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HARNESSING INTELLECTUAL CAPITAL FOR INNOVATION: THE MODERATING EFFECT OF DIGITAL TRANSFORMATION IN MANUFACTURING INDUSTRIES

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Abstract: This study explores the interplay between intellectual capital (IC), digital transformation (DT), and innovation in Chinese manufacturing firms, emphasizing the moderating role of DT. Utilizing data from Shenzhen Stock Exchange-listed firms from 2013 to 2023, the research employs Ordinary Least Squares (OLS) and Partial Least Squares (PLS) regression models to test the hypotheses. The findings reveal that DT significantly enhances the positive effect of IC on innovation. The study underscores the importance of fostering IC through human, structural, and relational capital and leveraging DT to maximize innovative outcomes. These insights are particularly relevant for policymakers and business leaders aiming to boost innovation in the knowledge economy. The results advocate for regulatory frameworks and incentives that support innovation driven by IC and DT, highlighting the substantial economic benefits these elements can bring. This research contributes to a deeper understanding of how IC and DT interact to drive innovation, offering valuable implications for technology management, entrepreneurship, and economic policy.
Keywords: Intellectual capital; Digital transformation; Innovation; Manufacturing firms; Economic benefits

1 INTRODUCTION

The emergence of the 'new economy,' fueled by information and knowledge, has led to a growing focus on intellectual capital (IC). IC is vital in creating value, shaped by and further developed through unique organizational structures, innovation, and human resources[1]. The existing literature generally categorizes IC into three dimensions: human capital, relational capital, and structural capital[2,3]. Despite a broad consensus that IC enhances organizational value, the specific mechanisms by which it does so remain relatively understudied. Innovation has emerged as a critical outcome of IC's contribution to organizational success[4].

Innovation encompasses the knowledge initiatives, skills, techniques, and ideas that create new capabilities, thereby establishing competitive advantages for organizations and combining and reorganizing knowledge into advanced and beneficial products, services, and procedures[5]. Many studies have explored the relationship between intellectual capital (IC) and organizational innovation, yielding inconsistent results [6]. While much of the existing literature has examined IC and innovation broadly, few studies have delved into the specific factors that mediate this relationship. One such factor that has garnered significant attention from both academia and industry is digital transformation.

Digital transformation (DT) has become a focal point of research and a crucial catalyst for innovation in recent years. Researchers describe DT as the strategic integration of digital technologies like Artificial Intelligence (AI), cloud computing, big data, and blockchain to create new digital business models that enhance value creation for firms[7]. Studies have shown that big data plays a moderating role in the relationship between intellectual capital (IC) and innovation[8], while others have explored how DT influences entrepreneurship and the innovation process[9]. Despite these findings, there is a significant gap in the literature regarding the specific impact of DT on the interplay between IC and innovation.

In this paper, we aim to explore the interplay between intellectual capital (IC), digital transformation (DT), and innovation by examining the relationship between IC and innovation, as well as the influence of DT on this dynamic for several reasons. Firstly, the ongoing shift towards a 'new economy' driven by information and knowledge underscores the importance of IC as a fundamental driver of value creation. Understanding how DT affects IC is essential for organizations striving to succeed in this evolving landscape. DT has been a critical focus of China's government policy and industry development over the past decade. President Xi Jinping has repeatedly emphasized integrating the digital economy with the traditional manufacturing sector[10]. He asserts that China's progress toward becoming a developed nation depends on its transition from a high-speed growth industrial economy to a qualitatively advanced digital economy Xi further remarks that innovation is both the realization and manifestation of DT[11]. Thirdly, given the inconsistent findings in prior studies on IC and innovation[12,13], introducing DT as a moderating factor could provide new insights. This research aims to determine whether DT facilitates innovation and, if so, whether it enhances the positive correlation between IC and innovation. Such insights would help validate the effectiveness of DT and support further investment in DT-related projects and policies. Conversely, if DT does not significantly contribute to the IC-innovation relationship, it would prompt a reevaluation of current DT implementation strategies at governmental, industrial, and organizational levels. This study ultimately seeks to inform policy-making and strategic planning by leveraging the full potential of DT to foster innovation and economic growth.

The data for this research are derived from Shenzhen A-share listed manufacturing firms, spanning 2013 to 2023. We investigate the interplay between intellectual capital (IC), digital transformation (DT), and innovation within China's manufacturing sector, a sector actively encouraged to pursue more significant innovation. This research enhances our understanding of the optimal integration of IC and DT in the manufacturing sector and elucidates how DT influences the relationship between IC and innovation. Our empirical findings indicate that digital transformation (DT) strengthens the relationship between intellectual capital (IC) and innovation. Specifically, we observe that both human and structural capital positively correlate with innovation, with DT as a positive moderator in these relationships.

The structure of the paper is outlined as follows: Section 2 presents a comprehensive literature review, synthesizing existing research on the interplay between intellectual capital, digital transformation, and innovation. Section 3 develops the research framework and hypotheses based on insights from the literature review. Section 4 delineates the methodology employed in the study, including data collection procedures, analytical techniques, and model specifications. The findings of the empirical analysis are presented in Section 5, followed by a thorough discussion of the results in Section 6. Finally, Section 7 offers concluding remarks, summarizing key findings, discussing their implications, and suggesting avenues for future research.

2 LITERATURE REVIEW

The literature on digital transformation (DT) and its implications for firm innovation has witnessed considerable growth and attention in recent years. As organizations navigate the complexities of an increasingly digitalized landscape, scholars have sought to elucidate the mechanisms through which DT influences innovation processes and outcomes [14]. Many conceptual frameworks have emerged, aiming to capture the multifaceted nature of DT and its impact on organizational dynamics. While qualitative analyses have offered valuable insights into the conceptual underpinnings of DT and innovation, a notable gap persists in the quantitative exploration of this relationship. Thus, this literature review endeavors to bridge this gap by synthesizing existing research and providing a comprehensive understanding of the quantitative dimensions of the DT-innovation nexus. By examining empirical studies that employ quantitative methodologies, this review seeks to unravel the intricate interplay between DT and firm innovation, shedding light on the factors that drive and inhibit innovative activities within organizations [15,16].

The exploration of Intellectual Capital (IC) and its role in fostering innovation has been a focal point of scholarly inquiry in management, economics, and organizational behavior. IC, comprising human, structural, and relational capital, is a critical resource for organizations seeking to enhance their innovative capabilities and gain a competitive edge in dynamic market environments[17]. Extensive research has underscored the positive correlation between IC and innovation, highlighting the pivotal role played by human capital in driving organizational learning and knowledge creation. However, while the relationship between IC and innovation has garnered significant attention in the literature, the influence of DT and political connections on this relationship remains underexplored, particularly within the context of emerging economies such as China [18]. Thus, this literature review aims to fill this gap by examining the extant literature on IC, DT, and innovation, specifically focusing on the Chinese context. By synthesizing existing research findings, this review seeks to provide insights into the mechanisms through which DT and political connections shape the dynamics of IC and innovation, thereby contributing to a more nuanced understanding of innovation processes within the Chinese business ecosystem.

