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Review

Financial Materiality and Market Dynamics of ESG Performance in the Global Electronics Industry: An Empirical Analysis Amidst Diverse Regulatory and Technological Landscapes

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Abstract: The global electronics industry is facing escalating sustainability regulations and rapid technological change. This study quantitatively examines the financial implications of Environmental, Social, and Governance (ESG) performance for 13 multinational electronics firms from 2015 to 2025. Using panel regressions that control for Fama-French-Momentum factors, we find that sustained, long-term aggregate ESG and social (S) pillar scores are positively associated with stock excess returns. Vector Autoregression (VAR) analysis of a constructed ESG factor (HML_ESG) reveals limited dynamic linkage with traditional market risks, indicating that ESG factors exhibit distinct risk/return characteristics within this sector. These results are contextualized within a landscape of diverse global regulations (e.g., WEEE, RoHS, ESPR) and the growing influence of advanced technologies, including artificial intelligence and digital twins. The findings inform a "Global Regulatory-ESG Financial Salience Model," providing empirical evidence of ESG's financial materiality. This research offers actionable insights for firms navigating sustainability pressures and for investors evaluating performance in the evolving electronics industry, highlighting the market's potential recognition of strategic, long-term ESG commitments.

1. Introduction

The global electronics industry is undergoing a profound transformation, driven by the dual imperatives of advancing technological innovation and meeting escalating sustainability demands [8,29,30,66]. Across the world, regulatory bodies are enacting increasingly stringent measures to address the environmental and social impacts of this sector, particularly concerning electronic waste (e-waste) management, hazardous substance control, and the promotion of a circular economy (CE) [9–13,18,23,26,28,31–33,40,41,68]. Navigating this complex global regulatory maze while leveraging sustainable practices for competitive advantage is a critical challenge for multinational electronics corporations [1]. The "Global E-waste Monitor 2020" highlights the scale of this challenge, detailing increasing quantities and flows of e-waste globally [65].

While the European Union (EU) has been a frontrunner with comprehensive frameworks such as the Ecodesign for Sustainable Products Regulation (ESPR) [9,12,28,40], Waste Electrical and Electronic Equipment (WEEE) Directive [10,13,18,19,23,26,31,32], and Restriction of Hazardous Substances (RoHS) Directive [19,23,27,45,61], these often serve as catalysts or benchmarks for regulatory developments in other major economic zones. For example, North America has federal legislation such as the Resource Conservation and Recovery Act (RCRA) and influential state-level e-waste laws [20,46,62]. Asian economic leaders such as China and Japan have implemented their own RoHS-equivalent standards and robust appliance recycling laws [19,47,48]. Similar trends

towards Extended Producer Responsibility (EPR) and specific e-waste management rules are evident in South America, Africa, and Oceania [13,18,49–51]. The OECD's "Global Material Resources Outlook to 2060" further underscores the economic drivers and environmental consequences necessitating such global regulatory attention [64].

Concurrently, the sector is being reshaped by emergent technologies such as Artificial Intelligence (AI) [10,30,34,35], Digital Twins [35–38], and Digital Product Passports (DPPs) [9,12], which offer new capabilities for enhancing sustainability and compliance across global value chains. This backdrop of intense regulatory pressure [67] and technological transformation, coupled with investor and stakeholder focus on corporate Environmental, Social, and Governance (ESG) performance [66], has significantly increased. This study quantitatively investigates the financial materiality of ESG performance using a sample of globally operating multinational electronics firms. The key research questions are:

- RQ1: Is there a statistically significant association between ESG performance metrics and stock market excess returns of multinational electronics firms, after controlling for market risk factors?
- RQ2: Do the ESG factors for these global electronics firms exhibit distinct dynamic interactions with traditional market risk factors?
- RQ3: What are the financial implications of ESG performance in this sector, considering global regulatory pressures and technological enablers, thereby informing a conceptual model of "Regulatory-ESG Financial Salience"?

This research analyzes historical stock market data, ESG scores [2–4], and financial risk factors [5] for 13 multinational electronics firms. Preliminary findings suggest that sustained, long-term ESG performance, particularly overall and social metrics, is positively associated with stock returns, while a constructed ESG factor appears largely independent of traditional market risks. This study aims to provide nuanced quantitative evidence within this specific global industry context, acknowledging the vision for a "New Circular Vision for Electronics" advocated by bodies like the World Economic Forum [63]. The paper is structured as follows: Section 2 examines the theoretical framework and relevant literature. Section 3 describes the data, variables, and methodology. Section 4 discusses diagnostic tests. Section 5 presents empirical findings. Section 6 addresses these findings, provides a conceptual paradigm, and examines the worldwide implications and limitations. Section 7 concludes.

2. Theoretical Framework and Literature Review

This study integrates stakeholder theory, the Natural Resource-Based View (NRBV), and the Porter Hypothesis to understand the ESG-finance nexus in the global electronics industry. Stakeholder theory suggests that firms addressing diverse stakeholder interests, including ESG concerns related to environmental protection and social welfare, can build trust, enhance reputation, and potentially improve financial performance [17,24,52,66]. This is particularly relevant for the electronics sector, where stakeholder pressures increasingly focus on global environmental impacts such as e-waste and resource use [10,13,18,23,26,28,31,32,65,68], as well as social issues like labor conditions in international supply chains [13,15,19,23,43]. The NRBV posits that unique environmental capabilities and green innovations, crucial in an industry striving for eco-design and circularity [9,11,12,14,25,33,40,41,44], can be sources of sustainable competitive advantage [16,19,53]. The Porter Hypothesis argues that well-designed environmental regulations can spur innovation that enhances competitiveness [1,16,20,54,59], a perspective relevant given the global proliferation of electronics sustainability regulations. However, the impact of regulatory stringency can vary, with potential for negative consequences if regulations are not harmonized or effectively implemented across different jurisdictions [21–23,55,69]. The impact of corporate sustainability on organizational processes and performance itself is a significant area of study [60].

A complex tapestry of regulations governs sustainable electronics globally. Europe's WEEE [10,13,18,19,23,26,31,32], RoHS [19,23,27,45,61], and ESPR/Eco-Design directives [9,11,12,14,25,33,40,44], alongside its Circular Economy Action Plan including Digital Product

Passports [9,12,33,41], are highly influential. North America utilizes federal acts like the US RCRA and TSCA, complemented by state-level e-waste laws [20,46,62] and programs like Energy Star. Key Asian regulations include China's RoHS and Circular Economy Promotion Law [19,47], Japan's Home Appliance Recycling Law [48], and India's E-Waste (Management) Rules [13,49]. Similar regulatory objectives are pursued in South America (e.g., Brazil's National Solid Waste Policy [50]), Africa (e.g., South Africa's National Environmental Management Act [51]), and Oceania (e.g., Australia's Product Stewardship Act [56]). This global regulatory trend [1,67], while varied, signals a collective move towards greater producer responsibility and lifecycle management in electronics [1,22,23,55].

