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IIMBG Journal of Sustainable Business and Innovation

Unlocking the nexus: intellectual capital and environmental innovations among manufacturing firms in Uganda

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Received 20 June 2024
Revised 10 August 2024
Accepted 23 September 2024

Abstract

Purpose – This study aims to investigate the intricate relationship between intellectual capital and environmental innovations among manufacturing medium and large firms in Uganda, utilizing the SmartPLS methodology.

Design/methodology/approach – This research adopts a cross-sectional and quantitative approach, collecting data through a questionnaire survey from a sample of manufacturing medium and large (ML) firms in Uganda. The collected data underwent analysis to identify patterns and relationships using the SmartPLS structural equation modeling (SEM) technique.

Findings – The findings highlight a distinct pattern: structural capital is the strongest predictor of environmental innovations, with human capital being the next most significant factor. However, the positive relationship with relational capital did not attain statistical significance, suggesting the need for further exploration into inter-firm relationships.

Practical implications – For managers, investing in robust organizational structures and human capital development programs can enhance firms' capacity to drive eco-friendly initiatives, aligning with global sustainability agendas. Policymakers are encouraged to create an enabling environment that nurtures IC and incentivizes environmental innovation through supportive policies such as tax incentives and funding mechanisms for green technologies.

Originality/value – This study enriches the intellectual discourse on IC and environmental innovation by employing SmartPLS methodology to highlight the nuanced impact of its components, emphasizing the multifaceted nature of IC and its role in driving EI.

Keywords Intellectual capital, Human capital, Relational capital, Structural capital, Product innovation, Process innovation

Paper type Research paper

1. Introduction

In the contemporary landscape, heightened awareness surrounding environmental concerns has prompted a notable shift in both academic and practical spheres, with manufacturing firms

Conflict of interest statement: The authors declare that they have no competing interests. Additionally, they did not receive any funding from any source to finance this research project.

IIMBG Journal of Sustainable Business and Innovation
Emerald Publishing Limited
2753-4022
DOI 10.1108/IJSBI-06-2024-0028

increasingly prioritizing green practices to mitigate environmental damage and gain a competitive advantage (Yasmeen, Wang, Zameer, & Ismail, 2019; Zameer, Wang, & Yasmeen, 2020; Beltramino, Garcia-Perez-de-Lema, & Valdez-Juarez, 2022; Shahbaz, Ahmad, & Malik, 2024). Within this context, the concept of intellectual capital (IC) has gained prominence, denoting intangible resources crucial for enhancing a firm's value and environmental performance (Masoulas, 1998; Stewart, 1994). Specifically, IC encompasses human, organizational, and social capital, including the skills, innovative capacity, organizational assets, and relationships that contribute to a company's worth (Johnson, 1999; Bontis, 1999; Edvinsson & Malone, 1997). Moreover, the significance of IC extends beyond financial capital, particularly in today's information and knowledge-driven economy (Martín-de Castro, Díez-Vial, & Delgado-Verde, 2019; Soewarno & Tjahjadi, 2020).

Nevertheless, notwithstanding the growing recognition of IC's importance, limited attention has been directed toward its role in driving environmental innovation adoption (EIA) within the manufacturing sector, especially in developing economies like Uganda. While previous studies such as Ali *et al.* (2021) have shed light on the influence of IC in specific contexts, such as Pakistan, there remains a dearth of research specifically investigating its impact on EIA within Uganda's medium and large manufacturing firms. Consequently, this study endeavors to address this gap in the literature, aiming to provide empirical evidence of IC's pivotal role as a driver of EIA within Uganda's manufacturing sector. To this end, the research seeks to answer the following question: How does intellectual capital influence environmental innovation (EI) within the manufacturing sector, particularly among medium and large firms in Uganda?

Recent empirical findings emphasize the critical role of IC in fostering EI, especially within small and medium-sized enterprises (SMEs) in the manufacturing sector. For instance, Ali *et al.* (2021) revealed that both green human capital and green structural capital significantly enhance green innovation adoption among manufacturing SMEs. However, they found that the impact of green relational capital, while positive, was statistically insignificant in the context of Pakistani SMEs. Similarly, Shahbaz *et al.* (2024) emphasized the importance of Green Intellectual Capital (GIC) in fostering green innovation within SMEs, with green creativity serving as a crucial moderator. Yet, their study did not identify which specific dimensions of IC significantly predict EI. Conversely, a survey by Wang and Juo (2021) on high-tech firms demonstrated the positive effects of GIC constructs on economic performance, green performance, and green innovation, though it, too, failed to pinpoint the specific explanatory potential of individual IC dimensions. In addition, Su, Liu, Stefea, and Umar (2023) emphasized the need for governments to expedite the transformation of energy structures and promote ecological innovation for environmental protection, utilizing IC to propel technological advancements and sustainable practices. However, this study falls short in elucidating the specific mechanisms through which IC contributes to achieving carbon neutrality, as the primary focus remained on technological innovation as a predictive variable. Moreover, existing research on the nexus between IC and EI presents conflicting perspectives. On one hand, some studies suggest that higher levels of IC—encompassing human, structural, and relational dimensions—can significantly contribute to the development of environmentally-friendly technologies and processes (Yusoff, Darus, & Zain, 2022; Akbar, Rehman, & Ullah, 2023). These studies argue that the knowledge, skills, and networks inherent in a firm's IC enhance its ability to identify, develop, and implement innovative solutions to environmental challenges. On the other hand, other scholars have reported a limited or even negative relationship between IC and EI. These studies attribute such findings to factors like organizational inertia, lack of environmental awareness, or misaligned incentive structures within firms (Ullah, Akbar, & Rehman, 2022; Rehman, Akbar, & Ullah, 2023). In light of these mixed findings, the ongoing debate accentuates the need for further empirical research to clarify the nuanced relationship between IC and EI, particularly within the context of medium and large manufacturing firms in Uganda.

This research aims to make a significant contribution to sustainable development initiatives that align with global agendas, including the Sustainable Development Goals (SDGs), Africa Agenda 2063, Vision 2040, Uganda's Green Growth Strategy, climate action policies, and the COP 28 targets. By examining the influence of IC dimensions on EI among medium and large (ML) manufacturing firms in Uganda, the study directly supports these initiatives. It seeks to uncover the relationships between human capital, structural capital, relational capital, and EI, offering insights crucial for enhancing environmental sustainability efforts within Uganda's industrial sector. These insights are particularly relevant to Uganda's National Development Plan Three (NDP III), informing policies and strategies aimed at fostering industrial growth while advancing environmental stewardship and innovation in alignment with Vision 2040 and the Green Growth Strategy. Moreover, by providing empirical evidence and actionable recommendations, the study contributes to achieving SDG 9 - Industry, Innovation, and Infrastructure, promoting sustainable industrialization and innovation in Uganda. Addressing climate action policies and COP 28 targets, the research also provides practical insights to mitigate climate change impacts and foster sustainable development within Uganda's manufacturing sector. Overall, this study's findings hold promise for driving positive transformations and supporting the realization of multiple sustainable development goals at both national and global scales.

