Corporate transformation toward Industry 4.0 and financial performance: The influence of environmental, social, and governance (ESG)

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Corporate transformation toward Industry 4.0 and financial performance: The influence of environmental, social, and governance (ESG)

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Highlights

- A unique measure for corporate transformation toward Industry 4.0.
- Corporate transformation toward I4.0 in the UK is increasing over time.
- CTTI4.0 can be viewed as enablers of the circular economy.
- Corporate transformation toward I4.0 positively affects financial performance.
- ESG strengthen this relationship.

Abstract

Despite the importance of corporate transformation toward Industry 4.0 (CTTI4.0), almost no research exists on how companies communicate CTTI4.0 information in their annual reports and how this affects financial performance. To fill this gap, this paper uses computer-aided textual analysis to explore the current practices of CTTI4.0 in the UK context. It also uses quantitative analysis to examine the impact of CTTI4.0 information on financial performance. The analysis shows that strategic investment decision-making (SIDM) practices for CTTI4.0 have accelerated over the period, and these practices vary in industry sectors. Furthermore, it finds that CTTI4.0 disclosure has a positive impact on financial performance. In addition, it finds that environmental, social, and governance (ESG) practices moderate the relationship between CTTI4.0 disclosure and financial performance. This indicates that firms with better ESG performance tend to be more engaged in CTTI4.0 disclosure and better financial performance simultaneously. Our findings offer insights to decision-makers and regulatory bodies regarding the current practices of CTTI4.0 and its potential economic impact.

Paper type: Research paper.

Keywords: Business model, transformation, Industry 4.0, financial performance, ESG, strategic investment, decision-making, circular economy, UK, companies

1. Introduction

Over the last decade, companies have witnessed the transformation of their core manufacturing activities, including product planning and development, supply chain management procurement, and marketing. These transformations have been underpinned by investing in Industry 4.0 (I4.0) mechanisms (Jabbour et al., 2019; Chen et al., 2020). Recent research (e.g., de Sousa Jabbour et al., 2018) developed a conceptual framework incorporating I4.0 mechanisms and a circular economy. These two paradigms gained the interest of wider stakeholders, including communities, scholars, governments, decision-makers, practitioners, regulatory bodies, and standard setters worldwide. Although conceptual frameworks highlighting the links between the two perspectives continue to evolve, these two paradigms have remained topical in driving academia and industry in recent years (Rosa et al., 2020; Awan et al., 2021).

While there is much evidence that the concept of I4.0 has had a wide-ranging impact at the discursive level, the currently available research is less clear about what impact the concept has had thus far on industries (Madsen, 2019). Buer et al. (2018) proposed a research agenda that guides future I4.0 research and encourages researchers to examine many companies aiming to transform their operations using emerging I4.0 mechanisms. They also raised a call for empirical research to explore the influence of I4.0 mechanisms on organizational performance. Furthermore, researchers highlighted the sustainable vision of I4.0 and called for further research to fuse and explore these two paradigms comprehensively (Okorie et al., 2018; Machado et al., 2019). Based on a systematic review, Machado et al. (2019) attempted to identify how sustainable manufacturing research contributes to developing the I4.0 agenda by a broader understanding of the links between sustainable manufacturing and I4.0. A key objective of I4.0 is to improve the profitability of the manufacturing sector (Fuchs, 2018). However, there has been almost no research on I4.0-related information in annual reports and its impact on financial performance. Our paper aims to fill this research gap.

The UK provides a unique context for this study for many reasons. First, in 2013, a long-term action plan for the manufacturing industry in the UK called the 'Future of Manufacturing' was implemented (Foresight, 2013). The global market for energy efficiency has been estimated at US$1.2 trillion by 2020 (Foresight, 2013), with the UK placed to capture value in the efficient production, transport, and building efficiency sectors as well as alternative fuels and water treatment technologies. The strategic development of intellectual property to support this, in the form of a business model and technological innovation, will improve companies' financial performance and create economic value. Second, the UK employs almost three million people in its various guises and contributes approximately half of UK exports. There is little evidence to suggest that UK companies are engaging with the essential circular economy agenda at the scale necessary to proactively or productively capture value from the future value given the more profound sustainability challenges that are projected to arise. Third, UK companies combine the comprehensive integration of manufacturing systems, production processes, digital communication technologies, automated machines, and other I4.0 mechanisms to make supply chains and production processes more interconnected, efficient, and flexible, allowing mass customization virtual production (Alkaraan, 2021). Fourth, government strategies predominantly drive guidelines for I4.0 implementation. Examples of sustainability guidelines for I4.0 within the UK context include minimizing material inputs, waste management, reduced water usage, energy efficiency, low-carbon technologies, supply chains with spare capacity, material that is not land-filled but kept in productive loops, and products that use a smaller amount of materials and are close to consumers (see Foresight, 2013).

Narrative disclosure has become increasingly sophisticated over the last decade. It allows companies to overcome information asymmetries by presenting more information. Management is assumed to strategically 'select... the information [in corporate narrative documents] to display and present... that information in a manner intended to distort readers' perceptions of corporate achievements' (Godfrey, Mather, and Ramsay, 2003, p. 96). The predominant perspective on

impression management in a corporate reporting context is informed by economics-based theories, particularly agency theory (Merkl-Davies and Brennan, 2007). This means that companies reporting on strategic choices, such as CTTI4.0, are taken based on cost-benefit analysis. The paper aims to answer three research questions:

- RQ1: What is the current trend of CTTI4.0?
- RQ2: What is the influence of CTTI4.0 on financial performance?
- RQ3: Does ESG moderate the relationship between CTTI4.0 and financial performance?

To answer RQ1, we use textual analysis to identify CTTI4.0 disclosure in narrative sections of UK annual reports from 2013 to 2018. We use descriptive analysis to show the trends of this type of disclosure over time and among industries. We have supported our research using extracts from companies' annual reports. The study uses regression models to answer RQ2 and RQ3.

The study offers notable contributions to the existing literature. First, we provide a new measure for CTTI4.0 disclosure. Second, we are the first to explore CTTI4.0 disclosure in the UK context and show that CTTI4.0 disclosure practice accelerated over the sample period, which varies among industry sectors. Third, we provide new empirical evidence that CTTI4.0 disclosure positively impacts financial performance. Finally, we find that ESG practices moderate the relationship between CTTI4.0 disclosure and finance performance. Our findings offer insights to decision-makers and regulatory bodies regarding the current practices of technology road mapping toward I4.0 and its potential economic consequences.

The remainder of the paper is structured as follows. Section 2 reviews the literature and highlights the underlying study rationale. Section 3 outlines the research methodology. Section 4 presents the findings. Section 5 concludes the paper.

2. Literature and theoretical background

I4.0 and circular economy

The concept of I4.0 is relatively new and represents the current production paradigm, which combines information and communication technologies with digital manufacturing technologies. The I4.0 conception was introduced at the 2011 Hannover Fair event in Germany by the working group on a mandate from the Research Union Economy-Science of Germany's Federal Ministry of Education and Research. This indicates the beginning of I4.0, which enjoyed a meteoric rise in popularity and is currently topical with researchers, companies, and governments (de Sousa Jabbour et al., 2018). The key objective of I4.0 is to improve the profitability of the manufacturing sector (Fuchs 2018). Interchangeable concepts of I4.0 are widely used, such as smart manufacturing, digital transformation, and the fourth industrial revolution. The ongoing confusion regarding the concept of I4.0 remains a key barrier for the scope and theoretical foundation of academic investigations (see Osterrieder, Budde, Friedli, 2019; Culot, Nassimbeni, Orzes, and Sartor, 2020).

Since the introduction of I4.0, a growing research mainstream has been published on this concept in different settings using different research paradigms (Culot, Nassimbeni, Orzes, and Sartor, 2021). The underpinning feature of I4.0 is connectivity among machines, orders, employees, suppliers, and customers. I4.0 enables smart manufacturing processes, providing high performance associated with product design, production, and logistic systems through communication between machines and digital devices. The digital transformation processes of industries have been supported by the implementation of four key I4.0 mechanisms: the Internet of Things, cloud computing, big data, and artificial intelligence (see Frank et al., 2019; Benitez et al., 2020; Meindl et al., 2021). Digital transformation has been defined as using new digital technologies, such as *cyber-physical systems*, mobile, artificial intelligence, cloud, blockchain, and the Internet of Things technologies (a computational approach that collects and exchanges data acquired from electronic devices). These I4.0 mechanisms enable significant business improvements to augment customer experiences and streamline operations or create new business models. Zhong, Xu, Klotz, and Newman (2017) viewed cyber-physical systems, the Internet of Things, big data, and cloud

manufacturing as fundamental I4.0 mechanisms. Additive manufacturing, such as 3D manufacturing, represents agile and connected prototyping of parts and products on a large scale, enabling customization (Holmström, Holweg, Khajavi, and Partanen, 2016). Cyber-physical systems enable automation, monitoring, and control processes and objects in real time (Wang, Törngren, and Onori, 2015). The critical characteristics of I4.0 include integrated, adapted, optimized, and interoperable manufacturing processes. I4.0 applications enable real-time monitoring and controlling processes such as production status, energy consumption, the flow of materials, customer orders, and supplier information.

