EG Estudios Gerenciales
Journal of Management and Economics for Iberoamerica

Research article

Technological Capital and Corporate Social Responsibility: Optimal Strategies for Sustainable Financial Performance

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Abstract
This study aims to assess the joint effect of technological capital and Corporate Social Responsibility on corporate financial performance. A dynamic model using data from 434 Standard & Poor firms (2009–2017) confirms an inverted U-shaped relationship: moderate technological investment generates benefits, while excessive investment leads to diseconomies. Corporate social responsibility mitigates these risks and amplifies the financial and social value of innovation. It is recommended that firms, particularly in regulated sectors, strategically manage technological capital in alignment with sustainable practices to optimize outcomes and minimize reputational risks. This study contributes to literature by extending absorptive capacity theory, introducing corporate social responsibility as a moderator of the technological capital-performance relationship.
Keywords: technological capital; corporate social responsibility; innovation; sustainable financial performance; sustainability.

Capital tecnológico y responsabilidad social corporativa: estrategias óptimas para un rendimiento financiero sostenible

Resumen
El presente estudio tiene como objetivo evaluar el efecto conjunto del capital tecnológico y la Responsabilidad Social Corporativa en el desempeño financiero corporativo. Un modelo dinámico que utiliza datos de 434 firmas de Standard & Poor (2009–2017) confirma una relación en forma de U invertida: la inversión tecnológica moderada genera beneficios, mientras que la inversión excesiva conduce a deseconomías. La responsabilidad social corporativa mitiga estos riesgos y amplifica el valor financiero y social de la innovación. Se recomienda que las empresas, particularmente en sectores regulados, gestionen estratégicamente el capital tecnológico en alineación con prácticas sostenibles para optimizar los resultados y minimizar los riesgos de reputación. Este estudio contribuye a la literatura al extender la teoría de la capacidad de absorción, introduciendo la responsabilidad social corporativa como moderadora de la relación entre capital tecnológico y rendimiento.

Palabras clave: capital tecnológico; responsabilidad social corporativa; innovación; desempeño financiero sostenible; sostenibilidad.

Capital tecnológico e responsabilidade social corporativa: estratégias ótimas para um desempenho financeiro sustentável

Resumo
O presente estudo tem como objetivo avaliar o efeito conjunto do capital tecnológico e da Responsabilidade Social Corporativa no desempenho financeiro corporativo. Um modelo dinâmico, que utiliza dados de 434 empresas da Standard & Poor´s (2009–2017), confirma uma relação em forma de U invertida: o investimento tecnológico moderado gera benefícios, enquanto o investimento excessivo conduz a deseconomias. A responsabilidade social corporativa mitiga esses riscos e amplia o valor financeiro e social da inovação. Recomenda-se que as empresas, particularmente em setores regulados, gerenciem estrategicamente o capital tecnológico em alinhamento com práticas sustentáveis para otimizar os resultados e minimizar os riscos de reputação. Este estudo contribui para a literatura ao estender a teoria da capacidade de absorção, introduzindo a responsabilidade social corporativa como moderadora da relação entre capital tecnológico e desempenho.
Palavras-chave: capital tecnológico; responsabilidade social corporativa; inovação; desempenho financeiro sustentável; sustentabilidade.

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JEL classification: M14; O33; G32.

How to cite: Lescano-Silva, C. (2025). Technological Capital and Corporate Social Responsibility: Optimal Strategies for Sustainable Financial Performance. *Estudios Gerenciales, 41*(175), 169-181. https://doi.org/10.18046/j.estger.2025.175.7321

DOI: https://doi.org/10.18046/j.estger.2025.175.7321

Received: 03-03-2025
Accepted: 21-08-2025
Available online: 21-10-2025

Universidad icesi

1. Introduction

In a business environment characterized by constant innovation and increasing regulatory pressure, organizations must balance investment in technological capital (Ki_{it}) with strategies for implementing corporate social responsibility (CSR_{it}). While advanced technologies can improve productivity and strengthen competitive advantage, excessive investment may lead to diseconomies of scale and rising costs (Ramadani et al., 2017; Ramadani et al., 2019). This challenge is particularly relevant for firms seeking to harmonize financial growth with social and environmental commitments.

Previous studies have examined the relationship between investment in Research and Development (R&D) and business performance under a linear approach. For example, Anwar & Muis (2024) found that higher Ki_{it} generally improve performance metrics, while Chetia & Behera (2024) confirmed similar trends in emerging market contexts. However, recent research suggests that the relationship between technological capital and firm performance is not linear but follows an inverted U-shaped pattern.

Zhou& Wu (2010) first identified that excessive Ki_{it} accumulation could trigger organizational inefficiencies. More recently, Yang, Shi, Bhutto & Ertz (2024) emphasized the role of knowledge saturation in this decline, while Zhu et al. (2023) highlighted the financial burden of integrating advanced technologies beyond the optimal threshold.

Despite the growing body of research on innovation and CSR_{it}, few studies have explored their joint impact on firm performance using a nonlinear and dynamic perspective. This gap is critical both theoretically and practically. Theoretically, it restricts the evolution of absorptive capacity theory by neglecting the moderating role of CSR_{it} in technology-performance links. Practically, it limits managerial insight into how strategic alignment between Ki_{it} and sustainability efforts can prevent overinvestment inefficiencies and enhance long-term financial outcomes.

In a business environment where technological innovation has become a key driver of competitiveness, organizations face increasing pressures not only in terms of financial performance but also regarding stakeholder expectations for responsible practices. The need to manage innovation sustainably is critical, yet few studies have explored how CSR_{it} can moderate the effects of technological investment. This gap in literature limits managers' ability to make informed decisions about balancing technology investment and sustainability.

Our study is relevant because, by addressing the nonlinear relationship between Ki_{it} and CSR_{it}, it provides an integrated approach that can transform how companies manage their investments and maximize both financial benefits and social and environmental impacts. By offering an innovative theoretical model, we extend absorptive capacity theory, demonstrating how CSR_{it} can act as a strategic moderator that optimizes the outcomes of technological investments.

