CEO CHARACTERISTICS, FIRM RISK EXPOSURE AND INDUSTRIAL REVOLUTION 4.0 ADOPTION IN MALAYSIA

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by

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LIST OF ABBREVIATIONS

4IR	Industrial Revolution 4.0 / Fourth Industrial Revolution
AI	Artificial intelligence
AR	Augmented reality
Bindp	Board independence
Bsize	Board size
C4IR	Centre for the Fourth Industrial Revolution
CEO	Chief executive officer
CEOage	CEO age
CEOfamily	Family CEO
CEOfedu	CEO with foreign tertiary education
CEOfemale	Female CEO
CIO	Chief information officer
CurrentRatio	Current ratio
DCIO	The appointment of a chief information officer
DComm	The establishment of a board technology committee
DIR4	IR4.0 adoption
DTech	The acquisition of IR4.0 technology
DTMT	The hiring of TMT with IR4.0 experience
Fage	Firm age
Fgrowth	Firm growth
Fsize	Firm size
GEOdiv	Geographical diversification
INDdiv	Industrial diversification
Industry4WRD	National Policy on Industry 4.0
IoT	Internet of Things
IR4.0	Industrial Revolution 4.0 / Fourth Industrial Revolution
Leverage	Financial leverage
MCO	Movement Control Order
R&D	Research and development
ROA	Return on assets
ROS	Return on sales

sdROA	Standard deviation of return on assets
sdROS	Standard deviation of return on sales
SEW	Socioemotional wealth
TMT	Top management team
UET	Upper Echelons Theory
VR	Virtual reality
WEF	World Economic Forum

LIST OF APPENDICES

CIRI-CIRI CEO, PENDEDAHAN RISIKO FIRMA DAN PENERIMAAN REVOLUSI PERINDUSTRIAN 4.0 DI MALAYSIA

ABSTRAK

Tesis ini menyelidik hubungan antara ciri-ciri CEO dan penerimaan revolusi perindustrian 4.0 (IR4.0) dalam firma, dengan mengambilkira peranan pemoderasi pendedahan risiko firma. Berdasarkan teori upper echelons (UET), tesis ini meneroka pengaruh ciri-ciri CEO, termasuk CEO keluarga, CEO wanita, CEO dengan pendidikan tinggi luar negara, dan CEO yang berusia, terhadap penerimaan IR4.0, yang boleh dilihat sebagai pengembangan pengambilan risiko pengurusan. Penerimaan IR4.0 digambarkan melalui empat dimensi: pemerolehan teknologi, kepakaran IR4.0 dalam pasukan pengurusan atasan (TMT), pelantikan ketua pegawai maklumat (CIO), dan penubuhan jawatankuasa teknologi peringkat lembaga. Menggunakan set data panel bagi 944 firma tersenarai di Bursa Malaysia dari 2015 hingga 2023 yang menghasilkan jumlah 8,163 pemerhatian, tesis ini menganalisis data daripada laporan tahunan firma dan pangkalan data S&P Capital IQ. Analisis menggunakan regresi panel probit dengan spesifikasi model fungsi kukuh, yang merangkumi kawalan tambahan, ukuran alternatif, dan analisis subsampel yang mengecualikan tahun ekstrem Covid-19 untuk memastikan kesahan keputusan. Hasil kajian menunjukkan bahawa ciri-ciri CEO memberi kesan signifikan terhadap penerimaan IR4.0. Sebagai contoh, CEO keluarga, disebabkan oleh ikatan dengan identiti keluarga dan matlamat perniagaan yang unik bagi memastikan kelangsungan firma, adalah kurang cenderung untuk mengambil risiko dan melabur dalam IR4.0, serta kurang kemungkinan untuk mengupah ahli TMT berpengalaman IR4.0 atau melantik CIO. Walaubagaimanapun, kesan pemoderasi pendedahan risiko firma

menunjukkan bahawa CEO keluarga lebih berkemungkinan untuk menerima IR4.0 apabila terdapat ketidakpastian aliran pendapatan yang lebih tinggi (diukur dengan sisihan piawai pulangan aset *(ROA)* dan pulangan jualan *(ROS)*), tetapi kurang kemungkinan untuk menerima IR4.0 apabila firma semakin berdiversifikasi dari segi industri atau geografi. CEO wanita juga menunjukkan ciri berisiko rendah, menjadikan mereka kurang cenderung untuk menerima IR4.0 atau melantik CIO. Sebaliknya, CEO dengan pendidikan tinggi luar negara lebih cenderung untuk menerima IR4.0 melalui pemerolehan teknologi. Analisis selanjutnya juga menunjukkan bahawa apabila firma berhadapan dengan risiko kewangan seperti tahap keumpilan *(leverage)* yang lebih tinggi, CEO wanita menjadi lagi kurang cenderung untuk melabur dalam IR4.0, tetapi CEO dengan pengalaman pendidikan luar negara menjadi lagi cenderung untuk menerima IR4.0. Akhirnya, CEO yang berusia, dengan sifat berisiko rendah, juga kurang cenderung untuk melantik CIO dalam transformasi IR4.0, kemungkinan kerana mereka tidak mempunyai tempoh perkhidmatan yang panjang seperti rakan sejawat mereka yang lebih muda. Tesis ini memberikan sumbangan teori dengan memperluaskan UET ke dalam konteks penerimaan IR4.0, menggabungkan perspektif modal teknologi dan insan. Selain itu, tesis ini mengintegrasikan konsep dari pelbagai disiplin, termasuk ciri-ciri CEO dan UET (teori pengurusan strategik), pendedahan risiko firma (perspektif kewangan korporat dan risiko), dan penerimaan IR4.0 (perspektif penerimaan teknologi). Tesis ini menggambarkan kesan ciri-ciri CEO terhadap penerimaan IR4.0 sambil mengambilkira faktor kontekstual seperti pendedahan risiko firma. Ia berfungsi sebagai rujukan untuk membangunkan strategi dan dasar IR4.0, selaras dengan Dasar Kebangsaan mengenai Industri 4.0 (Industry4WRD), Dasar Revolusi Perindustrian Keempat (4IR) Negara, dan penubuhan Pusat Revolusi Industri Keempat (C4IR) di Malaysia.