The paper follows a structured outline: Section 2 conducts a critical review of existing literature and formulates hypotheses. In Section 3, the research methodology is expounded upon. Section 4 showcases empirical results, while Section 5 discusses the implications of these findings. Finally, a concluding section integrates insights, explores implications, and suggests directions for future research.

2. Literature review and hypothesis development

2.1 Theoretical underpinning

This study's conceptual framework integrates Resource-Based Theory (RBT) from Barney (1991) and extends into Dynamic Capability Theory as proposed by Teece, Pisano, and Shuen (1997). RBT asserts that firms gain competitive advantage through valuable, rare, unique, and non-substitutable internal resources and capabilities, including human, structural, and relational capital, pivotal for facilitating EI. Building upon RBT, Dynamic Capability Theory explores how firms integrate, construct, and reconfigure internal and external competencies to drive EI. Dynamic capabilities enable firms to adapt to changing environments, allocate resources effectively, and innovate in response to sustainability challenges. EI, viewed as a dynamic capability within this framework, reflects firms' ability to innovate eco-friendly products and processes to address sustainability concerns. Dynamic capabilities empower firms to actively shape and leverage competencies, fostering innovation and strategic advantage amid evolving business landscapes. Grounded in Dynamic Capability Theory (Teece *et al.*, 1997), this study aims to elucidate the complex relationship between IC and EI, revealing how firms utilize resources to drive sustainable innovation in dynamic environments.

2.2 The concept of intellectual capital

IC encompasses intangible assets crucial for creating organizational value and competitive advantage. Stewart (1997) defines IC as intellectual materials like knowledge, information, and experiences, pivotal in generating wealth through high-value assets. Edvinsson and Malone (1997) emphasize IC's intangible value derived from human expertise, skills, and motivation, alongside technological resources enhancing competitive positioning. Nahapiet and Ghoshal (1998) stress IC's social dimension, highlighting collective knowledge and learning capacity within organizations. Bontis (1999) expands IC to include copyrights, patents, trademarks, and design rights. Marzo (2014) presents three perspectives: knowledge, emphasizing IC's foundation in human and technological resources; value, emphasizing broader value creation; and intangible resources. This study adopts three IC components: human capital, structural capital (organizational or process), and relational capital (client, social, business, or cognitive), widely recognized and employed in IC research frameworks (Roos & Roos, 1997; Subramaniam & Youndt, 2005; Cabrita & Bontis, 2008; Salonius & Käpylä, 2013; Seleim & Bontis, 2013).

2.3 The concept of environmental innovations

Environmental innovation is characterized by the introduction of new or significantly improved products, services, processes, organizational changes, or marketing solutions that aim to reduce resource consumption and minimize the release of harmful substances throughout their life cycle (Eco-innovation Observatory, 2016). It is considered a subset of innovation that specifically focuses on ecological sustainability and improvements (Klemmer, 1999). Scholars such as Halila and Rundquist (2011) and Ar (2012) emphasize that EI contributes to a sustainable environment through ecological advancements. However, there is some terminological ambiguity in the literature, with terms like green innovation and eco-innovation used interchangeably. EI can be viewed as any organizational innovation that generates environmental benefits and involves changes and novel practices aimed at reducing environmental impacts (Kammerer, 2009). It encompasses a wide range of initiatives, including advancements in energy-saving, pollution prevention; waste recycling, green product designs, and corporate environmental management (Chen, Lai, & Wen, 2006). Furthermore, EI may also integrate environmental protection concepts into product design and packaging to enhance their differentiation advantages (Chen *et al.*, 2006).

2.4 Intellectual capital and environmental innovations

The OECD/Eurostat (2018) underscores that a company's resources, including its employees, tangible and intangible assets like knowledge-based capital, acquired business expertise, and financial resources, significantly influence its ability to achieve objectives, particularly through innovation activities. People are highlighted as crucial resources for innovation, providing the creativity and new ideas essential for conceiving, developing, and implementing innovations. Internal drivers of EI complement external pressures, encompassing factors such as green absorptive capacity and environmental orientation (Mady, Abdul Halim, Omar, Abdelkareem, & Battour, 2022). Research by Ali *et al.* (2021) indicates that green human capital and green structural capital substantially enhance EI adoption, while green relational capital, although positively correlated, does not significantly impact green innovation adoption in manufacturing SMEs in Pakistan. Environmental knowledge is identified as a strategic resource necessary for orienting firms towards EI, acquired from diverse sources including customers, regulators, and non-governmental organizations (De Marchi, 2012; Sanni, 2018). Aboelmaged and Hashem (2019) argue that firms require absorptive capacity to effectively utilize both internal and external environmental knowledge for adopting environmental innovations. Human capital emerges as pivotal in driving EI (Danquah & Amankwah-Amoah, 2017; Ogbeibu, Emelifeonwu, Senadjki, Gaskin, & Kaivo-oja, 2020; Singh, Del Giudice, Chierici, & Graziano, 2020), while informal relationships play a critical role in environmental product innovation development (Delgado-Verde, Amores-Salvadó, Martín-de Castro, & Navas-López, 2014). Abdullah, Zailani, Iranmanesh, and Jayaraman (2016) support this view by highlighting a positive association between firm-owned resources and EI, contrasting with findings by Woolman and Veshagh (2007), who identified insufficient resources, such as limited environmental knowledge and skills among staff, as barriers to EI development.

Herein the following hypothesis has been formulated;

H1. There is a significant positive relationship between intellectual capital and environmental innovations.

2.4.1 Human capital and environmental innovations. Human capital (HC) is widely recognized as a critical asset for any organization, as improved employee performance directly impacts productivity, thereby enhancing the firm's profitability. HC comprises the collective skills and capabilities of employees who contribute to achieving the organization's business objectives (Bontis, Crossan, & Hulland, 2002). Generally, HC is positively associated with overall firm performance (Allameh, 2018). Green human capital (GHC) represents a specific type of HC focused on environmental protection, encompassing the skills, innovation, abilities, capacities, and responsibilities of workers in relation to environmental stewardship (Chen, 2008). Moreover, HC is viewed as a catalyst for both structural capital (SC) and relational capital (RC) (Chahal & Bakshi, 2014). HC provides firms with a competitive advantage and fosters green innovativeness (Chen *et al.*, 2006), enhancing environmental practices at the organizational level (Yong, Yusliza, Ramayah, & Fawehinmi, 2019). Firms with a higher level of HC are more inclined to adopt EI. Therefore, we propose the following hypothesis:

H2. There is a significant positive relationship between Human capital and environmental innovations.

2.4.2 Structural capital and environmental innovations. Structural capital, also known as organizational capital, encompasses intangible resources such as trademarks, patents, databases, and organizational abilities that contribute to enhancing a company's image and reputation (Roos & Roos, 1997). These resources enable firms to develop core competencies and capabilities (Salunke, Weerawardena, & McColl-Kennedy, 2019; Nagano, 2020). In the context of environmental sustainability, SC includes organizational assets related to ecological protection, such as information systems, regulatory compliance mechanisms, and innovation culture (Chen, 2008; Wang, Xue, & Yang, 2019). SC provides institutional knowledge about organizational structures, practices, and policies regarding environmental initiatives (Wang *et al.*, 2019). It directly enhances the efficiency of HC by facilitating internal coordination, fostering a culture of sustainability, and improving access to relevant information (Cinquini, Passetti, Tenucci, & Frey, 2012). Moreover, environmental practices in firms are not solely reliant on HC; organizational resources, including SC, also play a crucial role in driving environment-related activities (Jardon & Dasilva, 2017). Herein, the following hypothesis is formulated:

H3. There is a significant positive relationship between structural capital and environmental innovations.