Rosa et al. (2020) highlighted the business model's usefulness for value creation, generating revenue, and reducing costs. I4.0 mechanisms have great potential to reduce impacts on the environment and the opportunity to reduce risk and improve productivity. I4.0 mechanisms enable the transition to a circular economy. For example, the Internet of Things is helpful even in reusing, recycling, and repairing items in many companies. Maintaining synergies between I4.0 mechanisms and the circular economy is the key characteristic of current CTTI4.0 practices.

Socially sustainable issues are inherent in the *United Nations Sustainable Development Goals* (Awan et al. 2018). In 2015, world leaders set out a declaration of commitment to *sustainable development goals* (SDGs) intending to balance the planet's economic, social, and environmental needs by 2030. This includes supporting the international community's vision of increasing sustainability through cleaner technology processes and manufacturing strategies (Kerin and Pham, 2019). Creative thinking has become an important mechanism driving green innovation within organizations and plays a critical role in enhancing sustainability performance (Awan et al., 2019). The circular economy is an economic system that helps accomplish long-term sustainable development goals (Awan, 2019; Awan et al., 2020; Kanwal and Awan, 2020; Awan et al., 2020; Awan et al., 2021a, b). The circular economy is a regenerative system in which resource input and leakage are minimized by slowing, closing, and narrowing material and energy loops (Geissdoerfer et al., 2018). The circular economy is an industrial system that enables renewable energy usage and aims to

eliminate waste through superior materials, products, systems, and business models. This allows decoupling economic growth from finite resource constraints and provides boardrooms with a new strategy for creating value, generating revenue, reducing costs, being resilient, and creating legitimacy (Manninen et al., 2018). This could enhance corporate financial performance.

2.2. CTTI4.0 and SIDM practices and performance

Successful companies are led by effective boards, whose roles are to promote the company's long-term sustainable success, generate value for shareholders, and contribute to society. Conventional business models are based mainly on a linear conception of the value chain. By associating a cost with the end and waste products, a linear value chain can be joined up either with other value chains, as in the industrial integration and collaboration networks, or with itself, as conceived in a "closed-loop," "cradle-to-cradle" or circular economy strategy. These all articulate "3R", the reduce-reuse-recycle waste hierarchy, and apply a different stage, from product to industrial processes. For manufacturing companies to successfully address sustainability issues, a set of different challenges must be managed. Industry reports and examples from company case studies have indicated that it is likely that out to 2020-2030, manufacturing will predominantly emphasize processes and material efficiency instead of completely sustainable solutions.

Furthermore, to sustain, the manufacturing industry will need to develop novel processes, innovations, and methods to meet demanding sustainability targets and create new economic growth (Foresight, 2013). Through the remanufacturing of products, there are opportunities to increase the efficiencies of resources, reduce waste, and support cleaner, more sustainable production. Remanufacturing is a crucial stage of a circular economy. Greater automation and I4.0 mechanism implementation toward I4.0 and a circular economy require significant strategic investment in equipment and infrastructure (Kerin and Pham, 2019).

The revised UK corporate governance code (2018) has reinforced and expanded on the long-standing requirements of the UK Companies Act for directors to remain mindful of their duties to consider the interests of key stakeholders. The objective is to create a shift in focus from meeting short-term financial goals toward a long-term, future-oriented business model and value-based approach to running a company, with CTTI4.0 practices amended in strategic boardroom choices. Such strategic transition requires investment in I4.0 mechanisms such as the industrial Internet of Things, smart manufacturing, digitalization, cloud computing, artificial intelligence, big data, simulation, augmented reality, horizontal and vertical systems integration, autonomous robots, cyber-physical systems, and cybersecurity (Li, 2018; Alcácer and Cruz-Machado, 2019).

SIDM reflects the art and science of steering and controlling organizational resources to achieve the desired strategy. Alkaraan and Northcott (2013) reveal the complex nature of SIDM practices. Contextual factors shape SIDM practices; a comprehensive overview of these factors is necessary to direct SIDM outcomes. Strategic investment projects are substantial investments that involve high levels of risk and produce intangible outcomes with a significant long-term impact on corporate performance. Typical examples include company acquisitions and mergers, the introduction of significant new product lines, installing new manufacturing processes, advanced manufacturing, and business technologies, and substantial shifts in production capability (Northcott and Alkaraan, 2007; Alkaraan and Northcott, 2007; Adel and Alkaraan, 2019). SIDM processes are extensive, multifaceted, and competitively oriented. Successful SIDM practices require reliable, accessible, accurate, consistent, timely, and contextual information (Alkaraan and Northcott, 2006; Alkaraan, 2020). Successful CTTI4.0 practices increase profit, decrease costs, enhance customer experience, optimize, and innovate.

Prior research shows that disclosure correlates with financial performance based on signaling and agency theories (Hassanien and Hussainey, 2015; Hassanein et al., 2019; Albitar et al., 2020). These theories suggest that managers of profitable firms are more likely to voluntarily provide important

information in their annual reports to signal their firms' profitability, increase investors' confidence, and increase their compensation. Therefore, the present study posits the following hypothesis to answer Question 2:

H1: There is a positive relationship between CTTI4.0 *and corporate performance.*

Based on agency theory, prior research also shows that governance affects corporate disclosure (Alnabsha et al., 2018; Alshbili et al., 2019; Elamer et al., 2019; Grassa et al., 2019). Elmagrhi et al. (2019) also provide evidence that governance affects corporate environmental performance. Fatemi et al. (2018) provide evidence that ESG performance positively affects firm performance. Eliwa et al. (2019) find that firms with high ESG performance disclose more ESG-related information. These findings suggest that ESG affects both disclosure and firm performance and, therefore, could strengthen the CTTI4.0-financial performance relationship. We, therefore, hypothesize that:

H2: ESG could strengthen the relationship between CTTI4.0 *and financial performance.*

3. Research method

3.1 Conceptual framework

The conceptual framework underpinning this study draws on theoretical triangulation insights, predominantly corporate social responsibility (CSR) theories: Carroll theory, triple bottom line theory, and stakeholder theory. Carroll's pyramid includes four parts of CSR responsibilities: economic responsibilities (be profitable), legal responsibilities (obey laws and regulations), ethical responsibilities (do what is just and fair, avoid harm), and discretionary (philanthropic) responsibilities (be a good corporate citizen), representing the expectations that society has of organizations at a given point in time (Carroll, 1991). Boardrooms will attest to the importance of profitability and return on investment, including financial effectiveness, cost-effectiveness, investments, operations, and marketing strategies, toward long-term success. In today's global business environment, economic performance and sustainability have become urgent topics.

Companies are required to comply with laws and regulations as a condition of operation. This includes performing in a manner consistent with expectations of government and law, complying with regulatory bodies, and fulfilling all their obligations to societal stakeholders.

Triple bottom line theory (TBL), proposed by Elkington (1998), focuses on sustainability as the primary objective and incorporates three performance dimensions: economic, social, and environmental, enabling sustainable results. Based on TBL, the most critical objective of firms is to sustain profitability for the long term. The social sustainability dimension includes the social affairs of the relevant societies, human rights, and health services, whereas environmental sustainability includes paying attention to environmental changes and obeying environmental regulations. Stakeholder theory (Freeman, 1984) is described broadly by Freeman in his article "Strategic Management, A Stakeholder Approach" (Freeman, 2010). Stakeholder theory has been used to describe the nature of the company and how boardrooms think about the interests of business constituencies. I4.0 organizational stakeholders can affect organizations or are affected by them and can comprise international institutional regulations, suppliers, and customers (Awan et al., 2021). Stakeholder theory and reasoned action theory help rationalize the institutional logic underpinning the interactions among antecedents and highlight the rationale for organizational transitions to adopt universal social compliance codes (Venkatesh et al., 2021).