Methodological limitations in previous studies include the use of static approaches that fail to capture how the effects of technological investment evolve over time (Qi & Deng, 2019). This study employs dynamic Generalized Method of Moments (GMM) regression models, which correct for endogeneity and allow the assessment of how Ki_{it} affects return on assets (ROA). Although the relationship between Ki_{it} and performance has been widely explored, the moderating role of CSR_{it} has received less attention. Yang et al. (2024) demonstrated that CSR_{it} initiatives can buffer the negative effects of overinvestment, while Zhu et al. (2023) provided evidence that sustainability-driven strategies can shift the optimal Ki_{it} threshold. This study provides empirical evidence on the role of CSR_{it} in shifting the optimal Ki threshold and smoothing the fall in ROA. Much previous research, such as Xiao et al. (2024) and Chen et al. (2023) have focused on specific industries or developed economies. This study expands the scope by analyzing data from 434 S&P firms across multiple sectors, with implications for both developed and emerging markets.

This gap is of substantial theoretical and managerial relevance, as contemporary firms operate in an environment characterized by accelerated technological change; heightened environmental, social, and governance (ESG) demands; and intensified global competition. Failing to achieve an effective alignment between technological capital accumulation and sustainability imperatives exposes firms to the phenomenon of technological overinvestment, which may result in diminishing marginal financial returns and increased exposure to stakeholder scrutiny.

Therefore, this study makes a double theoretical and empirical contribution: i) It confirms the inverted U-shaped relationship between Ki_{it} and performance, using a robust econometric approach; ii) It demonstrates how CSR_{it} moderates this relationship, reducing the negative effects of excess Ki_{it} and optimizing its positive impact.

In this context, CSR_{it} has emerged as a strategic factor that counteracts the adverse consequences of high investment in Ki_{it} (Yang et al., 2024). However, the literature has not yet delved into the specific mechanisms by which CSR_{it} interacts with (R&D) investment or the distinction between its strategic and reactive impact. This gap is particularly relevant in regulated or technology-intensive industries, where the interaction between innovation and sustainability is critical (Chen et al., 2023).

This study addresses the theoretical gap through a model that explains how CSR_{it} moderates the inverted U-shaped relationship between Ki_{it} and business performance. The empirical findings allow us to identify the optimal threshold of investment in Ki_{it}, beyond which profits begin to decline. Likewise, the role of CSR_{it} in mitigating these effects is analyzed, facilitating firms' adaptation to high levels of Ki_{it}.

Based on data from 434 S&P firms between 2009 and 2017, this study raises two main hypotheses: (1) the relationship between Ki_{it}and business performance follows an inverted U-shaped trajectory; and (2) CSR_{it} moderates this relationship, reducing the negative effects of overinvestment in technology and maximizing its benefits. Using a dynamic Generalized Method of Moments (GMM) regression model, results prove the importance of integrating technological innovation with sustainability to optimize business performance. From a theoretical and practical perspective, this study contributes to business management by identifying strategies to maximize investment in Ki_{it} without compromising stakeholder engagement. In addition, it proposes a conceptual framework applicable to various contexts, from emerging economies to highly regulated sectors, opening new lines of research on the interrelationship among sustainability, technology, and business impact.

This study addresses a critical gap in literature by integrating the moderating role of Corporate Social Responsibility (CSR) into the non-linear relationship between technological capital and financial performance within a dynamic framework, thus providing a novel empirical perspective on sustainable technology investment.

The following sections present a literature review, a description of the methodology used, an analysis of results, and a discussion of theoretical and managerial implications.

2. Theoretical background and research hypotheses

This study is based on three fundamental pillars: organizational learning theory, stakeholder theory, and the concept of absorptive capacity. These perspectives underpin the non-linear relationship between technology capital (Ki_{it}), corporate social responsibility (CSR_{it}), and business performance, providing a comprehensive approach to optimize technology investment and integrate it with sustainable strategies.

2.1 Innovation and technological capital

The success of innovation depends on the development and integration of internal and external knowledge (Chen, Vanhaverbeke & Du, 2016). This accumulation process generates technological capital (Ki_{it}) (Hall & Hayashi, 1989), defined as the ability of a firm to use various technologies (Usai et al., 2021), foster learning, and generate innovation (Luan, Chen, He & Park, 2024). Ki_{it} boosts absorption capacity, stimulates creativity, and accelerates the development of new products (Cohen & Levinthal, 1990; Jamai et al., 2021). It is considered a measure of accumulated technological knowledge and its current applicability, thus playing a key role in product and service innovation (Akter et al., 2023).

2.2 Nonlinear relationship between technological capital and business performance

Previous research shows that the relationship between Ki_{it} and business performance follows an inverted U-curve: while moderate levels of investment drive innovation and efficiency, excessive levels generate diseconomies of scale (Izotova & Bolívar-Ramos, 2024; Ugur, Trushin & Solomon, 2016). In the early stages, technological capital improves competitiveness by facilitating access to new technologies and knowledge (Chetia & Behera, 2024). In addition, the combination of managerial skills and flexible organizational structures strengthen performance (Luan et al., 2024). As Ki_{it} increases, the generation of new knowledge and specialization intensifies and optimizes the absorption capacity (Luan et al., 2024). This ability allows for the assimilation of advanced technologies, reduces integration costs (Zahra & George, 2002) and improves organizational flexibility. It also reinforces CSR_{it}, facilitating the adoption of sustainable practices (George et al., 2021). However, overinvestment in R&D can negatively affect business performance (Barrett et al., 2024). Ki_{it} growth out of control increases organizational complexity and reduces returns to shareholders. In addition, absorptive capacity faces difficulties when learning costs outweigh the benefits, hindering the efficient integration of new capabilities (Mota Veiga et al., 2023).

Although investment in R&D improves operational efficiency and innovation (Usai et al., 2021), its positive impact decreases when the firm must unlearn previous knowledge to assimilate new one (Mota Veiga et al., 2023). The costs associated with learning and reassessing knowledge can reduce exploratory activities (Anwar & Muis, 2024). This challenge is particularly evident in industries such as pharmaceuticals, where exploiting existing resources generates greater benefits than exploring new technologies (Rothaermel, 2001).