Emerging technologies are increasingly critical for the electronics industry to meet these global sustainability goals. Artificial Intelligence offers significant potential for optimizing resource utilization, enhancing supply chain transparency, and improving e-waste recycling processes [10,30,34,35]. Digital Twins facilitate sustainable product design, predictive maintenance, and lifecycle management, supporting eco-design and circular economy principles on a global scale [35–38]. Smart tags and blockchain are foundational for implementing effective Digital Product Passports, enhancing traceability and end-of-life decision-making across international supply chains [9,10,12,57]. The strategic deployment of these technologies is vital for managing complexity and driving sustainable practices worldwide [8,29,30,34–38,58].

The financial implications of ESG performance for globally operating firms remain a central theme in sustainable finance [7,16,17,24,52–54,59]. Numerous studies have explored this link, with results often varying by industry, region, and methodology [7,19,60]. Asset pricing models like the Fama-French framework [5] are standard for assessing whether ESG factors explain returns beyond known risks [7]. Panel data methods allow for robust analysis across firms and time [6,7], while VAR models can reveal dynamic interactions between ESG and market factors [6]. This study applies these quantitative tools to major global electronics players, using ESG data sourced via tools like Python's yesg library [2] and interpreted according to established rating methodologies [3,4].

3. Data, Variables, and Methodology

3.1. Data

This study analyzed monthly data from March 2015 to March 2025 for a panel of 13 multinational electronics corporations with significant global operations, including headquarters in the United States (e.g., Apple, Intel), Asia (e.g., Samsung, LG), and Europe (e.g., Infineon). Stock price data were retrieved using the yfinance Python library. Environmental, Social, and Governance (ESG) scores were primarily obtained using the Python yesg library [2]. The methodologies of Sustainalytics [3] and MSCI [4] were reviewed for contextual understanding. Data for the Fama-French five-factor model plus momentum (FF6) [5] were sourced from Kenneth R. French's Data Library.

3.2. Variables

For the analysis, several variables were constructed. The dependent variable for the panel regression was Excess_Return_it, defined as the monthly excess return for firm i at time t. This was calculated by subtracting the risk-free rate, obtained from the Fama-French dataset, from the firm's stock return. The key independent variables in the panel regression included Lagged_Total-Score_it-l, representing the overall ESG score for firm i at time t-l, where l signifies various lag lengths of 1, 3, and 6 months. Another key independent variable was Avg12M_Lagged_Total-Score_it, a 12-month moving average of the 1-month lagged total ESG score. Similar lagged and averaged variables were also established for the individual E-Score, S-Score, and G-Score components. Control variables for the panel regression consisted of the contemporaneous monthly returns of the six Fama-French-Momentum factors: MKT_RF_t, SMB_t, HML_t, RMW_t, CMA_t, and WML_t [4]. For the VAR analysis, specific variables were employed, including HML_ESG_t, which is a High-Minus-Low ESG factor. This factor was derived by monthly sorting firms in the sample into three portfolios based on their Lagged_Total-Score, with HML_ESG_t being the equally-weighted average return of the

highest ESG portfolio minus that of the lowest ESG portfolio. The VAR analysis also incorporated the six Fama-French-Momentum factors previously mentioned.

3.3. Methodology

Panel regression (primarily Two-Way Fixed Effects) and Vector Autoregression (VAR) methods were employed using statsmodels [6]. The panel regressions assess the ESG-return relationship (RQ1), controlling for firm-fixed effects (α_i), time-fixed effects (λ_t), and FF6 market factors: $Excess\_Return\_it = \alpha\_i + \lambda\_t + \beta1*ESG\_Score\_it\text{-}l + \Sigma\_k \beta\_k*ControlFactor\_kt + \varepsilon\_it$ [7]. A VAR (1) model (lag selected by BIC) explores dynamic interplay (RQ2) via Granger causality, IRFs, and FEVDs. Jensen's alpha for the HML_ESG factor is estimated via OLS with HAC robust standard errors.

4. Diagnostic Testing of Variables and Regression Models

To establish the econometric soundness of the subsequent empirical analyses, a series of diagnostic examinations was performed on the dataset and the proposed regression frameworks. These tests are crucial for ensuring the validity and reliability of the study's findings.

4.1. Assessment of Inter-Variable Correlations

Examining the pairwise links between the main variables utilized in the panel regressions, including several lagged ESG scores and the Fama-French-Momentum factors, a Pearson correlation analysis was conducted. The correlation matrix (available from the author upon request) revealed generally low levels of association between the ESG metrics and the market risk factors. This outcome alleviates concerns regarding potential issues of severe multicollinearity, which could otherwise compromise the precision and interpretability of the estimated coefficients for the ESG variables in the panel regression analyses.

4.2. Unit Root Tests for Time Series Stationarity

Time series variables employed in the Vector Autoregression (VAR) model, namely, the constructed HML_ESG factor, MKT_RF, SMB, HML, RMW, CMA, and WML, were subjected to the Augmented Dickey–Fuller (ADF) test to assess their stationarity. The results, summarized in **Table 1**, confirm that all series are stationary at conventional significance levels (all p-values < 0.01), indicating that they do not contain a unit root and can be appropriately included in the VAR model in their level form.

Table 1. Augmented Dickey-Fuller (ADF) Test for Stationarity of VAR Input Variables.

Variable	ADF Statistic	P-value	Conclusion
HML_ESG	-10.987	0.000	Stationary
MKT_RF	-11.543	0.000	Stationary
SMB	-10.312	0.000	Stationary
HML	-8.765	0.001	Stationary
RMW	-9.987	0.000	Stationary
CMA	-9.123	0.000	Stationary
WML	-10.501	0.000	Stationary

4.3. Examination of Residual Serial Correlation

Following the estimation of each panel regression model, the Durbin–Watson (DW) test statistic was calculated from the model residuals to detect the presence of first-order serial correlation. These statistics are noted with the primary regression outputs in Section 5. For the VAR model, DW statistics

for the residuals of each equation are presented in **Table 2**. The values obtained are all close to 2.0, suggesting the absence of significant first-order autocorrelation in the VAR model's residuals. Firm-clustered standard errors were also consistently employed in panel regressions.

Table 2. Durbin-Watson Statistics for VAR (1) Model Residuals.