CEO CHARACTERISTICS, FIRM RISK EXPOSURE, AND INDUSTRIAL REVOLUTION 4.0 ADOPTION IN MALAYSIA

ABSTRACT

This thesis investigates the relationship between CEO characteristics and the Industrial Revolution 4.0 (IR4.0) adoption, considering the moderating role of firm risk exposure. Drawing on upper echelons theory (UET), the thesis explores how CEO characteristics, specifically family CEOs, female CEOs, CEOs with foreign tertiary education, and older CEOs, influence IR4.0 adoption, which can be viewed as an extended managerial risk-taking. This thesis proposed that IR4.0 adoption could be reflected through four dimensions: technology acquisition, the hiring of top management team (TMT) with IR4.0 expertise, the appointment of chief information officers (CIOs), and the establishment of board-level technology committees. Using a panel dataset of 944 publicly listed firms on Bursa Malaysia from 2015 to 2023, resulting in a total of 8,163 observations, this study analyses data sourced from company annual reports and the S&P Capital IQ database. The analysis employs a panel probit regression with a robust function model specification, incorporating additional control, alternative measures, and further analysis excluding Covid-19 extreme years to ensure validity. The findings reveal that CEO characteristics significantly affect IR4.0 adoption. For instance, family CEOs, due to their attachment to family identity and unique business goals aimed at ensuring firm survivability, are less likely to take risks and invest in IR4.0. Specifically, they are also less likely to hire TMT members with IR4.0 experience or appoint a CIO. However, the moderating effects of firm risk exposure show that risk-averse family CEOs are more likely to adopt IR4.0 when there is higher income stream uncertainty (measured by the standard

deviation of ROA and ROS), but less likely to adopt IR4.0 when the firm is increasingly industrially or geographically diversified. Female CEOs also exhibit risk-averse tendencies, making them less likely to adopt IR4.0 or appoint a CIO. Conversely, CEOs with foreign tertiary education, who exhibit greater risk-seeking tendencies, are more likely to adopt IR4.0, particularly through technology acquisition. Further analysis also shows that when firms face higher financial risk due to elevated leverage levels, risk-averse female CEOs become even less likely to invest in IR4.0, but risk-seeking CEOs with foreign tertiary education become even more inclined to adopt IR4.0. Lastly, older CEOs, consistent with their risk-averse nature, are less likely to appoint a CIO as part of their approach to IR4.0 transformation, possibly due to having fewer years remaining in their tenure compared to their younger counterparts. This study makes theoretical contributions by extending UET to the context of IR4.0 adoption, incorporating both technological and human capital perspectives. Furthermore, this thesis integrates concepts from multiple disciplines, including CEO characteristics and UET (strategic management theory), firm risk exposure (corporate finance and risk perspective), and IR4.0 adoption (technology adoption perspective). This thesis attempts to illustrate the effects of CEO characteristics on IR4.0 adoption while accounting for contextual factors such as firm risk exposure. It serves as a reference for developing strategies and policies to encourage firms' IR4.0 adoption, in line with the National Policy on Industry 4.0 (Industry4WRD), the National Fourth Industrial Revolution (4IR) Policy, and the establishment of the Centre for the Fourth Industrial Revolution (C4IR) in Malaysia.

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Our world is constantly changing, and this pace of change is faster than ever in human history. Over the past few decades, more data have been shared online, doubling every 40 months (McAfee & Brynjolfsson, 2012). The amount of data has grown exponentially, and the latest information, which is constantly being generated every second, has replaced the outdated data which could be no longer relevant. Statistics show that each person generates at least 1.7 megabytes of data every second, equivalent to storing an 850-page book (Stengel, 2021). This surge in real-time data, covering all aspects of human life, including industries and economic activities, as well as advancements in automation, machine learning, and the Internet. This has also paved the way for the Industry 4.0, which is also known as the Fourth Industrial Revolution (Gunal, 2019; McKinsey Explainers, 2022; Ooi et al., 2018), Industrial Revolution 4.0 (Idris, 2019; Juhary, 2020), 4IR (George & Howard, 2020; McKinsey Explainers, 2022), I4.0 (Bag et al., 2020; Ling Li, 2022; Rodríguez-Espíndola et al., 2022), and IR4.0 (Ali, 2022; Tan et al., 2022). Due to Covid-19 pandemic, the revolution has even sped up and rendered faster than ever (Neto et al., 2020).

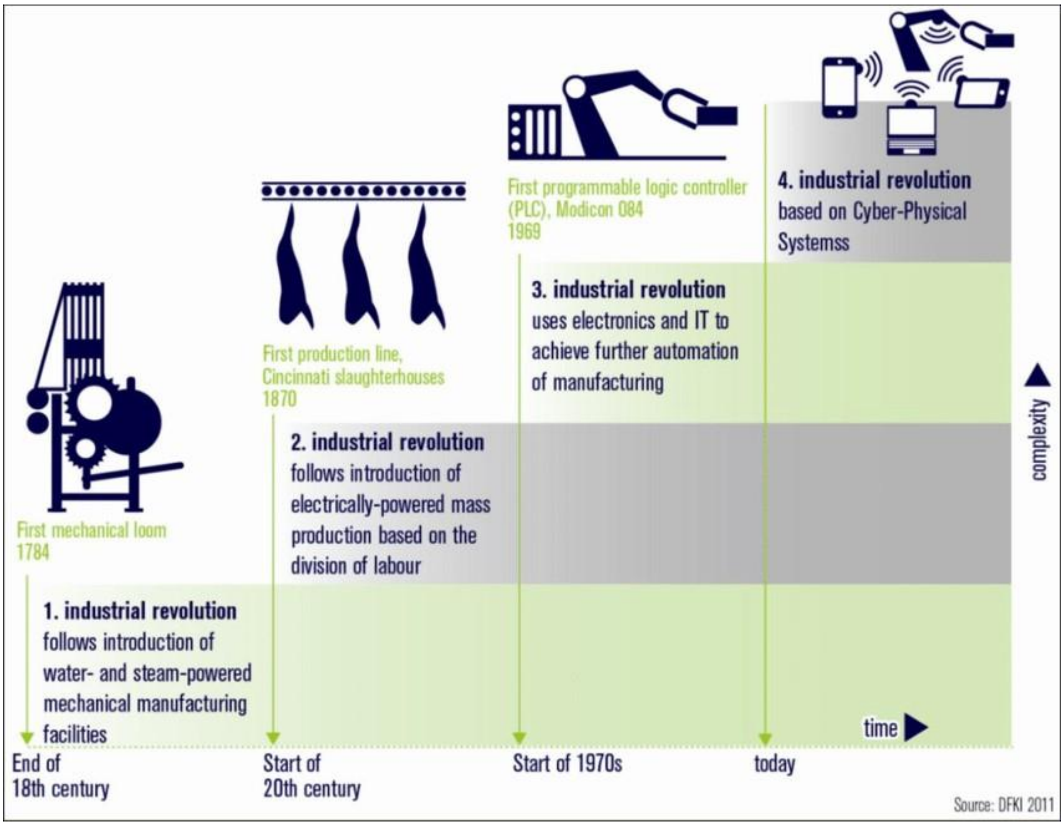
1.1.1 Industrial Revolutions 1.0, 2.0, and 3.0

The word “revolution” has long appeared in human history. For instances, industrial revolution (Carus-Wilson, 1941), social revolution (Aiyappan, 1965), political revolution (Silver, 1974), scientific revolution (Allen, 2011), and cultural revolution (David-Fox, 1999). It brought different meanings based on the contexts.