In summary, investments in R&D must be balanced to avoid rising costs and decreasing returns (Chetia & Behera, 2024). As Ki_{it} exceeds a certain threshold, it becomes difficult to convert knowledge into business opportunities, thus affecting absorption capacity (Dzenopoljac et al., 2025). Factors such as the availability of specialized talent and the company's previous trajectory condition this process. Therefore, investment in R&D does not guarantee linear returns (Chetia & Behera, 2024; Yeh, Chu, Sher & Chiu, 2010). Moreover, the costs of generating new knowledge may increase and reduce the effectiveness of Ki_{it} per unit of investment (Chetia & Behera, 2024). Figure 1 presents the expected effects of investments in technological capital on the company's financial results.

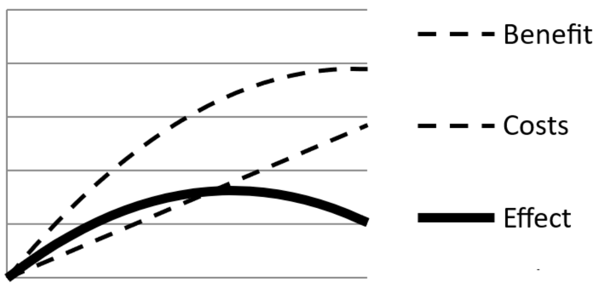

Figure 1. Expected effect of technology capital investments on performance.
Source: own elaboration.

Therefore, we propose the following hypothesis:

H1: Investment in technology capital has a non-linear, inverted U-shaped effect on the firm's returns.

2.3 Moderating Role of Corporate Social Responsibility (CSR_{it})

Previous research has shown that the impact of technological capital on business performance varies according to the degree of adoption of CSR_{it} practices (Gallardo- Vásquez et al., 2019). Recent studies suggest that CSR_{it} moderates this relationship by attenuating the negative effects of excessive technological investment (Yang et al., 2024). Although it is generally considered a positive factor in business strategy, its impact is not uniform and depends on its integration with the firm's technology strategy (Chen et al., 2023).

CSR_{it} moderates the inverted U-shaped relationship between technological capital and business performance in two ways: i) By shifting the inflection point towards higher levels of technological capital. CSR_{it} enables companies to sustain higher levels of investment in technology, before experiencing diminishing returns, by improving market acceptance and reducing regulatory costs associated with disruptive innovations (Sun, Yao & Govind, 2019). In highly regulated industries, such as energy and manufacturing, implementing sustainability criteria allows technology investments to exceed traditional thresholds without generating resistance from stakeholders (Li et al., 2023). ii) Attenuating the negative slope of the inverted U-shaped relationship. When technological capital has already passed the tipping point, CSR_{it} mitigates its negative impact on financial performance by facilitating cooperation with stakeholders, thus reducing the costs associated with adapting to new regulations, and improving corporate reputation (George et al., 2021). Companies with well-established sustainability strategies experience lower volatility in their returns, as they can take advantage of government incentives and green financing programs to offset the costs associated with the overaccumulation of technological knowledge (Chen et al., 2023).

Based on these mechanisms, we propose the following hypothesis:

H2: CSR moderates the inverted U-shaped relationship between technological capital and business performance, thus enabling (1) to sustain higher levels of investment in technology before experiencing diminishing returns, and (2) to mitigate the negative effects of excess technological investment on financial performance.

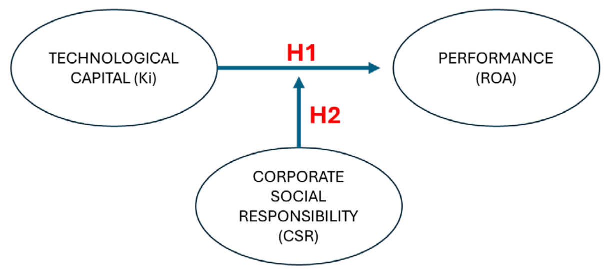

Figure 2. Conceptual model of the relationship between technological capital and firm returns.
Source: own elaboration.

3. Method

3.1 Sample and Data

To test our hypotheses, we analyzed a sample of firms from the S&P500 index, distributed across 11 industrial sectors. These firms operate in highly competitive markets, where sustaining their competitive advantage requires optimizing existing capabilities and developing new competencies. The sample was constructed from data from the CSRHub and Bloomberg databases from 2009 to 2017. Sixty-six observations with missing data in R&D or assets were eliminated to ensure longitudinal consistency. The resulting dataset constitutes an unbalanced panel, as the number of firm-year observations varies across firms due to the absence of data in some periods on key variables such as R&D investment or total assets. CSRHub provides a globally recognized measure of non-financial corporate performance, combining more than 850 data sources to assess environmental, social, and governance (ESG) practices. Its composite index includes four key dimensions: community impact, employee relations, environmental responsibility, and corporate governance, thus making it one of the most robust tools for CSR_{it} analysis in academic and management research (CSRHub LLC).

3.2 Dependent Variable: Business Performance (ROA_{it})

Business performance is a multidimensional concept evaluated through several indicators including production, finance, or marketing (Katsikeas et al., 2016). Following Wolff & Pett (2006), we use return on assets (ROA_{it}) as a key metric because it reflects both profitability and operational efficiency. ROA_{it} is relevant to shareholders when measuring the efficiency in using assets to generate profits and forecast future returns (Mizik & Jacobson, 2003). In addition, it has been widely used in studies on the relationship between CSR_{it} and business strategy (Barnett & Salomon, 2012).

It is calculated as:

$$ROA\_\{it\} = EBITDA\_\{it\} / TOTAL\ ASSETS\_\{it\}$$

EBITDA - Earnings Before Interest,Taxes,Depreciation and Amortization

3.3 Independent variable: Technological Capital (Ki_{it})

Technological capital was measured with the permanent inventory method. The stock of Ki_{it} is calculated from R&D, discounting a depreciation rate of 15% (Griliches, 1979). This measure has been widely used in literature to reflect the accumulation of technological knowledge within firms (Goel, 1990). Its advantage lies in its ability to capture the evolution of the knowledge stock over time, providing a more stable estimate and less sensitive to annual fluctuations in R&D spending. The standard formula is:

$$Ki\_\{it\} = (1-d)\ Ki\_\{i,t-1\} + R\_\{i,t-1\}$$

Where:

Ki_{i,t-1} is the technological capital stock of firm i in the previous year,

R_{i,t-1} represents R&D investments in the previous year and d the amortization rate.