Variable	Durbin-Watson
HML_ESG	2.0327
MKT_RF	2.0122
SMB	1.9819
HML	2.0625
RMW	2.0070
CMA	2.0438
WML	2.0372

4.4. Test for Heteroskedasticity and Model Specification in Panel Regressions

Heteroskedasticity tests using the Breusch–Pagan (BP) test were conducted for panel regressions. For the primary Two-Way Fixed Effects model, the BP test (LM-statistic = 6.99, p-value = 0.430) did not reject homoskedasticity. **Table 3** summarizes key panel model specification tests, guiding the choice of the Two-Way Fixed Effects model as the primary approach due to its robustness in controlling for unobserved heterogeneity and common time shocks, despite the F-test for entity effects not being significant.

Table 3. Panel Model Specification Tests Summary.

Test	Statistic	P-value/Note	Conclusion
F-test (Entity FE vs Pooled OLS)	0.876	0.5713	Entity FE not significant
Hausman (Informal)	Comparison	FE:0.0000, RE:0.0000. Diff:0.0000	Choice less clear (F-test not sig.)
Breusch-Pagan (Entity FE resid)	LM:6.99	Pval:0.430	Homoskedasticity

5. Empirical Results

This section presents the main findings from the panel regressions and VAR analysis.

5.1. Panel Regressions of Global Electronics Firm Stock Returns on ESG Performance

Table 4 summarizes the key Two-Way Fixed Effects panel regression results for the 13 multinational electronics firms (N=1519 firm-month observations), controlling for the six Fama-French-Momentum factors. This table highlights the most salient ESG variables; comprehensive outputs for all tested ESG metrics and alternative model specifications are available and can be accessed via the supplementary material.

Table 4. Summary of Panel Regression Results: Excess Returns on Key Lagged ESG Scores (Two-Way Fixed Effects with FF6 Controls, N=1519).

ESG Variable	Coefficient	Std. Error	T-stat	P-value	Significant (5%)
Lagged_Total-Score	0.0006	0.0002	2.3222	0.0204	TRUE

Lagged6M_Total-Score	0.0006	0.0002	2.7619	0.0058	TRUE
Avg12M_Lagged_Total-Score	0.0008	0.0002	4.6279	0.0000	TRUE
Lagged_S-Score	0.0005	0.0002	2.1862	0.0290	TRUE
Lagged6M_S-Score	0.0006	0.0002	2.4464	0.0146	TRUE
Avg12M_Lagged_S-Score	0.0007	0.0002	3.1168	0.0019	TRUE

The analysis indicates a statistically significant positive association between longer-term, sustained ESG performance and stock excess returns. The 12-month average lagged total ESG score (Avg12M_Lagged_Total-Score) shows the most robust positive relationship. A similar significant positive impact is observed for the 12-month average lagged Social-score (Avg12M_Lagged_S-Score). Shorter-term lags and individual Environmental and Governance scores generally did not exhibit statistically significant associations in this primary model. A sub-period robustness check (Table 5) indicated some variations, particularly in the post-2020 period, where some S-score significances were borderline, potentially reflecting evolving market conditions or the impact of the smaller sample size in sub-periods.

Table 5. Sub-period Analysis Summary: Two-Way FE Regressions (ESG only models).

Period	ESG_Variable	Coefficient	P_Value	Significant_5pct	N_Obs	R_squared
First Half	Lagged_Total-Score	0.0000	0.8813	FALSE	793	1.01E-05
First Half	Lagged6M_Total-Score	0.0007	0.3497	FALSE	793	0.0010
First Half	Avg12M_Lagged_Total-Score	0.0006	0.4866	FALSE	793	0.0006
First Half	Lagged_S-Score	0.0004	0.3257	FALSE	793	0.0012
First Half	Lagged6M_S-Score	0.0006	0.3370	FALSE	793	0.0012
First Half	Avg12M_Lagged_S-Score	0.0008	0.2127	FALSE	793	0.0016
Second Half	Lagged_Total-Score	0.0007	0.3958	FALSE	726	0.0007
Second Half	Lagged6M_Total-Score	0.0002	0.4036	FALSE	726	0.0002
Second Half	Avg12M_Lagged_Total-Score	0.0011	0.1923	FALSE	726	0.0018
Second Half	Lagged_S-Score	0.0026	0.0524	FALSE	726	0.0016
Second Half	Lagged6M_S-Score	0.0005	0.4352	FALSE	726	0.0010
Second Half	Avg12M_Lagged_S-Score	0.0020	0.3647	FALSE	726	0.0037

5.2. VAR Analysis of HML_ESG Factor and Market Factors

A VAR (1) model was estimated. Key diagnostic plots for the VAR input data, including time series plots of the HML_ESG factor and key market factors, their density distributions, and a scatter plot matrix, are presented in Figures 1, 2, and 3, respectively, to visualize their characteristics and co-movements before formal testing.

Figure 1. Monthly returns of the constructed HML_ESG factor, MKT_RF, SMB, and HML factors over the sample period.
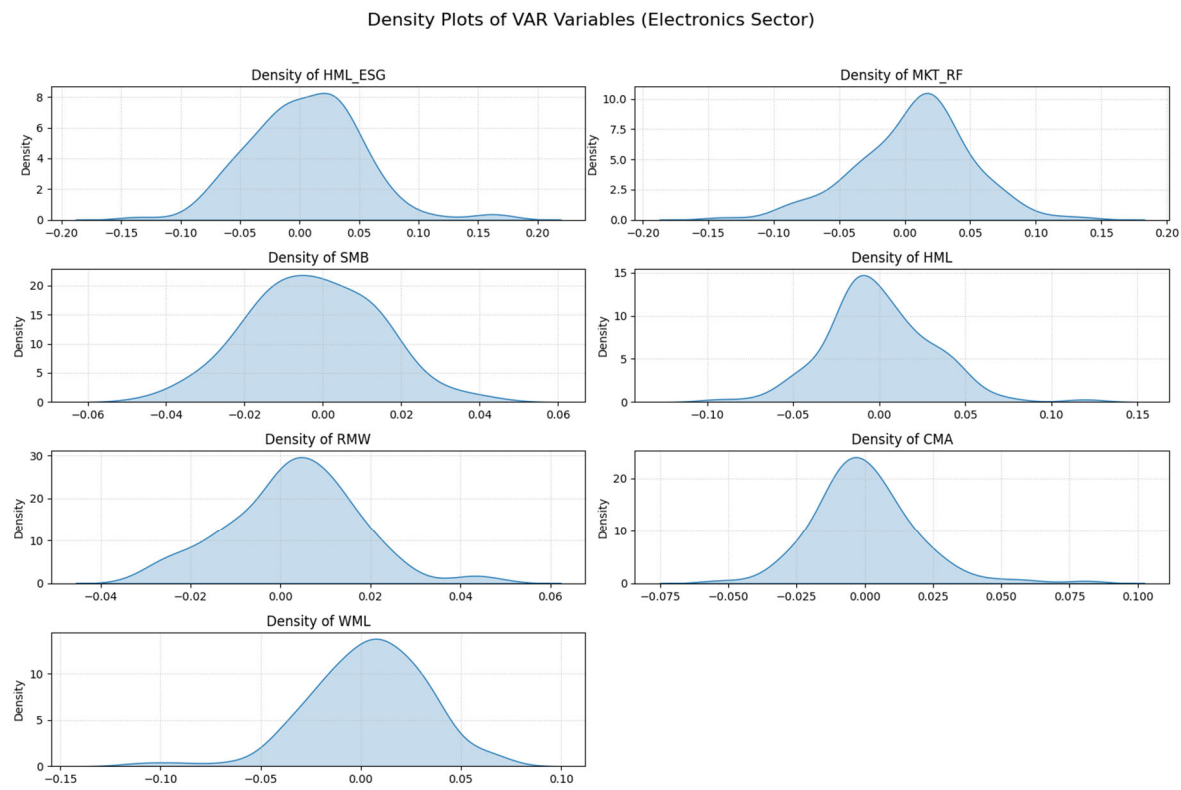