2.4.3 Relational capital and environmental innovations.. Relational capital refers to the interactions that a firm has with external counterparts for knowledge-sharing, which in turn enhances the organization's learning and innovative activities (Paz Salmador & Bueno, 2007). In the context of environmental sustainability, green RC is characterized by the firm's associations with clients, dealers, and platforms for information sharing and participation in environmental protection efforts (Chen, 2008). In today's competitive business environment, RC holds significant value, particularly as customers are considered major stakeholders for any firm (Tonial, Cassol, Selig, & Giugliani, 2019). Additionally, RC represents an elusive resource for organizations that focuses on environmental issues through partnerships with suppliers, clients, and government entities (Welbourne & Pardo-del-Val, 2008). According to Huang and Kung (2011), RC involves the cooperation and commitment of a firm with customers, suppliers, and other stakeholders on environmental sustainability initiatives. As RC progressively fosters green practices within the organization, the following hypothesis is developed for this study:

H4. There exists a significant positive relationship between relational capital and environmental innovations.

3. Methodology

3.1 Research design, population, and sample

This study employed a cross-sectional and quantitative research design to investigate the influence of IC on EI adoption among manufacturing medium and large (ML) firms in Uganda. The cross-sectional approach involved collecting data from a sample at a specific moment to examine patterns and relationships (Alinda, Tumwine, & Kaawaase, 2024). This design facilitated the gathering of data and responses from manufacturing companies in a single instance, thereby enhancing the credibility and applicability of the findings (Alinda *et al.*, 2024). Quantitative methodology was chosen to quantify data and draw generalizable conclusions from a representative sample of ML manufacturing firms, guided by principles outlined by Creswell and Plano Clark (2017).

Addressing challenges posed by the manufacturing subsector in Uganda, which comprises numerous small businesses often lacking clear addresses and contact details (UBOS, 2018), the study targeted ML manufacturing firms across central, eastern, northern, and western regions, totaling 713 enterprises. From this pool, a sample of 256 firms affiliated with the Uganda Manufacturers' Association was determined using Yamane's (1967) method as adopted from Alinda *et al.* (2024).

$$n = \frac{N}{1 + N * (e)^2}$$

The sample size was calculated based on a 95% confidence level and a 5% acceptable sampling error.

$$n = \frac{713}{1 + 713 * 0.05^2} = 256$$

Firms were categorized as medium or large based on criteria established by the Uganda Investment Authority (UIA, 2020), which included annual turnover and workforce size. Medium-sized firms were defined by an annual turnover ranging from UGX 360 million (approximately US$97,000) to UGX 1.2 billion (approximately US$323,000), employing between 51 and 100 individuals. Large firms, on the other hand, exceeded UGX 1.2 billion in turnover and employed more than 100 individuals. The researcher employed a stratified sampling method, selecting a total sample of 256 firms distributed across four regions. Key personnel such as production managers, chief finance officers, human resource managers, operations managers, and environmental managers were targeted due to their direct involvement in EI decisions within manufacturing firms (Alinda *et al.*, 2024). Purposive sampling was utilized to ensure the selection of individuals with relevant expertise and roles in EI (Alinda *et al.*, 2024). The findings from Table 1 indicated a notable concentration of manufacturing firms in the central region, comprising 90.4% of the total surveyed. This concentration is likely influenced by factors such as proximity to markets and the availability of resources (Alinda *et al.*, 2024). The central region's favorable geographic location likely enhances access to markets and resources, thereby attracting manufacturing firms to establish operations there.

3.2 Demographic characteristics

Table 2 provides demographic insights into the surveyed manufacturing firms. A significant portion (57.2%) of respondents fell within the 36–45 age range, indicating experienced leadership within the firms. This age group likely reflects both industry expertise and career advancement stages. Moreover, 54.6% of participants held bachelor's degrees, highlighting a highly educated workforce capable of engaging in EI initiatives (Alinda *et al.*, 2024). Gender distribution showed a disparity, with men comprising 60.6% of respondents compared to

Table 1. Geographical distribution of the firms

Region	Medium	Large	Acquired	Target	Response rate (%)
Central	167	21	188	229	82.1
Western	4	1	5	7	71.4
Eastern	12	1	13	18	72.2
Northern	1	1	2	2	100.0
Acquired	184	24	208	256	81.3
Target	220	36			
Response rates (%)	83.6	66.7			

Source(s): Primary data

Table 2. Respondents characteristics, total $n = 657$ respondents

	Count	Valid percent	Cumulative percent
Gender			
Male	398	60.6	60.6
Female	259	39.4	100.0
Age group			
Less than 35 years	207	31.5	31.5
36–45 years	376	57.2	88.7
46–55 years	67	10.2	98.9
above 55 years	7	1.1	100.0
Highest level of education			
Diploma	76	11.6	11.6
Bachelor's degree	359	54.6	66.2
Master's degree	207	31.5	97.7
PhD	9	1.4	99.1
Others	6	0.9	100.0
Tenure			
Less than 5 years	135	20.5	20.5
5–10 years	407	61.9	82.5
11–15 years	92	14.0	96.5
16 years and above	23	3.5	100.0
Position			
Environmental manager	58	8.8	8.8
Operations manager	144	21.9	30.7
Human resource manager	199	30.3	61.0
Production manager	123	18.7	79.8
Chief finance officer	133	20.2	100.0

Source(s): Primary data

39.4% women, underscoring the need for gender diversity in promoting inclusive perspectives in EI efforts (Alinda *et al.*, 2024). In terms of experience, 61.9% reported 5–10 years in the manufacturing sector, indicating a solid foundation in eco-innovation (Alinda *et al.*, 2024). Human resource managers (30.3%) and operations managers (21.9%) played significant roles in driving EI, while environmental managers constituted a smaller proportion (8.8%), suggesting integration of EI responsibilities across managerial functions (Alinda *et al.*, 2024).