An I4.0 paradigm will include SIDM practices regarding business model transformation, a step toward more sustainable manufacturing processes through stakeholder-oriented value creation restructuration. Therefore, the current boardroom practices at UK companies can be viewed as the new era of SIDM practices. The new era is predominantly characterized as direct and indirect environmental, social, and economic contributions. Meanwhile, de Sousa Jabbour et al. (2018) argue that productive synergies between I4.0 mechanisms and environmentally sustainable manufacturing processes rely on understanding the roles played by critical success factors, which organizations should consider carefully when simultaneously implementing I4.0 and

environmentally sustainable manufacturing. Their study articulates top management responsibilities regarding foreseeing organizational opportunities for integrating I4.0 mechanisms and environmentally sustainable manufacturing into existing production systems. The principal proposition underpinning their framework is that I4.0 can unlock the full potential of environmentally sustainable manufacturing processes. They have suggested secondary propositions, including the level of management commitment and national culture. They stated that management leadership and national culture play critical roles in integrating these two domains. The mentioned propositions are employed in our conceptual framework, as depicted in Figure 1. SIDM practices at boardrooms should consider stakeholders' interests, such as employees, customers, suppliers, and the community.

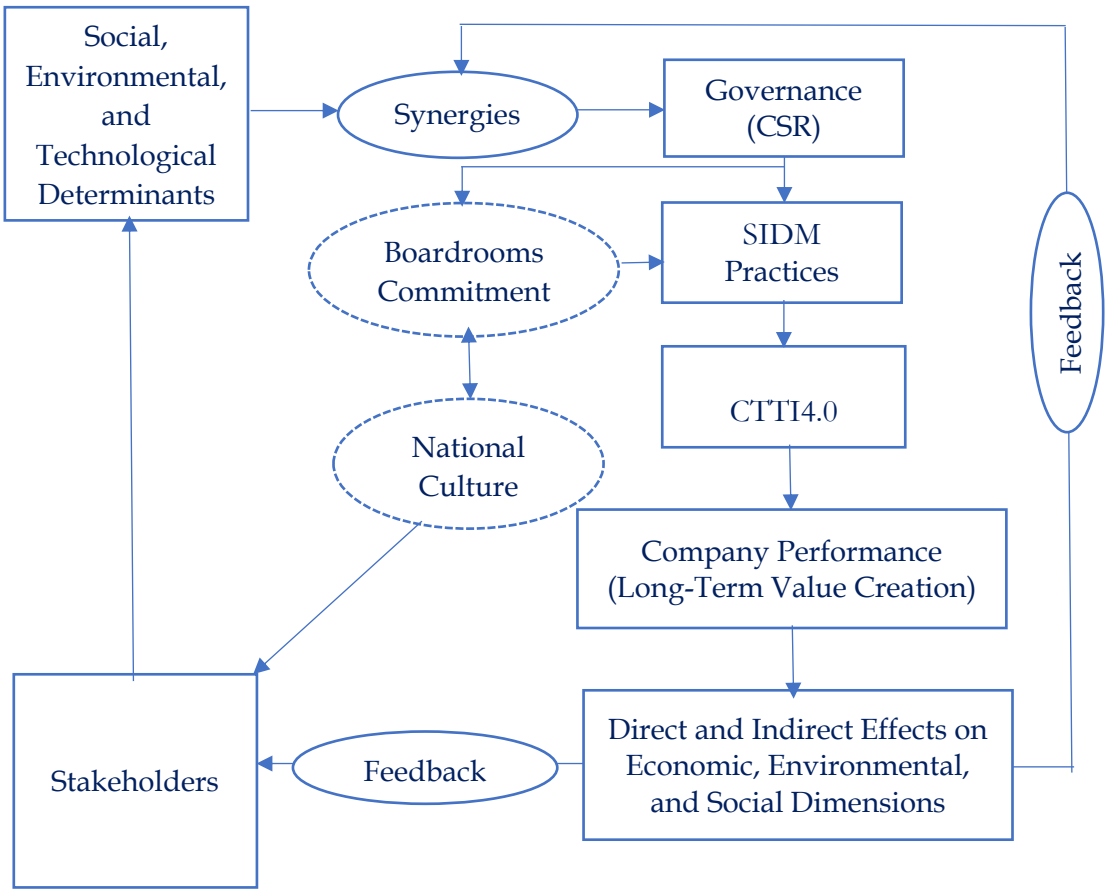


Figure 1: Conceptual stakeholder-oriented model of the influence of social, environmental, and technological determinants on SIDM and CTTI4.0

Corporate governance mechanisms include a set of relationships among a company's management, board, shareholders, and stakeholders. Governance mechanisms support economic efficiency and sustainability. Investment in I4.0 mechanisms enables companies to realize sustainable industrial value creation on sustainability, economic, social, and environmental dimensions. Value creation networks in I4.0 help to realize closed-loop product life cycles. Retrofitting enables an easy and cost-efficient way of upgrading existing manufacturing equipment. Corporate governance also provides the structure through which the objectives of the company are set. Corporate governance mechanisms recognize the interests of stakeholders and their role in contributing to the company's long-term success. Corporate governance builds an environment of trust, transparency, and accountability necessary for fostering long-term investment, financial stability, and business integrity, thereby supporting more robust growth and more inclusive societies.

3.2. Research design and empirical setting

Sample and data collection

The initial sample of this study includes all UK FTSE All-Share nonfinancial firms that published their annual reports from 2013 to 2018. Following prior research (Hassanein et al., 2019), we excluded financial firms due to the differences in disclosure regulations. We also have excluded firms with zero scores based on our developed disclosure measurement. We excluded firms with missing data. Annual reports have been downloaded from firms' websites. We use computerized textual analysis to score the total disclosure on CTTI4.0 practice, benefits associated with business model transformation disclosure, challenges with business model transformation, I4.0 components disclosure, and business model transformation mechanisms disclosure. We use CFIE-FRSE, a program that explores accounting and financial market text using natural language processing and corpus linguistics methods (El-Haj et al., 2019), to score the annual reports based on our constructed wordlist to capture CTTI4.0 disclosure.

Selection of disclosure items

To measure CTTI4.0 disclosure, we followed previous literature for constructing a word pool (Loughran and McDonald, 2011; Andreou et al., 2020; Karim et al., 2021). The selection of disclosure topics is carried out in three stages. *First*, we create I4.0 components through a comprehensive review of I4.0 frameworks adopted by top professional organizations, i.e., Boston Consulting Group, McKinsey & Company, Deloitte, KPMG, and i-SCOOP. This process produces a preliminary list of CTTI4.0 component keywords (List 1). The findings of this review reveal inconsistencies regarding I4.0 terminologies underpinning each framework proposed by these professional organizations.

Furthermore, to validate the preliminary index, we examined the critical components of I4.0 against five self-selected annual reports (2018) for UK companies.1 Third, we added synonyms and amended the preliminary CTTI4.0 index. In this stage, synonyms were identified and added to the preliminary index (Appendix 1). Additionally, we uploaded a sample of 20 annual reports to LancBox software to identify words used in the annual reports when addressing CTTI4.0 to ensure that the words were used frequently (Karim et al., 2021). We discussed the keywords to ensure that our scores were reliable and that discrepancies were analyzed and resolved. Finally, this stage resulted in another version of the preliminary index, classified into four proxies: CTTI4.0 practices through business model transformation mechanisms, I4.0 components, benefits, and challenges associated with business model transformation mechanisms.

Content analysis

This stage focuses on content analysis to measure CTTI4.0. The disclosure level is measured simply by counting CTTI4.0 components related to (i) sentences or (ii) words before transforming

- [1] Rolls Royce Company, Industry: designs, manufactures, and distributes power systems for aviation, Number of employees: 45,500.
- Rio Tinto Company, Industry: metals and mining corporations, Number of employees: 47,000.
- AstraZeneca Company, Industry: pharmaceutical and biopharmaceutical company, Number of employees: 61,000.
- Company, Industry: multinational oil and gas company, Number of employees: 73,000.
- CRH Company, Industry: construction, Number of employees: 89,831.

this number into a natural logarithm. The coding (measurement) unit underlying our study will be based on sentences or paragraphs to overcome the limitation of counting the disclosures using the word as a measurement unit. The word meaning relies on its syntactical role within the sentence, and the word by itself does not convey a meaning (Linsley and Shrives, 2006).

Then, the method applied computer-aided textual analysis by using CFIE-FRSE, software developed by Lancaster University (El-Haj et al., 2019). This is helpful to score the annual reports based on a constructed wordlist to capture the narrative disclosures of CTTI4.0. Then, the procedure double-checked the score for a random sample of 10 annual reports manually to ensure the CFIE measurement's reliability and consistent outcomes. Furthermore, following previous literature (Karim et al., 2021; Albitar, 2021), the study also used NVivo 12 Pro to score a random sample of another 10 annual reports using the same wordlist to validate the CFIE measurement, and the outcomes remained consistent as well.