2.1 Intellectual Capital and Innovation

Intellectual Capital (IC) has emerged as a pivotal instrument for value creation, prompting interdisciplinary research endeavors to explore how the capital market responds to its potential to enhance firm value. IC underscores the strategic utilization of resources and human capital to develop competitive products and services, thereby driving firm solid performance and value creation [19]. In extant literature, various studies have illuminated the multifaceted impact of IC on innovation. For instance, Hayton (2005) identified a positive correlation between human capital and corporate innovation[20]. Cabrillo and Dahms (2018) delved into the moderating role of strategic knowledge management on the relationship between IC and firm innovation and market performance, revealing nuanced interactions[21].

Similarly, Hayaeian et al. (2022) and Zhang et al. (2018) explored the moderating effects of knowledge management strategies and supplier knowledge integration on the relationship between IC and innovation, uncovering positive associations[8,22]. Furthermore, Li et al. (2019) investigated the intricate relationship among IC, knowledge sharing, and innovation performance in construction firms in China, demonstrating the direct and indirect pathways through which IC influences innovation[13]. These studies collectively contribute to a deeper understanding of how IC fuels innovation and underscore the importance of strategic knowledge management practices in harnessing its full potential.

In examining the significance of Intellectual Capital (IC), we adhere to the three established dimensions advocated by numerous contemporary IC scholars[23]: human capital, structural capital, and relational capital. Human capital, considered the foundation of IC, encompasses the knowledge and learning capabilities inherent in human resources and their capacity to generate tangible and intangible assets. Widely regarded as the most valuable asset for firms seeking to enhance their value, human capital efficiency reflects how effectively a firm's human resources contribute to its overall value. For instance, Elsharnouby and Elbanna (2021) demonstrated how human capital fosters corporate innovation by streamlining existing organizational structures and spearheading the development of novel products and services[24]. Additionally, Chatterji and Patro (2014) highlighted that valuable human resources bolster innovation and perpetuate itself by retaining current staff and attracting new talent, fostering a culture of innovation within firms[25]. Furthermore, extending beyond the confines of individual firms, Han and Li (2015) posited that robust human capital enables firms to adapt and reconfigure in response to the dynamic and ever-evolving business landscape[26].

Structural capital encompasses the knowledge embedded within organizational structures and processes, encompassing organizational strategy, networks, corporate culture, technology infrastructure, data repositories, publications, and management processes. As highlighted by Bontis (2001), structural capital constitutes a vital component of intellectual capital (IC), which comprises communicative capital (customer relations) and organizational capital[27]. The organizational structure is a control mechanism, providing the framework for implementing strategic objectives. As defined by Bontis, strategy entails delineating long-term goals, devising action plans, and allocating resources to achieve these objectives. Structural capital plays a pivotal role in fostering the innovative capacity of firms, as documented by research. For instance, Farzaneh et al. (2022) elucidate that structural capital positively correlates with human capital, fostering organizational learning and ultimately driving innovation within firms[28].

Relational capital refers to the dynamics of "who you reach and how you reach," as Bian and Zhang (2014) articulated, emphasizing the cultivation of mutual trust and goodwill through prior interactions to gain preferential access to valuable resources[29]. Within social capital, relational capital is distinguished by its focus on the networks forged by enterprises with relevant stakeholders[30]. In corporate innovation, Zhou et al. (2024) suggest that relational capital provides firms and employees greater access to timely information, thereby augmenting the acquisition and application of new knowledge and expertise[31]. In the contemporary Chinese landscape, Chen and Chen (2004) assert that the social networks embedded in enterprises significantly influence their economic behavior[32]. Furthermore, a robust social network grants enterprises access to invaluable information and opportunities[33], fostering a deeper understanding of the dynamic external environment and enhancing receptivity to innovative changes [34].

2.2 Digital Transformation and Innovation

Digital technologies have ushered in new opportunities for innovators and entrepreneurs, concurrently generating and capturing significant economic and social value [35]. Warner and Wäger (2019) posit that digital transformation (DT) constitutes an ongoing process wherein organizations integrate new digital technologies into their daily operations, with agility as a fundamental mechanism for driving strategic renewal across various dimensions—business models, collaborative approaches, and organizational culture[36]. Hinings et al. (2018) also delineated three novel institutional arrangements for DT: digital organizational forms, digital institutional infrastructure, and institutional building blocks[37]. Frank et al. (2019), on the other hand, proposed a conceptual framework that bridges the concepts of Servitization (value addition to the customer) and Industry 4.0 (value addition to the manufacturing process) from a business innovation perspective. Their framework delineates three levels of Servitization (smoothing, adapting, and substituting) and three levels of digitization (low, moderate, and high), facilitating a comprehensive understanding of the synergies between these two transformative paradigms[38].

Researchers have observed a positive impact of digital transformation (DT) on entrepreneurship and the innovation process[9]. Moreover, DT plays a vital role in expanding companies' access to global markets, thereby fostering international trade and competition, which, in turn, acts as a catalyst for innovation, leading to growth and entrepreneurship benefits[39]. As Nambisan (2022) highlighted, the emergence of novel and potent digital technologies, platforms, and infrastructures has profoundly transformed the landscape of innovation and entrepreneurship. The effectiveness of DT is contingent upon the extent to which organizations utilize digital technologies effectively. By facilitating seamless access to global markets, DT enhances firms' competitiveness and stimulates innovation, unlocking growth opportunities and fostering an entrepreneurial ecosystem conducive to sustained economic development[40].

The preceding discussion underscores the acknowledgment that digital transformation (DT) holds sway over firm innovation to a certain degree. However, while existing literature has furnished conceptual frameworks of DT and innovation and conducted qualitative analyses, quantitative examinations of the relationship between DT and corporate innovation have been scarce. Moreover, while the relationship between Intellectual Capital (IC) and innovation has garnered attention, the Chinese context remains underexplored, particularly regarding the influence of DT and political connections on IC and innovation [41]. This absence of research leaves a gap in understanding the nuanced dynamics in the Chinese business ecosystem. Therefore, there is a pressing need for empirical studies that delve into the quantitative aspects of the DT-innovation nexus and explore the intricate interplay between IC, DT, and political connections in driving innovation within the Chinese context. Such research endeavors would contribute to a more comprehensive understanding of the factors shaping innovation dynamics and inform strategic decision-making in academia and industry.

3 RESEARCH FRAMEWORK AND HYPOTHESES DEVELOPMENT

The research framework for this study is built on the intersection of intellectual capital (IC), digital transformation (DT), and innovation within the context of Chinese manufacturing firms. By drawing on resource-based theory, this framework examines how various components of IC—human capital efficiency (HCE), structural capital efficiency (SCE), and relational capital efficiency (RCE)—interact with DT to influence firm innovation. Building on the existing literature, our research framework posits several hypotheses to explore these relationships. Firstly, we hypothesize that each component of IC (HCE, SCE, and RCE) positively correlates with different innovation outputs, such as utility models, designs, and inventions (H1, H2, H3). Secondly, we propose that DT acts as both a driver and an enhancer of IC, creating a positive feedback loop that fosters greater innovation (H4).

