Brazilian Journal of Operations & Production Management

ISSN 2237-8960 (Online)

ABEPRO ASSOCIAÇÃO BRASILEIRA DE ENGENHARIA DE PRODUÇÃO

RESEARCH PAPER

Industry 4.0 Adoption And Firm Efficiency: Evidence From Emerging Giants In Asia Pacific Region

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How to cite: Rehman, S. U. (2023). Industry 4.0 adoption and firm efficiency: Evidence from emerging Giants in Asia Pacific region. *Brazilian Journal of Operations & Production Management*, Vol. 20, No. 3 edition special, e20231958. https://doi.org/10.14488/BJOPM.1958.2023

ABSTRACT

Purpose - Industry 4.0 links smart production processes with embedded system production technologies to open the door to a new technological era that fundamentally alters industry value chains and business structures. This study examines the effects of Industry 4.0 on firm efficiency.

Methods - Based on a cross-country sample of 1440 firms operating in the top twelve Giants of Asia-Pacific countries and a control sample with another set of 1440 similar-sized firms from non-adopting firms.

Findings - The empirical evidence shows that Industry 4.0 positively impacts firm efficiency. Next, the Tobit model is used for the robustness of the main findings. Further, study also examine the mediating role of intangible assets (human capital and firm reputation) for the impact of Industry 4.0 on firm efficiency. Study findings support the hypotheses that intangible assets mediate the Industry 4.0-firm efficiency relationship.

Implications - Study findings have managerial implications for production and operation managers on enhancing firm efficiency. Drawing upon practice-based-view theory, this study is the first to explore the mediating role of intangible assets (human capital and firm reputation) between in-Industry 4.0 and firm performance.

Originality - This study shed light on the significance of intangible asset congruence in enhancing Industry 4.0 impact.

Keywords: Industry 4.0; Firm Efficiency; Asia Pacific Region; Tobit Model; Intangible Assets; Human Capital; Firm Reputation.

1. INTRODUCTION

Industry 4.0 opens the door for a social and technological revolution that will fundamentally alter the world's landscape (Lalic, Majstorovic, Marjanovic, Delić, & Tasic, 2017). The information is built into the component and can be handled, for example, by placing orders for missing pieces and customizing production parameters. Clients are informed of the production state concurrently (Díaz-Chao, Ficapal-Cusí, & Torrent-Sellens, 2021). More data are produced after the plant is operating. Collecting, examining, and retrieving precise output

*This article is from Call for Papers, "When titans meet –Industry 4.0, Lean and Circular Economy Opportunities towards operational excellence and Sustainability". Due to their relevance and contribution to the field, the articles were published in the September/2023 Special Issue of the Brazilian Journal of Operations & ProductionManagement.

Financial support: None.
Conflict of interest: The authors have no conflict of interest to declare.
Corresponding author: doctor.saifkhanfg@gmail.com
Received: 11 August 2023.
Accepted: 21 August 2023.
Editor: Daniel Nascimento, Guilherme Tortorella, Rodrigo Goyannes Gusmão Caiado, Juan Manuel Maqueira.

and product performance data for development is possible. New technologies and processes are improved and optimized by industry 4.0 technologies. To combat the negative effects of the past, businesses and non-profit organizations invest a lot of time, money, and effort today (Díaz-Chao et al., 2021). Manufacturing lines, business operations, and teams can now cooperate regardless of place, time zone, network, etc., thanks to Industry 4.0 technologies. In a smart factory, scaling output up or down is quicker. A production facility benefits from larger revenues as a result. The Internet of Things (IoT) and Industrial Internet of Things (IIoT) devices will link the user experience and produce extremely lean production thanks to the cloud and big data (Lalic et al., 2017). Cloud storage is incredibly effective, feature-rich, adaptable, current, and reliable. Cloud also offers a well-liked platform for linking products to the business across international borders, and it is well-equipped to manage huge data produced by IoT.

Industry 4.0 has gained traction among businesses globally since its introduction by the International Organization for Standardization in 1996. Despite its spectacular global expansion, managers and scholars continue to discuss the possible benefits and drawbacks of Industry 4.0 adoptions (Reza, Malarvizhi, Jayashree, & Mohiuddin, 2021). Furthermore, previous empirical research on the actual impact of this certifiable standard on firm performance is inconclusive: while several studies suggest that Industry 4.0 adoptions have a significant impact on improving firm performance, others call the standard into question. Heras-Saizarbitoria & Boiral (2013) provide up-to-date and thorough assessments of the empirical research on Industry 4.0. The authors outline prior studies' principal findings and indicate analytical limitations and research gaps (Reza et al., 2021). Most empirical analyses, they claim, (i) focus on a single country, (ii) use cross-sectional data, (iii) analyze information gathered through questionnaires based on managers' perceptions, and (iv) ignore contextual factors such as the culture and values of the region in which firms operate (Reza et al., 2021). As a result, to gain a better knowledge of the real effects of Industry 4.0 adoptions, more empirical research based on longitudinal and emerging market samples anchored in secondary data sources is required to investigate the relationship between Industry 4.0 adoptions and company efficiency. As an independent variable, I utilize efficiency.

Performance is how effectively a machine or system can achieve its goal, while efficiency is how many/much resources are used to achieve that goal. Efficiency includes both individual contribution and system organization. System organization helps people operate efficiently (Heras-Saizarbitoria & Boiral, 2013). The organizational system determines efficiency. A company's resource organization determines its efficiency. Efficient goal-setting requires greater effort. And it's about improving performance with minimal effort and expense. Efficiency means maximizing value without wasting time, money, energy, or raw materials (Reza et al., 2021). Thus, efficiency is a more relevant outcome of Industry 4.0 adoptions in emerging markets as it covers all the likely affected aspects of performance. Thanks to businesses ' increasing technology adoption, the global Industry 4.0 market is predicted to grow rapidly (Oduro & De Nisco, 2023). Furthermore, the Industry 4.0 market is being pushed by the increasing trend of internet penetration and digitization, driven by the increasing demand for efficiency and cost-effective productivity in industries. Thus, the relationship between Industry 4.0 and firm efficiency may contribute to the existing knowledge as empirics merely show the determinants of its adoptions and its impact on firm Performance (Oduro & De Nisco, 2023). Profitability may be an outcome variable inflated/deflated by other factors like changes in product price, competitiveness, and market demand. Firm efficiency can be used to test the effectiveness of Industry 4.0 adoption.

According to some authors, a business's value-creating strategy includes three resources -physical capital resources (Mahoney & Pandian, 1992), human capital resources (Barney, 2000), and organizational capital resources are examples of these. Physical capital resources are the physical technology resources (Ritter & Lettl, 2018), raw material access, geographic location, and equipment of a company. Human capital resources, on the other hand, represent education, expertise, justice, intellectuality, relationships, and the firm's managers' and employees' ideas and visions. Control and coordination of business structures, formal and informal planning procedures, and systems are all stied to organizational capital resources (Barney, 2000). In the current study context, I postulated that Industry 4.0 (physical capital resources) may impact firm efficiency in the Asia Pacific region. However, the relationship between Industry 4.0 and firm efficiency may depend on human capital resources as the mere adoption of Industry 4.0 technologies does not guarantee success unless a firm has the human resources to capitalize on the embedded benefits Industry 4.0 has for adopting firms. In addition, firm reputation, a more compatible indicator for quantifying the effects of Industry 4.0, plays an important role in boosting business performance and lowering firm risk (Tian, Chu, Hu, & Li, 2014). Firms' reputation improves due to Industry 4.0 adoption by the firm. Likewise, a firm reputation is a significant resource because it creates a chance for sustained profitability (Zhu et al., 2014) and provides goodwill, and moral capital, which minimizes negative stakeholder valuations (Godfrey, 2005). As a result, I believe that Industry 4.0 adoption is vital for boosting a company's image and reputation among its stakeholders (Tian et al., 2014). A firm's strong reputation acquired through Industry 4.0 adoption will not only lead to positive assessments from stakeholders but will also have a beneficial impact on the firm. As a result, human capital and reputation may mediate the association between Industry 4.0 and firm efficiency.

This study investigates the mediator effects of firm intangible resources – human capital and firm reputation – on the relationship between Industry 4.0 adoption and firm efficiency. I postulate that the relationship between Industry 4.0 adoption and firm efficiency is more than just a direct association. I assume that Industry 4.0 adoption, frequently connected with greater human capital and a stronger reputation (Hamdoun, Achabou, & Dekhili, 2022), can contribute to firm efficiency.

This study makes several additions to the literature. First, most studies of the impact of Industry 4.0 on firm performance focus on accounting performance indicators. In contrast, I examine the impact of Industry 4.0 on firm efficiency, defined as a firm's ability to produce the most output with the least number of inputs. This is significant since, empirically, Industry 4.0 increases efficiency. Furthermore, it is easier for firms to manipulate financial data than input-output figures. Thus, Industry 4.0 and firm efficiency may have a more direct and observable link than Industry 4.0 and financial performance. Second, I also constructed Industry 4.0 index through a content analysis approach. The approach allowed us to quantify and empirically investigate the impact of Industry 4.0 and its components on firm efficiency. I show that, on average, Industry 4.0 significantly impacts firm efficiency at an acceptable 10% significance level. The results on the association between industry 4.0 index components and a firm's efficiency may be misleading without considering their interaction effect.

Third, this research study helps to understand how the relationship between Industry 4.0 and firm efficiency is mediated by intangible assets (human capital and firm reputation). Previous research on Industry 4.0 has examined how adopting Industry 4.0 affects firm performance. These published studies concentrate on a direct impact and implicitly assume that the mere adoption of Industry 4.0 is sufficient to improve performance. I show that firm intangible assets mediate the relationship between Industry 4.0 and firm efficiency. Lastly, our sample comprises firms from the Asia Pacific Region. Asia Pacific, led by China, is a fast adopter of Industry 4.0 technologies. As fast-growing companies tap the potential of new technologies, Asia Pacific is undergoing a major business shift. Across the region, not only are the numbers of start-ups increasing, but so are their size and importance. Simultaneously, new industry verticals emerge, garnering investment dollars and encouraging an increasing number of start-up founders to enter the market. As a result, our research adds to the existing literature on the influence of Industry 4.0 adoption on company efficiency.