In the book “The Fourth Industrial Revolution”, the author Professor Klaus Schwab, who is also the founder and executive chairman of the World Economic Forum (WEF), describes “revolution” as an abrupt and radical change (Schwab, 2017). “Industrial revolution” involves a sudden and drastic transformation and transition to new manufacturing processes (Schwab, 2017). It is an essential and beneficial mark of progress due to new technologies invented and innovative perspectives formed (Ashton, 1997; Schwab, 2017). These advanced technologies and novel ideas significantly change the economic systems and social structures (Schwab, 2017) with some likely out-turn, such as improved material living standards, and provoke more remarkable intellectual ingenuity (Ashton, 1997). However, the abruptness of these changes may take several years to fully develop and materialise (Schwab, 2017), and have far-reaching and long-lasting impacts on societies and shape the course of history. For instance, before the steam power and electricity eras, our ancestors woke with the sun and retired for the night as darkness descended. However, the invention of electricity has brightened the nights, enabling continued activities despite the absence of daylight, hence the expression, “the night is still young”. To some extent, industrial revolutions may have changed human lives entirely.

The world has witnessed the First, Second, Third and Fourth Industrial Revolutions, sometimes known as Industrial Revolutions 1.0, 2.0, 3.0 and 4.0, yet not all places have reached the same transformation stage. Some areas remained untouched by these advancements and still lacked access to certain Industrial Revolution products such as electricity and the Internet. Figure 1.1 shows the timeline and characteristics of Industrial Revolutions 1.0, 2.0, 3.0 and 4.0.

According to the German Research Center for Artificial Intelligence (German: *Deutsches Forschungszentrum für Künstliche Intelligenz*, DFKI), the First Industrial Revolution (IR1.0) took place from the end of 18th century to the early 20th century. It began in Britain and gradually spread globally (Allen, 2011). This period was marked by significant advancement in mechanisation, water and steam power in manufacturing, such as textile production.



Source: DFKI (2021) and Hirsch-Kreinsen (2016)

Figure 1.1 Timeline and Characteristics of Industrial Revolution 1.0 to 4.0

The installation of the first conveyor belt in the Cincinnati Slaughterhouse in 1870 raised the curtain of the Second Industrial Revolution (IR2.0), which unfolded roughly from the 20th century to the early 1970s. This phase was characterised by substantial progress in industrialisation using electricity. In this stage, electricallypowered mass production, division of labour and assembly lines emerged as the production method.

The onset of the Third Industrial Revolution (IR3.0), also known as the Digital Revolution, started in the 1970s and continues to the present day. There were notable strides in manufacturing using technologies such as electronics, information technology systems (IT) and the Internet. Some remarkable transformations in this stage include computerisation, automation, and digital technology adoption.

1.1.2 Industry Revolution 4.0 (IR4.0)

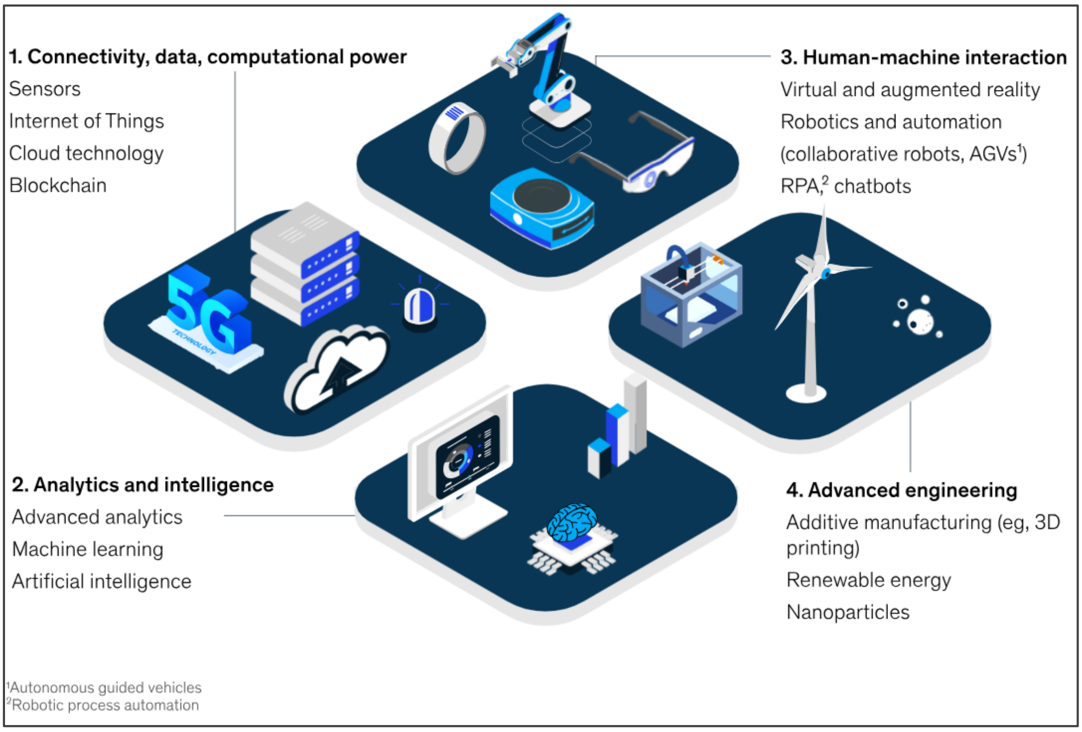
It is essential to note that various researchers and sources may present different Industrial Revolution periods or definitions for each phase. Nevertheless, Figure 1.1 provides a broad overview and general understanding of the historical progression of the Industrial Revolution. Likewise, there is no widely accepted concept of the "Fourth Industrial Revolution". While IR3.0 represents the era of digital technology, IT and automation, the Fourth Industrial Revolution (IR4.0) is frequently employed to depict the ongoing digital transformation of the IR3.0, in which it is building on the IR3.0, rather than a distinct phase (McKinsey Explainers, 2022). In other words, IR4.0 is a contemporary development of IR3.0 technology within the broader context of technological advancements in terms of Cyber-Physical Systems (CPS), hence being illustrated as an ongoing revolution in Figure 1.1 by DFKI (2021). CPSs are integrated systems of internet-enabled physical objects with computers and control components (i.e. sensors and actuators). CPSs can autonomously monitor themselves, gather real-time data about their operation, and communicate with both internal and external entities. CPSs are essential in creating autonomous vehicles, smart homes, smart factories and smart cities. The final goal of IR4.0 is to create an inclusive and human-centred future via converging technologies (World Economic Forum, 2023b).