3.1 Intellectual Capital and Innovation

Resource-based theory (RBT), also known as the theory of firms, originated in economics through the seminal work of Penrose (1959)[42]. The theory centers on two key concepts: resources and capabilities. Resource-based theorists have variously defined resources, including tangible and intangible items [43]. RBT provides a valuable framework for understanding the relationship between Intellectual Capital (IC) and innovation by highlighting the importance of valuable, rare, and difficult-to-imitate resources in achieving and sustaining a competitive advantage [44]. IC is viewed as a critical resource conducive to creating competitive advantages because it is inherently difficult to imitate and substitute [45].

IC drives innovation by cultivating a culture of continuous learning, problem-solving, and creativity[46]. Employees with specialized knowledge and expertise play a crucial role in developing new ideas and technologies. RBT recognizes that specific knowledge within organizations is tacit and thus difficult for competitors to replicate. This implicit knowledge, often embedded in the skills and experience of employees, serves as a unique source of innovation. Furthermore, RBT acknowledges that the unique organizational culture—another component of IC—that promotes knowledge sharing, collaboration, and learning can be a rare and difficult-to-imitate facet of IC. Such a culture significantly enhances the firm's innovation capabilities by fostering an environment where creative and innovative ideas can thrive. Resource-based theory suggests that Intellectual Capital (IC) is a valuable, rare, and difficult-to-imitate resource that significantly enhances a firm's innovation capabilities. By effectively leveraging and managing IC, organizations can differentiate themselves, cultivate a culture of innovation, and maintain a competitive edge in dynamic markets. Therefore, this paper predicts the following hypothesis:

H1: IC is positively associated with innovation.

3.2 Digital Transformation and Innovation

In addition to intellectual capital (IC), the intangible capital component of resource-based theory (RBT) also recognizes the competitive advantages information technology brings. Researcher emphasized that information technology is an "information processing system that has the potential to provide a lasting competitive advantage," which is very pertinent to digital transformation (DT) and innovation. Within this framework, we redefine the notion of intangible capital to underscore the significance of innovation as a comparably crucial aspect of other types of IC. The Resource-Based Theory (RBT) offers valuable insights into the correlation between Dynamic Capabilities (DT) and innovation by emphasizing the strategic significance of resources and capabilities in attaining and maintaining a competitive advantage. According to RBT (Resource-Based Theory), resources refer to all the assets, capacities, organizational processes, information, and knowledge over which a corporation controls[47]. When digital resources contribute to a competitive advantage, they are regarded as strategic assets. Companies with advanced digital resources are better positioned to innovate and adjust to the always-changing business environment [40].

The concept of dynamic capabilities, introduced by RBT, pertains to a company's capacity to effectively incorporate, construct, and adapt internal and external skills to tackle swiftly evolving circumstances. Digital transformation (DT) is a dynamic capability that allows organizations to create adaptable and flexible processes, systems, and structures [38]. Adaptability is essential for promoting innovation, enabling companies to react quickly to shifts in the market, new technology, and client needs. In addition, RBT asserts that sustained competitive advantage is derived from resources that possess value rarity and are challenging to replicate [44]. Digital transformation (DT) can provide distinctive skills, such as sophisticated analytics, artificial intelligence, and instantaneous data processing, significantly improving a company's innovation ability. Efficiently managing and strategically utilizing digital resources allows companies to innovate, adjust to evolving conditions, and sustain a competitive edge in the digital age. This study examines the impact of digital transformation (DT) on company innovation by analyzing data from industrial companies listed in the Chinese A-share market. We thus have the following hypothesis:

H2: DT is positively associated with innovation.

3.3 The Influence of Digital Transformation

Managers must strategically choose, cultivate, and combine all valuable resources to establish company management capabilities. Grant (1991) defines capabilities as the amalgamation of resources that are the foundation for organizations to generate and maintain value and competitive advantages. These material and intangible resources are combined to cultivate capabilities[48]. For example, integrating technology, scientific equipment, and human resources results in establishing research and development capacities. Organizations must comprehend the connections between resources, capabilities, and performance to determine their strengths and shortcomings [45].

Effective identification and management of digital transformation (DT) are crucial for successful innovation. Digital transformation (DT) involves the application of artificial intelligence (AI), big data, cloud computing, and blockchain technology to achieve different corporate goals, such as innovation [39]. Furthermore, digital transformation (DT) improves intellectual capital (IC) resources, establishing a favorable feedback loop where DT encourages the generation and advancement of IC, ultimately contributing to innovation.

Digital transformation (DT) processes play a crucial role in preserving competitive advantages within manufacturing companies, mainly due to the industry's distinct difficulties in embracing novel procedures and practices. For instance, artificial intelligence (AI), big data, cloud computing, and blockchain have the potential to optimize and improve management procedures, thereby adding value to the organization's intellectual assets and promoting innovation. DT enhances human capital by utilizing AI and big data to improve employees' learning efficiency, fostering a competitive environment that motivates them to work harder and think more strategically. This ultimately leads to increased business creativity[36].

Moreover, DT enhances business connections with other parties, enabling prompt communication and precise forecasts. By leveraging big data and AI technologies, companies can accurately forecast product demand, reducing transportation costs and improving operational efficiency. Digital technologies aid companies in preserving their financial well-being while enhancing their connections with funding sources. As a result, DT improves the amount of relational capital, leading to a higher level of corporate creativity. A limited amount of research has investigated the role of DT in influencing the connection between IC and innovation. Buenechea-Elberdin et al. (2018) emphasized the need to consider the technological level of companies as a variable that influences the relationship between intellectual capital (IC) and innovation[49]. This should be considered in future studies. Consequently, companies are highly interested in the methods by which intellectual capital (IC) might be utilized for innovation and the influence that digital technology (DT) has in this procedure. Consequently, our objective is to investigate the impact of intellectual capital (IC) on innovation in manufacturing companies, considering the moderating influence of dynamic capabilities (DT). Based on the discussion above, we expect the following:

H3. DT positively moderates the relationship between IC and innovation.

Figure 1 illustrates the relationships between Chinese firms' intellectual capital (IC), invention, and digital transformation (DT). It posits that components of IC—human capital efficiency (HCE), structural capital efficiency (SCE), and relational capital efficiency (RCE)—positively influence invention categories such as utility models, designs, and inventions. The model also highlights a bidirectional relationship between IC and DT, suggesting that advancements in digital technologies like AI, blockchain, big data, and cloud computing enhance IC, which drives further digital transformation.