The outlines of the current study are as follows. Section 2 describes the Emerging Giants in Asia Pacific, followed by the research background in section 3. Section 4 describes the hypotheses development based on theoretical background. Section 5 provided the sample description followed by variables construction for empirical testing. Section 6 describes the modeling technique, while Section 7 discusses the results. Sections 8 and 9 provide a conclusion and research implication, respectively.

2 EMERGING GIANTS IN ASIA PACIFIC

Asia Pacific has long been the engine of global prosperity, powered by the network of industrial supply chains that have transformed it into the world's factory, but two revolutions are now significantly transforming its growth profile: the first is that Asian economies that used to supply Western customers are now becoming marketplaces in their own right as their incomes rise, and the second is that the ability to deliver things digitally has changed the primary engine of regional growth (Keane, Yu, Zhao, & Leong, 2020).

For the study, I collected firms' level data from ten emerging giants in the Asia Pacific. According to Darren Yong, Head of Technology, Media and Telecommunications, KPMG Asia Pacific," The new platforms and software applications offered by Asia Pacific's developing titans are daring, ambitious, and cutting-edge. They are daring in who they collaborate with, which markets they target, how construct their business models, and how they modify company culture and mission statements. Perhaps most crucially, they are reshaping and pioneering the technology environment in the coming years while also considering what is valuable to their clients now." Another indicator I looked at was the total value of the 12 Leading Emerging Giant start-ups in the 12 Asia Pacific markets studied (see Figure 1). While Mainland China and India were predictably near the top due to the size of their economies, five of the twelve markets had average valuations of US$300 million or more among their respective ten Leading Emerging Giants lists. In comparison, eight of the twelve markets had average valuations of US$100 million or more. The numbers show the size of high-value start-ups in Asia, even in regions investors see as less mature.

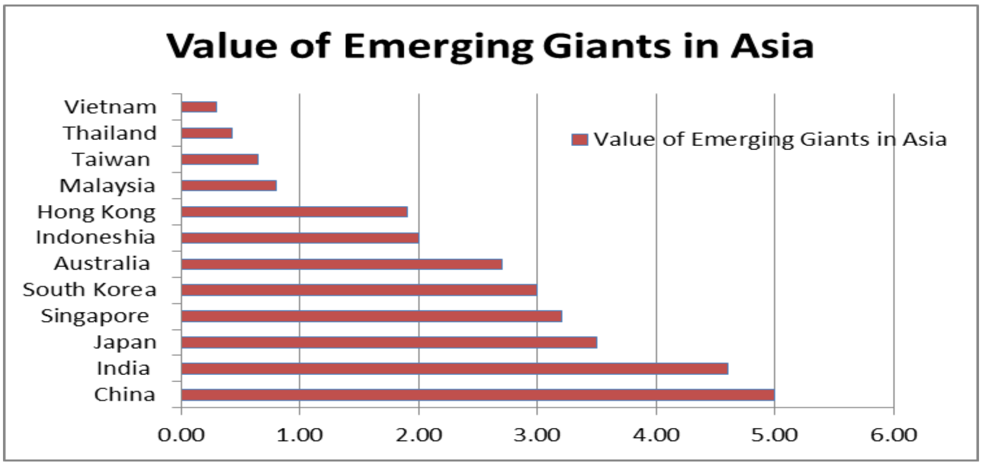

Figure 1 - Value of Emerging Giants in Asia
Source: Author creation from data source
(https://kpmg.com/xx/en/home/insights/2022/07/emerging-giants-in-asia-pacific.html)

3. RESEARCH BACKGROUND

Conceptual research approaches considerably improve a researcher's ability to shape sound theories on operations management. Irrespective of the proposed theory framework, it should satisfy Dubin's five basic needs for a theory (Meredith, 1993): it improves understanding; it is motivating; it entails variables and their associations; it should not comprise composite variables; and it comprehends the boundary criteria (Stein & Meredith, 1993).

3.1 Practice-based view (PBV)

Bromiley & Rau (2016a) proposed the PBV perspective after reviewing top Resource-Based View (RBV) papers. They contend that applying RBV in operations management research does not always assist researchers in aligning with their study aims. The RBV view has certain assumptions, such as profit-maximizing corporations and managers in rational firms. Two other assumptions in RBV are resource heterogeneity and immobility (Hitt, Carnes, & Xu, 2016). PBV is better for operations management researchers to clarify the entire firm and unit performance set based on redeemable practices (Bromiley & Rau, 2016a). Adopting specific methods and analyzing stage-wise or end-performance results at a firm, plant level, or other business units are the dependent variables in PBV. The explanatory variable in PBV determines the difference at the firm or other business unit level. The basic assumption of PBV is that firms exhibit a wide range of performance within an industry and differ in activities that may benefit them (Bromiley & Rau, 2016b). Thus, using practices can help to understand performance deviations. Firm-level practices' payback may vary across organizations due to the effect of multiple mediators/moderators on each practice. Resultantly, PBV may solve many RBV-related concerns. PBV, like RBV, is an umbrella term that allows researchers to propose various theories to clarify the distinctive influence of technology adoption on firm-level outcomes.

In the current study, I used Industry 4.0 as a firm-level practice that a firm employ to improve its manufacturing capabilities. Improved operational excellence implies increased operational flexibility, efficiency, and effectiveness, all of which influence the development of intangible assets to support remanufacturing and recycling-based production operations (Lu, 2017). Industry 4.0 practices resulted in the development of intangible assets, further supported by the Dynamic Capability View theory.

3.2 Dynamic capability view (DCV)

Previous researchers in operations management studies have employed dynamic capacity theory, specifically for executing strategic choices under multiple business scenarios (Arndt, 2019; Vogel & Güttel, 2013). Leemann & Kanbach (2022) defined dynamic capabilities as "the ability to anticipate and shape opportunities and threats, to seize opportunities, and to sustain competitiveness through improving, integrating, defending, and, fourthly, when necessary, reconfiguring the firm's tangible and intangible assets." In the current study context, I used intangible assets as mediators as industry 4.0 adoption influences intangible assets, and the assets improve firm efficiency. I used two proxies of intangible assets, including human capital and the firm's reputation (Vogel & Güttel, 2013). I used human intellectual capital as the value of an organization's human knowledge, skills, and inventive and creative ideas. Second, the firm's reputation is also linked to Industry 4.0 adoption and the firm's efficiency simultaneously.

3.3 Industry 4.0 and its Benefits

Many analysts think we live through a manufacturing technological revolution. This revolution is built on a diverse set of digital manufacturing technologies (sensors, actuators, horizontally and vertically integrated production, robots, additive manufacturing), new IT-enabled management processes (e.g., real-time enterprise resource planning and production control, data analytics, and artificial intelligence applications), and new business and revenue models (Hofmann & Rüsch, 2017). The Fourth Industrial Revolution (after mechanization, electrification, and automation) or Industry 4.0 is the goal of widespread usage of these technologies in the Industry (Dalenogare, Benitez, Ayala, & Frank, 2018). The autonomous communication and coordination of components and machines in factories and value chains is the most noteworthy characteristic of Industry 4.0 (Hofmann & Rüsch, 2017). The goal of Industry 4.0 is to establish a highly flexible and efficient manufacturing process that enables the production of personalized items under mass-production economic conditions (Lichtblau et al., 2015).

Manufacturers have implemented Industry 4.0 advancements ahead of their competitors. Modular, data-driven automation gives them supply chain management in the next manufacturing and delivery era. Industry 4.0 improves performance, versatility, robustness, and profitability. Industry 4.0 also helps manufacturers make better, more efficient goods (Oesterreich & Teuteberg, 2016). This generates more and faster while making products cheaper and more reliable. These advancements enable data democratization and broadened insights; Industry 4.0 will connect gadgets outside the factory. Modern firms value data. Sensor and equipment data is crucial and organized. In factories, creativity is improved, not replaced. Capacity building and culture change are the most important (Lu, 2017). Analytics and emerging technology training would prepare the human resource for a changing world and keep them relevant. Explaining these advances across its value chain and inter-organizational supply chain networks is crucial. It is crucial to explain these advances across its value chain and inter-organizational supply chain networks. It would employ machine learning to make smarter decisions from real-time supply chain data.

4. HYPOTHESES DEVELOPMENT

4.1 Industry 4.0 and firm performance

The emergence of Industry 4.0 has sparked widespread speculation about its potential impact on firm performance (Dalenogare et al., 2018). "Industry 4.0" refers to the digitalization and technological transformation that industrial enterprises undertake. Cloud computing, the Internet of Things, Internet of Services, wireless sensor networks, big data, or robotics and artificial intelligence, as well as the convergence of traditional physical elements and digital elements (or cyber-physical systems), have created a powerful technical lever for systemic transformation in industrial firms (Oesterreich & Teuteberg, 2016). Industry 4.0 entails (1) the development of more versatile and additive production systems; (2) smart working/smart manufacturing, which particularly affects the integration of human employment with production systems; and (3) new forms of strategic decision-making focused on real-time bidding (Dalenogare et al., 2018).

Research tying Industry 4.0's inventive stems to economic performance has already begun to yield some meaningful evidence. From the economic and financial firm Performance standpoint, Industry 4.0 technologies have been highlighted as drivers of productivity advances and financial returns by generating innovations that significantly alter production and employment methods (Torrent-Sellens, Ficapal-Cusí, & Enache-Zegheru, 2023). I4.0 technologies such as EITI have been validated for use in digital automation/robotics (Torrent-Sellens et al., 2023), flexible/additive manufacturing systems (Favoretto, Mendes, Filho, Gouvea de Oliveira, & Ganga, 2022), and data-driven decision making (Favoretto et al., 2022). Furthermore, in terms of performance efficiency, I4.0-induced changes in industrial firm efficiency models have been linked to reductions in cost, as well as savings in production inputs or energy. Research into the relationship between Industry 4.0 and the more economic returns of corporate has yielded conflicting results.