Table 3 elucidates further characteristics of the surveyed manufacturing firms. Notably, a considerable majority (88.5%) fell into the medium-sized category, with 51–100 employees, aligning with prevailing local standards. Additionally, 90.4% of the surveyed firms were

Table 3. Firm characteristics, total $N = 208$ manufacturing firms

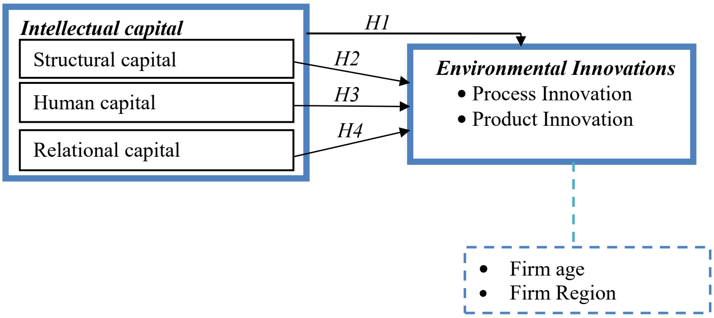
	Count	Valid percent	Cumulative percent
Number of employees			
Less than 101	184	88.5	88.5
101 and above	24	11.5	100.0
Geographical region of firm			
Central	188	90.4	90.4
Western	5	2.4	92.8
Eastern	13	6.3	99.0
Northern	2	1.0	100.0
Years this firm has been in operation			
Less than 5 years	7	3.4	3.4
5–10 years	76	36.5	39.9
10–16 years	65	31.3	71.2
15 years and above	60	28.8	100.0
Nature of the manufacturing business			
Food and beverages	66	31.7	31.7
Chemicals, paint, soap, foam products	37	17.8	49.5
Textiles, clothing and footwear	32	15.4	64.9
Metal and furniture products	33	15.9	80.8
Sawmilling, paper	12	5.8	86.5
Packaging and label	12	5.8	92.3
Bricks and cement	11	5.3	97.6
Printing	5	2.4	100.0

Source(s): Primary data

situated in the central region, likely due to strategic proximity to essential resources and markets (Alinda *et al.*, 2024). The distribution of firms across 5–10 years (36.5%) and 10–16 years (31.3%) of existence suggests a maturity in organizational structures conducive to EI initiatives (Alinda *et al.*, 2024). The substantial representation of the food and beverage sector underscores its acknowledgment of responsibility owing to its direct impact on human sustenance. Conversely, the limited presence of the printing sector highlights untapped potential for advancing EI within this industry segment.

3.3 Questionnaire and variable measurement

We employed a self-administered questionnaire with closed-ended items, utilizing a six-point Likert scale inspired by Spector (1992) to ensure clarity in responses and foster distinct expressions of agreement or disagreement with the research questions, thereby minimizing ambiguity and enhancing data quality. The deliberate choice of the six-point scale aimed at its efficacy in garnering precise responses. Additionally, the questionnaire method was selected for its efficiency in reaching a diverse respondent pool and deriving average ratings. The questionnaire's design drew from relevant literature on IC and EI, operationalizing EI based on insights from Carrillo-Hermosilla, Del Río, and Könnölä (2010), Cheng and Shiu (2012) and Alinda *et al.* (2024), while IC was conceptualized in terms of human capital, structural capital, and relational capital, drawing from the works of Kianto, Sáenz, and Aramburu (2017) and Bontis (1999). Moreover, in this study, Figure 1 illustrates the authors' conceptualization of the study variables and their interrelationships derived from existing literature, along with the direction of the hypotheses formulated.



Source(s): Figure by authors

Figure 1. The authors conceptualization of the study variables

3.4 Control variables

Previous research has highlighted the potential influence of firm-specific factors on a company's pursuit of EI (Balasubramanian, Shukla, Mangla, & Chanchaichujit, 2021). Moreover, Bartov, Gul, and Tsui (2000) emphasize the importance of accounting for confounding variables to avoid unjustified rejections of research hypotheses that might otherwise be supported. Consistent with this perspective, the present study acknowledges the intrinsic attributes of a firm's geographical location and age as control variables. The structural depiction of the study model is provided in Figure 1 for reference.

Figure 1 illustrates the authors' conceptual framework outlining key study variables. Central to the model are three dimensions of IC: HC, RC, and SC. These elements play pivotal roles in influencing the primary outcome, EI. HC represents the skills and knowledge of individuals within the organization, while RC encompasses external networks and collaborations. SC includes organizational infrastructure, systems, and processes that facilitate innovation. The arrows denote hypothesized positive relationships between these IC dimensions and EI, suggesting that investments in human, relational, and structural capital bolster the organization's capability for EI.

3.5 Validity and reliability

In research, validity concerns the accuracy of measurement in representing the intended concept (Field, 2009). To ensure precision, a team comprising experts from academia, policymaking, and EI research assessed survey questions using a rating scale (Nunnally, 1978). Content Validity Index (CVI) scores, derived from expert feedback, surpassed the threshold of 0.7, confirming robust content validity (Field, 2009). Furthermore, instrument reliability was assessed using Cronbach's alpha coefficient, with values exceeding 0.7, indicating high internal consistency (Nunnally, 1978). These findings collectively validate the questionnaire's reliability and validity in consistently measuring the intended concepts.

The reliability analysis in Table 4 underscores the robustness and internal consistency of the measurement scales utilized in this study. Cronbach's Alpha and Composite Reliability serve as critical metrics for assessing reliability, with higher values indicating stronger internal consistency. Across the IC dimensions, HC and RC demonstrate satisfactory reliability, achieving Cronbach's Alpha values of 0.704 and 0.737, and Composite Reliability values of 0.713 and 0.741, respectively. SC exhibits slightly higher reliability, with a Cronbach's Alpha of 0.767 and Composite Reliability of 0.769. Overall, the IC construct maintains acceptable reliability, with Cronbach's Alpha and Composite Reliability values of 0.736 and 0.741, respectively. Similarly, for innovation dimensions, Process Innovation, Product Innovation, and EI exhibit strong internal consistency, reflected in Cronbach's Alpha values of 0.722,

Table 4. Reliability of the research items

Variables	Cronbach's alpha	Composite reliability
Human capital	0.704	0.713
Relational capital	0.737	0.741
Structural capital	0.767	0.769
Intellectual capital	0.736	0.741
Process innovation	0.722	0.762
Product innovation	0.887	0.892
Environmental innovations	0.805	0.827

Source(s): Primary data

0.887, and 0.805, and Composite Reliability values of 0.762, 0.892, and 0.827, respectively (Alinda *et al.*, 2024). These findings affirm the reliability and internal consistency of the measurement instruments used to assess both IC and innovation constructs within the study framework.

Table 5 provides insights into the validity of research constructs based on the Average Variance Extracted (AVE) and Content Validity Index (CVI). The intellectual capital dimensions—Human Capital (AVE = 0.530, CVI = 0.875), Relational Capital (AVE = 0.655, CVI = 0.870), and Structural Capital (AVE = 0.518, CVI = 0.818)—demonstrate satisfactory validity, indicating effective measurement of these constructs. The overall Intellectual Capital construct (AVE = 0.568, CVI = 0.860) also meets validity criteria, reflecting coherent measurement. Similarly, Process Innovation (AVE = 0.551, CVI = 0.714) and Product Innovation (AVE = 0.529, CVI = 0.857) exhibit adequate validity, affirming the measurement instruments' appropriateness for capturing innovation dimensions (Alinda *et al.*, 2024). Variance Inflation Factor (VIF) values below 5 indicate minimal multicollinearity concerns in regression models. These findings collectively emphasize the validity and reliability of the study's constructs, enhancing the credibility of its findings.