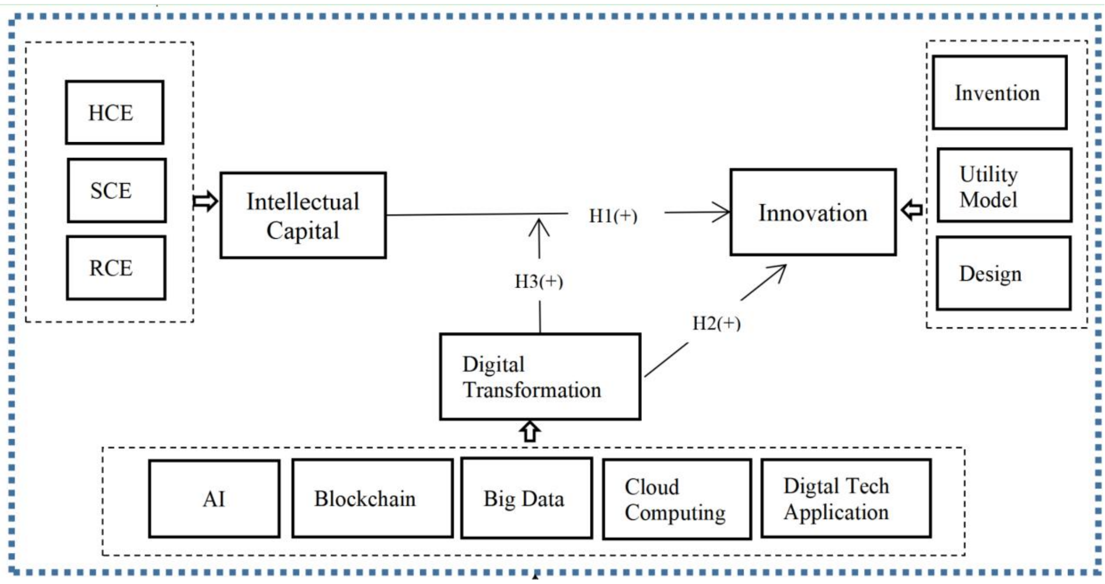

Figure 1 The Research Framework of This Study

4 METHODOLOGY

The research framework, founded on antecedent literature and theoretical underpinnings, directs the selection of variables and data collection procedures. This study employs a quantitative approach and utilizes data from manufacturing firms listed on the A-share market in Shenzhen from 2013 to 2023. The selection of this dataset is strategic, as it is consistent with the research's emphasis on a sector essential to China's economic landscape. In 2013, a critical juncture occurred when listed firms were required to disclose patent information, facilitating a thorough examination of innovation. Data on financial indicators, innovation metrics, and digital transformation elements were obtained from reputable sources, such as the CSMAR database and the official website of the Shenzhen Stock Exchange. The extraction of digital transformation data from annual reports was facilitated by Python programming, which employed predetermined keywords indicative of digital technologies prevalent in the manufacturing sector. The study assures temporal depth and breadth to elucidate the dynamics of IC, DT, and innovation over the study period by combining these disparate datasets to construct a robust sample of 5140 observations.

The methodology explores the operationalization of critical constructs and the establishment of measurement mechanisms in greater detail. Human capital, structural capital, and relational capital are the three dimensions through which intellectual capital (IC) is operationalized. These dimensions are quantified using established proxies, including the complexity of the organizational structure, employee education levels, and marketing expenditure. Annual reports implement a systematic keyword-based search strategy to identify digital transformation (DT) elements, including artificial intelligence, big data, cloud computing, blockchain, and digital technology applications. Ensuring exhaustive coverage of pertinent digital technologies, these keywords are derived from a synthesis of academic literature, public policies, and market reports. The number of patents submitted by firms, encompassing inventions, designs, and utility models, is the operationalization of innovation, the focal outcome variable. This quantitative indicator is a tangible representation of firms' technological advancements and inventive activity. This study elucidates the complex relationship between IC, DT, and innovation using thorough statistical analyses and data processing techniques. It provides valuable insights into the mechanisms that drive innovation in China's manufacturing sector.

4.1 Data and Sample

We used the sample of manufacturing firms listed on the A-share Shenzhen Stock Exchange. The data we analyzed spanned from 2013 to 2023. The emphasis on the manufacturing sector stemmed from China's position as the leading manufacturing nation worldwide. This sector is highly knowledge-intensive, rapidly expanding, and crucial to the Chinese economy[50].

We obtained financial and innovation data from the China Stock Market & Accounting Research (CSMAR) database. Data for digital transformation (DT) was collected using Python programming to extract information from the official website of the Shenzhen Stock Exchange. The annual reports were initially extracted using Python, and a content analysis was then conducted based on predefined DT elements. We did not include Special Treatment (ST and ST*) firms in the sample. We performed data cleaning and processing using Stata, where we eliminated observations with missing data and excluded the top 1% of outliers to ensure the reliability of our results. Combining the CSMAR data and the findings from the content analysis, we created a thorough dataset consisting of 5,140 observations spanning from 2013 to 2023.

4.2 Measurement of IC

Most prior studies have measured intellectual capital (IC) through three elements: human capital, structural capital, and relational capital [21]. Building on this established framework, our paper also considers these three main components of IC: human capital, structural capital, and relational capital. The calculation of the IC model is as follows:

The initial step involves assessing the company's capacity to generate value added (VA) for all parties involved. Building on prior research [21,22,35], VA can be expressed as follows: $VA=S-B$ (1)

where S is net sales revenues (output); B is the cost of goods sold (input).

4.2.1 Human capital (HCE)

The concept of human capital encompasses a range of valuable attributes such as knowledge, experiences, skills, productivity, and employee competence. Various researchers have extensively studied these attributes [21.22.35]. HCE is calculated as: $HCE = VA/HC$ (2)

HC refers to employee compensation at a specific moment, as discussed by various researchers. HCE reflects the value of VA produced per dollar invested in HC.

4.2.2 Structural capital (SCE)

IC items, including strategy, organizational networks, patents, and brand names, are all included in structural capital (SC). Based on past research, this paper calculates SCE as follows: $SCE = SC/VA$ (3)

SC is calculated by subtracting HC from VA. Consequently, SCE serves as an indicator of the value of SC within the organization for each dollar of value generated. As HCE increases, SCE also increases.

4.2.3 Relational capital (RCE)

Relational capital encompasses connections with stakeholders, including suppliers, clients, governments, and the broader society. It also includes additional relational assets such as firm image and customer loyalty. We used marketing, selling, and advertising expenses to proxy relational capital. Relational capital efficiency (RCE) was calculated as the ratio of these expenses to value-added (VA).

This study measures RCE as follows: $RCE=RC/VA$ (4)

RC refers to relational capital, assessed through marketing, selling, and advertising expenditures, while RCE denotes relational efficiency. IC comprises four individual efficiencies and encompasses the aggregation of these three efficiencies: $IC= HCE + SCE+RCE$ (5)

Enhanced IC signifies increased efficiency in utilizing intellectual capital resources, resulting in more significant value generation for the firm.

4.2.4 Measurement of digital transformation

This study employed the Python programming language to collect DT data from manufacturing firms' annual reports on the Shenzhen Stock Exchange. The selection of relevant keywords about DT characteristics was informed by scholarly research and practical market insights. Drawing from academic literature [51] governmental policies, and analytical reports (such as 'The Implementation Plan for Promoting the Actions of 'Migrating to Cloud, Using Digital Tools and

Enable Intelligence and Fostering the Development of New Economy'; 'Reports On The Work of The Government'; 'The 2020 Digital Trends Report'), five essential elements (i.e., AI, Big data, Cloud computing, Blockchain, Digital tech application) along with associated keywords for each DT component were identified. Using Python, the researchers searched for the predetermined keywords in the annual reports to assess the overall frequency count of DT-related keywords for each observation annually, thereby capturing the degree of DT.