The term “Industry 4.0” originated from a technology strategy project initiated by the German government, namely Industrie 4.0 (https://www.plattform-i40.de/, 2006). It was revived in 2011 at the Hanover Fair (Juhary, 2020), the world’s largest trade fair, and subsequently popularised by Klaus Schwab, the World Economic Forum Founder and Executive Chairman, in 2016. As stated by McKinsey Explainers (2022), the term “Industry 4.0” was practically non-existent in the Google Search before 2014. However, in 2019, almost 70% of the McKinsey’s survey respondents considered Industry 4.0 a top strategic priority and stated that their organisations have already piloted or implemented new technology. The notion of Industry 4.0, which is also known as the Fourth Industrial Revolution (Gunal, 2019; McKinsey Explainers, 2022; Ooi et al., 2018), Industrial Revolution 4.0 (Idris, 2019; Juhary, 2020), 4IR (George & Howard, 2020; McKinsey Explainers, 2022), I4.0 (Ling Li, 2022; Rodríguez-Espíndola et al., 2022) and IR4.0 (Ali, 2022; Tan et al., 2022), has since gained global attention and remains a prominent topic today.

For readability, this thesis consistently refers to the term “IR4.0” throughout this thesis. In the following section, this thesis delves deeper into the four foundational disruptive technologies and nine pillars of IR4.0, as it constitutes the central theme of this research — “IR4.0 adoption”, and provide insights on the methodology to measure IR4.0 adoption. These sections are essential to provide readers with a foundational understanding of IR4.0 and to help the readers to comprehend the process of data collection and identification used in the study.

1.1.3 Four Foundational Disruptive Technologies of IR4.0

While the first three Industrial Revolutions involved the transition from manual labour to steam power, electric power, and digitisation, IR4.0 was developed based on the IR3.0’s digital technology and involves a Cyber-Physical System (CPS). CPS integrates sensing, actuation, computation, control, communication, and networking into physical objects or infrastructure, connecting them to the Internet and/or each other. After all, following a report released by McKinsey & Company in 2020, four fundamental disruptive technologies characterised the IR4.0. As shown in Figure 1.2, the four disruptive technologies are as follows: (i) connectivity, data, and computational power such as sensors, Internet of Things, cloud technology, blockchain; (ii) analytics and intelligence such as advanced analytics, machine learning, artificial intelligence; (iii) human–machine interaction such as virtual and augmented reality, robotics and automation, collaborative robots, autonomous guided vehicles, robotic process automation; and (iv) advanced engineering such as additive manufacturing, 3D printing, renewable energy, and nanoparticles.



Source: Agrawal et al. (2020) in McKinsey & Company's Report

Figure 1.2 Four Foundational Disruptive Technologies Which Characterised IR4.0

These disruptive technologies fundamentally alter manufacturing methods and processes and unleash new degrees of firm efficiency and innovation, ultimately reshaping and transforming industries, leading to industrial revolution.

1.1.4 Nine Pillars of IR4.0 Technology

In addition to the four foundational disruptive technologies introduced by McKinsey & Company's Report (Agrawal et al., 2020), IR4.0 is expected to give rise to a smart and efficient industrial ecosystem, underpinned by a set of nine key technologies known as the nine pillars of IR4.0 (Ministry of Investment, Trade and Industry Malaysia, 2023; Northern Corridor Economic Region (NCER) Malaysia, 2023).

Source: Northern Corridor Economic Region (NCER) Malaysia (2023)

Figure 1.3 The Nine Pillars of Industrial Revolution 4.0 Technology

Figure 1.3 depicts the nine pillars of IR4.0: cloud computing, additive manufacturing (3D printing), augmented reality, big data, autonomous robots, simulation, system integration, Internet of Things, and cybersecurity. It is worth noting that these nine pillars share significant similarities with the four foundational disruptive technologies outlined by McKinsey & Company's Report (Agrawal et al., 2020), and play critical roles in supporting the entire IR4.0 ecosystem.

1.1.4(a) Cloud Computing

The term "cloud computing" has existed since the early 2000s (Buyya et al., 2008), but the transition to cloud computing has only gained momentum starting in 2020 due to the Covid-19 pandemic (Moore, 2022). In general, cloud computing delivers a shared pool of IT resources, such as servers, storage, software, databases, networking, and analytics, over the Internet (the "cloud"), without requiring the customers to own, install, manage and maintain the resources on-premises (IBM, 2023; Ooi et al., 2018). It is the on-demand delivery with a pay-as-you-go basis, usually by paying a monthly subscription fee or bill based on usage, offers flexibility to the customers to subscribe or rent the resources whenever they need to meet their fluctuating demands, minimises the IT investment and also the upfront and maintenance costs (Khorshed et al., 2012; Ooi et al., 2018). In addition, cloud computing is so convenient that customers can access the resources anytime, anywhere, with any preferred device as long as they connect to the Internet. To cater for the increasing demand for cloud computing, cloud service providers (CSP) such as Amazon Web Services (AWS), Google Cloud, Microsoft Azure, IBM Cloud, and Oracle Cloud host the resources at remote data centres in different geographical regions worldwide. Amidst the wave of revolution, firms which are not embracing cloud computing are constraining their potential for growth, innovation and more remarkable performance (Ooi et al., 2018).

1.1.4(b) Additive Manufacturing

Similarly, “additive manufacturing”, better known as “3D printing” (Ministry of Investment, Trade and Industry Malaysia, 2023), is a technology that was invented as early as the 1980s (Guo & Leu, 2013; Shahrubudin et al., 2019) and gained popularity around the 2000s. It also went by various names, such as additive fabrication, additive processes, layer manufacturing, direct digital manufacturing, rapid manufacturing, rapid prototyping, and solid freeform fabrication. In additive manufacturing, three-dimensional objects are built by adding material layer by layer (hence the term “additive”). This is contrasted with traditional subtractive manufacturing, in which the object is formed by subtracting, removing or cutting away from a material to give shape to the object (Guo & Leu, 2013). In additive manufacturing, an existing object is scanned, or a new model is generated using computer-aided design (CAD) to form a digital 3D model. Then, the model is transformed into a physical 3D object through layering and printing using various materials, including plastics, polymers, resins, metals and ceramics. As materials are layered or printed one layer at a time, additive manufacturing makes geometric and material complexities possible (Guo & Leu, 2013), fostering innovation in product development. Additive manufacturing encourages rapid prototyping; with the ease of scanning and printing, it also allows “copy-paste”, permitting the duplication or swift creation of replacement parts. During Covid-19, there has been a significant global rise in additive manufacturing demand as it facilitated “art-to-part” (Choong et al., 2020). From personal protective equipment (PPE) to emergency dwellings, additive manufacturing helped safeguard the healthcare personnel and isolated the infected patients. It maintains its significance in today's world by enabling on-demand part production, minimising waste and inventory, offering flexibility and the possibility to customise the designs as needed, and facilitating decentralised manufacturing (Choong et al., 2020).