Research model

We use the ordinary least squares (OLS) model to test our research hypotheses. We also run random-effects, fixed-effects, Tobit, and generalized method of moments (GMMs) models to address any concerns regarding the potential existence of endogeneities. The primary model can be shown as follows.

$$CFP = \beta 0 + \beta 1\ CTTI4.0\ score + \beta 2\ ESG\_practice + \beta 3\ Firm\_size + \beta 4\ Liquidity + \beta 5\ Beta + Industry\ Fixed\ Effects + Year\ Fixed\ Effects + \varepsilon \quad \text{Equation (1)}$$

where CFP: corporate financial performance measured by return on assets (ROA) and return on equity (ROE); CTTI4.0 *score: authors' self-constructed disclosure index for measuring* CTTI4.0*; ESG_practice: ESG practice reflects the companies' performance over the environmental, social, and governance factors; Firm_size: the natural log of total assets; Liquidity: measured by current ratio; Beta: best risk ratio.*

4. Findings

Objective 1: The UK current* CTTI4.0 *practice

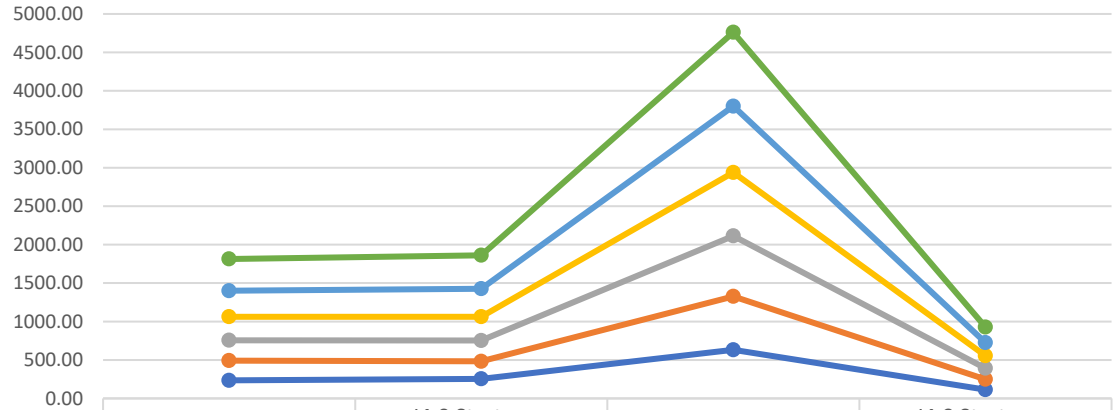
The results of this study reveal that boardrooms of UK companies are aware of the value that I4.0 could deliver to their long-term business performance, as illustrated in Figures 1 and 2. Furthermore, the findings portrayed in Figures 1 and 2 provide an important signal that UK companies have entered a dynamic new phase since 2013, which accelerated over 2013-2018. The findings show that SIDM practices regarding CTTI4.0 practices accelerated approximately twofold in 2018 compared to 2013. As portrayed in companies' annual reports;

> *"Underpinning our business model and is our transformation agenda. We have around 1,000 projects across the Upstream aimed at sustainably improving both performance and how it feels to work in the Upstream. We believe in the potential of this agenda to transform the efficiency of our business, and we are delivering real value today to the bottom line" (BP Company, Annual Report, p.23).*

Such strategic choices embedded in SIDM practices will provide substantial opportunities for UK manufacturing companies ahead, as depicted in companies' annual reports;

> *"We entered the year with a determination to improve our efficiency and operating performance and a refined vision and strategy. We are embarked on an ambitious restructuring programme" (Chairman's statement of Rolls Royce Company, Annual Report, 2018, p.4).*
>
> *"We continue to implement various productivity initiatives and restructuring programmes to enhance the long-term efficiency of the business" (AstraZeneca Company, Annual Report, 2018, p.227).*
>
> *"I have seen how digital technology is transforming the way we work and has the potential to help us develop better medicines, faster and with clearer benefits for patients and value for society" (Chairman's statement of AstraZeneca Company, Annual Report, 2018, P.4).*

Figure 2
SIDM regarding CTTI4.0



	CBMT Mechanisms	I4.0 Strategy - Components	I4.0 - Strategy Benefits	I4.0 Strategy- Challenges
2018	413.29	434.56	959.77	203.32
2017	338.28	364.49	862.23	170.19
2016	306.14	308.55	825.86	162.99
2015	264.10	270.99	786.68	143.78
2014	257.34	227.83	693.88	133.89
2013	234.31	254.77	632.37	114.30

Furthermore, it is more likely that boardrooms are aware of the contributions of optimization and customization in smart manufacturing processes embedded in their CTTI4.0 practices. This is consistent with earlier studies (e.g., Alcácer and Cruz-Machado, 2019). CTTI4.0 practices can be viewed as a strategic transition in boardroom practices at UK companies. This will enable boardrooms to effectively, quickly, and flexibly respond to market trends through dynamic capabilities framework, as portrayed in companies' annual reports;

> "*Strategically, we have sustained our investments in the technologies that will ensure our long-term competitiveness and innovation ambitions" (Chairman's statement, Rolls Royce Company, Annual Report, p.4).*
>
> *"New technologies are helping us build intelligent operations throughout our business" (AR, p.41).*
>
> *"Inspection robots are helping us deliver against our strategic priority of modernizing and transforming BP" (BP Company, Annual Report, p.41).*
>
> *"New technologies are helping us increase the amount and quality of data we gather from our operations and speed up our analysis, allowing us to act more quickly" (BP Company, Annual Report, p.44).*

"We also invested $94 million on the implementation of our R&D restructuring (2017: $201 million; 2016: $178 million)" (AstraZeneca Company, Annual Report, 2018, p.26).

"*BP continues to play an active role in relation to the energy transition. We are carefully considering our mix of natural gas and oil while investing in new technology and businesses that have the potential to contribute to a lower carbon world through our 'reduce, improve, create' framework" (BP Company, Annual Report, p.87).*

"Restructuring charges are classified as non-operating items where they relate to an announced major group restructuring. A major group restructuring is a restructuring programme affecting more than one of the group's operating segments that is expected to result in charges of more than $1 billion over a defined period. Following the Gulf of Mexico oil spill in 2010 and since the fall in oil prices in late 2014, major group restructuring programmes were initiated. The group's restructuring programme, originally announced in 2014, has now been completed" (BP Company, Annual Report, p.276).

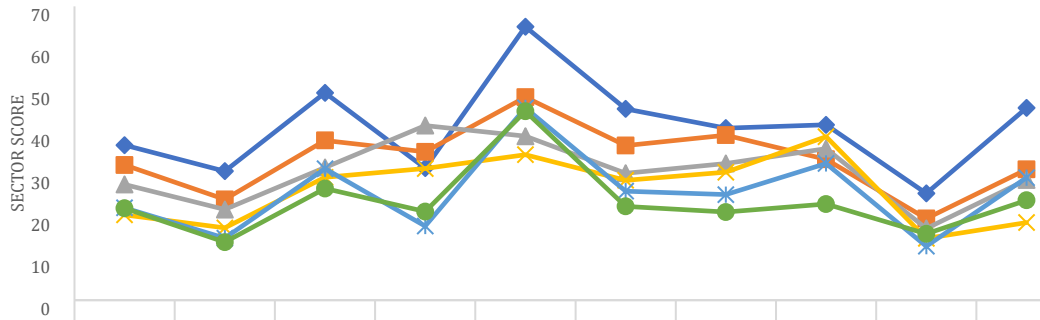
"Advanced materials and electric and hybrid technologies will be as crucial to our success as artificial intelligence and digitalisation" (Chairman's statement, Rolls Royce Company, p.4).

"As competition for world-class assets increases, the effective use of technology will be a differentiating factor among competitors for those assets. This will push the industry to treat data as a valuable asset and will shift traditional supplier relationships towards more dynamic and richer partner ecosystems rates" (Rio Tinto Company, Annual Report, p.12).

"We continue to implement various productivity initiatives and restructuring programmes with the aim of enhancing the long-term efficiency of the business. However, anticipated cost savings and other benefits from these programmes are based on estimates, and the actual savings may vary significantly or may not be achieved at all. In particular, these cost-reduction measures are often based on current conditions and cannot always take into account any future changes to the pharmaceutical industry or our operations, including new business developments or wage or price increases" (AstraZeneca Company, Annual Report, 2018, p.227).