Table 1 presents a comprehensive compilation of key words associated with different facets of digital transformation (DT), including Artificial Intelligence (AI), Big Data, Cloud Computing, Blockchain, and Digital Tech Application. Each category encompasses a wide array of terms that reflect the diverse technological landscape within DT. For instance, under AI, terms such as machine learning, deep learning, and natural language processing signify advanced techniques utilized in AI applications, showcasing its sophistication across domains like business intelligence and data analysis. Similarly, the Big Data section features keywords like data mining and data visualization, emphasizing the significance of processing large datasets for valuable insights, spanning applications from text mining to augmented reality. Cloud Computing terms range from stream computing to green computing, showcasing the versatility of cloud-based solutions in real-time data processing and energy efficiency. Blockchain-related keywords, including distributed computing and intelligent financial contracts, underscore its role in secure transactions and financial services. Lastly, Digital Tech Application keywords like mobile internet and smart transportation highlight the pervasive influence of digital technologies in modern life, encompassing areas from e-commerce to smart city initiatives.

Table 1 Keywords of DT

Elements	Keywords
AI	AI, business intelligence, image understanding, investment decision support systems, intelligent data analysis, intelligent robots, machine learning, deep learning, semantic search, biometric technology, face recognition, speech recognition, identity verification, automatic driving, natural language processing
Big Data	Big data, data mining, text mining, data visualization, heterogeneous data, credit checking, augmented reality, mixed reality, virtual reality
Cloud Computing	Cloud computing, stream computing, graph computing, memory computing, multi-party secure computing, brain-inspired computing, green computing, cognitive computing, converged architecture, hundreds of millions of concurrency, exabytes of storage, internet of things, cyber-physical systems
Blockchain	Blockchain, digital currency, distributed computing, differential privacy technology, smart financial contracts
Digital Tech Application	Mobile internet, industrial internet, internet medical, E-commerce, mobile payment, third-party payment, NFC payment, smart energy, B2B, B2C, C2B, C2C, O2O, network union, smart wear, smart agriculture, smart transportation, smart customer service, smart home, smart investment, smart environmental protection, smart marketing, digital marketing, internet finance, digital finance, fintech, financial technology

4.2.5 Measurement of innovation

Drawing from prior studies[51] this research assessed innovation levels by examining the number of patents generated by firms. The study included three patent types: inventions, designs, and utility models produced by the firms. Data on innovation were gathered from the CSMAR database. The decision to utilize patent counts, covering inventions, designs, and utility models, was aligned with the research objectives, which aimed to elucidate the impact of input intellectual capital (IC) on innovation outcomes, as well as the mediating role of digital transformation (DT) in this relationship. The choice of patent counts as a measure of innovation output has been widely accepted within the research community, thus making it a suitable metric for assessing innovation outcomes in this study.

4.2.6 Empirical models to test hypotheses

This paper developed the following models to test the main hypotheses of this study:

$$INNO_{j,t}=\beta_0+\beta_1IC_{j,t}+\beta_{2\text{-}8}Controls_{j,t}+\varepsilon_{j,t} \quad (1)$$

$$INNO_{j,t}=\beta_0+\beta_1DT_{j,t}+\beta_{2\text{-}8}Controls_{j,t}+\varepsilon_{j,t} \quad (2)$$

$$INNO_{j,t}=\beta_0+\beta_1IC_{j,t}+\beta_2DT_{j,t}+\beta_3DT_{j,t}*IC_{j,t}+\beta_{4\text{-}10}Controls_{j,t}+\varepsilon_{j,t} \quad (3)$$

Where $INNO_{j,t}$ represents the firm's innovation in firm j, year t, measured by ln (total number of patents +1). $IC_{j,t}$ represents the intellectual capital in firm j, year t, measured by the sum of human, structural, and relational capital. $DT_{j,t}$ is the overall frequency count of the key words related to DT elements in table 1, measured by ln (total number of DT feature words+1). $DT_{j,t}*IC_{j,t}$ represents the interaction between DT and IC. The control variables in this study include $Sales_{j,t}$, which is measured according to the sales growth of firm j in year t; $Size_{j,t}$ is measured using the natural logarithm of the total assets of firm j in the beginning of year t; $IND_{j,t}$ is measured according to the percentage of independent directors on the board; $Education_{j,t}$ is measured according to the number of years of overseas education experience that managers have; and $R\&D_{j,t}$ is measured according to the R&D expenses divided by the total sales of firm j, year t. $Leverage_{j,t}$ is the leverage ratio of firm j, year t, and $ROA_{j,t}$ is the return on assets of firm j, year t.

5 RESULTS

5.1 Main Findings

Table 2 presents the correlations among the variables under study, providing insights into the relationships between intellectual capital (IC), digital transformation (DT), innovation, and other firm-specific characteristics. INNOj,t, ICj,t, and DTj,t are positively correlated with each other. Specifically, the correlation between INNOj,t, and ICj,t is 0.027 (p =

0.052), and between INNOj,t, and DTj,t is 0.020 ($p = 0.001$), indicating significant relationships. Moreover, ICj,t and DTj,t are positively correlated (correlation = 0.082, $p = 0.000$), suggesting a complementary relationship between intellectual capital and digital transformation. Additionally, R&D expenditure demonstrates a significant positive correlation with both innovation ($r = 0.022$, $p < 0.05$) and intellectual capital ($r = 0.074$, $p < 0.001$), highlighting the importance of research and development activities in fostering innovation and building intellectual capital. Conversely, leverage exhibits a weak and insignificant correlation with most variables, implying that firms' financial leverage may not strongly influence innovation, intellectual capital, or digital transformation. These correlations provide valuable insights into the interrelationships among crucial variables and offer a foundation for further multivariate analysis to elucidate the underlying mechanisms driving firm-level innovation in the context of intellectual capital and digital transformation.

Table 2 Descriptive Statistics and the Correlations of the Variables

	$INNO_{j,t}$	$IC_{j,t}$	$DT_{j,t}$	$Education_{j,t}$	$R\&D_{j,t}$	$Leverage_{j,t}$	$Size_{j,t}$	$Growth_{j,t}$	$ROA_{j,t}$	$IND_{j,t}$
$INNO_{j,t}$	1.000									
$IC_{j,t}$	0.027^{*}	1.000								
	(0.052)									
$DT_{j,t}$	0.020^{***}	0.082^{***}	1.000							
	(0.001)	(0.000)								
$Education_{j,t}$	0.020	0.029^{**}	-0.004	1.000						
	(0.153)	(0.036)	(0.795)							
$R\&D_{j,t}$	0.022	0.074^{***}	0.176^{***}	0.054^{***}	1.000					
	(0.116)	(0.000)	(0.000)	(0.000)						
$Leverage_{j,t}$	-0.008	-0.021	-0.003	-0.008	-0.008	1.000				
	(0.554)	(0.127)	(0.808)	(0.547)	(0.547)					
$Size_{j,t}$	0.103^{***}	0.071^{***}	0.112^{***}	0.047^{***}	0.116^{***}	0.056^{***}	1.000			
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)				
$Growth_{j,t}$	0.009	-0.020	0.001	-0.021	0.060^{***}	0.007	-0.036^{**}	1.000		
	(0.582)	(0.210)	(0.936)	(0.179)	(0.000)	(0.683)	(0.025)			
$ROA_{j,t}$	0.033^{***}	0.416^{***}	-0.017	0.020	0.014	-0.104^{***}	-0.063^{***}	-0.049^{***}	1.000	
	(0.019)	(0.000)	(0.216)	(0.153)	(0.329)	(0.000)	(0.000)	(0.002)		
$IND_{j,t}$	0.039^{***}	0.057^{***}	0.047^{***}	-0.036^{**}	0.043^{***}	0.026^{*}	0.011	0.027^{*}	-0.012	1.000
	(0.005)	(0.000)	(0.001)	(0.010)	(0.002)	(0.060)	(0.442)	(0.094)	(0.371)	