Technological tools optimize daily operations, improving manufacturing and management efficiency as part of Industry 4.0 (Frank, Dalenogare, & Ayala, 2019). Industry 4.0 will help high-efficiency companies use new technology. Companies can utilize resources for competitive advantage. Equipment failures generate unexpected production shutdowns and the requirement for emergency technicians and specialists. Industry 4.0 increases predictive maintenance, which monitors equipment to detect faults. Sensors on machinery communicate data to the cloud through specific systems for maintenance (Dalenogare et al., 2018). Thus, unlike preventive maintenance, which involves part replacement even if the machine doesn't need it, predictive maintenance can check for action in advance, saving equipment damage and inspection hours (Frank et al., 2019).

Big data controls temperature, humidity, inventory, and other plant data, improving working conditions. A better air-conditioned workplace, among other aspects, boosts employee satisfaction, productivity, and profitability. The integration and autonomy of operational equipment have automated factory tasks virtually. This allows employing professionals to do more complicated; strategic operations focused on results (Dalenogare et al., 2018). It is well known that as part of the Industry 4.0 deployment, technological tools optimize day-to-day operations, resulting in better efficiency in manufacturing and management processes. Industry 4.0 will help organizations with much-advanced efficiency operations by utilizing new and powerful technical resources (Dalenogare et al., 2018). Businesses can optimize resources to get better results and gain a competitive advantage. As a result, implementing Industry 4.0 technology is predicted to boost business efficiency. The following hypothesis is developed.

H1. Industry 4.0 technologies exert a positive effect on firms' efficiency.

4.2 The mediating role of intangible assets

Following earlier research, I used two proxies of intangible assets. These include human capital and firm reputation.

4.2.1 Human capital as a mediator

A lack of skilled workers is one key reason enterprises differ in performance. This may result in frontier technologies or a mismatch between relatively low-skilled workers and technologies invented primarily in technology-driven firms to fit their factor endowments (Zhu, Chew, & Spangler, 2005). Firms may be able to embrace new and more productive technologies, match cutting-edge technology with more qualified individuals, and conduct R&D when the supply of competent workers is drastically reduced (Wright & McMahan, 2011; Zhu et al., 2005). These actions will most likely result in increased firm productivity and economic growth. Meanwhile, the Industry 4.0 technological frontier is not moving in unison across industries. Technological developments have favoured workers with higher levels of human capital over those with lower levels of human capital, resulting in quicker growth in total factor productivity in more human capital-intensive businesses. (Delery & Roumpi, 2017).

Firms that adopt Industry 4.0 are more likely to extend their efforts internally to benefit their employees. Indeed, human capital retention and development are crucial to corporate growth, mostly through training programs that expand employees' knowledge base. Furthermore, human development and training at work represent the demand for workplace settings that promote health and well-being while allowing for skill development (Bornay-Barrachina, López-Cabrales, & Valle-Cabrera, 2017). As a result, Industry 4.0 serves as a resource for managers seeking information. Industry 4.0 practices increase learning, adaptation to change, and self-fulfilment by combining the settings that allow the optimal application of employees' knowledge (Bornay-Barrachina et al., 2017; López-Cabrales, Real, & Valle, 2011). Industry 4.0 enable firms to build the capacity of their managers, resulting in better resource management (Babasanya, Oseni, & Awode, 2018). In emerging countries, investing in human capital through skill development is vital. Human capital development through the Industry 4.0 plan is considered a strategic alternative.

Human capital is a highly sought-after resource for firms in today's knowledge-based economy, as it contributes to their viability and success. Because it is distinct and difficult for competitors to copy, it is an important component of intellectual capital for businesses (Todericiu & Stăniţ, 2015). Furthermore, firms can use it in various ways and across various industries without losing value. Human capital can increase a company's worth, create long-term profitability, and assist it in gaining a competitive advantage (Riley, Michael, & Mahoney, 2017). However, gaining a competitive edge through human capital requires luring and keeping the right people while improving their management and structure. (Lawler, 2009). (Riley et al., 2017) shown that businesses that outperform their rivals in recruiting, training, and using human resources reap cost and learning benefits.

Human capital encourages innovation and boosts a firm's flexibility (Paillé, Chen, Boiral, & Jin, 2014). Paillé et al., (2014) recognized human capital as a crucial contributor to developing a competitive advantage. It eventually improves company performance in emerging economies. Intangible resources that are difficult to replicate can help to create firm efficiency (Nieves & Quintana, 2018). The reasoning prompted us to investigate the role of human capital in mediating the Industry 4.0-firm efficiency relationship; firms engaging in Industry 4.0 adoption also focus on their human capital, which has the potential to use the technology efficiently to boost productivity. As a result, the study hypothesizes as follows:

Hypothesis 2a. The Industry 4.0-performance relationship may be mediated by human capital in Emerging Asian MNEs.

4.2.2 Firm reputation as a mediator

According to the resource-based view, a hard-to-copy intangible resource sets a company apart (Wu, Ngai, Wu, & Wu, 2020). Industry 4.0 is now crucial to corporate reputation management. Industry 4.0, which involves intense managerial involvement, is mostly used by corporations to manage their reputation. Brand capital depends on Industry 4.0 adoption. Indeed, Industry 4.0 humanize industrial processes (Hamdoun et al., 2022) and boosts a company's credibility (McWilliams & Siegel, 2000). According to the resource-based perspective, Industry 4.0 adoption can improve a company's reputation with stakeholders, including consumers, employees, government, and suppliers (McWilliams & Siegel, 2000). Risk management strategies can benefit from Industry 4.0 adoption.

Reputation helps companies succeed. This intangible asset safeguards the company's lifetime and competitiveness (Galbreath & Shum, 2012). Reputation enhances market position, blocks competitors, and offers a corporation moral power. Advanced technology improves efficiency, client communication, and growth in all organizations. Staff and customers use technology for regular tasks. In today's global market, companies without innovative technologies will lag. Industry 4.0 guarantees cutting-edge business operations (Galbreath & Shum, 2012). Success without the high costs of incorrect counsel, taking chances, and other mistakes (Bontis, Booker, & Serenko, 2007). Clients like companies that follow industry standards. Industry 4.0 might be hard to demonstrate after a first impression. Thus, assistance can make the organization appear modern and proactive to clients and partners. It helps improves productivity, security, and more (Agyemang & Ansong, 2017). Digital tools streamline employee communication and monitoring. Cost-effectively store and safeguard massive data sets. Highly reputed firms will likely use Industry 4.0 to optimize costs and boost efficiency. They use Industry 4.0 to boost their efficiency more than their counterpart (Galbreath & Shum, 2012). Therefore, the study hypothesis is as under:

2b. The Industry 4.0-performance relationship may be mediated by business reputation in Emerging Asian MNEs.

4.3 Conceptual framework

In figure 2, the conceptual framework of the study is provided. First, the direct impact of Industry 4.0 is empirically tested on firm efficiency. I include control factors in the main regression to avoid any estimation biases. Intangible assets are represented by human capital and firm reputation. The dot lines represent the mediation effect. Hypotheses 2a and 2b represent the mediation effect. Control factors are included in each regression.

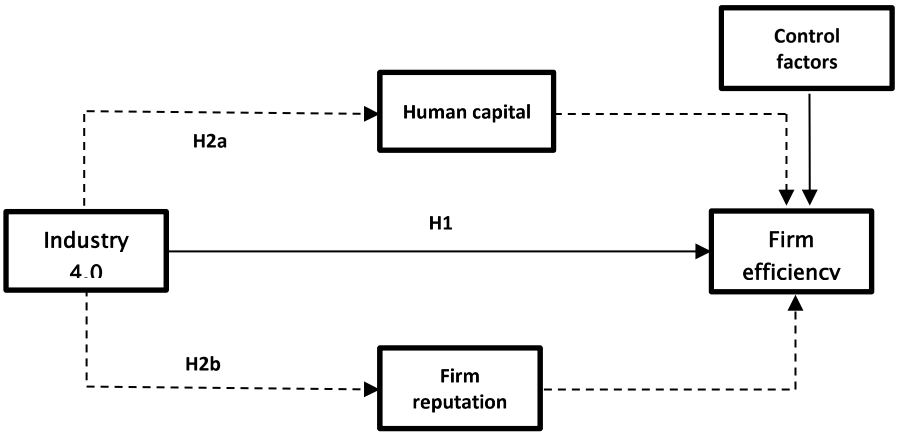

Figure 2 - Conceptual framework

5. SAMPLE CONSTRUCTION

First, I have collected information from Thomson Reuters, which provides information regarding financial variables. Second, I included firms that published their financial reports yearly and registered on the stock exchanges. Third, I exclude firms delisted during the sample period. This limited our sample significantly. I got data on country-level factors from different sources like the World Bank. This restricted our sample seriously. The sample description is provided in Table 1.

Table 1 Sample selection

Country	Firms	Percentage
China	222	15.417
India	210	14.583
Japan	132	9.167
Singapore	98	6.806
South Korea	116	8.056
Australia	95	6.597
Indonesia	92	6.389
Hong Kong	98	6.806
Malaysia	100	6.944
Taiwan	92	6.389
Thailand	96	6.667
Vietnam	89	6.181
total	1440	100.000

Notes: This Table shows the criteria for the final sample. Our sample consists of the period that spans the years 2015 to 2022. I obtain firm yearly data from different sources. I identified financial institutions using the ICB industry classification in Thomson Financial DataStream (codes 7 and 8). I winsorized the financial variables to 2% and 98% percentile values.

6. EMPIRICAL STRATEGY

6.1 Firm efficiency

I used the stochastic production frontier model to measure firm efficiency. This method compares the firm to the most efficient firm (i.e., the one with the "best practices") rather than the average company (Faccio, Marchica, & Mura, 2016). To begin, I define the production function as follows:

$$Y_{it} = \int (X_{it}: \beta). TE_{it} \tag{1}$$

In the first portion of the equation, I use a production function $Y_{it} = \int (X_{it})$ to connect the output Y_{it} and the inputsX_{it}. Technical effectiveness (TE_{it}) considers the effectiveness of the input factors. In other words, if TE_{it} = 1, a firm efficiently uses its inputs and achieves its maximum viable outcome, whereas if TE_{it} < 1 indicates some inefficiency. Because the output is always positive, if TE_{it} = 1 is defined in the range from 0 to 1. Following that, the stochastic frontier analysis makes two assumptions. if TE_{it} is a stochastic variable having a distribution that all enterprises share. As a result, I define it as if $TE_{it} = \exp(-\mu_{it)}$. To account for random shocks in production (machinery breakdown), the error term is indicated asexp $(v_{it)}$. Thus, the stochastic production function model is expressed as:

$$Y_{it} = \int (X_{it}: \beta). \exp(-\mu_{it}) . \exp(v_{it}) \tag{2}$$

In logarithm form, it is expressed as under

$$LnY_{it} = \sum_{j=1}^{k} \beta_{it} LnX_{it} + v_{it} - \mu_{it} \quad (3)$$

In equation 3, v_{it} represents two-sided error term that is normally distributed. μ_{it} is the variable for technical inefficiency? It has a positive sign and measures the distance from the efficient frontier.