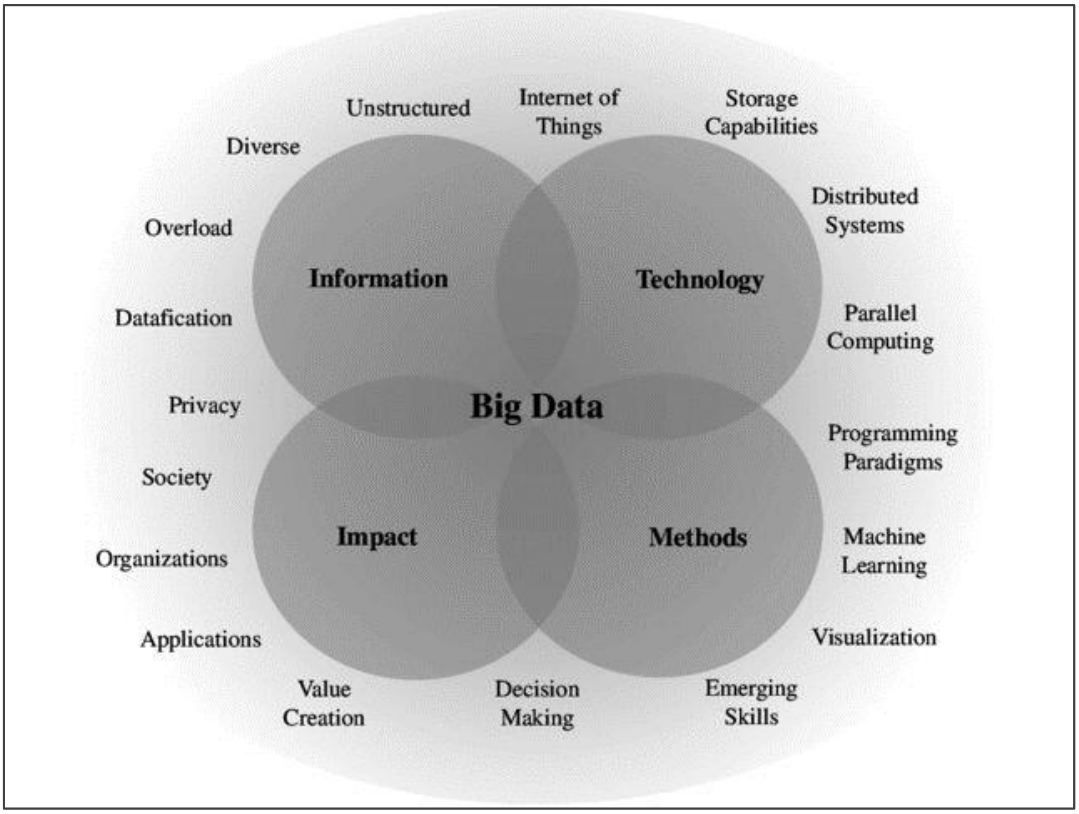
1.1.4(c) Augmented Reality (AR)

Besides 3D printing, another vital invention related to 3D technology is Augmented reality (AR). While 3D printing focuses on the physical creation of objects using the printing method, AR primarily elevates human interactions with the world and modifies how human perceive the real world by superimposing digital elements such as texts, images, sounds, videos, or 3D models. However, it is essential to highlight its difference with virtual reality (VR). The concept of virtual reality can be traced to the 1960s, and this technology advanced to augmented reality at the beginning of the 1990s (Cipresso et al., 2018). While virtual reality creates computer-generated virtual environments that completely replace the real world, immersing users in a digital realm, augmented reality captures and processes a user's physical environment and augments it with virtual elements (Ro et al., 2018). As per Merriam-Webster.com, "augmented" is an adjective which signifies "made greater, larger, or more complete". Augmentation may provide additional context, information, or experiences to the users and enrich their perception of reality. Augmented reality is typically accomplished through devices like smartphones, tablets and AR glasses (i.e. Microsoft HoloLens or Google Glass) (Ro et al., 2018), and has been applied in gaming, education, healthcare, navigation, design and decor, as well as marketing and advertising. This invention improved user experience by incorporating visual, auditory, haptic, somatosensory and olfactory stimulation (Cipresso et al., 2018), fostering greater interactivity and engagement with customers and revolutionised consumers' behaviours tremendously (Ro et al., 2018).

1.1.4(d) Big Data

Big data is a buzzword that has emerged in the wake of the IR4.0, and it is a topic of extensive discussion in academia and industry. However, there is no universally agreed-upon definition. Generally, the word "big" illustrates that the data encompasses large and complex datasets that pose significant challenges for conventional data management, processing, and analysis tools and techniques to deal with. De Mauro et al. (2016) defined "big data" as "the information asset characterized by such a high volume, velocity and variety to require specific technology and analytical methods for its transformation into value" and stated that there are four main themes of big data, namely information, technology, methods, and impact. Figure 1.4 depicts the big data themes and the related topics in existing literature.

In the past, big data was mainly associated with its 3Vs: *volume* (high volume or a large amount of data), *velocity* (high-speed data where data arrived and processed near real-time) and *variety* (data could be structured, semi-structured, and unstructured data), current discussions have expanded to include two additional Vs, namely *veracity* (quality and reliability of data) and *value* (data could be useless unless it is turned into meaningful and valuable insights) (De Mauro et al., 2016; Ishwarappa & Anuradha, 2015; Vaidya et al., 2018). The significance of big data hinges on firms' ability to leverage it to gain insights and make well-informed business decisions. Business Intelligence (BI) is a technology-driven process involving software and methodologies to acquire, assess, and visualise business data. In contrast, Data Science entails the application of coding, data mining, analytical proficiency, and modelling techniques to reveal valuable insights (Ling Li, 2022). Both BI and Data Science play pivotal roles in turning big data into meaningful information and facilitating data-informed decision-making within an organisation.