Figure 2. Kernel density estimates for the monthly returns of HML_ESG, MKT_RF, SMB, and HML factors.
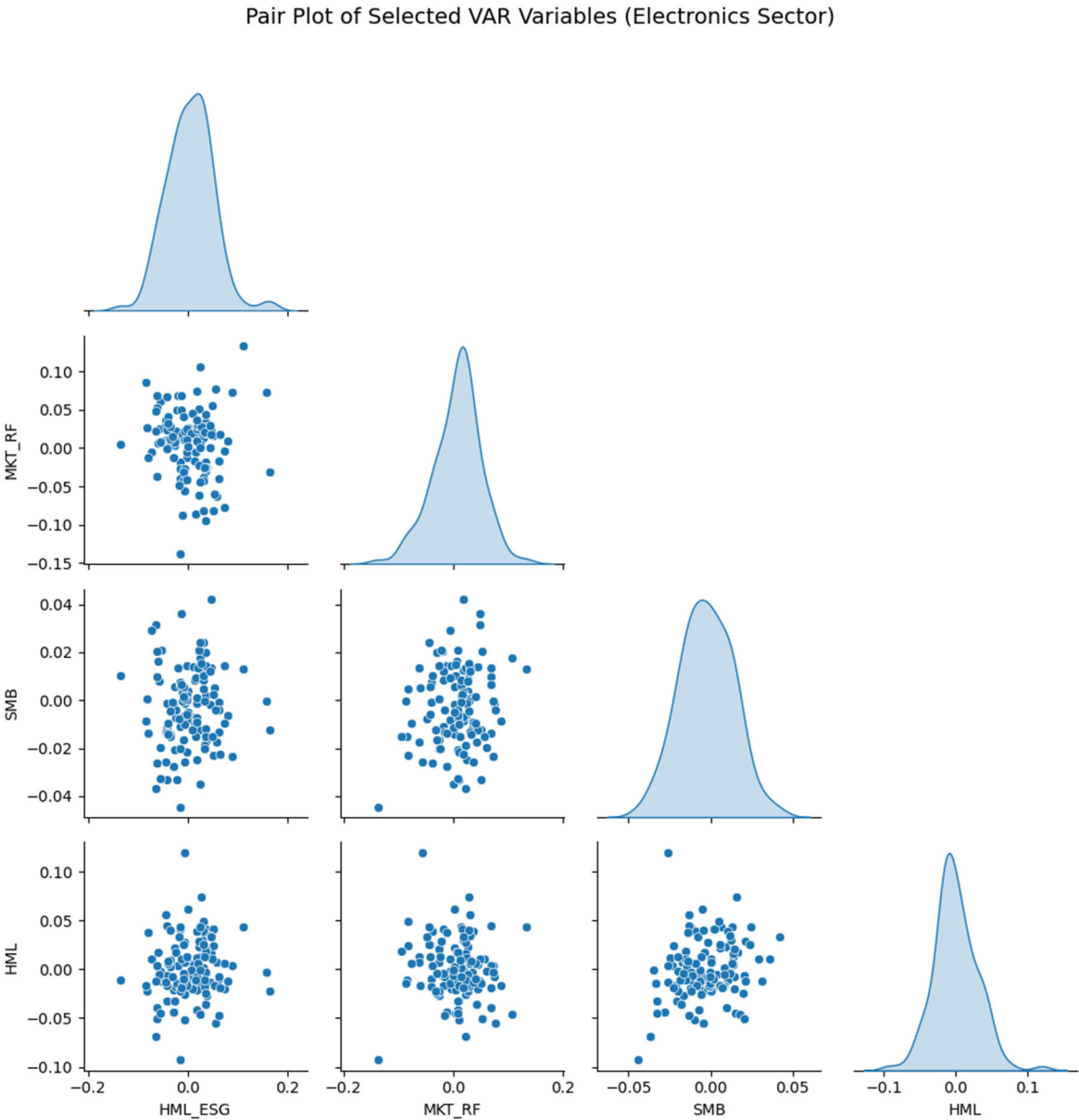
Figure 3. Scatter plot matrix showing pairwise relationships between HML_ESG, MKT_RF, SMB, and HML factors.

Granger causality tests (Table 6) showed no statistically significant causality from the block of FF6 factors to HML_ESG (p=0.723) or vice-versa for individual factors.

Table 6. Granger Causality Tests from VAR (1) Model.

Causality Direction	F-Stat	P-Value	Significant (5%)
MKT_RF, SMB, HML, RMW, CMA, WML -> HML_ESG	0.61	0.723	FALSE
HML_ESG -> MKT_RF	0.63	0.427	FALSE
HML_ESG -> SMB	0.99	0.321	FALSE
HML_ESG -> HML	0.6	0.438	FALSE
HML_ESG -> RMW	0.03	0.853	FALSE
HML_ESG -> CMA	0.12	0.73	FALSE
HML_ESG -> WML	1.22	0.27	FALSE