The Cobb-Douglas production function is used to model technical efficiency. Its parameters interact with 2-digit industry dummy variables to account for industry idiosyncrasies. The model of the efficiency frontier of firm I (i = 1,..., I) in J two-digit sectors (j = 1,..., J) over T periods (t = 1,..., T) is as follows:

$$LnY_{it} = \sum_{j=1.....j} [\beta_{0j} + \beta_{1j} LnC_{it} + \beta_{2j} LnI_{it}] . ID_{itj} + \emptyset_t + V_{it} - \mu_{it} \quad (4)$$

In equation 4, the sale is the variable of firm output. $\mathrm{LnC_{it}}$ represents the log of each capital i. Total fixed assets plus working capital are used to approximate capital, defined as current assets minus current liabilities. $\mathrm{LnI_{it}}$ represent the logarithm of the number of employees. Capital and labor are basic inputs into production that result in output sales. ID_{itj} stands for a vector of industrial (j) dummy variables. All elements of the production function in model 4 — the constant term and production inputs (capital plus labor) — interact with 2-digit industry dummy variables to benefit from a lithe, functional form. The random error is denoted by V_{it}, and the firm's efficiency is denoted by μ_{it}. μ_{it} = 0 if the firm is completely efficient. A positive μ_{it} represents any inefficiency. The inefficiency factor (μ_{it}) of the Model is not easily observable and must be calculated using usual assumptions where.

$$V_{it} - iidN(0, \sigma_v^2) and\ \mu_i \sim iidN^+(0, \sigma_\mu^2) \quad (5)$$

The following equation is used to obtain the minimum squared error predictor of the ith firm's technical efficiency:

$$E(\exp\{-\mu_{it}\} \,|\varepsilon_i) = E(\exp\,[\beta(t).\mu_i]|\varepsilon_i = 1 - \emptyset[\sigma_i^* - (\mu_i^*|\sigma_i^*)]/1 - \emptyset[-(\mu_i^*|\sigma_i^*).\exp\left\{\mu_i^* + \tfrac{1}{2}\sigma_i^{*2}\right\} \quad (6)$$

Where $\varepsilon_{it} = V_{it} - \mu_{it.}\mu_i^* = (\mu\sigma_i^2 - T\varepsilon_I\sigma^2)/(\sigma_V^2 - T\sigma^2)$ and $\sigma_i^{*2} = (\sigma_v^2\sigma^2)/(\sigma_v^2 T\sigma^2)$

µ is identified by the minimum squared error predictor, and v is the residual difference (u). Details can be found in (Kumbhakar, Lien, & Hardaker, 2014). Model (4) is estimated in a series of short panels (2010-2012, 2013-2015, 2016-2019, and 2019-2022) to account for time-varying changes in technical efficiencies. According to (Faccio et al., 2016), the short periods used to evaluate technical efficiency mitigate any potential bias of the estimated parameters in a fixed-effect stochastic frontier model while also allowing for a practical estimation. I performed the estimation technique by Industry and country wise. This is the recommended strategy in econometrics; instead of estimating the Model with country-specific dummies, it is less constrained. Estimating is also much more practical. Finally, year dummy variables are included to account for time-variant effects, allowing us to capture industry-specific pricing volatility in short panels.

6.2 Industry 4.0 index

I look for answers to a series of queries about whether or not the company employed a certain technology to evaluate the adoption of Industry 4.0 technologies. The reference year for implementation in this scenario is 2014 or earlier. However, a few forerunners are the only ones using some highly cutting-edge Industry 4.0 technologies since they are not widely available (or never have been). This makes assessing the spread of these technologies in a representative sample of manufacturing companies, which includes a large number of listed firms, challenging (Frank et al., 2019). As a result, I focus on a collection of eight Industry 4.0 technologies already available on the market and hence can be adopted by firms, but large firms may use them more extensively. I use this information to create an index of Industry 4.0 technologies (Industry 4.0), which records the firm's involvement in these technologies in great detail (Frank et al., 2019). A higher index value shows increased utilization of Industry

4.0 technologies as more advanced manufacturing technologies are implemented.

I used the content analyses approach to assign value to each construct used in Index. For this purpose, I extracted information from the published reports. Intangibles and knowledge-based resources have been key value drivers in modern economies for several decades. Despite the importance of intangibles and knowledge-based resources, attempts to communicate them in annual reports have failed repeatedly (Nielsen et al., 2017). Costs or potential loss of competitive advantage due to the revelation of information concerning resources, know-how, and processes could be grounds for this communication failure. A major factor is also a lack of direction. From the user's standpoint, IC information may be ineffective if an entity fails to clearly describe how IC contributes to value creation (Bagnoli, Massaro, & Costantini, 2021). However, current rules have provided a framework for conveying intangibles and knowledge-based resources and incorporating them into the value-generating process. Companies must provide information about their business model (BM) and pertinent risks in their annual report under EU Directive 2014/95 and the UK Companies Act. Because IC is a substantial source of competitive advantage, particularly in high-tech industries, organizations should demonstrate the most crucial intangible variables' contributions to value creation in the BM portion of the report (Simoni, Schaper, & Nielsen, 2022).

Since our research is a pioneer in extracting Industry 4.0 index, I carefully employed the context analysis approach. First, I use specific words that could be used to deduct any relevant information to assign 0 or 1 to each construct of the Industry 4.0 index. I also consulted with technology experts to assign specific wording to each construct. I used eight constructs of technologies for Index 4.0 (see Table 2). The details of the wording used in the content analysis approach are provided in Appendix B.

Table 2 - Technologies used to construct Industry 4.0 index technologies

	Technologies	
1	Product lifestyle management (PLM) Systems	X.L. Liu, et al., (2020)
2	Additive Manufacturing (for prototyping/production)	de Freitas Vilela and Filho (2022)
3	Digital Visualization	Junge, A. L. (2019)
4	Supplier Data Exchanges	Cordeiro, Ordóñez, and Ferro (2019)
5	automated operations	Jiang et al., (2016)
6	Real-Time Control System	(Albers et al., 2016)
7	HMI (Human-Machine Interaction)Technologies	(Di Nardo et al., 2020)
8	Use of Mobile/wireless for providing services	Junge, A. L. (2019)

The results of the content analysis are reported in Table 3. I started our data period in 2015 since most of the firms started disclosing relevant information in that year. The firms are included in the sample if they remained listed for the entire period and their annual report is available. I use the information on these technologies to construct an Industry 4.0 index that continuously captures the firm's involvement in these technologies. A higher index value indicates more intensive use of Industry 4.0 technologies as more advanced manufacturing technologies are applied. In Table 3, I can see Food, beverages, Textiles, clothing, Wood, paper, print, Pharma, chemicals, and Plastics mean values are below than overall mean value of the sample. This implies that these firms are less technology-intensive than Plastics, Mineral products, Metal, metal products, Electrical and electronics, Machinery, and Transport equipment.

Table 3 - Industry 4.0 index technologies in different sectors

	Sector	Firm	Percentage	Industry 4.0 index (mean)
1	Food, beverages	124	8.611	2.483
2	Textiles, clothing	103	7.153	2.172
3	Wood, paper, print	160	11.111	2.982

4	Pharma, chemicals	134	9.306	2.561
5	Plastics	147	10.208	3.211
6	Mineral products	103	7.153	3.172
7	Metal, metal products	169	11.736	4.162
8	Electrical, electronics	154	10.694	4.029
9	Machinery	142	9.861	3.137
10	Transport equipment	110	7.639	3.182
11	Other	94	6.528	2.091
	Total	**1440**	**100**	**3.016**

Figure 2 shows each Industry 4.0 technology usage in percentage by sample firms. As per statistics, 47% of firms use Mobile/wireless, followed by PLM Systems (46%) and Supplier Data Exchanges (43%). These three technologies are the most ones that our sample firms use. Meanwhile, above 30% of our sample firms use automated operations (32%) and HMI Technologies (31%). Additive Manufacturing (29%), Digital Visualization (27%), and Real-Time Control Systems (24%) are the least used Industry 4.0 technologies. There were 2286 firms' year observations where firms did not apply any Industry 4.0 technologies.

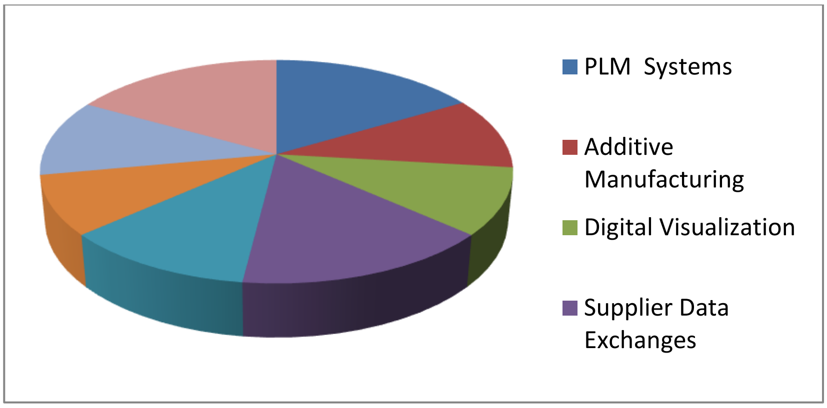

Figure 2 - Uses of Industry 4.0 Index Technologies in Different Sectors

6.3 Asset valuation

6.6.1 Human capital

I used two proxies of human capital as intangible assets. The first is a synthetic index developed through factor analysis (BlueStaff-ratio) with as inputs the ratio of "white collars" to "blue collars," the workforce's average number of years of education, and the percentage of employees with a university degree, the second is the percentage of employees engaged in R&D (Staff-R&D). I believe BlueStaff-ratio and staff-R&D are two different human capital benefits. However, BlueStaff-ratio measures a company's knowledge-intensive asset management. R&D, on the other hand, R&D is a company's willingness to use its people resources to evaluate, assimilate, and apply new information. I used previous measurements.