The initial reserve of Ki is estimated as: *K*

$$K_i(i;0)=R(i,0)^{d-1}$$

The initial reserve of Ki_{it} is estimated to be R_{i,1}$^{d-1}$ (e.g., Goel, 1990). The extended model would be:

$$K_i(i;0)=R(i,0)^{d-1}$$

3.4 Moderating variable: Corporate Social Responsibility (CSR_{it})

The CSRHub database assesses CSR_{it} through four main dimensions, combined in a monthly ranking by company, it has been widely used in studies since 2013; for instance, Arminen et al. (2018). Each dimension is subdivided into three subcategories, with a total of twelve indicators. The community dimension considers human rights, supply chain, product quality and safety, product sustainability, community development, philanthropy. The employees' dimension includes diversity, labor rights, treatment of unions, compensation, benefits, training, health, worker safety. Environment includes environmental policy, environmental reporting, waste management, resource management, energy use, climate change policies and performance. While corporate governance considers leadership ethics, board composition, executive compensation, transparency and reporting, and stakeholder treatment. To obtain the annual ranking, we calculate the average of the monthly values, excluding firms with less than 12 months of data to ensure temporal consistency and representativeness.

Since CSR_{it} is an endogenous variable, we incorporate its lagging value (CSR_{t–1}), following the theory of learning (Evans & Honkapohja, 2001), which allows us to capture its evolution and dynamic impact on business performance.

3.5 Interaction between technological capital and CSR_{it}

We define the interaction between technological capital and CSR_{it} as the product of their lagging values:

$$Ki\_\{i,t-1\} \times CSR\_\{i,t-1\}$$

$$Ki^2\_\{i,t-1\} \times CSR\_\{i,t-1\}$$

A moderator adjusts the direction or intensity of the relationship between an independent variable and a dependent variable (Baron & Kenny, 1986; Holmbeck, 1997). In an inverted U-shaped relationship, moderation can influence the tipping point or slope, making it steeper or attenuated (Haans, Pieters & He, 2016). In this context, CSR_{it} can shift the threshold to higher levels of Ki_{i,t} or mitigate its negative impact on business performance.

3.6 Control variables

To ensure the robustness of the analysis, we include control variables that can influence the relationship between Ki_{it}, CSR_{it}, and business performance. Firm size: Measured as the logarithm of the number of employees, given its impact on the accumulation of technological capital (Menne, Winata, & Hossain, 2016) and its role in enhancing innovation capacity (Asimakopoulos, Revilla & Slavova, 2020). Lagging ROA: We consider past financial performance because it can affect the allocation of resources to innovation and CSR (Waddock & Graves, 1997). Sectoral and temporal effects: We include dummy variables for sectors and years, controlling industrial differences and macroeconomic fluctuations. All data was obtained from the Bloomberg database. Table 1 presents a summary of the variables of the model, their definition, and operationalization. Table 2 presents the notation and description of the variables.

Table 1. Variables and measurement

Variable	Definition	Operationalization
ROA	Return on Assets	ROA=Operating profit/Total assets
Technological Capital (Ki)	Accumulated knowledge	Permanent inventory function with 15% obsolescence rate
CSR	Corporate Social Responsibility	Monthly Annually Averaged Global Ranking (CSRHub)
Firm	Logarithm of the number of employees	Log(Number of Employees)
Year	Annual dummy variable	Values 0 o 1
Sector (A)	Sectoral dummy variable	Values 0 o 1

Source: own elaboration.

Table 2. Notation of the variables

Variable	*Notation*	*Description*
Technological capital	*Ki_{it}*	*Technological capital of firm i in year t*
Lagged technological capital	*Ki_{i,t−1}*	*Lagged value of technology capital*
Corporate Social Responsibility (CSR)	*CSR_{it}*	*Level of CSR measured by CSRHub*
Lagged CSR	*CSR_{i,t−1}*	*Lagged value of CSR*
Interaction (technology × CSR)	*Ki_{i,t−1} × CSR_{i,t−1}*	*Moderating effect of CSR*
Quadratic Interaction	*Ki²_{i,t−1} × CSR_{i,t−1}*	*Quadratic effect moderated by CSR*
Dependent variable	*ROA_{it}*	*Return on assets of firm i in year t*
Firm size	*Log_Employ_{it}*	*Logaritm employee of firm i in year t*
Standar error	*ε_{it}*	*Random error term*

Source: own

4. Statistical method

To test our hypotheses, we used a dynamic and stochastic model, given the endogenous nature of the model and the independent variables. We applied a gradual hierarchical regression to assess the explanatory power of each set of variables (Aiken & West, 1991). The estimated models (M1 – M4) are the following:

Hypothesis 1:

ROA_{it}= Step 1: β0 + β1 Log_Employ_{it} + β2 ROA_{i,t-1} + β3 CSR_{it} + β4 A2_{it} + β5A3_{it} + β6A4_{it} + β7A5_{it} + β8A6_{it} + β9A7_{it} + β10A8_{it} + β11A9_{it} + β12S2_{it} + β13S3_{it} + β14S4_{it} + β15S5_{it} + β16S6_{it} + β17S7_{it} + β18S8_{it} + β19S9_{it} + β20S10_{it} +β21S11_{it}
(M1)

Step 2:+ β22 Ki_{i,t-1} *(M2)*

Step 3:+ β23 Ki²_{i,t−1} + ε_{it}

Hypothesis 2:

ROA_{it}= Step 1: β0 + β1 Log_Employ_{it} + β2 ROA_{i,t-1} + β3 CSR_{it} + β4 A2_{it} + β5A3_{it} + β6A4_{it} + β7A5_{it} + β8A6_{it} + β9A7_{it} + β10A8_{it} + β11A9_{it} + β12S2_{it} + β13S3_{it} + β14S4_{it} + β15S5_{it} + β16S6_{it} + β17S7_{it} + β18S8_{it} + β19S9_{it} + β20S10_{it} +β21S11_{it}+ β22 Ki_{i,t-1} + β23 Ki²_{i,t−1} + β24 Ki_{i,t−1} × CSR_{i,t−1} + β25 Ki²_{i,t−1} × CSR_{i,t−1} + ε_{it}
(M4)

5. Results

The coefficients β21 to β25 are the slopes of the parameters of the main variables, and β0 is the constant of the equation.