Impulse Response Functions (IRFs) are depicted in Figures 4, 5, and 6. Figure 4 shows the responses of the HML_ESG factor to one standard deviation shocks in each of the Fama-French-Momentum factors. Figure 5 illustrates the responses of the Fama-French-Momentum factors to a one standard deviation shock in the HML_ESG factor. Figure 6 presents selected cross-responses among the Fama-French-Momentum factors themselves. Collectively, these plots visually confirm generally weak and statistically insignificant dynamic linkages involving the HML_ESG factor over the 12-month forecast horizon.
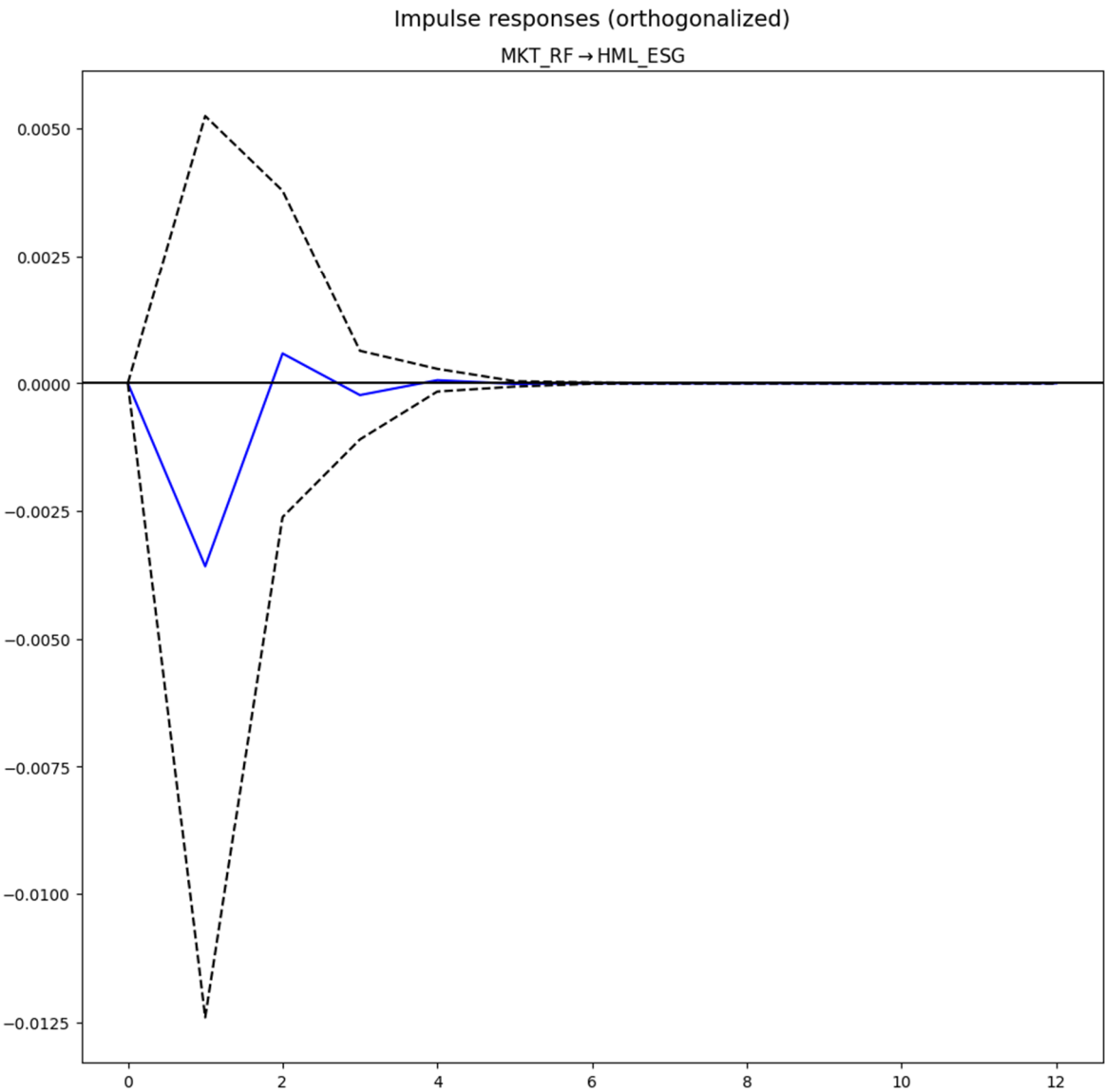