The reputation rankings from the reputation Institute were used to produce our second mediating variable. This evaluation offers a holistic approach to corporate reputation and applies a rigorous technique that has received considerable academic endorsement. The Reputation Institute develops the ranking through a multi-item online survey that uses a seven-point Likert scale to gauge the opinions of a wide range of people about various facets of CRep across seven key reputational dimensions: innovation, leadership, workplace, goods and services, citizenship performance, and governance.

6.4 Firm efficiency determinants

The employed econometric Model is based on panel data dependence methods. This study intends to investigate the nature of the relationship between Industry 4.0 and firm efficiency. I regress Industry 4.0 on firm efficiency after controlling for several firms and country-level factors to achieve this. The Model is as under.

$$Firm\ efficiency_{it} = \beta_0 + \beta_1 Index - 4.0_{i,t} + \beta_2 firm\ level\ factors_{i,t} + \beta_3 country\ level\ factors_{i,t} + \beta_4 year\ effect_{i,t} + \beta_5 industry\ effect_{i,t} + \varepsilon_{i,t} \quad (7)$$

In equation 7, $\varepsilon_{i,t}$ represents the error term. All variables are defined in Appendix A.

7. RESULTS

7.1 Descriptive statistics and variance inflation factors (VIF)

Table 4 lists the variables' descriptive statistics and VIF for the sample firms. Our final sample includes 1440 firms and spans the top 12 Asian Pacific Economies from 2015 to 2022. Efficiency has a mean value of declines as one advances from 0.318 to the higher of 1.627 in this sample, which shows the "best practice" efficiency frontier. The average efficiency is around 1.024, with a standard deviation of 0.926. Our main independent variable is Industry 4.0, which has a mean value of 3.016 and ranges from 0 to 8.000. It has a standard deviation of 1.128. The sample firms have a mean value of total assets of USD 11.405 million, a leverage ratio of 1.94, which is marginally higher, and a cash position of 0.28. The average age of the sample firms is 19.23 and ranges from 12 to 56. I also included corporate governance factors (board independence and gender diversity). Board independence has a means value of 29.037 which ranges from 10.203 to 74.307. Board gender diversity is represented by the ratio of female to male directors. Its mean value is 21.71, implying that for a board of ten members, females account for nearly 3, which is quite satisfactory compared to the rest of the world. Further, descriptive statistics of country-level controls are also provided. I also provided VIF of variables. The values of variables are far below a benchmark of 10, indicating no issue of collinearity.

Table 4 - Descriptive statistics and VIF

Variables	Mean	S/D	Min	Max	VIF
Firm efficiency	1.024	0.926	0.318	1.627	
Industry 4.0	3.016	1.128	0.000	8.000	2.190
Corporate governance factors					
Board independence	29.037%	1.543	10.203	74.307	1.672
Gender diversity	21.71%	0.892	11.982	64.876	2.184
Firm-specific factors					
Firm size	11.405	1.088	4.312	18.099	2.797
Firm age	19.23	2.170	12.000	56.000	1.551
Leverage ratio	1.942	1.118	0.681	2.781	3.293
Cash flow	0.286	0.906	0.082	0.356	3.844
Country-level factors					
Institutional quality	0.637	0.898	0.554	0.893	2.930
Access to financing	0.599	1.756	0.827	0.493	2.283
Business licensing and permits	0.645	1.343	0.478	0.283	3.293
GDP growth	0.632	2.374	2.162	8.717	3.508
All variables are defined in Appendix A. S/D represents standard deviation.					

7.2 Industry 4.0 and firm efficiency (H1)

This section empirically examines the Industry 4.0- firm efficiency relationship. The study used STATA version 15 and the xtgls command to analyze the data. The random effect GLS model analyzes the panel data rather than fixed effect models. For several reasons, random effects models appear to be better relevant for the current study. According to the Hausman test, a random effects model is adequate for analyzing our data. Fixed effects models only reflect within-firm effects, whereas random effects models allow us to test for between-firm impacts (Borenstein, Hedges, Higgins, & Rothstein, 2010). Thus, random effects models enable us to investigate the Industry 4.0- firm efficiency relationship. The study controls for several variables to address the endogeneity concern.

The results are reported in Table 5. The results show a positive and statistically significant impact of Industry 4.0 adoption on firm efficiency (p<.10). After controlling for a wide range of firm-level control variables, the results are economically inconsequential. In addition, I hold industry and country effects for a year. Industry 4.0 describes "smart" and interconnected production systems that perceive, forecast, and interact with the physical world to make decisions about production in real time. Our findings show that Industry 4.0 boost productivity, energy efficiency, and sustainability in production (Dalenogare et al., 2018). It boosts production by lowering downtime and maintenance expenses. Resultantly, it improves firms' efficiency. Industry 4.0 and firm efficiency's significant relationship may be attributed to the capability of firms to use Industry 4.0 as a competitive advantage.

Further, I also used Tobit regression to support our main findings. I assign one if a firm is within the efficient frontier and 0 otherwise. The Model shows the likelihood of Index-4 impact on firm efficiency. In Tobit regressions, the coefficient of interest is once again positive and statistically significant (p<.10). A positive coefficient suggests that firms using Industry 4.0 are likely to be efficient. As a result, the adoption of Industry-4.0 is related to the likelihood of firm efficiency.

table 5 - Industry 4.0 -firm efficiency relationship (Hypothesis 1)

	The random effect GLS model		Tobit model	
Variables	**Coefficient**	**S/E**	**Coefficient**	**S/E**
Industry 4.0	0.095*	0.054	0.086*	0.051
Firm-specific factors				
Board gender diversity	0.077**	0.035	0.070**	0.033
Board independence	0.027*	0.015	0.025*	0.015
Firm size	0.038**	0.018	0.035**	0.018
Financial leverage	-0.023*	0.013	-0.021**	0.012
Cash flow	0.127**	0.062	0.125**	0.060
Firm age	0.011**	0.006	0.010**	0.005
Country-level control		`		
Access to financing	0.035**	0.017	0.032**	0.017
Business licensing and permits	0.088***	0.023	0.080***	0.021
Institutional quality index	0.018***	0.006	0.016***	0.006
GDP growth	0.114***	0.028	0.104***	0.027
Constant	0.552***	0.156	0.502***	0.149
Year and industry effect	Yes		Yes	
Wald chi(2)	162***			
Pseudo R_2			0.298	

Due to the analyses' sensitivity, I used various control factors. According to the research, board gender diversity improves firm efficiency. The board gender diversity coefficient estimate is positive and statistically significant at 5%, indicating that including women on corporate boards improves firm efficiency (Xie, Zhou, Zong, & Lu, 2020). This is also compatible with the idea that female members are more proactive, and their engagement ensures firm efficiency (Luo, Lee, Chiu, & Lee, 2023). However, board independence affects firm efficiency at an acceptable 10% significant level. This is consistent with prior research suggesting that women are more proactive.

Similarly, firm size and age (p<.05) are related to firm efficiency. Both firm size and age show significant firm efficiency, however. The positive association suggests that corporations having large size and maturity are more likely to boost their efficiency (Luo et al., 2023). In contrast, I discovered that financial leverage negatively impacts firm efficiency (p<.10). When a firm operates in a competitive market and has to improve efficiency, excessive leverage imposes a significant risk, resulting in poor performance (Luo et al., 2023). Leverage reduces a company's ability to invest as funding becomes more expensive. The coefficient estimate for cash flow is positive and statistically significant, indicating that higher cash flow improves firm efficiency (Samo & Murad, 2019).

I also take into account macroeconomic factors that could affect firm efficiency. Access to financing influences firm efficiency (p<.05; see Table 5). Firms in markets where financing is easily available are more likely to improve Performance (Bollaert, Lopez-de-Silanes, & Schwienbacher, 2021). The quality of institutions has a statistically significant positive impact on firm efficiency (p<.01). The Institutional Quality Index (IQI) is a composite measure used to assess Institutional Quality (Bollaert et al., 2021). Improved institutional quality leads to improved firm efficiency. GDP growth positively impacts firm efficiency (p<.10). The findings show that higher national GDP growth influences firm efficiency. Lastly, business licensing and permits also have a positive and statistically significant impact on firms' efficiency.

7.3 The mediating role of intangible assets (Hypotheses 2a and 2b)

At this stage, I empirically evaluated the mediating role of intangible assets (human capital and business reputation). Separate regression models are utilized for this purpose. To begin, I used our primary Model to investigate the direct impact of Industry 4.0 on firm efficiency.

$$firm\ efficiency_{i,t} = \alpha + \beta_1 Industry\ 4.0_{i,t} + \beta_2 firm\ level\ control\ factors\ _{i,t} + \beta_3 country\ level\ control\ factors\ _{i,t} + \beta_4 year\ effect_{i,t} + \beta_5 industry\ effect\ _{i,t} + \varepsilon_i \quad (8)$$

I also include the role of intangible assets as mediators to assess them empirically. The regression model below is employed.

$$firm\ efficiency_{i,t} = \alpha + \beta_1 Industry\ 4.0_{i,t} + \beta_2 intangible\ assets_{i,t} + \beta_3 firm\ level\ control\ factors\ _{i,t} + \beta_4 country\ level\ control\ factors\ _{i,t} + \beta_5 \mathrm{year\ effect}_{i,t} + \beta_6 \mathrm{industry\ effect}\ _{i,t} + \varepsilon_i \quad (9)$$

The results are reported in Table 6. In column 1, the direct impact of Industry 4.0 on firms' efficiency is statistically insignificant. In columns 2 and 3, I introduced human capital (Blue Staff-ratio and Staff-R&D) to observe its mediation role. Both measures of human capital positively and significantly impact firms' performance (p<.05). The relation aligns with earlier findings, which depicted the positive role of intangible assets in improving firms' efficiency. Intangible assets are critical to firm decisions and are thought to improve Performance (Ferdaous & Rahman, 2019). These strategic assets can drive organizations' competitive advantage and financial stability (Fang, Gao, & Hu, 2021). Given the rise of creative and intellectual products, there is a well-established literature on the relationship between intangible assets and firms' performance (Fang et al., 2021).