Control variables are Log_Employ_{it}, ROA_{i,t-1}, A2it, A3it, A4it, A5it , A6it, A7it, A8it, A9it, S2it, S3it, S4it, S5it, S6it, S7it, S8it, S9it, S10it, S11it, which correspond to size of the company, lagging value of ROA_{it}, and fictitious variables of year and sector, respectively.

To correct possible endogeneity problems, we used Generalized Method of Moments (GMM) estimators (Wooldridge, 2015). They were implemented using the xtabond2 command in STATA (StataCorp, 2017), following the dynamic panel methodology proposed by Arellano & Bond (1991) extended by Arellano & Bover (1995) and later refined by Blundell & Bond (1998). Specifically, we applied the two-step system GMM estimator with Windmeijer's finite- sample correction for standard errors, which increases efficiency and corrects downward bias in the standard errors typical of two-step estimation.

The GMM model offers key advantages: i) Endogeneity correction without external instruments, using lagging variables as internal instruments (Wooldridge, 2015); ii) Control of unobserved endogeneity, eliminating biases in the estimation when it is constant over time and correlated with the explanatory variables (Roodman, 2015); iii) Incorporation of the dynamic structure of the model, allowing current performance to depend on previous values, this improves the accuracy of analysis (Wooldridge, 2015).

Additional tests were performed to verify the validity of the model: i) Hansen's overidentification test (see Table 4), which confirms the suitability of the instruments, complying with the optimal range recommended by Roodman (2015). ii) Arellano-Bond autocorrelation test (AR1 and AR2) (see Table 4), which rules autocorrelation in first-order residuals, ensuring the validity of the GMM method by following the dynamic panel methodology proposed by Arellano & Bond (1995) and later refined by Blundell & Bond (1998); iii) Following the methodology of Blundell & Bond (1998), we use lagging values from investment in R&D as internal instruments.

From an econometric perspective, the proposed models meet robustness and validity criteria (Wooldridge, 2015). This methodological approach ensures a rigorous analysis of the impact of technological capital and CSR_{it} on business performance, minimizing biases and specification errors.

Descriptive statistics and the correlation matrix of independent and control variables are presented in Table 3. Results of model 3 (see Table 4) confirm the existence of an inverted U-shaped relationship between technological capital (Ki_{it}) and business performance (ROA_{it}), in line with previous studies. Yang et al. (2024) found similar results, as did Zhou and Wu (2010). In turn, Zhu et al. (2023) highlighted the same pattern in a different context. At low and moderate levels, investment in technology drives operational efficiency and innovation, improving financial performance. However, when a certain threshold is exceeded, benefits begin to decline, suggesting increasing costs of organizational complexity and difficulties in integrating new technologies (Qi & Deng, 2019). Empirical analysis confirms that CSR_{it} moderates this relationship in a dual way (see model 4): i) It shifts the tipping point toward higher levels of Ki_{it}, allowing firms to sustain greater investments in technology before experiencing diminishing returns. ii) It attenuates the negative slope of the inverted U, mitigates the adverse effects of technological overinvestment and favor financial stability (George et al., 2021).

To assess the robustness of these findings, we performed a sensitivity analysis considering the firm's previous performance and size. Effect of previous performance: CSR_{it} is more effective as a moderator in companies with high previous performance. In underperforming firms, CSR_{it} fails to fully counteract the negative effects of over- investment in technology, suggesting that its effectiveness depends on the firm's financial ability to absorb additional costs (Hull & Rothenberg, 2008); ii) Effect of firm size: The inverted U-ratio is maintained in large and medium-sized firms, but in small firms, the negative impact of overinvestment in technology is more severe. This indicates that large firms may better distribute the costs associated with innovation, while small firms face greater financial and operational constraints (Cohen & Levinthal, 1990). In other words, CSR_{it} is more effective in high-performance and large companies because they have more resources to manage technological overinvestment. In contrast, in small firms or firms with poor previous performance, CSR_{it} alone is not enough to mitigate the negative effects of technological overaccumulation (Kramer & Porter, 2011). This aligns with Hull & Rothenberg (2008), who stress the synergy between Corporate Social Responsibility (CSR) and innovation for long-term performance, and with Cohen & Levinthal (1990), who underscore the importance of absorptive capacity in optimizing knowledge integration. The inverted U-ratio and the moderating effect of CSR_{it} are most pronounced in the following industries: i) Technology, companies such as Microsoft and Apple have reached optimal levels of technological investment, where CSR_{it} has been key to the uptake of disruptive innovations. ii) Manufacturing, CSR_{it} extends the inflection point, allowing companies such as Tesla and General Electric to maintain high levels of investment in technology without facing steep declines in profitability. iii) Energy, CSR_{it} is fundamental to accept clean and sustainable technologies. Firms such as Exxon Mobil have increased their investment in technology without affecting their profitability thanks to sustainability-oriented CSR_{it} strategies (Kramer & Porter, 2011). These results show that CSR_{it} has a more relevant role in industries where social and regulatory acceptance is key.

While CSR_{it} mitigates the negative effects of overinvestment in technology, its impact is limited. The moderating effect of CSR_{it} is significant to some extent, after which it becomes marginally decreasing. Firms that overinvest in CSR_{it} without aligning it with their technology strategy experience a reduction in their positive impact. In highly regulated sectors, the benefit of CSR_{it} as a moderator is greater, while in less regulated sectors, its effect is weaker. These findings coincide with Xiao et al. (2024), who argue that investment in CSR_{it} and technology can be interdependent, but must be strategically aligned to maximize their impact.

Model 3 (M3) confirms the inverted U-ratio between Ki_{it} and ROA ($\beta = 0.002466$, $p = 0.000$ for Ki_{it}; $\beta = -0.0000000562$, $p = 0.000$ for Ki^2_{it}), with a turning point at 2,283.83, with 97.11% of observations located below this threshold. CSR_{it} shifts this threshold and smooths the negative curve, thus mitigating the effects of overinvestment in technology. These results remain robust in sensitivity analyses by company size and previous performance.

Figure 3 illustrates this relationship, showing that financial performance improves initially with an increase in technological capital, but decreases once an optimal threshold is exceeded. This finding reinforces the idea that, although investment in technology is key to competitiveness, its impact on financial performance is not unlimited and depends on factors such as efficiency in innovation management and the ability to integrate technology within the organization.

Table 3. Descriptive and Correlation.