Source: De Mauro et al. (2016)

Figure 1.4 Big Data Theme and the Related Topics in Existing Literature

1.1.4(e) Autonomous Robots

The term “autonomous robot” is related to “autonomy” and “robot” (Bekey, 2005). According to Bekey (2005), autonomy refers to “the systems capable to operating in the real-world environment without any form of external control for an extended period of time”, while a robot is a machine that “senses, thinks, and acts”. An autonomous robot perceives its surroundings (sense), think or make decisions using its sensory input or programmed knowledge (think), and subsequently operate or complete the tasks (act) independently without direct human control or intervention (autonomy). Firstly, to sense and gather the information from the surroundings, the robots are equipped with various sensors such as cameras, Light Detection and Ranging (LIDAR) and Radio Detecting and Ranging (RADAR). Secondly, to think, identify, process and interpret the data, the robots are fitted with algorithms and pre-programmed through machine learning or artificial intelligence techniques. Lastly, to act accordingly, the robots, with their unique physical components may move, manipulate the object, or perform the required task. Robots' autonomy level can vary widely, ranging from simple actions like distinguishing between coloured balls to more sophisticated actions such as autonomous driving (self-driving car). Autonomous robots not only accomplish given tasks precisely and intelligently within the specified time constraint (Vaidya et al., 2018), but could also free the workforce from doing repetitive, dull, hazardous, or dirty tasks, allowing them to focus on more stimulating and valuable aspects of their work, leading to enhanced innovation, growth, and overall firm performance. Artificial Intelligence (AI) refers to the ability of a digital computer or computer-controlled robot to simulate human intelligence and execute tasks linked with intelligent beings (Ling Li, 2022) while Machine Learning (ML) is a branch of AI and computer science which enables computer systems to learn and adapt from experience automatically. This could be done through developing algorithms and statistical models and training the computer systems to learn and improve their performance on that specific task without being explicitly programmed. Both AI and ML are essential in developing autonomous robot. AI is a fundamental structure for decision-making and environmental interaction, while ML enhances the robot's capacity to learn, adapt, and make decisions. Other AI technologies include Deep Learning, Artificial Neural Networks (ANNs), and Natural Language Processing

(NLP). Combined, they enhance autonomous robots' capabilities, versatility, and efficiency when performing tasks and manoeuvring through dynamic scenarios.

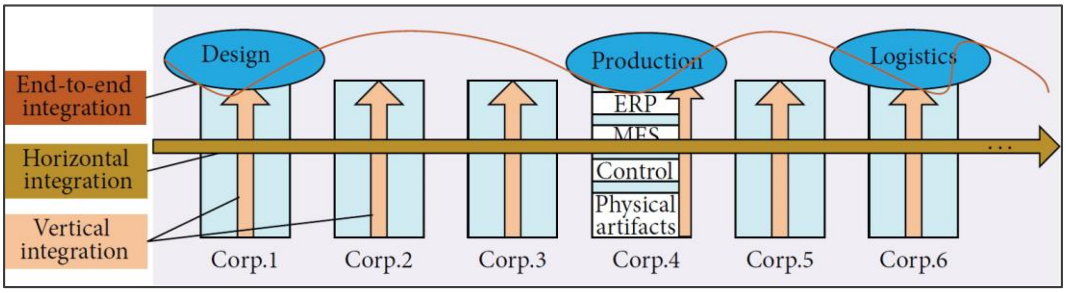
1.1.4(f) Simulation

The Merriam-Webster Dictionary defines simulation as "the imitative representation of the functioning of one system or process by means of the functioning of another". In the IR4.0 context, simulation entails generating virtual models and environments replicating real-world situations, processes, or settings, which could be carried out through computer-based or mathematical representation. This allows users to conduct experiments, observe, and analyse data without directly manipulating the actual system or environment. Simulation is a valuable tool for training and scenario planning, assessing the performance of machinery and products, and handling real-time data through digital representations, for instance, modelling financial markets and economic scenarios to assess risks and devise investment strategies. While simulation technology originated in the IR2.0, it was widely adopted only during the IR3.0 when the advent of computer graphics and two-dimensional (2D) animations marked a ground-breaking development for simulation in the early 1990s. With contemporary 3D modelling, simulation remains the core of the IR4.0 (Gunal, 2019). In short, making decisions can be challenging, but simulation bolsters the rational basis and contributes to the business decisions quality (Vaidya et al., 2018).

1.1.4(g) System Integration

System integration combines various computing systems and software packages, forming a more extensive system with novel functionalities and enhancing the system's value (Essien et al., 2020). Within the framework of IR4.0, there are three categories of integration (Sony, 2018; Vaidya et al., 2018; S. Wang et al., 2016): vertical integration, horizontal integration, and end-to-end (E2E) integration. Figure

1.5 illustrates the flows of the three system integrations. Vertical integration interconnected different hierarchical subsystems within the organisation to create a flexible and reconfigurable manufacturing system specific to that organisation. Horizontal integration facilitates inter-corporation or inter-organisation collaboration in the value chain and forms a new, efficient, digitised ecosystem. End-to-end integration aims to link and enhance all processes, systems, and networks engaged across the entire product life cycle, from design and development to production and delivery support, enabling customisation of products and services across the value chain. In essence, system integration is the backbone of IR4.0, enabling the seamless flow of information, automation and cooperation that defines and realises this period of industrial advancement (Sony, 2018; Vaidya et al., 2018; Wang et al., 2016).



Source: Wang et al. (2016)

Figure 1.5 The Flows of the Horizontal, Vertical and End-To-End Integration

1.1.4(h) Internet of Things (IoT)

As aforementioned, CPSs are integrated systems of internet-enabled physical objects with computers and control components (i.e. sensors and actuators). Internet of Things (IoT) refers to the network of these physical objects or “things”. These “things” or devices could be everyday objects such as household appliances, vehicles, wearable devices, or more specialised objects such as medical devices, agricultural sensors and industrial machines. While there is no universally accepted definition of

IoT, it is crucial to highlight that computers, tablets, and smartphones are generally not categorised as IoT devices despite their significant roles in shaping the IoT ecosystem; for example, human switches on smart home devices (e.g., adjust the thermostat or close the blinds with a voice command) using the smartphone (Ornes, 2016). IoT devices are specialised for specific tasks and primarily communicate and operate without constant human intervention. In contrast, computers, tablets and smartphones can perform various tasks, including running applications and browsing the internet, and most importantly, they rely on human interaction to function. The world is currently transitioning to 5G generation of cellular networks and looking ahead to 6G connectivity (Li, 2022). The IoT may create a highly interconnected "smart" world where the networking or connections between objects and their surroundings and between objects and people become increasingly intertwined (Rose et al., 2015).