In columns 2 and 3, I find a significant industry 4.0-firm efficiency relationship (p<.01 for Blue Staff-ratio in column 2 and p<.05 for Staff-R&D in column 3). In addition, including human capital (Blue Staff-ratio and Staff-R&D) improves the coefficient estimates and level of significant Industry 4.0-firm efficiency relationship. This shows a partial mediation effect of human capital. Furthermore, the Chow test is employed for coefficient comparisons to examine the effect of human capital as a mediator. The results indicate that both proxies of human capital improve Industry 4.0 and firm efficiency relationships. Figures in columns 4 and 5 of Table 6 reveal a significant increase in Industry 4.0 between columns 1 and 2 and 1 and 3. This demonstrates that human capital boosts the effect of Industry 4.0 on firm efficiency, hence verifying Hypothesis 2a. The results of the control variables are similar, as reported in Table 6 above. For brevity, the results are suppressed.

Table 6 - Mediating role of human capital (Hypothesis 2a)

	Firm efficiency			Chow Test	
Variables	1	2	3	1 - 2	1- 3
Industry 4.0	0.079*	0.170***	0.168***	0.155***	0.184***
Intangible assets					
Blue Staff-ratio		0.133**			

Staff-R&D			0.142**
Firm-specific factors			
Board gender diversity	0.080**	0.073**	0.074**
Board independence	0.028*	0.026*	0.026*
Firm size	0.039**	0.036**	0.036**
Financial leverage	-0.024*	-0.022*	-0.022*
Cash flow	0.131**	0.120**	0.122**
Firm age	0.063**	0.061**	0.058**
Country-level control			
Access to financing	0.035**	0.034**	0.035**
Business licensing and permits	0.089***	0.086***	0.088***
Institutional quality index	0.068***	0.078***	0.081***
GDP growth	0.116***	0.112***	0.114***
Constant	0.559***	0.542***	0.554***
Year and industry effect	Yes	Yes	Yes
Wald chi(2)	1362***	1355***	1356***

For the mediation effect, separate regressions are used. I also include models' control factors, year, Industry, and country dummies. For brevity, the findings of control factors are suppressed. ***p < 0.01, **p < 0.05; *p < 0.1.

In Table 7, I provided results regarding the mediation effect of firms' reputations. According to our results depicted in Table 7, it is evident that a firm reputation positively impacts firm efficiency (see columns 3 and 4). In addition, the inclusion of firm reputation mediates the Industry 4.0-firm efficiency relationship as the results indicate that Industry 4.0 has a positive and statistically significant impact on firm efficiency (p<.01; see column 2) as the significance and absolute value of Industry 4.0 both increases when firm reputation effect is included. A possible explanation for Industry 4.0 could be that Industry 4.0 promotes completely new, extremely dynamic, ad hoc, networked, and real-time modes of collaboration within and across businesses. This has a variety of benefits, including the ability to create personalized items with little expenditure of time and resources. But the industry 4.0 adoption is more beneficent if a firm is highly repudiated. The Chow test value in the last column shows the differences in Industry 4.0 coefficients between direct and mediation impact, indicating a significant increase. Thus, firm reputation mediates Industry 4.0 on firm efficiency, supporting our Hypothesis 2b.

Table 7 - Mediating role of firm reputation (Hypothesis 2b)

	Coefficient	**Coefficient**	**Cho test**
Variables	1	2	Columns 1 and 2
Industry 4.0	0.101*	0.211***	0.386***
Intangible assets			
Firm reputation		0.222***	
Firm-specific factors			
Board gender diversity	0.074**	0.073**	
Board independence	0.026*	0.026*	
Firm size	0.037**	0.036**	
Financial leverage	-0.022*	-0.022*	
Cash flow	0.123**	0.120**	
Firm age	0.059**	0.058**	

Country-level control		
Access to financing	0.038**	0.036**
Business licensing and permits	0.096***	0.092***
Institutional quality index	0.020***	0.019***
GDP growth	0.124***	0.119***
Access to financing	0.372***	0.575***
Constant	0.552***	0.556***
Year and industry effect	Yes	Yes
Wald chi(2)	1362***	1355***
For the mediation effect, separate regressions are used. I also include models' control factors, year, Industry, and country dummies. For brevity, the findings of control factors are suppressed. ***p < 0.01, **p < 0.05; *p < 0.1.		

Furthermore, bootstrap analysis follows the (Liu & Lu, 2021) model to analyze the firm intangible assets' role in the Industry 4.0-firm efficiency relationship. The results of the Bootstrap analysis are shown in Table 8. From Table 8, I can see a strong indirect influence of Industry 4.0 on firm efficiency when an intangible asset (human capital and reputation) is included as a mediator, as the results shown in the Table are statistically significant. Our hypotheses 2a and 2b are also supported, which state that intangible assets mediate the Industry 4.0-firm efficiency relationship.

Table 8 - Conditional indirect Industry 4.0-firm efficiency relationship through intangible assets

Human capital as a mediator (Blue Staff-ratio and Staff-R&D)					
Independent variables	**Dependent variables**	**Indirect effects coefficients**	**Bootstrap S.E**	**P- value**	**Z- value**
Industry 4.0	Firm efficiency	0.330**	0.163	0.04	2.18
Industry 4.0	Firm efficiency	0.351**	0.122	0.03	2.05
Firm reputation as a mediator					
Independent variables	**Dependent variables**	**Indirect effects coefficients**	**Bootstrap S.E**	**P- value**	**Z- value**
Industry 4.0	Firm efficiency	0272*.*	0.104	0.01	2.29
Note: **Significant at the 0.01 level. ***Significant at the 1% level					

8. DISCUSSION AND CONCLUSION

This study examined how Industry 4.0 technology affects firm efficiency. Three postulated hypotheses utilizing dynamic capacities theory are investigated based on a basic sample of 1028 firms operating in Asia Pacific from 2010 to 2022 using the Random Effect GLS model. The primary goal of the analyses has been to determine whether Industry 4.0 technology can: 1) improves firm efficiency; and 2) the firm's intangible assets mediate the Industry 4.0 and firm efficiency relationship. First, Industry 4.0 has a positive and statistically significant impact on firm efficiency at an acceptable level of 10% significance. Hence, firms adopting Industry 4.0 are likely to be efficient. This positive linkage between Industry 4.0 and firm efficiency implies that adopting new technology improves firm efficiency (Masood & Sonntag, 2020). Industry 4.0 puts technology utilization front and center, giving producers greater visibility into every facet of their operations (Raj, Dwivedi, Sharma, de Sousa Jabbour,

& Rajak, 2020). Greater openness opens up the possibility of analyzing and quickly changing problematic or underperforming areas. For businesses in the manufacturing industry, this is among the biggest shifts. Once primarily reliant on paper and email documentation, workflows are recorded in real-time across an organization (Raj et al., 2020). This helps organizations achieve efficiency. However, I find only acceptable relationships at a 10% significance level, leaving the impact of Industry 4.0 on firm efficiency in interrogation.

Further, investigating the mediating role of two intangible strategic variables, human capital and reputation, is one of the primary contributions. Our findings first show that Industry 4.0 impacts firm efficiency only at an acceptable 10% significance level. This contradicts the findings of earlier research, which imply that Industry 4.0 strongly impacts financial performance. Therefore, the Industry 4.0-firm efficiency relationship may rely on a firm's level of resources as the relationship may vary across firms. Industry 4.0 motivates businesses to develop new management skills that promote more efficient use of resources, resulting in competitive advantage development. It is worth noting that numerous enterprises have recently implemented human resource management strategies, capitalizing on the mobility of local human capital in the region and collaborations struck with European firms. In contra argument, one can argue that firms can adopt Industry 4.0 technology only when they have sufficient human resources to capitalize on the competitive edge of Industry 4.0. Thus, the mediation role of human capital seems imminent because a firm with better human resources is likely to get more benefits than its counterpart. Our results support that human capital mediates the relationship between Industry 4.0 adoption and firm efficiency. Importantly, I used Blue Staff-ratio and Staff-R&D as proxies of human capital. Industry 4.0 adoption will be more beneficial if a firm has the human resources to exploit the built-in benefits. Both proxies show a mediation effect. The link between CSR and firm efficiency cannot be stronger without disruption innovations. Similarly, a firm's reputation also mediates the relationship between Industry 4.0 adoption and firm efficiency. In today's world, having a good reputation is critical for firms since it can lead to new opportunities and more revenue. A reputed firm has access to the best opportunities for personnel, and a bad reputation can impede that. A good reputation may lead to chances and unrestricted access to an ideal client base. The firm's reputation is advantageous as it provides more commercial opportunities, a better pool of potential personnel, increased corporate value, and reduced marketing expenses. A firm with a better market reputation is likely to be more efficient.

8.1. Conclusion

Many organizations now expect Industry 4.0 to be a ground-breaking system that fundamentally alters industrial organizations' value creation and performance. In firm efficiency, the set of new digital wave technologies applied to the Industry is confirmed as technologies or breakthroughs that improve efficiency. Using I4.0 technologies, in conjunction with the dynamic capabilities (intangible assets), generates efficiency for firms. The direct impact of Industry 4.0 on firm efficiency is confirmed by research findings only on an acceptable level. The good news is that intangible assets mediate the Industry 4.0 effect. So, the mere adoption of Industry 4.0 does not ensure efficiency; the firm's intangible assets boost its competitive advantage. Thus, firms with better intangible assets will likely be more efficient than their counterpart.

8.2. Research implication and future research

My research has several implications. First, the firms need to adopt Industry 4.0 to achieve efficiency and remain comparative in the marketplace. Second, adopting Industry 4.0 is more useful if a firm has an intangible asset to use Industry 4.0 as a competitive advantage. Thus, firms adopting Industry 4.0 should invest more in intangible assets to maximize the benefits.