Figure 4. Impulse responses of the HML_ESG factor to one standard deviation shocks in the Fama-French-Momentum factors. Dotted lines represent 95% confidence intervals.
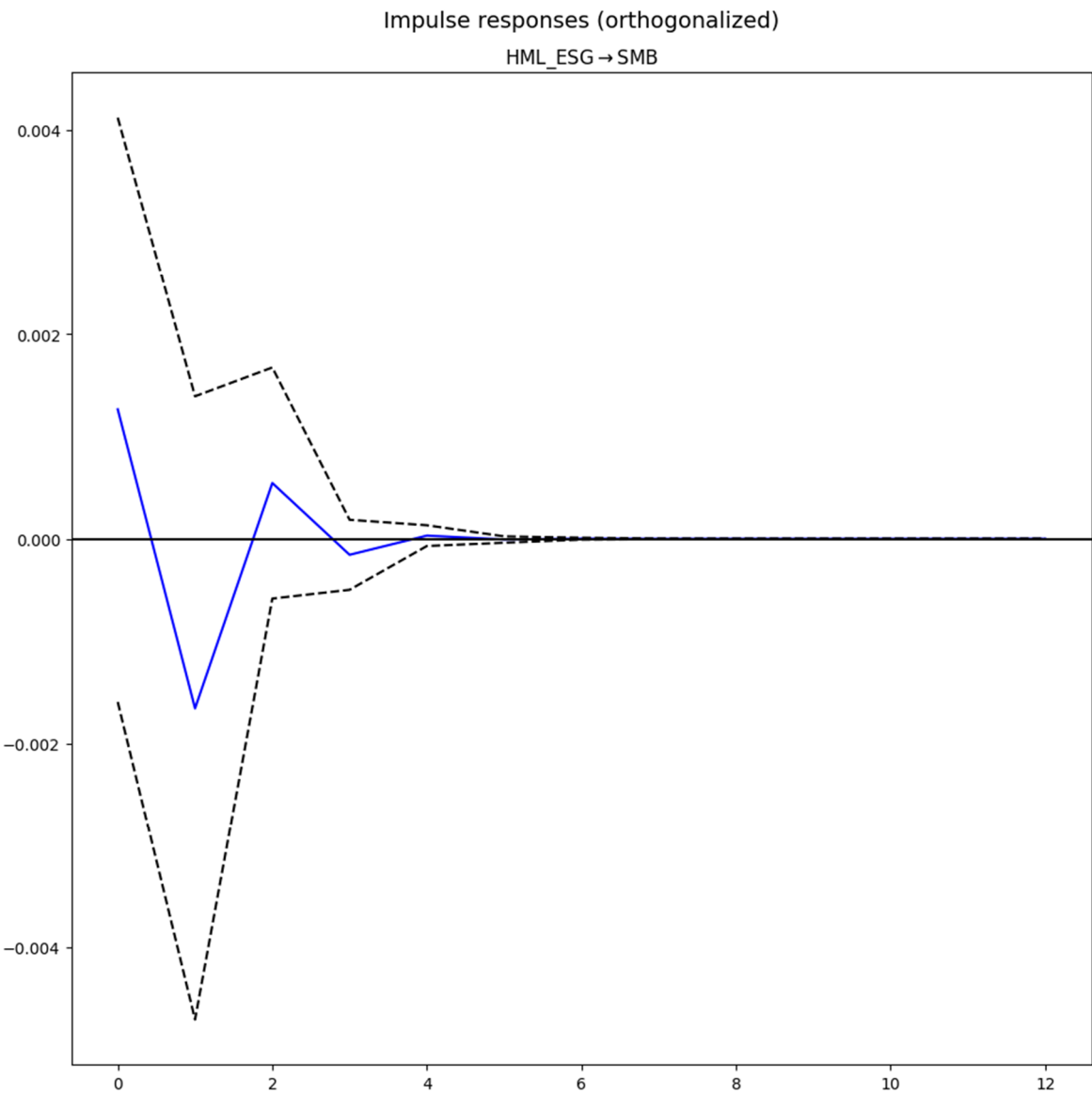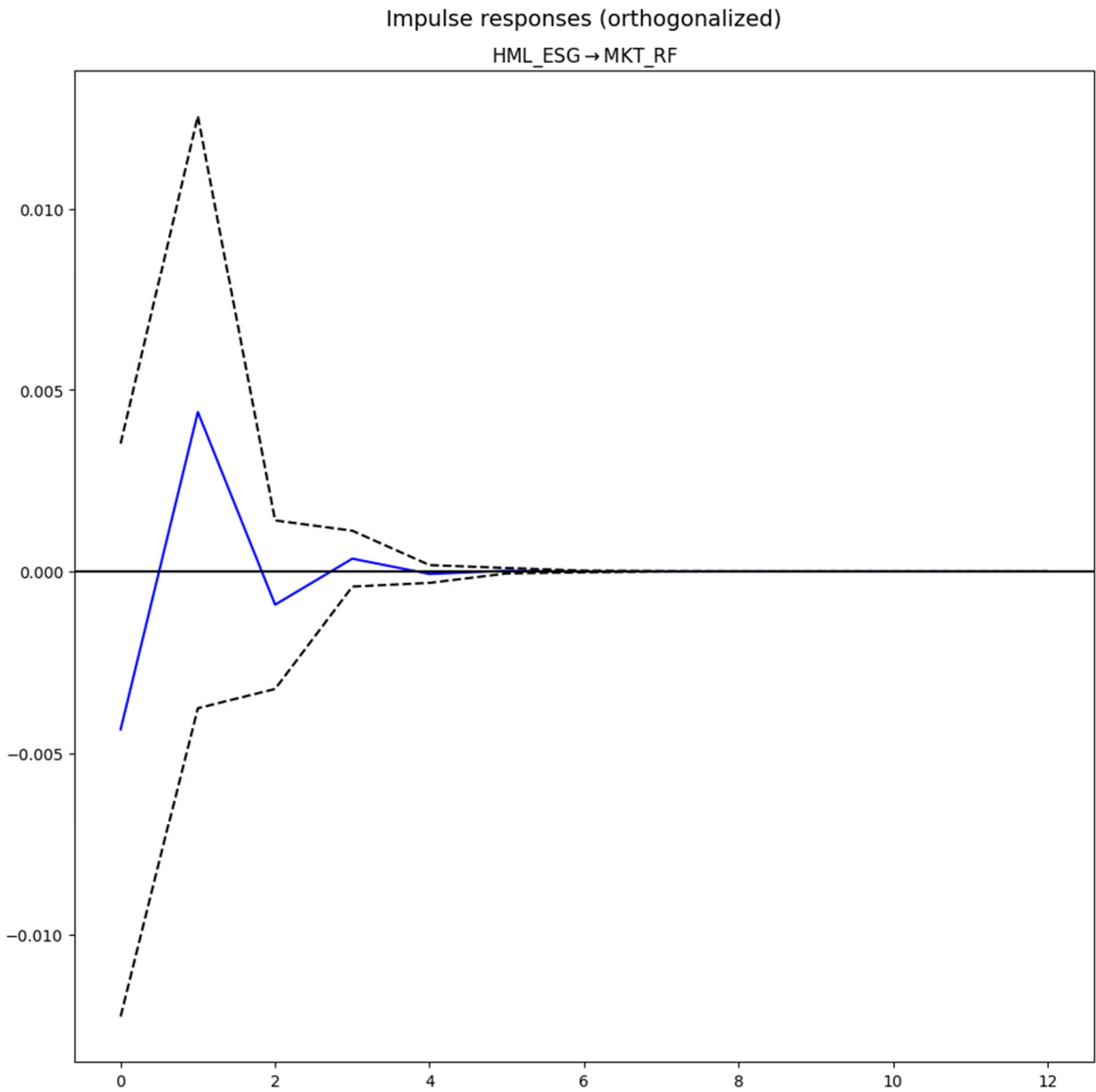
Figure 5. Impulse responses of Fama-French-Momentum factors to a one standard deviation shock in the HML_ESG factor. Dotted lines represent 95% confidence intervals.

The Forecast Error Variance Decomposition (FEVD) for HML_ESG is summarized in Table 7. The results show that HML_ESG's innovations explain approximately 96.7% of its forecast error variance after 12 periods. The FEVDs for the other factors in the system (available from the author upon request) further illustrate the limited explanatory power of HML_ESG for their variances.

Table 7. Forecast Error Variance Decomposition (FEVD) for HML_ESG (Selected Horizons).

Period	HML_ESG	MKT_RF	SMB	HML	RMW	CMA	WML
0	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.9684	0.0055	0.0023	0.0002	0.0031	0.0157	0.0049
2	0.9674	0.0056	0.0023	0.0002	0.0035	0.0157	0.0052
3	0.9673	0.0056	0.0023	0.0003	0.0035	0.0157	0.0052
4	0.9673	0.0056	0.0023	0.0003	0.0035	0.0157	0.0052
5	0.9673	0.0056	0.0023	0.0003	0.0035	0.0157	0.0052
6	0.9673	0.0056	0.0023	0.0003	0.0035	0.0157	0.0052

7	0.9673	0.0056	0.0023	0.0003	0.0035	0.0157	0.0052
8	0.9673	0.0056	0.0023	0.0003	0.0035	0.0157	0.0052
9	0.9673	0.0056	0.0023	0.0003	0.0035	0.0157	0.0052
10	0.9673	0.0056	0.0023	0.0003	0.0035	0.0157	0.0052
11	0.9673	0.0056	0.0023	0.0003	0.0035	0.0157	0.0052

Figure 6. Selected impulse responses among Fama-French-Momentum factors to one standard deviation shocks in other market factors. Dotted lines represent 95% confidence intervals.

