Drivers of and Challenges Facing Adoption of Industrial Revolution 4.0 Technologies: A Study of the Electrical and Electronics Industry in Malaysia

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Abstract: This paper examines the main drivers and challenges of adopting Industrial Revolution (IR) 4.0 technologies in the electrical and electronics (E&E) manufacturing industry in Malaysia. The E&E industry is selected as a case study because it is Malaysia's largest contributor to manufacturing employment, value added and exports. The empirical findings indicate that the two strongest drivers for adoption are internal benefits associated with improvements in production efficiency and cost reduction. The findings also suggest that the biggest challenges faced by the E&E industry are the shortage of necessary talents and skills, limited funds available for technological upgrading, and a lack of convincing business evidence to justify such investment.

Keywords: IR 4.0, technology adoption, electrical and electronics, Malaysia
JEL classification: O14, O31, L63

1. Introduction

The focus of economic development policy studies has shifted from the analysis of specialisation on the basis of factor endowments to techological upgrading. Under neoclassical economic policy assumptions, industrial transformation from labour-intensive to capital-intensive was a desirable policy outcome with capital accumulation (including human capital and foreign capital), and this transformation is argued to be the key driver of economic growth (Romer, 1986; Solow, 1956). By contrast, the heterodox approach emphasises technological upgrading through deliberate interventions from government as the driver of economic catch up and leapfrog (Kaldor, 1957; Nazeer et al., 2021; Rasiah & Jomo, 2013; Rasiah & Nazeer, 2016). For example, Kaldor (1957) denied a prevailing proposition that economic growth would be proportional to the rate of capital acculturation, and proposed a technical progress function, which is determined by the relationship between the growth rate in capital per worker and the growth rate in output per worker. Subsquent extensions to the heterodox

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Article Info: *Received* 13 October 2023; *Revised* 15 December 2023; *Accepted* 24 March 2024
https://doi.org/10.22452/MJES.vol61no1.3

approach to address the shortcomings of Kaldor's earlier models took on industrial strategies targeted at stimulating industrial upgrading (see Oqubay et al., 2020).

In this way, economic growth through technological upgrading could be achieved through two distinctive approaches. The neoclassical approach emphasises the achievement of economic convergence between the high and low income countries through specialising on relative factor endowments with the role of government to follow such market (relative) signals through strengthening law and order and building the infrastructure. By contrast, the second approach focuses on technology acquisition and upgrading through deliberate industrial strategies to achieve economic catch up. The movement in this technology ladder could involve climbing up from simple manufacturing activities of component assembly to manufacturing of frontier products. Stepping up the ladder also means that the main manufacturing activities should undergo rapid transition from original equipment manufacturing (OEM) to the original design manufacturing (ODM), then further to the original brand manufacturing (OBM) (Nazeer et al., 2021; Rasiah & Jomo, 2013; Rasiah & Nazeer, 2016). However, as Rasiah (2022) has argued, some frontier firms have remained in OEM activities but sought to reach the technology frontier by investing heavily into R&D. For example, the Taiwan Semiconductor Manufacturing Company (TSMC) has remained an OEM but is the leader in shaping the logic chips technology frontier. Nevertheless, there is evidence of industrial policies accounting for the rapid development of a number of the East Asian countries, such as Japan (Johnson, 1982), South Korea (Amsden, 1989), Taiwan (Wade, 1990), and Singapore (Rasiah, 2013, 2020). These countries successfully climbed up the technology ladder from the initial stage to the final stage and achieved an impressive industrial catch up by stimulating industrial structural changes (Jomo, 2019; Rasiah, 2017; Rasiah et al., 2016; Rasiah & Yap, 2016a).

Malaysia appeared to be climbing steadily up the technological ladder. However, prevailing issues prevented the transformation of its industrial structure into high technology-based and innovative-driven (Jomo & Edward, 1993; Rasiah & Yap, 2016b; Suffian, 2021). The electrical and electronics (E&E) is the dominant industry amongst a few manufactured products that have driven the export industry (Jomo, 2019; Lall, 1995). The Mid-Term Review (MTR) of the Twelfth Malaysia Plan (12MP) claimed that the expansion of Malaysian exports was driven by the high demand in the E&E industry, which contributed RM593 billion in 2022 (Ministry of Economy, Malaysia, 2023). In terms of job creation, approximately 600,000 Malaysians are employed in the E&E industry (Huong, 2023). However, the local content of manufactured exports remains low (Jomo, 2019; Lall, 1995). There have been three main challenges identified in the industrial transformation in Malaysia. Firstly, as illustrated before, Malaysia's industrial structure is rather narrow and shallow. Secondly, Malaysia's manufacturing industry has something of a dual structure. Foreign firms tend to have a dominant position in the export industry while local firms tend to concentrate in the manufacturing industry for the domestic market. There is a lack of scale effect for the local manufacturing industry due to the relatively small local market (Rasiah, 2011, 2020; Suffian, 2021). Furthermore, there is a limited degree of technological and supply linkages between foreign and local firms (Jomo, 2019; Lall, 1995; Rasiah, 2017). Thirdly, there is an issue in human resource planning (Jomo, 2019; Lall, 1995;). Malaysia still has an insufficient

base of vocational education at the tertiary education level as well as the technical and vocational education and training (TVET) level. Thus, there is a mismatch and gap between demand and supply in various kinds of skilled and unskilled workers in the labour market (Jomo, 2019; Lall, 1995a).