Despite the importance of the findings, our study has certain limitations. First, investigating the relationship between Industry 4.0 and firm efficiency is limited to one direction. It would be interesting to investigate the impact of firm efficiency on industry 4.0 adoption in a future study. Further, the individual role of basic components of Industry 4.0 (Cyber-Physical Systems, the Internet of Things, the Internet of Services, and Smart Factories) will be interesting as it may highlight the significance of each aspect in firm efficiency. Top management has a substantial operational challenge in integrating human resources into the I4.0 system. Such issues must be addressed via research efforts. This study informs practitioners and other academics on current trends in Industry 4.0 deployment and how far they help the change toward greater sustainability. They may apply our findings to creating Sustainable Development Goals (SDGs).

ACKNOWLEDGEMENTS

I thank many Technology Experts for their comments and guidance on Industry 4.0 index construction. I thank the two of our colleagues for their considerate comments and suggestions.

REFERENCES

Agyemang, O.S. and Ansong, A. (2017), "Corporate social responsibility and firm Performance of Ghanaian SMEs: Mediating role of access to capital and firm reputation", *Journal of Global Responsibility,* Vol. 8, No. 1, pp. 47-62. Doi: https://doi.org/10.1108/jgr-03-2016-0007

Albers, A., Gladysz, B., Pinner, T., Butenko, V. and Stürmlinger, T. (2016), "Procedure for defining the system of objectives in the initial phase of an industry 4.0 project focusing on intelligent quality control systems", *Procedia Cirp*, 52, pp. 262-267. Doi: https://doi.org/10.1016/j.procir.2016.07.067

Arndt, F. (2019), "Dynamic capabilities: A retrospective, state-of-the-art, and future research agenda", *Journal of Management & Organization*, pp. 1-4.

Babasanya, A. O., Oseni, I. and Awode, S. S. (2018), "Human capital development: A catalyst for achieving SDGs in Nigeria", *Acta Universitatis Danubius. Oeconomica,* Vol. 14, No. 4.

Bagnoli, C., Massaro, M. and Costantini, A. (2021), "Improving business model disclosure in the annual report: Insights from an interventionist research project", *Improving business model disclosure in the annual report: insights from an interventionist research project*, pp. 81-117. Doi: https://doi.org/10.3280/fr2021-002003

Barney, J. B. (2000), "Firm resources and sustained competitive advantage", *Economics meets sociology in strategic management* (pp. 203-227): Emerald Group Publishing Limited. Doi: https://doi.org/10.1016/s0742-3322(00)17018-4

Bollaert, H., Lopez-de-Silanes, F. and Schwienbacher, A. (2021), "Fintech and access to finance", *Journal of Corporate Finance,* 68, 101941. Doi: https://doi.org/10.1016/s0742-3322(00)17018-4

Bontis, N., Booker, L. D. and Serenko, A. (2007), "The mediating effect of organizational reputation on customer loyalty and service recommendation in the banking industry", *Management Decision,* Vol. 45, No. 9, pp. 1426-1445. Doi: https://doi.org/10.1108/00251740710828681

Borenstein, M., Hedges, L. V., Higgins, J. P. and Rothstein, H. R. (2010), "A basic introduction to fixed-effect and random-effects models for meta-analysis", *Research synthesis methods, Vol.* 1, No. 2, pp. 97-111. Doi: https://doi.org/10.1002/jrsm.12

Bornay-Barrachina, M., López-Cabrales, A. and Valle-Cabrera, R. (2017), "How do employment relationships enhance firm innovation? The role of human and social capital", *The International Journal of Human Resource Management, Vol.* 28, No.9, pp. 1363-1391.

Bromiley, P. and Rau, D. (2016a), "Operations management and the resource based view: Another view", *Journal of Operations Management*, Vol. 41, pp. 95-106. Doi: https://doi.org/10.1080/09585192.2016.1155166

Bromiley, P. and Rau, D. (2016b), "Social, behavioral, and cognitive influences on upper echelons during strategy process: A literature review", *Journal of Management,* Vol. 42, No. 1, pp. 174-202. Doi: https://doi.org/10.1016/j.jom.2015.11.003

Caiado, R. G. G., Scavarda, L. F., Gavião, L. O., Ivson, P., de Mattos Nascimento, D. L. and Garza-Reyes, J. A. (2020), "Fuzzy rule-based industry 4.0 maturity model for manufacturing and supply chain management operations", *International Journal of Production Economics.* Doi: https://doi.org/10.1016/j.ijpe.2020.107883

Cordeiro, G. A., Ordóñez, R. E. C. and Ferro, R. (2019), "Theoretical proposal of steps for the implementation of the Industry 4.0 concept", *Brazilian Journal of Operations & Production Management*, Vol. 16, No. 2, pp. 166-179. Doi: https://doi.org/10.14488/bjopm.2019.v16.n2.a1

Dalenogare, L. S., Benitez, G. B., Ayala, N. F. and Frank, A. G. (2018), "The expected contribution of Industry 4.0 technologies for industrial performance", *International Journal of Production Economics,* 204, pp. 383-394. Doi: https://doi.org/10.1016/j.ijpe.2018.08.019

de Freitas Vilela, J. M., and Faria Filho, J. R. (2022), "Industry 4.0 and 5g technology on firms network: a balanced competitive expansion conceptual model development", *Brazilian Journal of Operations & Production Management*, Vol. 19, No. 3, pp. 1-18. Doi: https://doi.org/10.14488/bjopm.2022.1426

Delery, J. E. and Roumpi, D. (2017), "Strategic human resource management, human capital and competitive advantage: is the field going in circles?", *Human Resource Management Journal,* Vol. 27, No. 1, pp. 1-21. Doi: https://doi.org/10.1111/1748-8583.12137

Díaz-Chao, Á., Ficapal-Cusí, P. and Torrent-Sellens, J. (2021), "Environmental assets, Industry 4.0 technologies and firm performance in Spain: A dynamic capabilities path to reward sustainability", *Journal of cleaner production,* 281, 125264. Doi: https://doi.org/10.1016/j.jclepro.2020.125264

Eslami, M. H., Jafari, H., Achtenhagen, L., Carlbäck, J. and Wong, A. (2021), "Financial performance and supply chain dynamic capabilities: The Moderating Role of Industry 4.0 technologies", *International Journal of Production Research*, pp. 1-18. Doi: https://doi.org/10.1080/00207543.2021.1966850

Faccio, M., Marchica, M.-T. and Mura, R. (2016), "CEO gender, corporate risk-taking, and the efficiency of capital allocation", *Journal of Corporate Finance,* 39, pp. 193-209. Doi: https://doi.org/10.1016/j.jcorpfin.2016.02.008

Fang, R., Gao, B. and Hu, N. (2021), "Intangible asset value of employee satisfaction in high-contact services", *International Journal of Hospitality Management,* 94, 102810. Doi: https://doi.org/10.1016/j.ijhm.2020.102810

Favoretto, C., Mendes, G. H. d. S., Filho, M. G., Gouvea de Oliveira, M. and Ganga, G. M. D. (2022), "Digital transformation of business model in manufacturing companies: challenges and research agenda", *Journal of Business & Industrial Marketing,* Vol. 37, No. 4, pp. 748-767. Doi: https://doi.org/10.1108/jbim-10-2020-0477

Ferdaous, J. and Rahman, M. M. (2019), "The effects of intangible assets on firm Performance: An empirical investigation on selective listed manufacturing firms in DSE, Bangladesh", *American Journal of Business,* Vol. 34, No. 3/4, pp. 148-168. Doi: https://doi.org/10.1108/ajb-11- Doi: 2018-0065

Frank, A. G., Dalenogare, L. S. and Ayala, N. F. (2019), "Industry 4.0 technologies: Implementation patterns in manufacturing companies", *International Journal of Production Economics,* 210, pp. 15-26. Doi: https://doi.org/10.1016/j.ijpe.2019.01.004

Galbreath, J. and Shum, P. (2012), "Do customer satisfaction and reputation mediate the CSR–FP link? Evidence from Australia", *Australian Journal of Management,* Vol. 37, No., pp. 211-229. Doi: https://doi.org/10.1177/0312896211432941

Hamdoun, M., Achabou, M. A. and Dekhili, S. (2022), "Could CSR improve the financial performance of developing countries' firms? Analyses of mediating effect of intangible resources", *European Business Review,* Vol. 34, No. 1, pp. 41-61. Doi: https://doi.org/10.1108/ebr-09-2019-0236

Heras-Saizarbitoria, I. and Boiral, O. (2013), "ISO 9001 and ISO 14001: towards a research agenda on management system standards", *International Journal of Management Reviews,* Vol. 15, No. 1, pp. 47-65. Doi: https://doi.org/10.1111/j.1468-2370.2012.00334.x

Hitt, M. A., Carnes, C. M. and Xu, K. (2016), "A current view of resource based theory in operations management: A response to Bromiley and Rau", *Journal of Operations Management,* Vol. 41, No. 10, pp. 107-109. Doi: https://doi.org/10.1016/j.jom.2015.11.004

Hofmann, E. and Rüsch, M. (2017), "Industry 4.0 and the current status as well as future prospects on logistics", *Computers in Industry*, 89, pp. 23-34. Doi: https://doi.org/10.1016/j.compind.2017.04.002

Jiang, Z., Zhou, T., Zhang, H., Wang, Y., Cao, H. and Tian, G. (2016), "Reliability and cost optimization for remanufacturing process planning", *Journal of Cleaner Production*, Vol. 135, pp. 1602-1610. Doi: https://doi.org/10.1016/j.jclepro.2015.11.037

Junge, A. L. (2019), "Digital transformation technologies as an enabler for sustainable logistics and supply chain processes–an exploratory framework", *Brazilian Journal of Operations & Production Management*, Vol. 16, No. 3, pp. 462-472. Doi: https://doi.org/10.14488/bjopm.2019.v16.n3.a9

Keane, M., Yu, H., Zhao, E. J., & Leong, S. (2020), "Chinas digital presence in the asia-pacific: Culture, technology and platforms: Anthem Press". Doi: https://doi.org/10.2307/j.ctv20pxxzt

Kumbhakar, S. C., Lien, G. and Hardaker, J. B. (2014), "Technical efficiency in competing panel data models: a study of Norwegian grain farming", *Journal of Productivity Analysis, 41*, pp. 321-337. Doi: https://doi.org/10.1007/s11123-012-0303-1