	ROA_{it}	ROA_{i,t-1}	Ki_{i,t−1}	Ki²_{i,t−1}	CSR_{i,t−1}	Ki_{i,t−1} × CSR_{i,t−1}	Ki²_{i,t−1} × CSR_{i,t−1}	Log_Employ_{it}
ROA_{it}	1.0000							
ROA_{i,t-1}	0.7418	1.0000						
Ki_{i,t−1}	0.0077	0.0002	1.0000					
Ki²_{i,t−1}	0.0005	-0.0052	0.8115	1.0000				
CSR_{i,t−1}	0.0929	0.1111	0.0075	-0.0062	1.0000			
Ki_{i,t−1} × CSR_{i,t−1}	0.0071	0.0012	0.9943	0.7806	0.0499	1.0000		
Ki²_{i,t−1} × CSR_{i,t−1}	-0.0005	-0.0059	0.8238	0.9991	-0.0026	0.7961	1.0000	
Log_Employ_{it}	0.1034	0.1351	-0.0399	-0.0170	0.3278	-0.0300	-0.0174	1.0000
OBS	3,697	3,263	2,324	2,324	3,263	2,324	2,324	3,541
MEDIA	6.26	6.29	33.17	12,598.07	52.41	1,752	65,618.80	9.77
STD DESV	6.74	6.80	107.25	271,808.10	6.60	5,568.51	1.36E+07	1.50
MINIMUM	-61.82	-61.82	0.00	0.00	0.00	0.00	27.56	4.37
MAXIMUM	42.28	42.28	3,600.48	1.36E+07	77.33	175,455.40	6.32E+08	14.65

Source: own elaboration.

Table 4. Results with ROA as a dependent variable

	Model 1 ROA	**Model 2 ROA**	**Model 3 ROA**	**Model 4 ROA**
Control Variable				
Log_Employ_{it}	0.1609 (0.206)	0.0488 (0.635)	0.0136 (0.862)	0.0174 (0.827)
ROA_{i,t-1}	0.5238 (0.000)	0.5255 (0.000)	0.5006 (0.000)	0.4999 (0.000)
CSR_{i,t-1}	-0.1373 (0.008)	-0.0626 (0.068)	-0.0584 (0.002)	-0.0601 (0.001)
Direct Effects				
Ki_{i,t−1}		0.0005 (0.042)	0.0024 (0.000)	-0.0185 (0.000)
Ki²_{i,t−1}			-5.62e-7 (0.000)	2.78e-5 (0.000)
Interaction Effects				
Ki_{i,t−1} × CSR_{i,t−1}				4.57e-4 (0.000)
Ki²_{i,t−1} × CSR_{i,t−1}				-5.9e-7 (0.000)
CONST	7.1712 (0.000)	4.3506 (0.002)	4.5769 (0.000)	4.0481 (0.000)
Hansen Test				
Chi2/p > Chi2	53.11/.020	78.38/.183	122.53/.081	117.23/.115
AR(1) z(p)	-7.30 (.000)	-5.26 (.000)	-5.20 (.000)	-5.20 (.000)
AR(2) z(p)	-0.05 (.961)	0.26 (.795)	0.16 (.873)	0.16 (.869)
No. Obs.	3,175	2,258	2,258	2,258
No. Firms	434	382	382	382
No. Instruments	55	90	125	125
Wald Chi2	1185.75 (0.000)	1754.85 (0.000)	19202.10 (0.000)	28795.57 (0.000)

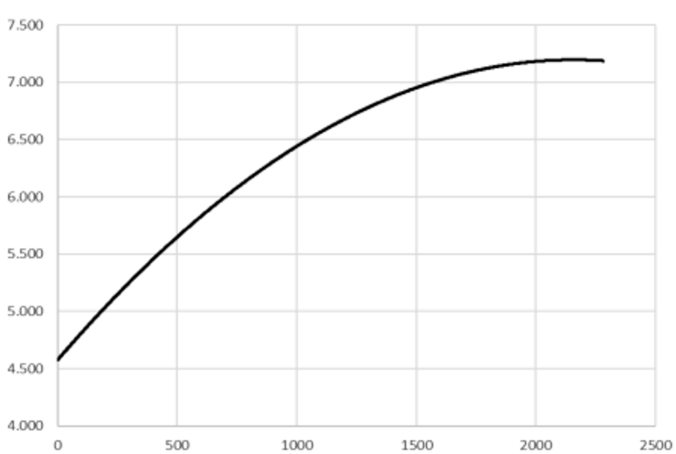

Figure 3. Inverted U-shaped ratio of technology capital and company results.
Source: own elaboration.

To delve deeper into the inverted U-shaped relationship between Ki_{it} and ROA_{it}, we divided the sample according to the tipping point and estimated the slopes separately for both subsamples, following the methodology of Haans, Pieters & He (2016). Results, available upon request, confirm that: i) To the left of the inflection point, the relationship between Ki_{it} and ROA_{it} is positive and significant, indicating that the increase in technological capital improves financial performance at low and moderate levels; ii) To the right of the inflection point, the relationship is negative and significant, which shows that, beyond a certain threshold, higher levels of technological capital generate decreasing returns.

These findings support Hypothesis 1 (H1) and validate the existence of an inverted U-shaped relationship between technological capital and financial performance.

Model 4 (M4) confirms the moderation of CSR_{it} in the relationship between Ki_{it} and ROA_{it}. The estimated coefficients show: i) First-order interaction: ß = 0.000457, p = 0.000 (positive and significant), indicating that CSR_{it} amplifies the positive effects of technological capital on financial performance. ii) Second-order interaction: ß = - 0.00000059, p = 0.000 (negative and significant), suggesting that CSR_{it} moderates the inverted U-shaped relationship, initially strengthening the positive effects and attenuating the subsequent fall in yields.

To better understand these effects, we decompose interactive terms into different levels of CSR_{it}, following the methodology of Aiken & West (1991). Results show that: i) In sectors with high CSR_{it} adoption, the inverted U-ratio is smoothed, implying that CSR_{it} strengthens the positive effects of Ki_{it} and reduces the negative impact of overinvestment in technology. ii) To evaluate this smoothing effect, we verify whether the coefficient of the interaction between Ki²_{i,t−1} and CSR_{it} is positive and significant. Results also validate Hypothesis 2 (H2) and demonstrate that CSR_{it} attenuates the negative slope of the inverted U-shaped relationship.