The above citations regarding SIDM practices provide evidence that dynamic capabilities have become an important strategic choice embedded in boardroom practices to achieve successful long-term performance through the implementation of I4. The findings of this study support the view of Helfat and Raubitschek (2018) and Warner and Wäger (2019). Nevertheless, the results of this study reveal that there are no collective unified processes regarding technology road mapping associated with CTTI4.0 practices. Accordingly, UK companies adopt various strategic choices regarding CTTI4.0 practices. This result confirms Warner and Wäger's (2019) view that incumbents build different dynamic capabilities for the strategic renewal of business models.

FIGURE 3: CTTI4.0 SECTOR/YEAR PRACTICES



	Communication Services	Consumer Discretionary	Consumer Staples	Energy	Health Care	Industrials	Information Technology	Materials	Real Estate	Utilities
2018	36.93	30.74	49.41	31.46	65.15	45.58	41.00	41.78	25.44	45.80
2017	32.21	24.00	38.05	35.33	48.36	36.84	39.31	33.55	19.45	31.17
2016	27.57	21.61	31.61	41.60	39.08	30.24	32.56	36.12	17.08	28.67
2015	20.33	17.22	29.26	31.38	34.67	28.57	30.50	38.96	14.71	18.50
2014	22.00	14.79	31.33	17.67	45.82	25.97	25.15	32.57	12.85	29.20
2013	21.91	13.83	26.60	21.11	45.00	22.35	21.00	22.91	15.81	23.80

This study confirms the findings of Frank, Dalenogare, and Ayala (2019), who argue that organizations differ significantly in terms of what types and the number of technologies they adopt and how advanced their level of I4.0 implementation is. This finding is not surprising, as CTTI4.0 practices vary according to strategic choices embedded in SIDM practices, companies' strategies, and industry type, as illustrated in companies' annual reports;

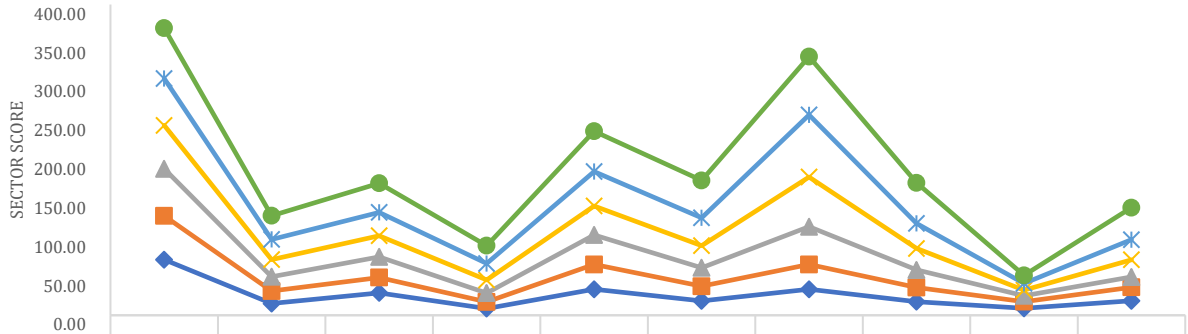
"We are also exploring emerging technologies to accelerate the design and testing of tomorrow's medicines. For example, artificial intelligence (AI) is being used increasingly in the pharmaceutical sector, building on the emergence of novel computing technologies, the exponential increase in data and deep learning algorithms" (AstraZeneca Company, Annual Report, p.25).

"This is underpinned by the strength of our retail convenience partnerships, technology such as our advanced fuels and use of digital technology, as well as our customer relationships" (BP Company, Annual Report, p.33).

"Our technology remains a significant source of competitive advantage. Our strategy is to focus on our premium lubricants and growth markets while leveraging our strong brands, technology, and customer relationships" (BP Company, Annual Report, p.35).

FIGURE 4

CTTI4.0-MECHANISMS



	Communication Services	Consumer Discretionary	Consumer Staples	Energy	Health Care	Industrials	Information Technology	Materials	Real Estate	Utilities
2018	64.86	30.43	37.47	23.00	51.85	48.16	75.00	52.19	10.42	41.20
2017	60.29	25.97	30.16	21.22	44.29	35.82	80.00	32.24	8.68	25.83
2016	55.93	22.04	27.17	16.80	37.31	28.37	63.94	27.60	7.24	22.17
2015	60.58	18.50	26.58	11.38	38.00	23.82	48.57	22.69	7.54	13.33
2014	56.33	16.00	19.80	8.56	32.00	18.84	32.00	18.26	8.64	17.40
2013	71.64	15.17	28.80	8.67	33.44	18.57	33.46	17.50	8.92	18.60

With such a strategic transition, strategic investment decision-makers at UK companies are beginning to use data to drive decision-making and improve efficiency in previously unimaginable ways. Integrating new methods of data collection and analysis, for example, through the expansion of existing products or creation of new digitized products, helps companies generate data on product use and, thus, refine products to best meet customers'

needs, as illustrated in companies' annual reports. In the manufacturing industry, production lines must be adapted to current demand quickly and flexibly, and product ideas must be brought to the market as promptly as possible. Advanced digital technology is already used in manufacturing, but with the transition toward I4.0, boardroom practices at UK manufacturing companies will be achieving greater efficiencies and changing traditional production relationships among suppliers, customers, and between humans and machines. This is consistent with the study of Cagle (2020), that improved storage capacity and processing power allow for collecting and tracking more information, while interconnected systems enable cross-departmental communication and planning. Figures 5 and 6 show how benefits and challenges associated with CTTI4.0 vary among companies;

"In 2018, we divested three wind energy operations in Texas, as part of a broader restructuring programme designed to optimize our US wind portfolio for long-term growth" (BP Company, Annual Report, p.39).

"We've invested in Fulcrum BioEnergy, which is constructing the first commercial scale waste-to-fuels plant in the US. The facility aims to use technology developed by BP and Johnson Matthey, to help convert household rubbish that would otherwise be sent to landfill, into fuel for transport. Fulcrum, in which BP owns an 8% interest, estimates that when it begins commercial operations, the plant will be able to convert around 175,000 tons of waste into about 11 million gallons of fuel each year" (BP Company, Annual Report, p.45).

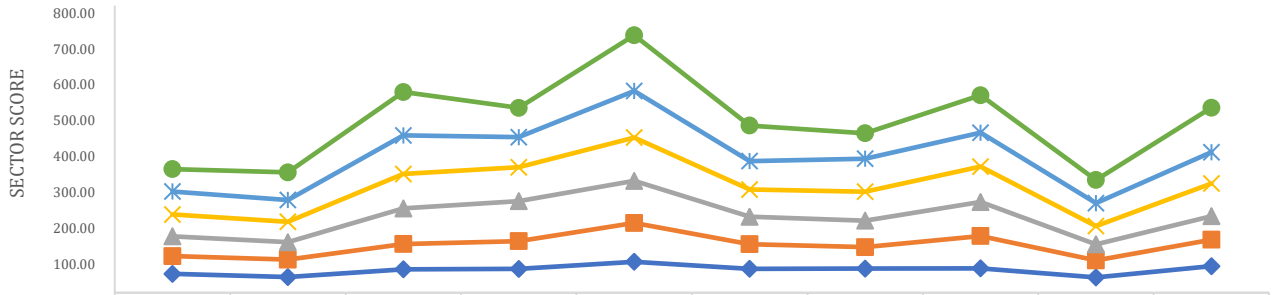
"Our future technological world is complex with many exciting new challenges across everything we do. We respond to this with broader and deeper collaboration with others and with a more dynamic approach to ensure that our technology brings the most value to our customers and our business. Strategic transformation, competitive environment, cyber threat" (Rolls Royce Company, Annual Report, 2018, p.13).

"We have teamed up with robotics partners, including Harvard University and University of Nottingham, to explore how robots could evolutionise the future of engine maintenance. 'Inspect' robots could be embedded within an engine to improve monitoring" (Rolls Royce Company, Annual Report, 2018, p.29).

"The Board recognises that, to be successful in this, requires not just organisational restructuring but a cultural shift in inspiring our people to take accountability, be innovative and continuously seek out improved and more efficient ways of working" (Rolls Royce Company, Annual Report, 2018, p.57).