Lalic, B., Majstorovic, V., Marjanovic, U., Delić, M. and Tasic, N. (2017), "The effect of Industry 4.0 concepts and e-learning on manufacturing firm performance: evidence from transitional economy", Paper presented at the IFIP International Conference on Advances in Production Management Systems. Doi: https://doi.org/10.1007/978-3-319-66923-6_35

Leemann, N. and Kanbach, D. K. (2022), "Toward a taxonomy of dynamic capabilities–a systematic literature review", *Management Research Review,* Vol. 45, No. 4, pp. 486-501. Doi: https://doi.org/10.1108/mrr-01-2021-0066

Liu, M. and Lu, W. (2021), "Corporate social responsibility, firm performance, and firm risk: the role of firm reputation", *Asia-Pacific Journal of Accounting & Economics,* Vol. 28, No. 5, pp. 525-545. Doi: https://doi.org/10.1080/16081625.2019.1601022

Liu, X. L., Wang, W. M., Guo, H., Barenji, A. V., Li, Z. and Huang, G. Q. (2020), "Industrial blockchain based framework for product lifecycle management in industry 4.0", *Robotics and computer-integrated manufacturing*, 63, 101897. Doi: https://doi.org/10.1016/j.rcim.2019.101897

López-Cabrales, Á., Real, J. C. and Valle, R. (2011), "Relationships between human resource management practices and organizational learning capability: The mediating role of human capital",*Personnel Review,* Vol. 40, No. 3, pp. 344-363. Doi: https://doi.org/10.1108/00483481111118658

Lu, Y. (2017), "Industry 4.0: A survey on technologies, applications and open research issues", *Journal of industrial information integration, 6*, pp. 1-10.

Luo, L.-M., Lee, H.-T., Chiu, C.-C., & Lee, C.-W. (2023), "The relations of corporate risk, operating efficiency, and firm size to managerial compensation: Evidence from Taiwan stock market-listed companies", *Asia Pacific Management Review,* Vol. 28, No. 2, pp. 194-203. Doi: https://doi.org/10.1016/j.apmrv.2022.09.001

Mahoney, J. T. and Pandian, J. R. (1992), "The resource-based view within the conversation of strategic management", *Strategic Management Journal, Vol.* 13, No. 5, pp. 363-380. Doi: https://doi.org/10.1002/smj.4250130505

Masood, T. and Sonntag, P. (2020) , "Industry 4.0: Adoption challenges and benefits for SMEs", *Computers in Industry,* 121, 103261. Doi: https://doi.org/10.1016/j.compind.2020.103261

Mancilha, G. and Gomes, J. (2018), "Comparative analysis between challenges in a Brazilian perspective and worldwide initiatives in Advanced Manufacturing", *Brazilian Journal of Operations & Production Management*, Vol. 15, No. 2, pp. 209-223. Doi: https://doi.org/10.14488/bjopm.2018.v15.n2.a4

McWilliams, A. and Siegel, D. (2000), "Corporate social responsibility and financial performance: correlation or misspecification?", *Strategic Management Journal,* Vol. 21, No. 5, pp. 603-609. Doi: https://doi.org/10.1002/(sici)1097-0266(200005)21:5%3C603::aid-smj101%3E3.0.co;2-3

Meredith, J. (1993), "Theory building through conceptual methods", *International Journal of Operations & Production Management, Vol.* 13, No. 5, pp. 3-11. Doi: https://doi.org/10.1108/01443579310028120

Nardo, M., Forino, D. and Murino, T. (2020), "The evolution of man–machine interaction: The role of human in Industry 4.0 paradigm", Production & manufacturing research, Vol. 8, No. 1, pp. 20-34. Doi: https://doi.org/10.1080/21693277.2020.1737592

Nieves, J. and Quintana, A. (2018), "Human resource practices and innovation in the hotel industry: The mediating role of human capital. *Tourism and Hospitality Research,* Vol. 18, No. 1, pp. 72-83. Doi: https://doi.org/10.1177/1467358415624137

Oduro, S. and De Nisco, A. (2023), "From Industry 4.0 adoption to innovation ambidexterity to firm Performance: a MASEM analysis", *European Journal of innovation management*. Doi: https://doi.org/10.1108/ejim-02-2023-0106

Oesterreich, T. D. and Teuteberg, F. (2016), "Understanding the implications of digitization and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry", *Computers in Industry,* 83, pp. 121-139. Doi: https://doi.org/10.1016/j.compind.2016.09.006

Paillé, P., Chen, Y., Boiral, O. and Jin, J. (2014), "The impact of human resource management on environmental Performance: An employee-level study", *Journal of Business Ethics,* 121, pp. 451-466. Doi: https://doi.org/10.1007/s10551-013-1732-0

Raj, A., Dwivedi, G., Sharma, A., de Sousa Jabbour, A. B. L. and Rajak, S. (2020), "Barriers to the adoption of Industry 4.0 technologies in the manufacturing sector: An inter-country comparative perspective", *International Journal of Production Economics,* pp. 224, 107546. Doi: https://doi.org/10.1016/j.ijpe.2019.107546

Reza, M. N. H., Malarvizhi, C. A. N., Jayashree, S. and Mohiuddin, M. (2021), "*ndustry 4.0–technological revolution and sustainable firm Performance"*. Paper presented at the 2021 Emerging Trends in Industry 4.0 (ETI 4.0). Doi: https://doi.org/10.1109/eti4.051663.2021.9619363

Riley, S. M., Michael, S. C. and Mahoney, J. T. (2017), " Human capital matters: Market valuation of firm investments in training and the role of complementary assets", *Strategic Management Journal,* Vol. 38, No. 9, pp. 1895-1914. Doi: https://doi.org/10.1002/smj.2631

Ritter, T. and Lettl, C. (2018), "The wider implications of business-model research", *Long Range Planning,* Vol. 51, No. 1, pp. 1-8. Doi: https://doi.org/10.1016/j.lrp.2017.07.005

Samo, A. H. and Murad, H. (2019), "Impact of liquidity and financial leverage on firm's profitability–an empirical analysis of the textile industry of Pakistan", *Research Journal of Textile and Apparel,* Vol. 23, No. 4, pp. 291-305. Doi: https://doi.org/10.1108/rjta-09-2018-0055

Simoni, L., Schaper, S. and Nielsen, C. (2022), "Business model disclosures, market values, and earnings persistence: evidence from the UK", *Abacus,* Vol. 58, No. 1, pp. 142-173. Doi: https://doi.org/10.1111/abac.12233

Stein, B. E. and Meredith, M. A. (1993), "*The merging of the senses*": MIT press.

Tian, G., Chu, J., Hu, H. and Li, H. (2014), "Technology innovation system and its integrated structure for automotive components remanufacturing industry development in China", *Journal of cleaner production,* 85, pp. 419-432. Doi: https://doi.org/10.1016/j.jclepro.2014.09.020

Todericiu, R. ands Stăniţ, A. (2015), "Intellectual capital–The key for sustainable competitive advantage for the SME's sector", *Procedia Economics and Finance,* 27, 676-681. Doi: https://doi.org/10.1016/s2212-5671(15)01048-5

Torrent-Sellens, J., Ficapal-Cusí, P. and Enache-Zegheru, M. (2023), "Boosting environmental management: The mediating role of Industry 4.0 between environmental assets and economic and social firm Performance", *Business Strategy and the Environment,* Vol. 32, No. 1, pp. 753-768. Doi: https://doi.org/10.1002/bse.3173

Vogel, R. and Güttel, W. H. (2013), "The dynamic capability view in strategic management: A bibliometric review", *International Journal of Management Reviews,* Vol. 15, No. 4, pp. 426-446. Doi: https://doi.org/10.1111/ijmr.12000

Wright, P. M. and McMahan, G. C. (2011), "Exploring human capital: putting 'human'back into strategic human resource management", *Human Resource Management Journal,* Vol. 21, No, 2, pp. 93-104. Doi: https://doi.org/10.1111/j.1748-8583.2010.00165.x

Wu, Y., Ngai, E. W., Wu, P. and Wu, C. (2020), "Fake online reviews: Literature review, synthesis, and directions for future research", *Decision Support Systems, 132*, 113280. Doi: https://doi.org/10.1016/j.dss.2020.113280

Xie, L., Zhou, J., Zong, Q. and Lu, Q. (2020), "Gender diversity in R&D teams and innovation efficiency: Role of the innovation context", *Research Policy,* Vol. 49, No. 1, 103885. Doi: https://doi.org/10.1016/j.respol.2019.103885

Zhu, W., Chew, I. K. and Spangler, W. D. (2005), "CEO transformational leadership and organizational outcomes: The mediating role of human–capital-enhancing human resource management", *The leadership quarterly,* Vol. 16, No. 1, pp. 39-52. Doi: https://doi.org/10.1016/j.leaqua.2004.06.001

Author contributions: there is contribution of a single author.

Appendix A Variables description

Independent Variables	Measurement
Board independence	Number of independent board members scaled by total member
Board gender diversity	Number of female directors scaled by male directors
Firm size	Natural log of total assets
Financial leverage	Firm debt scaled by total equity
Cash flow language	Firm cash flow ratio
Firm age	The difference between the year of incorporation and year of observation
Access to financing	https://www.worldbank.org/en/publication/globalfindex
Business licensing and permits	https://www.worldbank.org/en/publication/globalfindex
Institutional quality index	Data obtained from world bank source https://info.worldbank.org/governance/wgi/
GDP growth	Data obtained from the world bank source https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG

Appendix B Technologies used to construct Industry 4.0 index in content analysis

3D printing,
Artificial intelligence (AI)
Additive manufacturing (AM),
Augmented reality (AR),
Autonomous robots,
Big data (BD),
Block-chain,
Cloud computing (CC),
Cognitive computing (CgC),
Cloud,
Cyber physical systems (CPS),
Cyber security,
Digital twin,
Edge computing (EC)
GIS
Information communication technology (ICT),
the Industrial Internet of Things (IIoT)
IIoTs,
Industrial robots (robotics),
Industry internet,
Internet of services,
Internet protocol
The Internet of Things (IoT),
Manufacturing execution system
Machine learning (ML),

Mobile computing Physical internet, Radio Frequency Identification (RFID), Robotics, Sensors virtual reality (VR),