Note: p statistics in parentheses.
$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 3 provides a comprehensive overview of the H1, H2, and H3 regression outcomes. As indicated in the table, the results confirm hypotheses H2 and H3, as both digital transformation (DTj,t) and its interaction with intellectual capital (DTj,t*ICj,t) have substantial positive coefficients about innovation (INNOj,t). Specifically, DTj,t exhibits a significant positive effect on INNOj,t (coefficient=0.245; p=0.050), as shown in Model 2, while the interaction term DTj,t*ICj,t demonstrates an even more substantial impact (coefficient=0.288; p=0.004), as depicted in Model 3. Additionally, although intellectual capital (ICj,t) shows a slightly significant positive relationship with innovation (INNOj,t) in Model 1 (coefficient=1.177; p=0.089), this effect becomes statistically insignificant when considering the interaction with digital transformation. These findings highlight the facilitating role of digital transformation in enhancing intellectual capital and fostering firm innovation. Moreover, the inclusion of control variables such as Educationj,t, R&Dj,t, Leveragej,t, Sizej,t, Growthj,t, ROAj,t, and INDj,t in the regression models unveils further insights into the determinants of innovation outcomes. Educationj,t and R&Dj,t demonstrate significant positive impacts on innovation, while variables such as Leveragej,t exhibit no considerable influence.

Table 3 The Regression Results of H1, H2, and H3

	Model 1		Model 2		Model 3	
$INNO_{j,t}$	Coef.	P>t	Coef.	P>t	Coef.	P>t
$IC_{j,t}$	1.177^{*}	0.089			2.672	0.137
$DT_{j,t}$			0.245^{**}	0.050	0.628^{*}	0.053
$DT_{j,t}*IC_{j,t}$					0.288^{***}	0.004
$Education_{j,t}$	8.027^{**}	0.035	8.131^{**}	0.032	8.276^{**}	0.029

$R\&D_{j,t}$	1.587**	0.034	1.349*	0.074	1.521**	0.047
$Leverage_{j,t}$	-0.332	0.560	-0.328	0.565	-0.307	0.591
$Size_{j,t}$	6.886	0.394	6.496	0.411	6.851	0.396
$Growth_{j,t}$	2.741***	0.000	2.696***	0.000	2.667***	0.000
$ROA_{j,t}$	1.596*	0.059	1.376*	0.068	1.508*	0.074
$IND_{j,t}$	1.102*	0.057	1.081*	0.062	1.021*	0.078
Year	Yes		Yes		Yes	
N	5140		5140		5140	
Adj R-squared	30%		30%		31%	

Note:*p < 0.10, **p < 0.05, ***p < 0.01.

5.2 Additional Tests

Table 4 reveals the regression findings regarding the three components of intellectual capital (IC) and their interaction with digital transformation (DT) concerning their influence on innovation (INNOj,t). In Model 4, human capital efficiency (HCEj,t) and structural capital efficiency (SCEj,t) exhibit significant relationships with INNOj,t (HCEj,t coefficient=2.861, p=0.087; SCEj,t coefficient=2.955, p=0.063), while relational capital efficiency (RCEj,t) demonstrates a positive yet insignificant association. Conversely, Model 5 delves into the interaction effects, revealing that HCEj,t*DTj,t (coefficient=0.793, p=0.000) and SCEj,t*DTj,t (coefficient=2.399, p=0.006) significantly bolster innovation, emphasizing the role of digital transformation in amplifying the impact of human and structural capital on innovation. However, the interaction term RCEj,t*DTj,t does not yield significant results. Additionally, control variables such as Educationj,t, R&Dj,t, Sizej,t, Growthj,t, ROAj,t, and INDj,t demonstrate varying degrees of significance across models, further elucidating their contributions to innovation outcomes. Overall, Model 5 exhibits a superior explanatory power (33%) compared to Model 4 (29%), underlining the added value of incorporating interaction terms in understanding the drivers of innovation in the context of intellectual capital and digital transformation.

Table 4 The Regression Results of Three IC Elements

	Model 4		Model 5	
$INNO_{j,t}$	Coef.	P>t	Coef.	P>t
$HCE_{j,t}$	2.861*	0.087	6.430***	0.009
$SCE_{j,t}$	2.955*	0.063	3.341**	0.021
$RCE_{j,t}$	3.213	0.130	4.876*	0.080
$DT_{j,t}$			0.216	0.586
$HCE_{j,t}*DT_{j,t}$			0.793***	0.000
$SCE_{j,t}*DT_{j,t}$			2.399***	0.006
$RCE_{j,t}*DT_{j,t}$			0.809	0.443
$Education_{j,t}$	7.719**	0.043	8.084**	0.034
$R\&D_{j,t}$	1.468**	0.050	1.406*	0.067
$Leverage_{j,t}$	-0.325	0.571	-0.304	0.596
$Size_{j,t}$	9.335	0.257	9.506	0.248
$Growth_{j,t}$	2.535***	0.001	2.440***	0.001
$ROA_{j,t}$	1.959**	0.025	1.956**	0.025
$IND_{j,t}$	1.107*	0.056	1.065*	0.066
Year	Yes		Yes	
N	5140		5140	
Adj R-squared	29%		33%	

Note:*p < 0.10, **p < 0.05, ***p < 0.01.

The province of Guangdong is the source of the most significant number of observations in our sample, with 28%. Guangdong has pioneered the new development concept in recent years, leading initiatives to promote dynamic transformation, efficiency improvement, and qualitative change. The province has been actively pursuing high-quality development to improve standards in various areas, such as efficiency, fairness, sustainability, and security. It is worth noting that Guangdong has been at the forefront of national efforts to promote innovation-driven development and digital transformation (DT). The province has experienced a significant increase in research and development (R&D) expenditure during the 13th Five-Year Plan period, with a rise from CNY 180 billion to CNY 320 billion. This increased its proportion of GDP from 2.4% to 2.9%. This substantial investment has catapulted the province to the vanguard of regional innovation prowess, as evidenced by a significant increase in valid invention patents and PCT international patent applications. Guangdong is home to seven trillion-level industrial clusters encompassing various industries, including electronics information, green petrochemicals, intelligent home appliances, and advanced materials. Guangdong has transitioned from "old manufacturing" to "intelligent manufacturing" with over 55,000 large-scale industrial enterprises, solidifying its pivotal position in China's innovation landscape. As a result, this paper explores the complex relationship between intellectual capital (IC), digital transformation (DT), and innovation in the dynamic context of Guangdong province.