The time-series OLS regression of HML_ESG on the contemporaneous FF6 factors (Table 8) yielded an insignificant monthly alpha of 0.0061 (p=0.141).

Table 8. OLS Regression of HML_ESG Factor on FF6 Factors (Alpha Test).

Variable	coef	std err	z	P>|z|	25th percentile	Upper 95% CI
const	0.0061	0.0040	1.4740	0.1410	-0.0020	0.0140
MKT_RF	-0.1657	0.0900	-1.8330	0.0670	-0.3430	0.0110

SMB	0.2929	0.2420	1.2100	0.2260	-0.1820	0.7670
HML	0.0747	0.2670	0.2800	0.7790	-0.4480	0.5980
RMW	0.6050	0.3200	1.8880	0.0590	-0.0230	1.2330
CMA	0.0963	0.3730	0.2580	0.7960	-0.6350	0.8280
WML	-0.2878	0.2040	-1.4100	0.1590	-0.6880	0.1120

Notes: N=121. R-squared=0.065. Durbin-Watson=1.881.

These VAR results collectively suggest that the HML_ESG factor, within this sample of global electronics firms, demonstrates considerable independence from traditional market risk factors.

6. Discussion and Implications

The empirical findings of this study, based on an analysis of 13 multinational electronics firms, offer quantitative insights into the financial dimensions of ESG performance within the context of increasing global sustainability regulations and rapid technological advancements. The discussion now interprets these results in light of existing theories and their broader implications.

Addressing RQ1, the panel regression analysis suggests that sustained, long-term ESG performance, particularly in aggregate (Total-Score) and specifically through the Social (S) pillar, is positively and significantly associated with stock excess returns for the sampled firms (Table 4). This indicates that financial markets may recognize and potentially reward consistent and comprehensive ESG commitments by these global electronics players, aligning with aspects of stakeholder theory where addressing broader societal concerns can lead to enhanced firm value [17,24,52,66] and observed impacts of sustainability on organizational performance [60]. The specific salience of the S-score could reflect the heightened global investor and regulatory attention to social issues within the complex international supply chains of the electronics industry, such as labor practices, human rights, and community engagement [1,13,15,19,23,43,54]. The finding that markets appear to value *sustained* ESG performance (e.g., 12-month averages) over shorter-term fluctuations reinforces the idea that markets value deeply embedded, strategic commitments to sustainability rather than transient or superficial activities [1,16,29].

Regarding RQ2, the VAR analysis shows limited dynamic interaction between the constructed HML_ESG factor and traditional Fama-French-Momentum market risk factors for this sample of global electronics firms (Table 6, Figures 4–6, Table 7). The general absence of significant Granger causality and the FEVD results, where HML_ESG variance is largely self-explained, suggest that ESG performance in this sector might embody distinct risk characteristics not fully captured by conventional global market models [5,7,59]. This aligns with the broader inquiry into ESG as a unique financial factor [7,16]. Although the HML_ESG factor did not generate statistically significant alpha in this study (Table 8), its apparent orthogonality to established market factors is an area warranting further investigation.

6.1. The Global Regulatory Context and Technological Enablers for ESG

The global electronics industry faces a diverse yet increasingly converging set of sustainability regulations. While the EU's comprehensive framework (WEEE, RoHS, ESPR, CE Action Plan, DPPs) [9,10,12,13,18,19,23,25–28,31–33,40,41,44–46,61] is influential, similar objectives are pursued in North America (e.g., US RCRA, state e-waste laws [20,46,62]), Asia (e.g., China RoHS, Japanese recycling laws, Indian E-Waste Rules [13,19,47–49]), and other regions through EPR schemes and waste management legislation [1,13,18,50,51,56]. This global trend, aiming for a more circular electronics economy [63], necessitates sophisticated strategies for compliance and sustainable innovation [1]. Emerging technologies like AI, Digital Twins, and blockchain are crucial enablers for meeting these global regulatory demands and enhancing ESG performance, facilitating everything from supply

chain traceability to eco-design and circularity [10,12,30,34–38,57]. The financial materiality of ESG may reflect the market's valuation of firms' abilities to leverage these technologies effectively within this complex global landscape [1,29,30,58,67].

6.2. A Conceptual Global Regulatory-ESG Financial Salience Model (RQ3)

The empirical findings, interpreted within this global context, inform a "Global Regulatory-ESG Financial Salience Model" (Figure 7). This model, conceptually aligned with frameworks for navigating global electronics regulations [1], illustrates the potential pathways through which regulatory pressures and technological capabilities can interact with ESG performance to influence financial market outcomes.
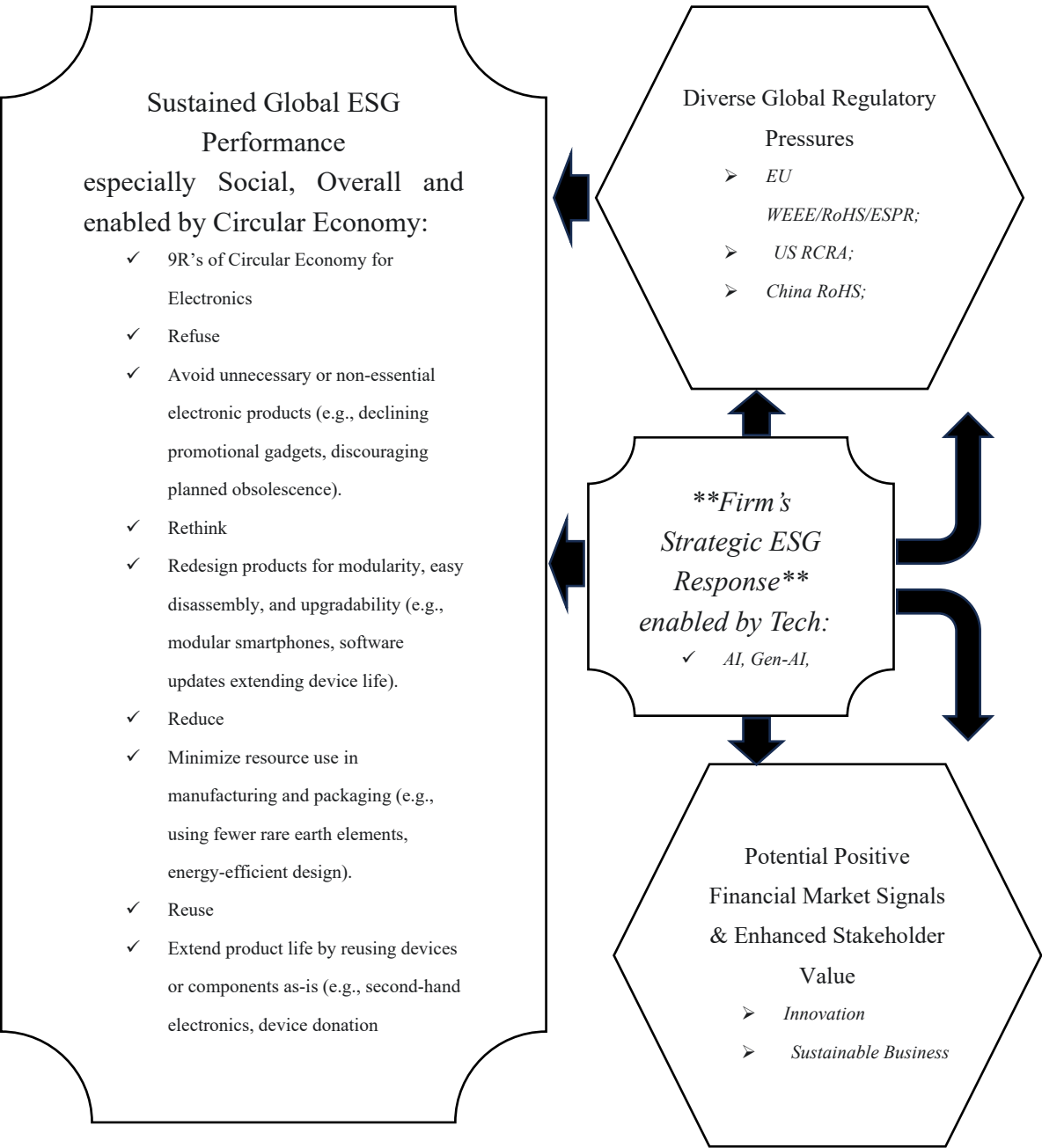
Figure 7. Conceptual Global Regulatory-ESG Financial Salience Model.