The critical value of the CSR_{it}, where the change of shape occurs, is determined by the relationship between the coefficient of the square term of Ki²_{i,t−1} and the coefficient of the interaction between CSR_{it} and Ki²_{i,t−1}. Calculations indicate that the change in shape occurs when the CSR_{it} reaches a value of 47.12.

Figure 4 illustrates the relationship between Ki_{it} (±2 standard deviations) and ROA_{it}, and distinguishes between high and low levels of CSR_{it} (±2 standard deviations). Results confirm that the change in shape is within the range of observed data of the CSR_{it} (mean +2 standard deviations), reinforcing the empirical validity of the moderation of the CSR_{it} in the relationship between Ki_{it} and ROA_{it}.

Understanding this dynamic is strategically critical because it not only informs financial optimization but also strengthens corporate legitimacy, regulatory compliance, and societal value creation. By framing technology investment within a CSR_{it}-oriented strategy, firms can transform potential risks into sustainable competitive advantages.

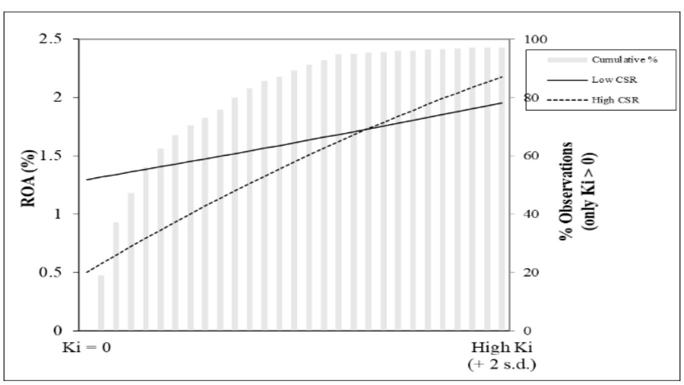

Figure 4. Relationship between technological capital and company results for high and low levels of CSR (± 2 standard deviations).
Source: own elaboration.

6. Discussion and conclusions

6.1 Theoretical implications

This study is based on organizational learning theory, stakeholder theory, and the absorptive capacity approach to model the nonlinear relationship between Ki_{it} and ROA_{it}. In line with these theoretical frameworks, we find evidence of an inverted U-shaped relationship, supporting previous studies as Izotova & Bolívar-Ramos (2024) and Qi & Deng (2019) that warn about the costs associated with integrating and managing an excess of knowledge.

From an applied perspective, this study contributes to research on the effects of innovation on business performance. While previous studies as Suklev & Rexhepi (2013) have addressed innovation in terms of competitive advantage and learning processes, our analysis introduces a new perspective: when managed strategically, technological capital not only improves operational efficiency but also strengthens the competitive position of firms. In addition, this study reinforces the idea that CSR_{it} moderates the inverted U-shaped relationship between Ki_{it} and ROA_{it}, aligning with studies that highlight its differentiated influence according to sector and strategy (Sun, Yao & Govind, 2019). However, we also identified limitations in the applicability of the model, such as the need to consider the capacity for technological absorption and the importance of integrating CSR_{it} into sustainable innovation strategies.

Our contingency model suggests that companies with lower investment in technology may perform better when they adopt sustainable practices, compared to those that make technology-intensive investments, due to the costs of integrating and absorbing new technologies. Although previous studies as Abazi-Alili, Ramadani, & Gërguri-Rashiti (2014) and Donate & Sánchez de Pablo (2015) have highlighted that high levels of Ki_{it} benefit innovation and productivity, our results indicate that these benefits are limited and that the costs associated with overinvestment can be significant (Ramadani et al., 2017; Ramadani et al., 2019). However, a strong CSR_{it} strategy can mitigate these costs, smoothing out the inverted U-ratio and allowing companies to maximize the positive impact of technology capital on their financial performance.

This study highlights the strategic role of CSR_{it} as a catalyst in the relationship between Ki_{it} and ROA_{it}. Companies that integrate sustainability into their technology management not only reduce the risks associated with knowledge over accumulation but also optimize the positive impact of their technology investments on financial performance. Findings presented in this study offer practical guidance for business leaders, helping them design balanced, sustainable and competitive strategies in a dynamic and constantly changing environment.

6.2 Managerial implications

Our findings provide key strategic orientations for managers looking to optimize the interaction between Ki_ {it} and CSR_{it} to maximize business performance. The main implications are highlighted below:

1. Managing the Ki_{it} tipping point. This study confirms that Ki_{it} drives ROA_{it} to an optimal level, after which the associated costs outweigh the benefits (Izotova & Bolívar-Ramos, 2024). To avoid diseconomies of scale, managers must identify and monitor this inflection point using advanced analytical tools that allow them to evaluate the return on technology investments in a dynamic and data-driven way.

2. CSR_{it} as a mitigator and amplifier of Ki_{it}. Findings indicate that CSR_{it} not only mitigates the negative effects of high Ki_{it} but also enhances its positive impact. This suggests that companies with well-structured sustainability strategies are better positioned to maximize the benefits of their technology investments (Li et al., 2023). In this sense, managers should develop sustainability policies aligned with their technological innovation goals, thus reinforcing their competitive advantage and meeting stakeholder expectations (George et al., 2021).

3. Sectorality in the integration of technological and sustainable strategies. The integration of technological and sustainable strategies varies across sectors. In industries sensitive to social and environmental factors, such as energy and manufacturing, the combination of clean technologies with sustainable practices generates competitive advantages. In the financial sector, artificial intelligence and blockchain improve efficiency, however, overinvestment without a sustainable strategy can increase risks and costs (Miller et al., 2023). CSR_{it} mitigates these effects by strengthening consumer confidence and reducing regulatory risks (George et al., 2021). In health and biotechnology, innovation in medical treatments entails high R&D costs and integration problems (Xiao et al., 2024), so CSR_{it}, with sustainability policies and equitable access, helps maintain profitability (Sun, Yao & Govind, 2019). In the automotive industry, the rise of electric and autonomous vehicles requires optimizing technological investment, as their excess without a sustainable approach generates inefficiencies and high recycling costs (Yang et al., 2024). Circular economy and reduction of the carbon footprint can counteract these effects (Zhu, Zou & Zhang., 2019). In telecommunications and digital media, digital transformation has increased reliance on technological infrastructure, posing sustainability and energy efficiency challenges (Zhou & Wu, 2010). Firms that adopt renewable energy in data centers can maximize their technology investment and reduce their environmental impact (Zhu et al., 2023). This study not only has implications for regulated sectors, but also for industries where rapid innovation can lead to diseconomies of scale if not managed with a sustainable approach. Managers in these sectors must prioritize investments in responsible innovation, ensuring compliance with environmental regulations, and responding to specific market needs.

