. show that ESG engagement improves governance and operational performance [13], while Krüger finds that ESG-related information significantly influences investor expectations and firm valuation [14]. Overall, ESG contributes to venture capital through signaling effects, growth identification, and downside risk reduction.

4. Discussion

4.1 Consensus Across Studies

Existing research generally agrees that ESG factors exhibit systematic risk characteristics and influence asset pricing at the market level rather than only at the firm-specific level [1]. There is also a broad consensus that higher ESG performance is associated with lower tail risk and stronger resilience during extreme market conditions [9,10]. Furthermore, most studies indicate that ESG integration improves portfolio risk-adjusted performance by reducing downside risk, even though its effect on abnormal returns remains debated [6,7].

4.2 Contradictions and Debates

However, several key debates remain unresolved. First, the existence and direction of the ESG premium are still inconclusive, with empirical results varying across markets and methodologies [6,8]. Second, there is no consensus on whether ESG represents an independent risk factor or merely reflects investor preferences, which affects its theoretical stability. Third, ESG rating systems exhibit relatively low cross-agency

consistency, with correlations typically between 0.5 and 0.7, which limits the robustness of empirical factor construction.

4.3 Mechanisms and Research Trends

The literature shows three major shifts in research focus. First, ESG research has moved from exclusion-based screening strategies to systematic factor integration into formal asset pricing models [1]. Second, attention has shifted from mean–variance frameworks to tail risk analysis, emphasizing extreme event behavior [9,10]. Third, research has expanded from public markets to private markets, particularly venture capital and private equity, where ESG is increasingly studied as part of investment decision-making [11,12].

4.4 Research Gaps and Limitations

Despite progress, several gaps remain. There is still no unified framework integrating factor pricing models with actuarial risk methods. ESG data availability in venture capital remains limited due to the private nature of firms and the lack of standardized disclosure. Existing studies are mostly cross-sectional and fail to capture long-term dynamics across the full investment lifecycle. Finally, ESG mechanisms in high-growth startups remain underexplored, as most theories are based on mature firm environments.

4.5 Reflections from Project Experience

Empirical practice shows that multi-factor models can incorporate ESG factors, but industry heterogeneity poses challenges in weighting ESG dimensions. Manufacturing industries tend to emphasize environmental factors, while service industries focus more on social dimensions such as data privacy and labor rights. Additionally, Tail Value at Risk (TVaR) is particularly useful for capturing extreme ESG-related risks, although its practical application in venture capital remains constrained by data limitations and model complexity.

5. Conclusion

This paper reviews the integration of ESG into factor pricing models and actuarial risk estimation. The literature evolves from single-factor to multi-factor models, from mean–variance analysis to tail risk focus, and from public to private markets. While ESG is widely associated with lower tail risk, its effect on returns remains uncertain. This study proposes an integrated framework combining financial econometrics, actuarial risk methods, and ESG theory, and highlights its relevance for venture capital risk assessment. It also summarizes key consensus areas and unresolved debates in the literature. Future research should focus on integrating factor models with tail-risk frameworks, conducting longitudinal VC lifecycle studies, developing industry-specific ESG factors, and applying machine learning techniques to improve ESG risk estimation under data constraints.

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Conflicts of Interest

The authors declare no conflict of interest.

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