Figure 7, a conceptual model illustrating the interplay between global regulations, technological enablement, ESG performance, and potential financial market signals in the electronics industry. This

model posits that (1) converging global regulatory pressures drive firms towards enhanced ESG management, (2) strategic adoption of technology is key to managing global ESG compliance and performance, (3) financial markets may recognize and reward sustained, material ESG efforts, and (4) ESG performance in this sector may represent a financially distinct factor. Proactive and technologically adept navigation of global sustainability regulations, as suggested by [1], can be financially salient.

6.3. Implications for Stakeholders

The study implies that multinational electronics firms should prioritize strategic, long-term ESG integration, leveraging technology to address diverse global regulatory demands, particularly in socially material areas [1,68,69]. For investors, the findings suggest potential value in considering sustained ESG metrics and the distinct risk profile of ESG in this sector. Policymakers globally can infer that well-designed regulations may be increasingly reflected in market valuations, potentially validating aspects of the Porter Hypothesis where regulation drives innovation [16,20,54,59].

6.4. Limitations and Future Research

The primary limitation of this study is the sample size (N=13 firms), which, although representing major global players, restricts the statistical power and generalizability of the quantitative findings beyond this specific group and timeframe. ESG data sourced primarily via yesg [2], reflects publicly available information and may differ from proprietary ESG datasets [3,4]. The construction of the HML_ESG factor is also specific to this study's sample and methodology. While Two-Way Fixed Effects models [6,7] were employed, unobserved variables or more complex endogeneity issues could still affect the ESG-finance relationship. The analysis provides a financial market perspective and does not directly measure the specific adoption levels of emerging technologies or the direct causal impact of individual regulatory enactments on operational innovation processes [1].

Future research should aim to expand the quantitative analysis to a larger and more geographically diverse sample of global electronics firms. Comparative studies examining the ESG-finance link under different national or regional regulatory regimes would be highly valuable. Investigating the moderating role of specific technological adoptions on the ESG-financial performance relationship is another promising avenue. Furthermore, event studies focusing on the market reaction to significant global or regional regulatory announcements on electronics sustainability could provide more direct evidence of regulatory impact. Finally, exploring alternative constructions of ESG factors and testing their robustness across different asset pricing models would contribute to the ongoing debate about ESG's role as a distinct financial factor in the global electronics industry.

7. Summary and Conclusions

This quantitative study examined the financial materiality and market dynamics of ESG performance for 13 multinational electronics firms operating globally, from 2015 to 2025. Panel regression analyses, controlling for Fama-French-Momentum factors, indicated that sustained, long-term total ESG scores and Social (S) pillar scores are positively and significantly associated with stock excess returns for this sample. A Vector Autoregression analysis of a constructed ESG factor suggested its limited dynamic linkage with traditional market risk factors, hinting at distinct ESG risk/return characteristics in this sector.

These findings, contextualized by global sustainability regulations and technological enablers, inform a "Global Regulatory-ESG Financial Salience Model." This model [1] suggests that firms effectively navigating global regulations and strategically investing in sustained, technologically-enabled ESG performance may achieve favorable financial market recognition. While the empirical evidence is based on a specific sample, it offers insights into the growing financial relevance of ESG

for global electronics companies, highlighting the importance of proactive sustainability strategies in an increasingly regulated and technologically evolving world. The study's limitations, particularly sample size, underscore the need for future research with broader global datasets to further validate these observations.

8. Patents

There are no patents resulting from the work reported in this manuscript.

Abbreviations

ADF	Augmented Dickey-Fuller
AI	Artificial Intelligence
BIC	Bayesian Information Criterion
BP	Breusch-Pagan
CE	Circular Economy
CMA	Conservative Minus Aggressive (Fama-French Factor)
DPP	Digital Product Passport
DW	Durbin-Watson
ESG	Environmental, Social, and Governance
ESPR	Ecodesign for Sustainable Products Regulation
EU	European Union
FE	Fixed Effects
FEVD	Forecast Error Variance Decomposition
FF6	Fama-French Six-Factor Model (including Momentum)
G-Score	Governance Score
HML	High Minus Low (Fama-French Factor)
HML_ESG	High Minus Low ESG Factor
IRF	Impulse Response Function

MKT_RF	Market Risk Premium (Fama-French Factor)
MSCI	Morgan Stanley Capital International
NRBV	Natural Resource-Based View
OLS	Ordinary Least Squares
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RMW	Robust Minus Weak (Fama-French Factor)
RoHS	Restriction of Hazardous Substances
RQ	Research Question
S-Score	Social Score
SMB	Small Minus Big (Fama-French Factor)
TSCA	Toxic Substances Control Act (US)
VAR	Vector Autoregression
WEEE	Waste Electrical and Electronic Equipment
WML	Winners Minus Losers (Momentum Factor)
XR	Extended Reality

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