1.1.4(i) Cybersecurity

The expansion of IoT can transform numerous facets of our lives and industries through networks and connectivity. Nevertheless, it also poses challenges concerning privacy, security, and management of extensive volumes of data. It is essential to recognise that the prevailing cybersecurity measures were primarily created for IT-centric devices and environments. As the interconnectivity of devices and systems continues to expand in IR4.0, digital security has grown in complexity; hence, traditional cybersecurity approaches may no longer be adequate (Malaysia Industry Forward Association, 2023). For instance, cloud security threats such as implanting malware and malicious files into organisations' systems, data loss, data breach, sensitive data leaked to untrusted third parties, and account hijacking are the possible risks and vulnerabilities associated with storing, processing, and accessing data and applications in the cloud computing environments. While IR4.0 brings significant advantages and opportunities, it also poses challenges and risks, making it a double-edged sword.

1.1.5 Upskilling, Reskilling and Hiring *People*

IR4.0 is not solely reliant on technology advancement; to embrace radical technological changes, organisations must ensure their workforce is well-prepared through upskilling and reskilling and, when necessary, recruiting new talent (Li, 2022; McKinsey Explainers, 2022). In other words, IR4.0 adoption is not merely about adapting to changing technology but also about managing people (i.e. human capital) during this change (Bag et al., 2018). This proposition is asserted by the Future of Jobs Report, published by the World Economic Forum (2023c) outlining the significance of upskilling and reskilling talent. Upskilling involves employees acquiring new skills to stay relevant and competitive in their current roles as the required skills evolve. Reskilling, on the other hand, is more challenging as it involves retraining the workers with new skills compatible with market requirements and enabling them to take on different roles or positions within their organisations. In the era of IR4.0, both organisations and employees acknowledge that work is increasingly digital (Li, 2022). Table 1.1 displays the top 10 job skills in 2015, 2020, and 2025, as documented in Li (2022).

According to The Future of Jobs Report 2020 (Schwab & Zahidi, 2020), over two-thirds (67%) of skills considered important in 2020 will have changed in 2025. For instance, in Table 1.1, complex problem-solving skill that topped the list are superseded by analytical thinking and innovation, as well as active learning and learning strategies skills in 2025. In addition, people management skill, which was of great significance in 2015 and 2020, have fallen out of the top 10 job skills in 2025. Hence, other than technology advancement, workforce upskilling and reskilling remain an issue in combating the growing skills gap and as a response to IR4.0 adoption. With this, this thesis concludes that both technology and people are two important elements in IR4.0 adoption.

Table 1.1 Top 10 Job Skills in 2025, 2020, and 2015

25/20/15*	in 2025	20/15*	in 2020	in 2015
1	Analytical thinking and innovation	1, 1	Complex problem-solving	Complex problem-solving
2	Active learning and learning strategies	2, 4	Critical thinking	Coordinating with others
3, 1, 1	Complex problem-solving	3, 10	Creativity	People management
4, 2, 4	Critical thinking and analysis	4, 3	People management	Critical thinking
5, 3, 10	Creativity, originality, and initiative	5, 2	Coordinating with others	Negotiation
6	Leadership and social influence	6	Emotional intelligence	Quality control
7	Technology use, monitoring, and control	7, 8	Judgment and decision making	Service orientation
8	Technology design and programming	8, 7	Service orientation	Judgment and decision making
9	Resilience, stress tolerance, and flexibility	9, 5	Negotiation	Active listening
10	Reasoning, problem-solving	10	Cognitive flexibility	Creativity

Notes: Data compiled by Li (2022) from Future of Jobs Report 2016 and Future of Jobs Report 2020 released by the World Economic Forum. * 25/20/15 indicates top job skills required in 2025, 2020, and 2015 respectively; 20/15 indicates top job skills required in 2020 and 2015.

1.1.6 IR4.0 in Malaysia

The previous section concludes that IR4.0 adoption is reflected in both technological and people aspects. This section illustrates the state of IR4.0 adoption in Malaysia and outlines two main reasons why this research focuses on the Malaysian context.

Firstly, in response to IR4.0, Malaysian government has rolled out a series of strategies to prepare the firms to ride the wave of IR4.0. Notably, the "Eleventh Malaysia Plan", introduced by the Economic Planning Unit in May 2015, is recognised as one of the most influential public policies related to the IR4.0 (Liao et al., 2018), even before the popularisation of the term IR4.0 by Klaus Schwab, the Founder and Executive Chairman of the World Economic Forum in 2016. This policy aims to transform its three primary manufacturing subsectors (Electrical and Electronics, Chemicals, Machinery and Equipment) towards more high-value, diverse and complex products. To further promote IR4.0 adoption, Malaysia launched its National Policy on Industry 4.0 (Industry4WRD) on 31 October 2018 to drive the digital transformation of the manufacturing and related services sector from 2018 to 2025. Malaysia has continued encouraging IR4.0 adoption by introducing the National Fourth Industrial Revolution (4IR) Policy in 2021. This policy is aligned with the National Policy on Science, Technology and Innovation (DSTIN) 2021-2030, which aims to develop Malaysia as a high-tech nation by 2030. In terms of international collaboration, the Government of Malaysia and the World Economic Forum have established the Centre for the Fourth Industrial Revolution (C4IR Malaysia) in Malaysia as an initiative for the World Economic Forum's global C4IR Network. Notably, it is the first centre in the ASEAN region. C4IR Network is a community with 18 centres actively engaged in matters related to technology governance, adoption, and expansion on national, regional, and global scales (World Economic Forum, 2023a).

Secondly, Malaysia's context provides a suitable avenue for IR4.0 adoption investigation. This knowledge gap can be attributed to the fact that IR4.0 is a relatively recent concept, as it was officially introduced by Klaus Schwab in 2016 (Schwab, 2017). Economically, Malaysia has been a notable success story in East Asian industrial policies, where the effective utilisation of the manufacturing sector has catalysed national growth. Despite Malaysia and Ghana gaining independence from the British Empire in the same year, Malaysia's substantial progress and development, particularly in manufacturing industries, has led to remarkable improvements in household incomes and living conditions (Hausmann & Rodrik, 2002; Tan et al., 2022). On the other hand, advanced technologies related to IR4.0 are at the same time driving changes in global value chains, and these changes are already impacting countries such as Malaysia, which has experienced "premature deindustrialisation" since the early 2000s (Asyraf et al., 2019; Tan et al., 2022).

"Premature deindustrialisation" happens when the country's industrial base declines before becoming a high-income economy, primarily attributed to heightened global competition and sluggish advancement in ascending the value chain (Asyraf et al., 2019; Tan et al., 2022). Malaysia's competitive edge in labour-intensive manufacturing is diminishing as neighbouring countries with lower labour costs and rapidly improving infrastructure outpace Malaysia. The only exception is Pulau Pinang State in Malaysia, which has maintained its industrial base and shifted towards high-technology manufacturing via the IR4.0 adoption (Tan et al., 2022). Consequently, Malaysian firms represent a diverse spectrum of companies at various stages of IR4.0 adoption.