FIGURE 5

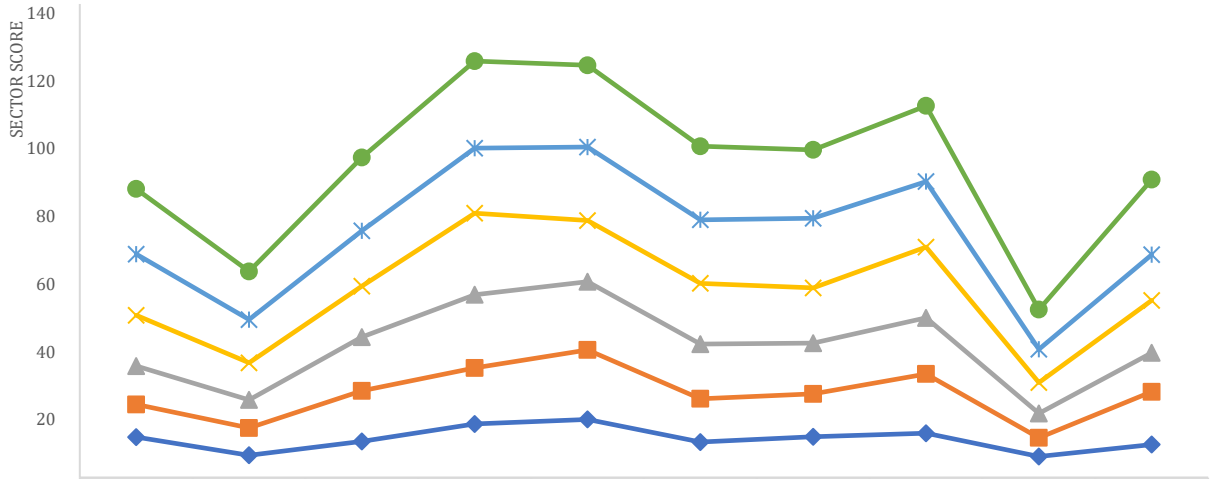
CTTI4.0 - BENEFITS



	Communication Services	Consumer Discretionary	Consumer Staples	Energy	Health Care	Industrials	Information Technology	Materials	Real Estate	Utilities
2018	62.57	76.96	120.94	81.55	155.39	99.03	70.71	104.26	64.37	124.00
2017	63.86	60.67	107.42	83.89	129.71	79.02	91.88	94.62	64.00	87.17
2016	61.00	56.80	95.94	94.30	120.54	75.96	80.88	98.56	50.90	91.00
2015	55.08	48.60	99.05	111.63	117.33	76.43	73.64	94.69	44.71	65.50
2014	49.33	48.48	70.60	77.22	108.27	68.77	59.92	90.17	47.30	73.80
2013	52.64	43.71	65.20	66.44	86.11	66.48	67.18	67.91	42.69	74.00

FIGURE 6

CHALLENGES ASSOCIATED WITH CTTI4.0



	Communication Services	Consumer Discretionary	Consumer Staples	Energy	Health Care	Industrials	Information Technology	Materials	Real Estate	Utilities
2018	19.286	14.222	21.647	25.727	24.154	21.734	20.235	22.37	11.744	22.2
2017	18.071	12.767	16.368	19.222	21.714	18.779	20.563	19.379	9.825	13.5
2016	15	10.963	15.056	24.1	18.077	17.955	16.313	20.92	9.105	15.5
2015	11.333	8.3	15.895	21.625	20.167	16.154	15	16.577	7.229	11.5
2014	9.667	8.071	14.933	16.556	20.545	12.79	12.692	17.522	5.515	15.6
2013	12	6.629	10.733	15.889	17.222	10.534	12.091	13.136	6.269	9.8

Objective 2: The impact of* CTTI4.0 *practices on financial performance

Descriptive statistics:

Table 1 shows the mean CTTI4.0 over time and across industries. Overall, UK nonfinancial companies are aware of the value that I4.0 could deliver to their long-term business performance. The total score for CTTI4.0 varies across industries. Some industries have been more willing to provide information about I4.0, while others show less response. We found that industries such as information technology and health care are more likely to provide more disclosure about transformation toward I4.0 in the annual reports. This shows evidence that these sectors have taken the initiative and advantage toward I4.0.

Table 1. CTTI4.0 score by industry year

Industry	Year						
	2013	2014	2015	2016	2017	2018	Total
Communication Services	158.182	137.333	147.333	159.5	174.429	183.643	161.065
Consumer Discretionary	79.343	87.333	92.62	111.407	123.4	152.352	110.925
Consumer Staples	131.333	136.667	170.789	169.778	192	229.471	173.495
Energy	112.111	120	176	176.8	159.667	161.727	151.446
Health Care	181.778	206.636	210.167	215	244.071	296.538	229.139
Industrials	117.931	126.371	144.969	152.522	170.456	214.5	155.302
Information Technology	133.727	129.769	167.714	193.688	231.75	206.941	181.966
Materials	121.455	158.522	172.923	183.2	179.793	220.593	174.763
Real Estate	73.692	74.303	74.2	84.316	101.95	111.977	88.66
Utilities	126.2	136	108.833	157.333	157.667	233.2	152.121
Total	1235.752	1312.935	1465.549	1603.544	1735.182	2010.942	1578.883

Table 2 shows the descriptive statistics. The mean value of CFP is 6.311, with a minimum value of -1.606 and a maximum value of 15.071. The mean value of CTTI4.0 is 145.91, representing the average frequency of words on corporate transformation toward Industry 4.0 disclosed in the annual reports, where the minimum number of words is one, and the maximum is 635 words, indicating that many companies provide information on CTTI4.0. The mean value of ESG practice is 48.814, indicating that most of our sample has good performance in terms of ESG practices. Regarding other control variables, we find that the mean firm size measured by the natural log of total assets is 20.312, liquidity is 1.886, and the beta ratio is 0.61.

Table 2: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
ROA	1426	6.311	5.021	-1.606	15.071
CTTI4.0 score	1535	145.91	95.55	1	635
ESG_practice	1076	48.814	17.70	3.27	94.71
Firm_size	1520	20.312	1.824	12.205	26.661
Liquidity	1535	1.886	1.99	.05	31.536
Beta	1535	.61	.535	-2.551	3.979

Table 3 shows the correlation matrix. The correlation coefficient between CTTI4.0 and CFP is significantly positive at a significance level of 1%. Additionally, the correlation coefficient between ESG practices and CFP is significantly positive at the 1% significance level. The correlation coefficients of all control variables are less than 0.8, reflecting no serious multicollinearity issue among variables. Furthermore, it can be decided that multicollinearity does not appear to be a concern in explaining the regression results from variance inflation factor (VIF) results tested separately (VIF ranges from 1.17 to 1.46 with a mean value of 1.17).

Table 3: Correlations analysis

Variable	(1)	(2)	(3)	(4)	(5)	(6)
(1) ROA	1.000					
(2) CTTI4.0 score	0.051*	1.000				
(3) ESG_practice	0.103*	0.121*	1.000			
(4) Firm_size	0.144*	0.199*	0.158*	1.000		
(5) Liquidity	0.078*	-0.121*	0.046*	-0.201*	1.000	
(6) Beta	-0.153*	-0.061*	-0.015*	0.249*	-0.016*	1.000

*shows significance at the 0.05 level

Multivariate analysis

The relationship between CTTI4.0 *score and corporate financial performance*

Tables 4 and 5 report our findings using different regression models, namely, OLS, fixed-effect model (FE), random-effect model (RE) and Tobit model. We use two different proxies for CFP, namely, return on assets (ROA) in Table 4 and return on equity (ROE) in Table 5. The tables show a positive relationship between CTTI4.0 and CFP at the 5 percent level, suggesting that firms that provide more information on CTTI4.0 have better CFP. Our findings align with agency and signaling theories and the disclosure literature (e.g., Hassanein and Hussainey, 2015 and Hassanein et al., 2019). Thus, our first hypothesis is accepted.

Regarding the effects of ESG practices on CFP, the results show a significant positive relationship between ESG practice and corporate financial performance, suggesting that firms with better performance in terms of ESG have better corporate financial performance. This result is consistent with agency theory and prior research (e.g., Fatemi et al., 2018; Elmagrhi et al., 2019). Among other control variables, firm size and liquidity show a positive and significant association with CFP at the 5% level. Beta is negative and significant with CFP at the 1% level, suggesting that companies with higher risk ratios are more likely to have lower financial performance, regardless of whether it is measured by ROA or ROE.