3.6 Data analysis

For data analysis, we employed SmartPLS Structural Equation Modeling (SEM) Version 3, for its compatibility with a sample size of 208 manufacturing firms and its robustness in managing larger datasets, as recommended by Hair, Hult, Ringle, Sarstedt, and Thiele (2017). Following Field's (2009) protocols, SPSS Version 23 was utilized for data cleaning, addressing missing data (which represented <5% of the dataset) through linear interpolation and rectifying discrepancies in item entries via numerical coding during data input. SmartPLS Version 3 facilitated both measurement and structural model analyses, allowing for a thorough

Table 5. Validity and variance inflation factor (VIF)

Variables	Average variance extracted (AVE)	Content validity index (CVI)	Variance inflation factor (VIF)
Human capital	0.530	0.875	1.377
Relational capital	0.655	0.870	1.470
Structural capital	0.518	0.818	1.480
Intellectual capital	0.568	0.860	1.442
Process innovation	0.551	0.714	1.704
Product innovation	0.529	0.857	1.565
Environmental innovations	0.540	0.810	1.634

Source(s): Primary data

interpretation of Partial Least Squares (PLS) path modeling outcomes, in line with the methodologies outlined by Hair *et al.* (2017) and Henseler *et al.* (2014). The selection of SmartPLS for a sample size of 208 is justified by its adaptability, robustness, and efficacy in accommodating both reflective and formative constructs, particularly in exploratory research contexts, as emphasized by Hair, Ringle, and Sarstedt (2013) and Henseler *et al.* (2014).

4. Results

4.1 The measurement model

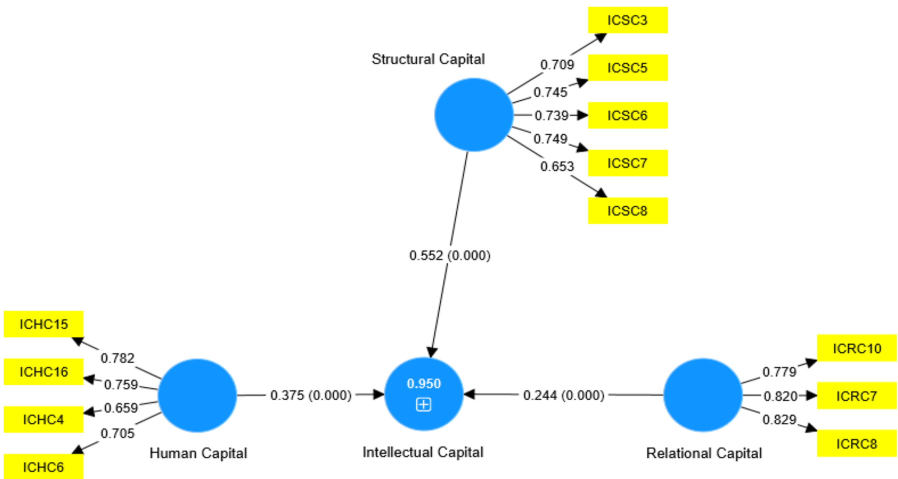
In this study, we adopted the measurement approach for EI from Alinda *et al.* (2024) and as depicted in Figure 3. For our statistical analysis, we utilized PLS-SEM software version 3, which is renowned for its flexibility and robustness, as highlighted by Vinzi, Trinchera, and Amato (2010) and Kock and Hadaya (2018). PLS-SEM is particularly adept at accommodating non-parametric datasets and varying sample sizes, thereby bolstering the reliability of our results (Anjum & Mumford, 2018). Its stable parameter estimations ensure consistent accuracy, even with larger sample sizes. Moreover, PLS-SEM excels in high prediction accuracy and facilitates valid causal inferences, particularly in scenarios where established theories are absent (Anjum & Mumford, 2018). Additionally, the software provides an effective means of visually representing variable relationships, enhancing the clarity and communication of our findings.

Table 6 and Figure 2 reveal that among the dimensions of IC, Structural Capital (SC) is the most significant predictor, emphasizing the crucial role of organizational structure, processes,

Table 6. F-square values and prediction value estimates for intellectual capital

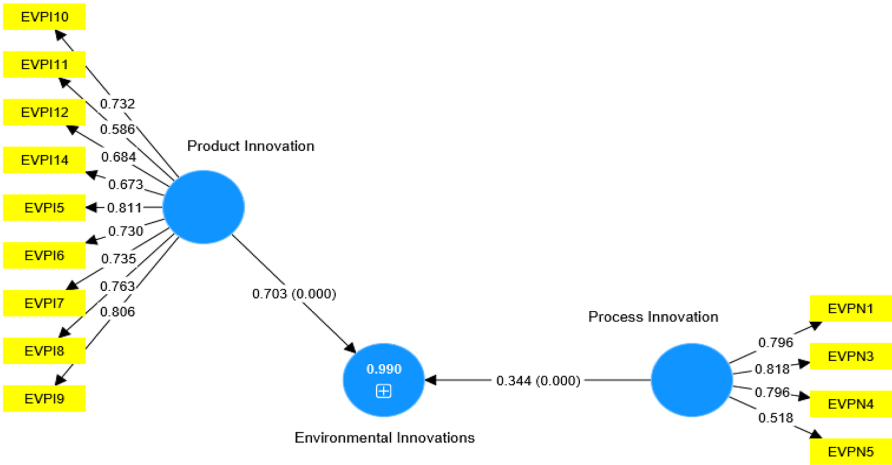
Intellectual Capital	F-square	*R*-square
Human capital	1.481	0.950
Relational capital	0.743	
Structural capital	4.270	

Source(s): Primary data



Source(s): Authors' estimation using SmartPLS 3

Figure 2. Measurement model for intellectual capital



Source(s): Adapted from Alinda *et al*. (2024)

Figure 3. Measurement model for environmental innovation

and systems in enhancing IC. Human Capital (HC) also plays a substantial role, underscoring the importance of investing in skills and knowledge development to drive organizational success. While Relational Capital (RC) does not show a quantifiable impact in this analysis, it likely contributes through fostering relationships and collaborations. These findings highlight the intricate dynamics among IC dimensions and suggest that effective management of both Structural and Human Capital, alongside nurturing relationships, is essential for improving organizational performance and competitiveness.

Figure 3, adopted from Alinda *et al.* (2024) and Table 7, reveal that process innovation plays a pivotal role in driving EI, with its strong influence reflected in its significant contribution to explaining EI variability. The high *R*-square value of 0.990 indicates that both product and process innovations together have a substantial impact on EI. This highlights that while process innovation is a major factor, the combined effect of product and process innovations is essential for advancing EI strategies. Therefore, these findings emphasize the need for a balanced focus on both types of innovation to effectively enhance EI.

The Heterotrait-Monotrait (HTMT) ratio serves as a robust measure to evaluate discriminant validity between constructs in research studies, ensuring the credibility of the measurement model. In our analysis, we utilized the HTMT ratio to assess the distinctiveness between IC components (human capital, relational capital, and structural capital) and EI dimensions (process innovation and product innovation). Results from Table 8 indicate that IC components exhibit satisfactory discriminant validity, with HTMT ratios below the threshold: 0.734 between human capital and relational capital, 0.567 between human capital and structural capital, and 0.362 between relational capital and structural capital. Similarly, for EI,

Table 7. F-square values and prediction value estimates for environmental innovations

Environmental innovations	F-square	*R*-square
Process innovation	4.625	0.990
Product innovation	19.300	

Source(s): Primary data

Table 8. Discriminant validity using the heterotrait-monotrait [HTMT] ratio

Intellectual capital	HC	RC	SC
Human capital [HC]			
Relational capital [RC]	0.734		
Structural capital [SC]	0.567	0.362	
Environmental innovations	PN	PI	
Process innovation [PN]			
Product innovation [PI]	0.649		

Source(s): Primary data

the HTMT ratio of 0.649 between process innovation and product innovation confirms their distinctiveness. These findings support the validity of the measurement model, affirming the unique contributions of IC components and EI dimensions to the research inquiry.