Malaysia is classified as an adopter of IR4.0 since 2015, and the nation's digital transformation is leading in the region (Ali, 2022; Liao et al., 2018). Although still at an infancy stage (Tay et al., 2021), Malaysia hosts a diverse spectrum of companies at various stages of IR4.0 adoption, with some having already embraced IR4.0 (Tan et al., 2022). Exploring the connection between CEOs' characteristics and IR4.0 adoption in these firms provide valuable insights for the development of effective IR4.0 policies, particularly in encouraging IR4.0 adoption among public listed firms in Malaysia. While there is an abundance of research investigating the relationship between IR4.0 technologies and firm performance, and highlight the importance of IR4.0 adoption in preventing premature deindustrialisation, this thesis does not examine the impact of IR4.0 adoption, as it falls beyond the scope of the study.

1.2 Problem Statement

While Malaysia has faced premature deindustrialisation since the early 2000s, the Pulau Pinang State, leveraging IR4.0 technology, managed to circumvent this trend by maintaining its industrial base and transitioning toward high-technology manufacturing (Tan et al., 2022), highlighting the importance of embracing IR4.0. There is abundance of research has evidenced the importance of IR4.0 adoption for both firms and national progress (Tay et al., 2021). With substantial evidence such as Lok et al. (2022), Shahzad et al. (2023), Tan et al. (2022) and Tay et al. (2021) documenting the benefits of adopting IR4.0 technologies, such as improved efficiency, a more competitive value chain, and enhanced performance in Malaysia, the contemporary issue with IR4.0 in Malaysia is not the potential benefits of IR4.0 adoption, but the challenges to increase IR4.0 adoption since Malaysia is in the infancy stage in adopting IR4.0 (Tay et al., 2021).

Firstly, embracing IR4.0 adoption poses significant challenges, as it requires not only technological investment (Shahzad et al., 2023), but also CEOs' strategic decisions to transform the firms culture and management (Davenport et al., 2020; Davenport & Mittal, 2020; Finzi et al., 2022), as CEO is the "change agent" (Finzi et al., 2022; Kitchell, 1997). As quoted in Finzi et al. (2022), "*The CEO is a change agent, recognizing that the world in their sector can be very different in a few years. They need to state their vision for what the industry or world will look like and then articulate how the company needs to change in order to adapt to that world*". While there are abundance of research investigating the relationship between CEO and managerial risk-taking, existing managerial risk-taking research has overlooked how CEO characteristics influence the IR4.0 adoption (i.e. a specific managerial risk-taking). Managerial risk-taking is a broad concept, and this thesis posits that IR4.0 adoption is an extended managerial risk-taking, a strategic choice made by the CEO. In other words, IR4.0 adoption serves as an example or a specific form of managerial risk-taking in the era of IR4.0. A risk-averse CEO may avoid taking risk (Hoskisson et al., 2017) to invest in technology and workforce during this industrial transition period. It is crucial, therefore, to identify which characteristics of the CEO, as the change agent, that will affect IR.4.0 adoption in the firm.

Secondly, as there is no clear definition on IR4.0 adoption, firms face significant barriers in embracing IR4.0, including unclear direction from CEOs on which dimensions to prioritize (Aiken & Keller, 2007). The key dimensions of IR4.0 adoption, such as acquiring new technologies, hiring a skilled top management team, appointing a CIO, and establishing a board technology committee, to address technology transformation in the firm require strategic alignment and clear communication. However, the impact of CEOs on these dimensions remains underexplored. Empirical findings on the relationship between specific CEO characteristics and the dimensions of IR4.0 adoption will expand perspectives and offer valuable insights into how to effectively implement IR4.0.

Thirdly, firms face varying levels of risk (Hoskisson et al., 2017; Palmer & Wiseman, 1999), such as income stream volatility, diversification challenges, or financial constraints, that could either facilitate or hinder managerial risk-taking activities like IR4.0 adoption. This adds complexity to the relationship between CEO and managerial risk-taking actions such as IR4.0 adoption. Addressing this gap is crucial to understanding how CEOs can drive IR4.0 adoption effectively, ensuring firms thrive in an uncertain and competitive environment.

Putting Malaysia forward as an example sheds light on the characteristics of CEOs involved in managerial risk-taking endeavours like IR4.0 adoption and the specific circumstances (i.e. firm risk exposure) under which they are encouraged or deterred from such risk-taking activities. A clear understanding of CEO characteristics that affect IR4.0 adoption, and the firm risks that moderated this relationship, is particularly crucial to developing countries such as Malaysia to transform the industrial sectors, where manufacturing and services are crucial in the national economy.

1.3 Motivation of the Study

The adoption of IR4.0 technology has garnered significant interest over the last few decades, particularly in supply chain management, technology, and innovation. Although anecdotal evidence is abundant, there needs to be more research on IR4.0 adoption in the context of corporate finance and firm risk. While a substantial body of recent research has focused on the outcomes and performance implications of embracing advanced IR4.0 technology such as cloud computing and IoT (Lok et al., 2022; Ooi et al., 2018; Shahzad et al., 2023; Tan et al., 2022; Tay et al., 2021), there is a noticeable gap in the understanding of how CEO characteristics influence managerial risk-taking such as IR4.0 adoption. Given CEOs' crucial role in transforming firms in the era of IR4.0 (Finzi et al., 2022), this represents an area that requires further exploration. Therefore, this research is motivated to investigate the relationship between CEO characteristics and IR4.0 adoption.

On the other hand, a universally accepted definition of IR4.0 adoption remains elusive. This research posits that IR4.0 adoption encompasses more than just implementing advanced technology; it also involves aligning the workforce (i.e. people) with current market demands. This includes actions such as hiring top management team (TMT) with IR4.0 experience, appointing the chief information officer (CIO), and establishing a board technology committee. In addition, from a risk perspective, analysing a firm's exposure to risk enables CEOs to identify potential firm risks that may influence their managerial risk-taking such as IR4.0 adoption. Hence, this research is motivated to investigate three variables: CEO characteristics (the independent variable), firm risk exposure (the moderating variable), and IR4.0 adoption (the dependent variable).

The contemporary management and finance literature, drawing on Upper Echelons Theory (UET), has documented that executives' experiences, values, and personalities of CEOs may affect strategic decisions within the organisation (Hambrick & Mason, 1984). Consequently, firms' innovation, investment, and technical transformation are rooted in their CEOs' cumulative discovering processes. Moreover, managerial discretion and executive job demands offers insights into the discussion on UET. According to Hambrick et al. (2005), both managerial discretion and executive job demands affects the UET predictive strength. Therefore, the two main factors of UET: managerial discretion and executive job demands help to provide