Table 4: The relationship between CTTI4.0 score and financial performance proxied by ROA

	(1)	(2)	(3)	(4)
VAR	OLS	FE	RE	Tobit
CTTI4.0 score	0.0117**	0.00811**	0.00917**	0.0117**
	(0.00459)	(0.00223)	(0.00149)	(0.00458)
ESG_practice	0.0233***	0.0185***	0.0198***	0.0233***
	(0.00810)	(0.00824)	(0.00810)	(0.00807)
Firm_size	0.240**	0.221**	0.230**	0.240**
	(0.108)	(0.110)	(0.108)	(0.108)
Liquidity	0.198**	0.182**	0.191**	0.198**
	(0.0914)	(0.0917)	(0.0914)	(0.0911)
Beta	-0.968***	-1.008***	-0.977***	-0.968***
	(0.298)	(0.301)	(0.298)	(0.297)
Year effect	Included	Included	Included	Included
Industry effect	Included	Included	Included	Included
Constant	12.63***	14.16***	13.13***	12.63***
	(2.314)	(2.126)	(2.182)	(2.300)
Observations	1,043	1,043	1,043	1,043

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 5: The relationship between CTTI4.0 score and financial performance proxied by ROE

	(1)	(2)	(3)	(4)
VAR	OLS	FE	RE	Tobit
CTTI4.0 score	0.109***	0.091***	0.102***	0.106***
	(0.0290)	(0.0180)	(0.0230)	(0.0259)
ESG_practice	0.0166***	0.009***	0.0134***	0.0165***
	(0.0516)	(0.0315)	(0.0482)	(0.0513)
Firm_size	2.489***	2.601***	2.489***	2.489***
	(0.691)	(0.701)	(0.691)	(0.689)
Liquidity	-0.620	-0.581	-0.620	-0.620
	(0.583)	(0.585)	(0.583)	(0.582)
Beta	-8.492***	-7.923***	-8.212***	-8.492***
	(1.885)	(1.213)	(1.615)	(1.880)
Year	Included	Included	Included	Included
Industry	Included	Included	Included	Included
Constant	30.54**	28.16**	29.11**	30.54**
	(13.42)	(13.58)	(13.42)	(13.38)
Observations	1,054	1,054	1,054	1,054

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

The moderating effect of ESG performance on the CTTI4.0 *score-CFP nexus*

To test the second hypothesis of our study, in table 6, we use the interaction of the CTTI4.0 score with ESG practice. More specifically, to determine the potential moderating effect of ESG performance on the CTTI4.0 score-CFP nexus, we regressed Equation (1), including the CTTI4.0 score*ESG_practice and using the two proxies of CFP. Noticeably, based on the interaction model, Table 7 shows a significant effect of ESG performance on the CTTI4.0 score-CFP nexus, and the coefficients of I4score*ESG_practice are significantly positive at the 1% level. This suggests that ESG performance moderates the relationship between CTTI4.0 and score-CFP; therefore, firms with better ESG performance tend to be more engaged in reporting CTTI4.0 along with better financial performance simultaneously. In other words, ESG practices can

enhance the ability of the CTTI4.0 score to explain variations in CFP compared with examining the CTTI4.0 score-CFP nexus directly. This is the first empirical evidence that explains the role of ESG performance on the CTTI4.0 score-CFP nexus.

Table 6: The moderating effect of ESG performance on the CTTI4.0 score-CFP nexus

Variable	(1) ROA	(2) ROE
CTTI4.0 score	0.00463	0.161*
	(0.00741)	(0.0754)
ESG_practice	0.00826**	0.0631***
	(0.00547)	(0.0275)
CTTI4.0 score#c. ESG_practice	0.000146**	0.00141**
	(0.0000615)	(0.000512)
Firm_size	0.157**	1.922***
	(0.0835)	(0.671)
Liquidity	0.213**	-0.362
	(0.0775)	(0.626)
Beta	-0.705***	-8.176***
	(0.257)	(2.142)
Constant	10.30***	12.61
	(1.653)	(13.42)
Observations	1,043	1,054

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Robustness check and additional analysis

The study employs a generalized method of moment (GMM) regression model as a robustness check to address the potential endogeneity issue arising from reverse causality association between CTTI4.0 and score-CFP; this also is to ensure that our main findings were not severely affected by the potential concerns of endogeneity problems (Blundell and Bond 1998). Following previous literature (Gerged et al., 2021), we incorporate the lagged versions of past CFP to differentiate

between a "static" and 'dynamic' panel data model. Including lags of the dependent variable (CFP in our study), the GMM estimation controls endogeneity by transforming the data internally, as a dependent variable's previous value is subtracted from its current value (Roodman, 2009). Table 8 shows the results from running the GMM model. The findings suggest that CTTI4.0 disclosure positively affects financial performance. This means that our main findings remain robust.

Table 7: Generalized method of moment (GMM) results – robustness analysis

	(1)	(2)
VAR	ROA	ROE
CTTI4.0 score	0.0141*	0.0623*
	(0.00468)	(0.0189)
ESG_practice	0.426**	0.331
	(0.243)	(0.214)
Firm_size	0.081*	5.076*
	(0.531)	(2.606)
Liquidity	0.164	0.549
	(0.192)	(0.919)
Beta	-0.718*	-5.852***
	(0.361)	(1.648)
L.ROA	0.551***	0.314***
	(0.0653)	(0.0481)
Year effect	Included	Included
Industry effect	Included	Included
Constant	8.256	17.8*
	(10.52)	(4.22)
Observations	792	832

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Following disclosure studies (e.g., Hussainey et al., 2003), we also run the regressions for each component of our CTTI4.0 disclosure score separately to explore each component's effect on financial performance. As seen from Table 8, we find that the results are in line with our main

findings when considering the CTTI4.0 mechanisms, I4 components strategy, and I4 strategy benefits, suggesting that firms that provide more information related to the CTTI4.0 mechanisms, I4 components strategy, and I4.0 strategy benefits have better CFP. However, we find a negative but not significant relationship between the challenge score of the I4 strategy and CFP.

Table 8: The relationship between each component of CTTI4.0 and **CFP**

	(1)	(2)	(3)	(4)
Variable	ROA	ROA	ROA	ROA
CTTI4.0 _stratgey_comp	0.0130***			
	(0.00458)			
CTTI4.0 _CBMT		0.0136*		
		(0.00621)		
CTTI4.0 _Chal			-0.00422	
			(0.00308)	
CTTI4.0 _Benfit				0.0995**
				(0.00147)
ESG_practice	0.0205**	0.0209**	0.0150*	0.0502***
	(0.00811)	(0.00820)	(0.00814)	(0.00918)
Firm_size	0.376***	0.384***	0.193**	0.370***
	(0.115)	(0.118)	(0.119)	(0.114)
Liquidity	0.217**	0.190**	0.175**	0.163*
	(0.0892)	(0.0888)	(0.0885)	(0.0872)
Beta	-0.887***	-0.954***	-0.941***	-0.929***
	(0.300)	(0.299)	(0.298)	(0.295)
Constant	14.84***	15.28***	12.32***	16.97***
	(2.111)	(2.178)	(2.169)	(2.127)
Observations	1,048	1,048	1,048	1,048
R-squared	0.157	0.143	0.161	0.191

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

5. Conclusion

This study aims to examine the relationship between CTTI4.0 practices and corporate financial performance and the role of ESG in this relationship. The findings of this study reveal that the current trend of CTTI4.0 can be viewed as an enabler of the circular economy. Such strategic transition in SIDM practice is positively associated with corporate financial performance. Furthermore, the findings reveal that ESG strengthens the relationship between CTTI4.0 and financial performance. Furthermore, CTTI4.0 cannot be viewed merely as a technology roadmap, but SIDM practices influence strategic choices to achieve successful long-term performance. Successful CTTI4.0 practices require a proper understanding of stakeholders' interests and expectations (Awan et al., 2021; Cheng et al., 2021).

Theoretical contributions

The findings offer insightful contributions regarding the knowledge around the influence of CTTI4.0 practices on financial performance. This contributes to the current debate regarding the extension of stakeholder theory to include sustainability governance (Awan et al., 2021; Venkatesh et al., 2021). The extracts are rooted in a reasoned action behavior perspective to offer insights that account for internal and external stakeholders. The study recognizes that collective dynamics are potent drivers of the current trends of SIDM and CTTI4.0 practices, thereby setting an imperative for the convergence of social sustainability and corporate governance by recognizing stakeholders' views and standards-setting attributes (Venkatesh et al., 2021). The results provide theoretical evidence of the influence of national culture and boardroom commitment on achieving synergy between I4.0 and the circular economy, in line with the view of de Sousa Jabbour et al. (2018b).