4.2 Structural model

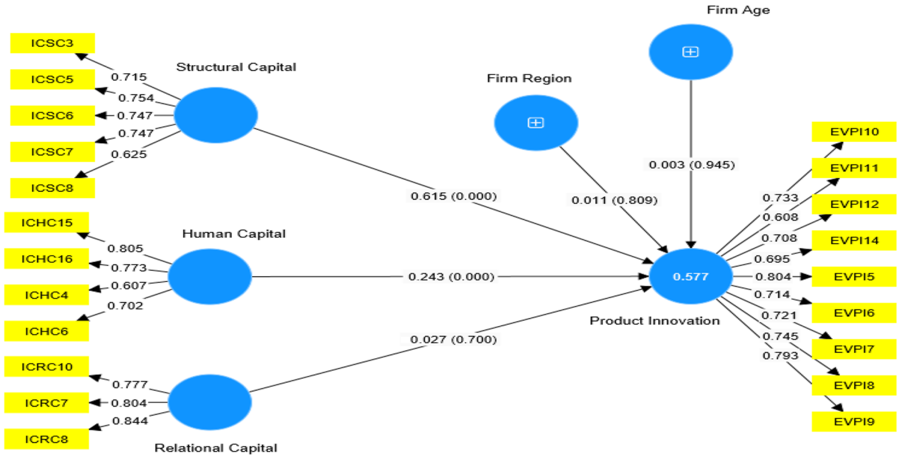
In this study, we employ structural equation modeling (SEM) as a sophisticated analytical framework to explore the complex relationships among latent constructs and assess causal pathways within our conceptual model. SEM, as endorsed by Wong (2019), provides a powerful methodological approach that allows for the simultaneous estimation of measurement errors and the modeling of relationships between latent variables (Wong, 2019). This approach is particularly well-suited for our research context, where it serves as a critical tool for hypothesis testing and theory validation. By using SEM, we aim to uncover the underlying mechanisms driving the observed relationships between IC and EI, evaluate the direct effects among key constructs, and develop a nuanced understanding of the causal pathways at play. SEM's capacity to integrate theory-driven models with rigorous statistical analysis aligns with recent advancements in empirical research, offering a comprehensive view of the complex interactions within our study. Thus, SEM is justified as the method of choice for analyzing IC and EI among ML manufacturing firms in Uganda, as it enables a detailed examination of the intricate dynamics and provides valuable insights into the mechanisms underlying EI practices.

4.2.1 Test of hypothesis. Table 9 and Figure 4 reveal that Structural Capital (SC) and Human Capital (HC) are significant drivers of product innovation. SC has a substantial effect on product innovation with a coefficient of $\beta = 0.615$ and a highly significant p-value ($p < 0.001$), highlighting its critical role in influencing innovative initiatives within firms. HC also shows a notable relationship with product innovation, with a coefficient of $\beta = 0.243$ and a significant p-value ($p < 0.001$), emphasizing the importance of employee skills and knowledge in fostering innovation. In contrast, Firm Region ($\beta = 0.011$, $p = 0.809$) and Firm Age ($\beta = 0.003$, $p = 0.945$) have minimal impact on product innovation, confirming their role primarily as control variables. Relational Capital (RC) demonstrates a negligible effect with a

Table 9. Model estimates for intellectual capital dimensions and product innovation

Model estimates	β	Std. Error	*T*-statistics	*p*-value
Firm region → Product innovation	0.011	0.046	0.242	0.809
Firm age → Product innovation	0.003	0.045	0.069	0.945
Structural capital → Product innovation	0.615	0.062	9.976	0.000
Human capital → Product innovation	0.243	0.052	4.686	0.000
Relational capital → Product innovation	0.027	0.070	0.385	0.700

Source(s): Primary data



Source(s): Authors' estimation using SmartPLS 3

Figure 4. Structural model for intellectual capital dimensions and product innovation

coefficient of $\beta = 0.027$ and a p-value of 0.700, suggesting it has a limited influence in this context. These findings underscore the dominant roles of SC and HC in driving product innovation and indicate that while firm-specific factors like region and age are controlled for, they do not significantly affect innovation outcomes.

Table 10 reveals that Structural Capital (SC) is the most significant predictor of product innovation, demonstrating a substantial explanatory power with an f-square value of 0.560, which accounts for approximately 57.7% of the variance in innovation outcomes. This highlights the crucial role of organizational structures, processes, and systems in driving innovation. The model's robustness is further validated by an adjusted R-square value of 0.567, confirming its strong explanatory capacity even after adjusting for control variables. Human Capital (HC) also contributes notably to product innovation, with an f-square value of 0.074, underscoring the importance of investing in employee skills and knowledge. In contrast, Relational Capital (RC) shows minimal influence with an f-square value of 0.001, indicating that relational factors have a limited impact on innovation in this context. These results emphasize the dominant roles of SC and HC in enhancing product innovation, suggesting that firms should focus on strengthening their organizational frameworks and human resources while recognizing that relational capital plays a lesser role.

Table 11 and Figure 5 provide valuable insights into the factors driving process innovation within firms. The analysis reveals that while Firm Region has a notable coefficient ($\beta = 0.107$), its statistical significance ($p = 0.076$) suggests that it may influence process

Table 10. Effect size and prediction estimates for model

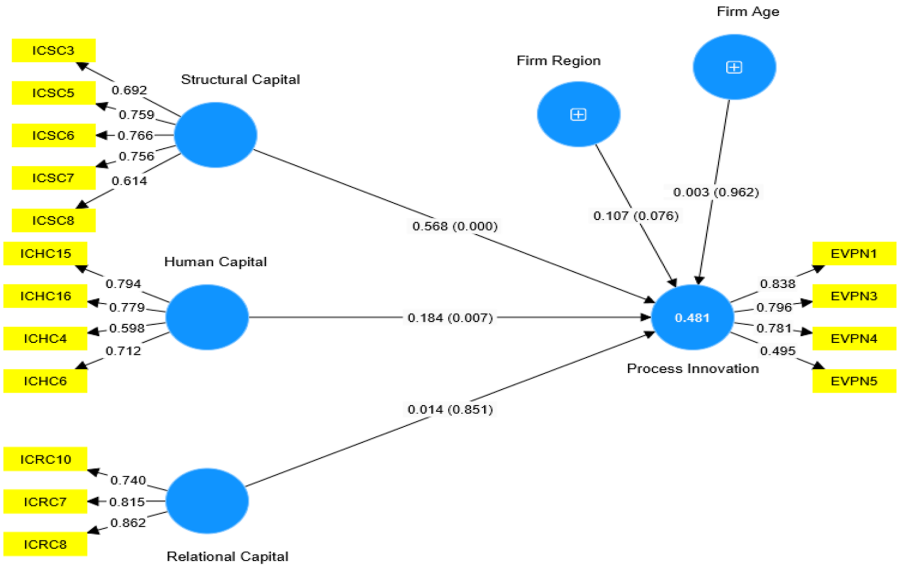
Variables	f-square	R-square	R-square adjusted
Firm region	0.000	0.577	0.567
Firm age	0.000		
Structural capital	0.560		
Human capital	0.074		
Relational capital	0.001		
Product innovation			