Table 5 presents the regression results of hypotheses specifically tailored for Guangdong province, offering valuable insights into the dynamics of intellectual capital (IC), digital transformation (DT), and their influence on innovation (INNOj,t) within this region. In Model 6, ICj,t emerges as a significant predictor of innovation, with a positive coefficient (Coef. = 3.601; p = 0.039), underscoring the role of intellectual capital in driving innovative endeavors within Guangdong. However, DTj,t fails to achieve statistical significance in this model, suggesting that standalone digital transformation may not significantly impact innovation within the province. Intriguingly, in Model 7, the interaction term DTj,t*ICj,t exhibits statistical significance (Coef. = 1.080; p = 0.000), indicating that the combined effect of digital transformation and intellectual capital significantly enhances innovation outcomes in Guangdong. This finding underscores the synergistic relationship between DT and IC, highlighting the importance of leveraging both factors in driving innovation within the province's dynamic ecosystem. Furthermore, control variables such as Educationj,t and R&Dj,t demonstrate varying degrees of significance across models, emphasizing their respective impacts on innovation outcomes. Model 8 exhibits the highest adjusted R-squared value (49%), indicating that including interaction terms substantially enhances the model's explanatory power, providing a more comprehensive understanding of the factors driving innovation within Guangdong province.

Table 5 The regression results of hypotheses for Guangdong province

Guangdong Province						
	Model 6		Model 7		Model 8	
$INNO_{j,t}$	Coef.	P>t	Coef.	P>t	Coef.	P>t
$IC_{j,t}$	3.601^{**}	0.039			1.210	0.869
$DT_{j,t}$			0.309^{*}	0.067	2.674^{***}	0.002
$DT_{j,t}*IC_{j,t}$					1.080^{***}	0.000
$Education_{j,t}$	5.499^{*}	0.055	6.480^{*}	0.060	6.518^{*}	0.056
$R\&D_{j,t}$	0.607^{**}	0.016	0.538^{**}	0.040	1.226^{**}	0.047
$Leverage_{j,t}$	-0.307	0.848	-0.038	0.981	-0.132	0.934
$Size_{j,t}$	3.558	0.208	5.345^{**}	0.047	3.585	0.203
$Growth_{j,t}$	4.669^{*}	0.073	2.990	0.228	4.501^{*}	0.082
$ROA_{j,t}$	0.820	0.779	3.805	0.141	1.812	0.536
$IND_{j,t}$	1.315	0.494	1.064	0.580	0.885	0.645
Year	Yes		Yes		Yes	
N	1445		1445		1445	
Adj R-squared	41%		38%		49%	

Note:*p < 0.10, **p < 0.05, ***p < 0.01.

Table 6 presents regression results examining the influence of COVID-19 on intellectual capital (IC), digital transformation (DT), and their interaction, alongside other control variables, on innovation (INNOj,t). The findings reveal nuanced relationships between these factors and innovation outcomes. Initially, in Model 10 and Model 11, COVID exhibits a negative and statistically significant coefficient (Model 10: coefficient= -1.837; p=0.028; Model 11: coefficient= -2.893; p=0.014), indicating that the presence of COVID-19 has a detrimental impact on innovation. However, the interaction term COVID*$DT_{j,t}$ yields intriguing results, with a negative and significant coefficient in Model 10 (coefficient= -0.061; p=0.037), suggesting that COVID-19 impedes the ability of digital transformation to foster innovation. Notably, Model 11 introduces the interaction term DTj,t*ICj,t, which exhibits a positive and statistically significant coefficient (coefficient= 0.286; p=0.004), indicating that the combined effect of digital transformation and intellectual capital positively influences innovation outcomes, albeit COVID-19's presence. However, the interaction term COVID*DTj,t*ICj,t does not attain statistical significance, suggesting that the joint impact of COVID-19, digital transformation, and intellectual capital on innovation is insignificant. Additionally, control variables such as Educationj,t and R&Dj,t demonstrate varying degrees of significance across models, emphasizing their respective impacts on innovation outcomes. Notably, Model 11 achieves the highest adjusted R-squared value (33%), indicating that the inclusion of interaction terms substantially enhances the explanatory power, providing deeper insights into the complex interplay between COVID-19, IC, DT, and innovation.

Table 6 The Regression Results of COVID-19

	Model 9		Model 10		Model 11	
$INNO_{j,t}$	Coef.	P>t	Coef.	P>t	Coef.	P>t
$IC_{j,t}$	0.719	0.698			2.582	0.150
COVID	-2.959	0.369	-1.837^{**}	0.028	-2.893^{**}	0.014
$COVID*IC_{j,t}$	1.499	0.687				
$DT_{j,t}$			0.203^{*}	0.075	0.724^{**}	0.029
$COVID*DT_{j,t}$			-0.061^{**}	0.037		
$DT_{j,t}*IC_{j,t}$					0.286^{***}	0.004
$COVID*DT_{j,t}*IC_{j,t}$					0.092	0.294
$Education_{j,t}$	7.686^{**}	0.040	7.753^{**}	0.038	7.847^{**}	0.036
$R\&D_{j,t}$	1.411^{*}	0.058	1.174	0.119	1.359^{*}	0.075
$Leverage_{j,t}$	-0.388	0.497	-0.377	0.509	-0.355	0.533
$Size_{j,t}$	8.388	0.297	8.001	0.309	8.036	0.317
$Growth_{j,t}$	2.481^{***}	0.001	2.427^{***}	0.001	2.409^{***}	0.001
$ROA_{j,t}$	1.714^{**}	0.042	1.527^{**}	0.042	1.605^{*}	0.057
$IND_{j,t}$	1.073^{*}	0.064	1.054^{*}	0.069	0.988^{*}	0.088
N	5140		5140		5140	
Adj R-squared	28%		28%		33%	

Note: *p < 0.10, **p < 0.05, ***p < 0.01.

5.3 Robustness Tests

We utilized Partial Least Squares Structural Equation Modeling (PLS-SEM) to ensure the reliability of our findings. Smart PLS 3.0 software was employed for hypothesis testing, using the bootstrapping method with 5,000 subsamples. Additionally, we explored the lag effect within our models by substituting the dependent variable ($INNO_{j,t}$) with $INNO_{j,t+1}$, $INNO_{j,t+2}$, and $INNO_{j,t+3}$, respectively. The results of our robustness tests, available upon request, indicate qualitative consistency with our primary findings. Notably, the relationship among intellectual capital (IC), digital transformation (DT), and innovation exhibit greater significance when the dependent variable is extended to $INNO_{j,t+2}$ and $INNO_{j,t+3}$.