Practical (managerial and policy) implications

The findings have practical implications for boardrooms regarding the strength of the relationship between CTTI4.0 disclosure and performance and the role of ESG. First, ESG disclosures are generally associated with CTTI4.0 and corporate performance. Our analysis reveals that ESG appears to be related to CTTI4.0 practices. Second, synergies between I4.0 and the circular economy can be viewed as predecision strategic control mechanisms associated with CTTI4.0 practices toward value creation and sustainable business modules with a comprehensive performance measurement system of direct and indirect effects on environmental, social, and economic dimensions. CTTI4.0 practices enable companies to achieve potential objectives such as increasing production efficiency, productivity, and quality, supplementing operational flexibility, contributing to safety issues and operational sustainability, and amalgamating the production system with critical stakeholders (Meindl et., 2021). Third, the findings offer insights to decision-makers and regulatory bodies regarding the current practices of SIDM and their potential economic consequences. However, maintaining a high level of synergies between I4.0 and the circular economy requires a high level of synergies among stakeholders to consolidate governance mechanisms associated with CTTI4.0 practices. Such integration and recognition would considerably reduce stakeholders' need to cope with the complexity of a portfolio of standards and performance measurement and help identify gaps relevant to noncompliance gestures (Venkatesh et al., 2021).

Social implications

The study deliberations are relevant to key SDGs and offer insights to decision-makers, regulatory bodies, and other stakeholders regarding the current practices of CTTI4.0 and potential environmental, social, and economic impacts. The findings of this study forecast the future usefulness of adopting I4.0 mechanisms toward the circular economy. Successful implementation of these initiatives requires a better understanding and analysis of stakeholders' interests and expectations to achieve the potential benefits of incorporating I4.0 mechanisms into manufacturing processes. Such understanding enables organizations to achieve effective planning

and control organizational and policy resources and successful value creation. These steps would provide an impetus to integrate I4.0 mechanisms with circular economy business models driven by stakeholders' interests, and expectations would allow for better environmental innovation solutions that support sustainable development goals (Awan et al., 2021). In addition, extracts from boardroom practices show value creation, generating revenue, and reducing costs embedded in collaboration and I4.0 applications. In the process, the system aims to build synergy among both internal and external partners to achieve the best results in SIDM practices. In addition, it offers the scope for customizing awareness programs to launch as industry best practices. Implications underpinning this study inform and influence human life better and offer guidance to other companies in different settings and contexts regarding the influence of technological, social, and environmental determinants on SIDM practices. Governance mechanisms enable suitable corporate culture heavily influenced by national culture and institutional factors, including technology and innovation.

Limitations and future scope

The study has limitations that need to be addressed in future research due to its time, location, sample selection, size, the selected companies' sector, and questions addressed. To move this agenda forward, we suggest that future research adopt our conceptual framework to provide new insights into the long-term organizational effects of such strategic transformation. The findings of our study remain within the UK context; future research may examine theatrical and practical insights regarding the synergies between I4.0 and the circular economy in different settings. Future research may adopt longitudinal studies toward a better understanding of the influence of ESG on SIDM and CTTI4.0 practices and the influence of moderating and mediation variables on the transition processes. Future studies may explore the challenges of stakeholders' involvement in such SIDM practices. Future research may examine the disclosure of CTTI4.0 in different settings to explore the relative impact of other contextual factors, such as national culture and political,

legal, and social factors. Finally, qualitative research paradigms may examine how decision-makers' attributes shape such strategic choices.

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Appendix 1- CTTI4.0

Boston Consulting Group (BCG)	Big data and analytics, artificial intelligence (AI), simulation, r*obotic process automation,* advanced robotics, additive manufacturing, augmented reality, horizontal/vertical integration, 3D printing, the industrial IoT, cloud, cybersecurity. Security is also an inherent part of the I4.0 strategy and vision.
McKinsey & Company (2015)	Augmented reality, human-robot collaboration, remote monitoring and control, digital performance management, 3D printing, real-time supply-chain optimization, advanced process control, digital quality management, data-driven demand prediction, data-driven design to value, simulation, predictive maintenance, smart energy consumption, remote maintenance, virtually guided self-services, remote monitoring and control, real-time yield optimization.
Deloitte (2020)	Internet of things (IoT), artificial intelligence (AI), cloud infrastructure, extensive data analysis, nano-technology, advanced robotics, sensors, blockchain, 3D printing, augmented reality, quantum computing, edge computing.
KPMG (2017)	Big data, cloud, cybersecurity, additive manufacturing, robotics, machine to machine comm, internet of things (IoT), augmented decision support, digital twin, demand-driven supply chain.
i-SCOOP Organisation	I4.0 strategy components include; digital transformation; digital transformation strategy; industrial IoT; internet of things (IoT); big data; edge computing; cloud computing; IoT platforms; cybersecurity; additive manufacturing; artificial intelligence; digitization; smart factory.

CTTI4.0: Strategy Component

digital economy; i4.0 initiatives; i4.0 technology; implementing i4.0 transformation; industry 4.0; long term decision; long-term business; long-term future; long-term goals; long-term growth; long-term importance; long-term profit growth; long-term projects; long-term returns; long-term strategic decision; long-term strategic growth; long-term strategic vision; long-term strategy; long-term sustainability; long-term sustainable value for shareholders; long-term sustainable value for stakeholders long-term targets; long-term value; long-term value for

shareholders; long-term value for stakeholders; long-term strategic investments; new business model; new organisational structure; new perspectives; new perspectives for business; new strategic portfolio; restructuring programme; revolutionary change; revolutionary process; roadmap#; shift our focus to; smart factory; smart manufacturing; strategic acquisition; strategic alliance; strategic changes; strategic control; strategic decision; strategic focus; strategic investment; strategic objectives; strategic performance; strategic plan; strategic portfolio; strategic priorities; strategic programs; strategic transformation; strategy review; technology leadership; technology roadmap; technology strategy; the fourth industrial revolution; transform the efficiency of our business; transformation journey; transformation of our business; transformation of our company; transformation of our operating model; transformation of our strategy; UK to leave the EU; uncertainty created by brexit; upgraded infrastructure; upgraded infrastructure

CTTI4.0: Company Business Model Transformation (CBMT)

3d printing; advanced technolog#; artificial intelligence; automation; cloud-based technologies; cutting-edge technologies; data analytics; data as an asset; digital applications; digital capabilities; digital communication interfaces; digital modelling digital technologies and analytics; digital transformation; digitalization strategies; disruptive technology; driverless vehicles; drones; emerging technolog#; greater automation; hybrid technology; innovation processes; integrated data platform integrated data platform; intelligent algorithms; internet of things; iot; machine learning; new technologies; next generation technolog#; next technolog#; novel computing technologies; process automation; robotic#; robots; smart analytics; technological advancement; technological innovation; the next generation of tools

CTTI4.0: Challenges

cyber risk; cyberattack; cybercrime; disruptive technolog#; long-term challenges#; new threat#; operational challenge#; real threat#; security exposure#; strategic challenge#; strategic risk

CTTI4.0: Benefits

accelerate product development; additive manufacturing; agile decision making; attractiveness with respect to tax; augmented decision support; automating activit#; better connected; blockchain transaction; communicating data; confidentiality and integrity; cost efficiency; demand-driven supply chain; digital capabilit#; digital solutions digitalisation of trade; enhance communication; enhance decision making; enhance our productivity; enhance product safety evaluation; enhance risk mitigation capabilities; enhance scientific innovation; enhance the long-term efficiency; enhanced service level#; enhancing long-term efficiency; flexible product#; flexible resource allocation; greater leadership accountability; high levels of efficiency improve

data analytics capability; improve data governance; improve decision making; improve overall customer experience; improved transport flows and costs; improvement of the business; increase collaboration; increasing customer satisfaction; intelligent operation#; keep people safe; long-term competitiveness; long-term growth; make operations safer; more efficient; more flexible resource allocation; more productive through digital solutions; more transformative and digital capabilities; most value to our customers; new digital service model; new opportunities; operational decision#; optimise business processes; optimise working capital; product improvement; product improvement and innovation; product innovation; provide greater automation reduce documentation; reduce operating costs; reduce turnaround times; reduction in inventories; revenue growth; revenue growth and profitability; revenue profitability; rising customer loyalty; rising customer satisfaction; risk mitigation capabilities; safeguarding and communicating data; safeguarding data; save business money; serve our customers better; simplify and improve processes; simplify processes; simplifying systems; stay competitive; support decision making; support manufacturing process; support operational process; support sales capabilities; support supply chain; support the evolving needs of the business; tax incentives; to keep people safe; trade incentives; transformative and digital capabilit#