Source(s): Primary data

Table 11. Model estimates for intellectual capital dimensions and process innovation

Model estimates	β	Std. Error	*T*-statistics	*p*-value
Firm region → Process innovation	0.107	0.060	1.774	0.076
Firm age → Process innovation	0.003	0.053	0.048	0.962
Structural capital → Process innovation	0.568	0.072	7.909	0.000
Human capital → Process innovation	0.184	0.068	2.718	0.007
Relational capital → Process innovation	0.014	0.075	0.187	0.851

Source(s): Primary data



Source(s): Authors' estimation using SmartPLS 3

Figure 5. Structural model for intellectual capital dimensions and process innovation

innovation, albeit the effect is not definitively significant and warrants further investigation. Firm Age, on the other hand, shows a negligible impact on process innovation ($\beta = 0.003$, $p = 0.962$), challenging the notion that older firms necessarily have more innovative processes due to accumulated experience or resources.

Structural Capital (SC) stands out as a significant predictor of process innovation, with a coefficient of $\beta = 0.568$ and a highly significant *p*-value ($p < 0.001$). This underscores the essential role that well-developed organizational structures, systems, and processes play in facilitating innovative activities. Similarly, Human Capital (HC) demonstrates a positive and significant association with process innovation ($\beta = 0.184$, $p = 0.007$), highlighting that investments in employee skills, knowledge, and development are crucial for driving innovation within firms.

In contrast, Relational Capital (RC) does not show a meaningful impact on process innovation, with a coefficient of $\beta = 0.014$ and a non-significant *p*-value ($p = 0.851$). This suggests that, in this context, the influence of relational networks and external relationships on process innovation may be limited, prompting a need for further research into how relational assets and collaborations might affect innovation under different conditions or in different settings. Overall, these results enhance the understanding of how various dimensions of IC contribute to process innovation, emphasizing the significant roles of SC and HC while indicating that RC's impact may vary based on contextual factors.

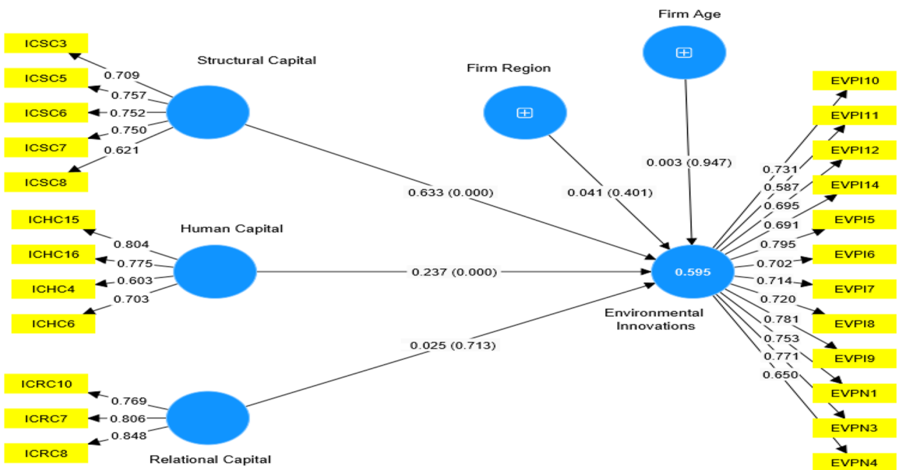
Table 12 offers an in-depth analysis of how various dimensions of IC influence process innovation, incorporating control variables such as Firm Age and Regional Distribution. SC emerges as the dominant predictor with a substantial f-square value of 0.392, signifying its strong impact on process innovation. This finding underscores the crucial role of well-developed organizational frameworks, processes, and systems in driving innovative activities. The model's overall explanatory power is demonstrated by an *R*-square value of 0.481, which indicates that nearly 48.1% of the variance in process innovation can be attributed to the independent variables included in the analysis. This reflects the significant combined effect of SC, along with other IC dimensions and control variables. The adjusted *R*-square value of 0.468 further reinforces the model's robustness, accounting for the influence of control variables and enhancing the credibility of the results. These findings not only highlight the pivotal role of SC in shaping process innovation but also provide a comprehensive view of how IC dimensions collectively contribute to the innovative capabilities of organizations, offering valuable insights for both theoretical and practical applications in managing and leveraging intellectual capital for innovation.

The model estimates in Figure 6 and Table 13 unveil significant relationships between IC dimensions and EI, emphasizing the influential roles of SC and HC in driving advancements in

Table 12. Effect size and prediction estimates for model

Variables	f-square	*R*-square	*R*-square adjusted
Firm region	0.021	0.481	0.468
Firm age	0.000		
Structural capital	0.392		
Human capital	0.034		
Relational capital	0.000		
Process innovation			

Source(s): Primary data



Source(s): Authors' estimation using SmartPLS 3

Figure 6. Structural model for intellectual capital dimensions and environmental innovations

Table 13. Model estimates for intellectual capital dimensions and EI

Model estimates	β	Std. Error	*T*-statistics	*p*-value
Firm region → Environmental innovations	0.041	0.048	0.839	0.401
Firm age → Environmental innovations	0.003	0.044	0.067	0.947
Structural capital → Environmental innovations	0.633	0.061	10.378	0.000
Human capital → Environmental innovations	0.237	0.052	4.562	0.000
Relational capital → Environmental innovations	0.025	0.069	0.368	0.713

Source(s): Primary data

eco-friendly practices within firms. Specifically, SC exhibits a robust and positive association ($\beta = 0.633$, $p < 0.001$), highlighting the facilitative role of well-established organizational frameworks in fostering EI. Similarly, HC demonstrates a significant and positive coefficient ($\beta = 0.237$, $p < 0.001$), highlighting the critical contribution of employee expertise and skills to the development of environmentally friendly products. Conversely, RC displays a non-significant coefficient ($\beta = 0.025$, $p = 0.713$), indicating limited direct impact from external stakeholder relationships on EI. These findings emphasize the significance of internal organizational factors, particularly structural and human capital, in propelling advancements in EI, offering valuable insights for managerial and policy interventions aimed at promoting eco-friendly initiatives within firms.