4. Strengthening organizational absorptive capacity. The effective implementation of technological and sustainable strategies depends on the organization's ability to adapt and learn. This study highlights the importance of strengthening organizational absorptive capacity through a) Continuous training to improve the integration of technological and sustainable knowledge (Cohen & Levinthal, 1990); b) Development of an organizational culture that values innovation and sustainability as strategic pillars (Levinthal & March 1993).

5. Balance between exploration and technological integration. Efficient exploitation of existing resources must complement the search for new technologies. This balance enables firms not only to innovate but also to maximize the return on their existing investments (Oke et al., 2022). Managers must design dual strategies combining: the exploration of new technological opportunities and optimizing the technological capabilities already acquired. This approach ensures a continuous flow of innovation without compromising operational stability or generating excessive costs.

6. Strategies to minimize the organizational costs of technological capital. While technological capital drives innovation and absorptive capacity, over-reliance can lead to fixed organizational costs, such as operational disruptions due to the adoption of new technologies (Burgelman, 1991). Resistance to change in the redefinition of established routines and procedures (Benjamin, 1961). Challenges in the implementation of new solutions that can affect organizational efficiency (Mota Veiga et al. 2023). Our results do not contradict the long-term benefits of technological capital but suggest that these may come with structural costs. Therefore, it is crucial to balance the introduction of new knowledge with existing organizational practices (Zahra & George, 2002), ensuring an efficient and sustainable technological transition (Leiponen & Helfat, 2010).

6.3 Limitations and future research

This study makes a significant contribution to understanding the relationship between technological capital, corporate social responsibility (CSR_{it}), and business performance. However, like all research, it has certain limitations that open opportunities for future academic explorations.

1. Technological capital (Ki_{it}) is operationalized through a proxy based on investments in R&D, a methodology widely used in the literature (Usai et al., 2021). However, this proxy does not fully capture the complexity of the concept, such as the ability to absorb knowledge within the company, innovations not registered in patents or without large formal investments in R&D, so it may affect the interpretation of results and their applicability to other contexts. Future research could explore alternative measures, such as the use of digital technologies and impact of innovation training within the company to more fully capture the evolution of technological capital in organizations.

2. The analysis is based on S&P 500 firms; findings reflect the reality of firms with high resources to innovate and corporate social responsibility. This limits its generalization

to small and medium businesses (SMEs) and emerging economies, where the dynamics of investment and sustainability are different. Future research could expand the analysis to other markets and sectors, exploring possible cultural, regulatory, and economic variations (Li et al., 2023). Likewise, it could examine SMEs and startups, whose access to technological capital and corporate social responsibility strategies may differ substantially from large corporations (Sun, Yao & Govind, 2019). This would make it possible to assess whether the inverted U-shaped relationship holds up in different business environments and how firms in less developed contexts manage their investment in technology.

3. While dynamic GMM models were used to mitigate endogeneity, this approach does not guarantee definitive causal inferences, due to the nature of the study (Wooldridge, 2016) based on secondary data and longitudinal analysis. To strengthen causal validity, future research could complement this approach with experimental or quasi-experimental studies that allow analyzing the underlying mechanisms of the observed relationships, and include qualitative analyses (interviews, cases, case studies) to better understand how companies manage the relationship between technological capital and corporate social responsibility. These approaches would enable a better understanding of the organizational dynamics that affect the relationship between technology, sustainability, and financial performance.

4. This study focuses on corporate social responsibility as a moderator, but other contextual and internal factors can influence the relationship between technological capital and business performance. Future studies could incorporate variables such as: Organizational culture and leadership, which can facilitate or restrict the absorption of technological knowledge; social norms and practices at the sectoral, national and international levels, which affect the implementation of technological and sustainable strategies; government policies and innovation ecosystems, which can incentivize or limit investment in technology capital and sustainability. Analyzing these factors would help identify the conditions under which companies can optimize their investment in technology and sustainability to improve their financial performance.

5. We measure business performance through return on assets (ROA_{it}), a financial metric that does not capture non-financial dimensions, such as social or environmental impact. To gain a more comprehensive view, future research could explore how technology capital and corporate social responsibility influence customer satisfaction and brand loyalty, corporate reputation and stakeholder perception, environmental impact, and carbon footprint.

7. Conclusion

This study builds on the theory of absorptive capacity (Cohen & Levinthal, 1990) by introducing corporate social responsibility as a strategic moderator in the non-linear relationship between technological capital and financial performance. By incorporating corporate social responsibility into the absorptive capacity framework, this study contributes to the literature by showing how corporate social responsibility acts as a moderating factor that not only enhances a firm's ability to assimilate, transform, and exploit technological knowledge but also mitigates the negative consequences of excessive Research and Development (R&D) investment. Corporate social responsibility is conceptualized as a catalytic mechanism that enhances a firm's ability to assimilate, transform, and exploit technological knowledge, while simultaneously mitigating the negative consequences of excessive Research and Development (R&D) investment. Empirical findings demonstrate that firms integrating sustainability into their innovation strategies not only mitigate risks associated with organizational complexity and learning costs but also optimize the financial returns of their technological capabilities. This contribution reinforces the contingent nature of absorptive capacity, showing that its effectiveness is shaped by the strategic alignment between technological investment and socially responsible practices.

Empirical analysis, based on a sample of 3,697 observations corresponding to 434 S&P firms between 2009 and 2017, supports these conclusions and provides robust evidence on how corporate social responsibility moderates this relationship and contributes to long-term business sustainability and competitiveness.

From a theoretical standpoint, this research offers a dynamic perspective by explicitly incorporating Corporate Social Responsibility (CSR) as a strategic moderator of the inverted U-shaped relationship between technological capital and financial performance, thereby advancing the understanding of sustainable technology investment.

Conflict of interest

The authors declare no conflict of interest.

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