6 DISCUSSION

In recent years, the intersection of innovation, Digital Transformation (DT), and Intellectual Capital (IC) has become a critical area of research within the context of strategic development and organizational management (Izzo et al.,2022). Intellectual capital encompasses an organization's collective knowledge, expertise, and intangible assets and has been acknowledged as a critical factor in establishing a competitive advantage and innovation. Simultaneously, the rapid development of digital technologies has prompted significant transformations in various sectors, reshaping business processes, consumer interactions, and value propositions. Firms that strive to navigate a dynamic and increasingly digitized business landscape are presented with new opportunities and challenges by the synergy between IC and DT. It is imperative for organizations that are endeavoring to remain relevant and prosper in the current fiercely competitive market to comprehend how these elements interact and impact innovation outcomes.

This study aimed to examine the impact of Intellectual Capital (IC) on innovation and the role of Digital Transformation (DT) and political connections in enhancing the effects of IC on innovation. Our research examined IC and DT in individual and collective contexts within Chinese manufacturing firms, contributing to the IC literature. Our analysis indicated that innovation was positively influenced by both IC and DT and that DT moderated the relationship between IC and innovation positively. Additionally, we observed that Human Capital Efficiency (HCE) had a beneficial impact on innovation. Furthermore, Structural Capital Efficiency (SCE) had a direct positive effect on innovation, which posited that structural capital was a critical factor in the exploitation process to facilitate innovation production. This study underscored the significance of integrating IC components and DT, as these strategies had the potential to optimize the impact of IC elements on innovation and support each other. The interaction between IC and DT functioned as a strategic management toolbox for innovation.

Based on the findings of this study, several recommendations can be proposed to enhance the innovation capabilities. Firstly, organizations should prioritize investments in intellectual capital (IC), particularly human and structural capital, as these elements have been identified as significant drivers of innovation. Efforts should be made to recruit and retain talented individuals and develop organizational structures and processes that facilitate knowledge creation and sharing. Additionally, recognizing the crucial role of digital transformation (DT) in moderating the relationship between IC and innovation, businesses should embrace technological advancements and integrate digital strategies into their operations.

This may involve adopting new digital tools and platforms, enhancing data analytics capabilities, and fostering a culture of innovation and experimentation. Moreover, policymakers and industry stakeholders should consider providing support and incentives to encourage manufacturing sectors where innovation is critical for economic growth. Organizations can position themselves competitively in today's rapidly evolving business landscape by fostering a conducive environment for innovation and digitalization.

This research explores the dynamics of the knowledge-based economy by analyzing the interplay between Intellectual Capital (IC), Digital Transformation (DT), and innovation within Chinese manufacturing firms. It illuminates how economic development and competitiveness are influenced by the creation, diffusion, and application of knowledge at the systemic level. It examines how firms utilize IC and DT to promote innovation and improve their competitive advantage at the organizational level. Furthermore, the role of human capital in fostering organizational success and innovation is investigated at the individual level.

7 CONCLUSION

This study comprehensively analyzes existing literature to explore how Chinese manufacturing firms operate. It focuses on how Intellectual Capital (IC) aligns with Digital Transformation (DT) initiatives to drive innovation in a rapidly evolving market. Additionally, it investigates how political connections affect the intricate relationship between intellectual capital, digital transformation, and innovation. By utilizing data from the A-listed share market in the Shenzhen stock exchange from 2013 to 2023 and employing Python programming to extract relevant information on AI, blockchain, cloud computing, big data, and digital technology applications, the study sheds light on the impact of both intellectual capital (IC) and dynamic capabilities (DT) on innovation. It reveals that dynamic capabilities significantly strengthen the link between intellectual capital and innovation outcomes. The findings suggest that human and structural capital positively influence innovation, with digital technology (DT) further enhancing these effects.

This study on the operational dynamics of Chinese manufacturing firms, particularly their alignment of Intellectual Capital (IC) with Digital Transformation (DT) for innovation, resonates deeply with the context of rapid globalization and technological advancement. In today's knowledge-driven economy, where innovation is pivotal in creating wealth and addressing global challenges, this research contributes valuable insights into how IC and DT intersect to drive innovation. By drawing from diverse disciplines such as economics, management, law, sociology, anthropology, psychology, and political science, the study sheds new light on the evolving role of knowledge in economic development and addresses pressing issues like environmental sustainability and education. By exploring IC and DT's impact on innovation within Chinese manufacturing, this study exemplifies how innovation can be leveraged to address complex global challenges and foster sustainable economic growth.

7.1 Theoretical Implications

The theoretical implications of this study extend to several critical areas within the realms of intellectual capital (IC), digital transformation (DT), and innovation. The findings contribute to the literature by elucidating the interplay between IC and DT strategies in driving innovation within Chinese manufacturing firms, offering a nuanced understanding of their combined effects on organizational performance. Secondly, by highlighting the moderating role of DT on the relationship between IC and innovation, the study enriches theoretical perspectives on dynamic capabilities and their impact on innovation outcomes.

7.2 Managerial Implications

The findings of this study have significant managerial implications for shareholders, managers, and policymakers within Chinese manufacturing firms. Recognizing the pivotal role of Intellectual Capital (IC) and Digital Transformation (DT) in fostering innovation, stakeholders at all levels should prioritize and allocate resources toward implementing IC- and DT-focused strategies and policies. Policymakers, including government officials and those involved in setting accounting standards, can leverage these findings to enforce regulations and incentives that promote innovation driven by IC and DT, thereby capturing the associated economic benefits.

7.3 Ideas for Future Research

Future research avenues stemming from this study's findings may explore several intriguing areas within intellectual capital (IC), digital transformation (DT), and innovation in Chinese manufacturing firms. Firstly, investigating the mediating mechanisms through which IC and DT influence innovation outcomes could provide deeper insights into the underlying processes driving this relationship. Additionally, exploring the role of organizational culture and leadership styles in facilitating the effective integration of IC and DT strategies for innovation could offer valuable managerial insights. Furthermore, longitudinal studies tracking the evolution of IC and DT practices over time and their impact on innovation performance could provide a more comprehensive understanding of their dynamic interplay. Moreover, comparative studies across different industries and regions within China could elucidate industry-specific nuances and regional variations in the relationship between IC, DT, and innovation. Lastly, examining the moderating effects of external environmental factors, such as regulatory frameworks and market competition, on the relationship between IC, DT, and innovation could enrich our understanding of the contextual factors shaping innovation dynamics in Chinese manufacturing firms.

7.4 Limitations

While this study offers valuable insights into the interplay between Intellectual Capital (IC), Digital Transformation (DT), and innovation within Chinese manufacturing firms, several limitations should be acknowledged. Firstly, the research is constrained by the availability and scope of the data collected from the A-listed share market in the Shenzhen stock exchange, which may not fully capture the diversity of firms operating in the sector. Additionally, the study's focus on a specific time frame from 2013 to 2023 may limit the generalizability of the findings to other periods characterized by different economic conditions or technological landscapes. Moreover, the analysis primarily relies on secondary data, which may be subject to inherent biases or inaccuracies. Furthermore, while efforts were made to control for relevant variables, there may still be unobserved factors influencing the relationships examined in the study. Finally, the study's methodology, including the use of Python programming for data extraction and analysis, may introduce technical challenges or limitations that could affect the robustness of the results.

COMPETING INTERESTS

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