The results presented in Table 14 reveal the key predictors of EI and the model's overall predictive strength, incorporating control variables such as firm regional distribution and age. SC stands out as the most influential factor, with an f-square value of 0.621, indicating its central role in shaping EI within ML manufacturing firms. This highlights that well-established organizational structures, processes, and systems are critical for driving environmental innovation. Human Capital (HC) also plays a significant role, with an f-square value of 0.073, underscoring the importance of employee knowledge, skills, and expertise in fostering EI. In contrast, Relational Capital (RC) shows a minimal influence on EI, with an f-square value of 0.001, suggesting that while relational networks and external collaborations may have some impact; their effect is relatively minor compared to SC and HC. The control variables, such as firm region and age, exhibit negligible effect sizes on EI, indicating that these factors do not significantly alter the relationship between IC dimensions and environmental innovation.

The model's robustness is confirmed by the *R*-square value of 0.595 and the adjusted *R*-square value of 0.585, which together demonstrate that the included variables explain a substantial portion of the variance in EI. These values highlight the effectiveness of the model in capturing the relationship between IC and EI. Overall, the findings emphasize the pivotal roles of Structural and Human Capital in enhancing EI. Organizations can substantially enhance their innovation capabilities and advance sustainability objectives by strategically

Table 14. Effect size and prediction estimates for model

Variables	f-square	*R*-square	*R*-square adjusted
Firm region	0.004	0.595	0.585
Firm age	0.000		
Structural capital	0.621		
Human capital	0.073		
Relational capital	0.001		
Environmental innovations			

Source(s): Primary data

harnessing these resources. Emphasizing the strengthening of organizational frameworks and investing in employee development are crucial for maximizing their impact on EI.

5. Discussion

The Resource-Based Theory, which underpins the structural model of this study, emphasizes that IC dimensions are crucial for predicting EI. The findings from testing H1 reveal a significant and positive relationship between IC and EI in medium and large manufacturing firms in Uganda. This emphasizes the importance of prioritizing and investing in IC, encompassing human, structural, and relational components, to foster innovation and knowledge creation within organizations. By emphasizing IC, firms can develop environmentally friendly product designs, sustainable manufacturing processes, and innovative technologies, thus reducing their ecological footprint and promoting environmental sustainability. ML manufacturing firms that recognize the synergy of human, relational, and structural capital are well-positioned to drive eco-friendly innovations. They leverage employees' skills, foster internal relationships, and optimize organizational structures to cultivate a culture of innovation where valuable ideas emerge from diverse sources. Notably, valuable insights can come from employees without formal leadership roles, as seen in cases where respondents suggested improvements in product packaging, yielding positive outcomes and highlighting the value of open collaboration.

Emphasizing a company's IC, embodied in employees' expertise and knowledge, is crucial for fostering innovation and achieving favorable outcomes. Additionally, strong internal relationships and efficient organizational structures, encapsulated within relational and structural capital respectively, further enhance this process. This integrated approach, recognizing the importance of human, relational, and structural capital, underscores their collective role in driving environmentally innovative practices for long-term success and growth.

These findings align with Barney's (1991) RBT, suggesting that a firm's unique and valuable resources, such as intellectual capital, confer a sustainable competitive advantage. Specifically, in this study's context, IC related to environmental sustainability facilitates effective implementation of EI, thereby enhancing organizations' competitive edge and environmental responsibility. This perspective emphasizes the need to develop and leverage valuable resources within firms to drive sustainability-oriented innovations effectively.

Furthermore, the findings resonate with Ali *et al.* (2021), who emphasized the significance of green human and structural capital in driving green innovation adoption within manufacturing SMEs. While relational capital showed a positive but insignificant impact, green IC, particularly green human and structural capital, emerged as key drivers of sustainable practices and environmental responsibility. This reinforces the importance of investing in employees' skills and knowledge and building efficient systems and processes to support sustainability initiatives. Additionally, Zhang and Li's (2024) observation regarding the positive impact of IC on product innovation performance further supports these findings. However, variations in the effects of IC across regions highlight the need for context-specific approaches. Similarly, Ullah, Mehmood, and Ahmad (2023) findings accentuate the pivotal role of green IC in enabling organizations to adopt green innovations and promote environmental sustainability. It is noteworthy that while structural capital exhibited the highest predictive potential followed by human capital, relational capital, although positively inclined, did not reach statistical significance.

6. Conclusions, limitations and future scope.

This study offers a comprehensive analysis of the interplay between IC and EI within medium and large manufacturing firms in Uganda, yielding critical insights into how these factors influence each other. The results underscore that structural capital is the foremost predictor of

EI, emphasizing the pivotal role of robust organizational frameworks, streamlined processes, and effective knowledge management systems. Human capital also proves to be crucial, highlighting the need for targeted investments in employee training and skill development to drive EI. Although relational capital exhibited potential, its impact did not reach statistical significance, suggesting a need for further research into how inter-firm dynamics and collaborations might affect EI.

For managers, these findings suggest a strategic focus on strengthening structural and human capital to build a sustainability-oriented culture. Aligning investments in organizational infrastructure and employee capabilities with global sustainability frameworks such as the Sustainable Development Goals (SDGs), Uganda's Vision 2040, the National Development Plan III (NDP III), and Africa Agenda 2063 is essential. Managers should prioritize enhancing organizational structures, optimizing processes, and advancing knowledge management systems while continuously developing employee skills to drive innovative and eco-friendly practices.

From a policy perspective, the study advocates for the creation of an environment that fosters intellectual capital and incentivizes environmental innovation. Policymakers are encouraged to implement measures such as tax incentives for green initiatives, funding for research and development in green technologies, and capacity-building programs focused on environmental innovation. Enhanced collaboration among government, industry, and academia could further accelerate Uganda's transition to a more innovative and competitive manufacturing sector, supporting broader developmental goals and enhancing global competitiveness.

Theoretical implications of this study enrich the understanding of how different dimensions of IC impact EI, revealing that while structural and human capitals are critical, the role of relational capital merits further investigation. Future research should delve into the mediating mechanisms underlying these relationships and explore how knowledge creation, dissemination, and utilization influence environmental innovation within organizational contexts. Investigating these aspects will refine theoretical frameworks and offer practical guidance for leveraging IC to achieve environmental sustainability.

6.1 Limitations and areas for further study

This study, while impactful, faces several limitations that should be addressed in future research. The focus on medium and large manufacturing firms in Uganda may limit the generalizability of the findings to other industries and geographic contexts. Additionally, the reliance on cross-sectional data constrains our ability to draw causal inferences, emphasizing the necessity for longitudinal studies that can track changes over time and validate the observed relationships. Future research should explore mediating mechanisms, such as organizational culture and knowledge management practices, which might influence the relationship between IC and EI. Moreover, examining moderators like firm size, industry type, and regional economic conditions will help determine how these factors impact the effectiveness of IC in fostering EI. Comparative studies across different sectors and countries are also recommended to gain insights into contextual variations and best practices for promoting sustainable innovation. Expanding the research scope to include diverse industries and regional contexts within Uganda, as well as other international settings, will enhance the generalizability of the findings and provide a broader perspective on IC's role in driving EI. In summary, while this study highlights the crucial role of IC in advancing EI among manufacturing firms in Uganda, addressing these limitations and pursuing the proposed research directions will offer a more comprehensive understanding of environmental innovation. This will not only enhance business performance but also contribute to the achievement of national and continental sustainable development goals, fostering a culture of innovation that supports long-term environmental and economic sustainability.

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