Against this backdrop, the current study examined the drivers and challenges of adopting industrial revolution (IR) 4.0 technologies in Malaysia. The basic conceptual framework of the IR4.0 technologies was conceived by the German government to introduce a new concept to their economic policies that utilised high-tech strategies in 2011 (Anderl, 2015; Kagermann et al., 2013; Mosconi, 2015). It is the driving component of the fourth technological revolution combining the usage of cyber-physical systems (Babiceanu & Seker, 2016; Lee et al., 2015; Wang et al., 2015), Big Data (Santos et al., 2017; Wan et al., 2017), Internet of Things (Ashton, 2009; Cooper & James, 2009; Gilchrist, 2016; Lee & Lee, 2015), Internet of Services (IoS), Artificial Intelligence (Brödner, 2018; Yao et al., 2017; Zhong et al., 2017), and Smart Factory (Anderl, 2015; Lasi et al., 2014; Mosconi, 2015). The concept's ultimate purpose is to create agile companies that can continuously learn and adapt following a dynamic changing market environment (Benitez et al., 2020; Dalenogare et al., 2018). The objective of this research is to understand the key sources, drivers and challenges that influence a firm's ability to adopt Industry 4.0-related technologies. This research also looks into the specific company characteristics that affect these factors (Bauer et al., 2018; Schuh et al, 2017; Yeap & Rasiah, 2023).

This study chooses the E&E industry as a case study because this industry has been a critical contributor to the Malaysian economy and is often considered one of the most technologically advanced industries in Malaysia. Thus, this industry could be used to measure the technological changes through targeted policymaking and better institutional synergy for a country seeking to deepen its engagement in high-value industrialisation (North, 1990; Rasiah, 2020; Williamson, 1985). For the past 50 years, Malaysia has tried to develop a holistic E&E ecosystem that can support front-end and back-end semiconductor manufacturing operations and trade. Foreign MNCs as well as local companies have established themselves in Malaysia to cater to the global supply chain (Yeap & Rasiah, 2023).

This paper consists of five sections. Following this introductory section, the second section reviews the major literature on technological changes in Malaysia, especially in the E&E industry in the country. The third section explains the data collection methods and data analysis. The fourth section reports the empirical findings on the drivers and barriers to technological adoption in the E&E industry in Malaysia. The fifth section is the conclusion.

2. Literature Review

Some pioneer studies examine the intricate linkage between productivity growth and industrial upgrading through technical change (Dahlman et al., 1987; Lall, 1992, 1994; Rosenberg, 1976). For example, Rosenberg (1976) stressed the "centrality" of technology in the process of economic growth by claiming that technological change basically happens when producers find a new input or raise productivity. The four

main categories of technological change are (1) to raise output per unit of input, (2) to develop new materials, (3) to raise the productivity of extraction or exploration, and (4) to develop new technology for reuse, recycling and usage of alternative inputs (Rosenberg, 1976). In this context, Rosenberg claimed that technology is a collection of "principles and techniques" which are embodied in a set of machines or commodities. Thus, innovative activities tend to be a continuous and gradual process, rather than the Schumpeterian notion of a discontinuous process (Schumpeter, 1927, 1928). Furthermore, Dahlman et al. (1987) asserted that new technology development or the invention of new products is not crucial for technological development in developing countries. Instead, they stressed the centrality of the acquirement of "capabilities needed for efficient production and investment" by creating a synergy between foreign and local technologies. In this sense, innovation and new production development are normally preceeded by the development of production capabilities in developed countries. However, developing countries could purchase "technology that already exists". What developing countries need is to build a production capability which is the foundation for innovation activities (Dahlman et al., 1987). Lall (1992) claimed that there is industrial upgrading through the trajectory of deepening technological capabilities from production capability to innovation capability through investment capability. More importantly, Lall (1996) asserted the importance of technological capabilities in the economic growth of developing countries. He operationally defined technological capabilities as a set of skills, such as technical, managerial and institutional skills which would contribute to making producers efficiently use equipment, information and knowledge. These technological capabilities are firm-specific and could be called "institutional knowledge" which is a combined stock of knowledge, skills and information over time (Lall, 1996, p. 28).

Based on the pioneering literature, Rasiah (2003, 2007) made a significant contribution to the existing literature by defining clearly the measurement of technological capabilities. Rasiah (2003) systematically separated technological capabilities into three broad categories, namely the human resource capabilities, the process capabilities and the R&D capabilities. Human resource capabilities incorporate three measurements, i.e., the training mode (TM), the training expense (TE) and the cutting-edge human resource (CHR) practices while process capabilities incorporate four measurements, i.e., equipment (E), machinery (M), information technology components (ITC) and quality control (QC) instruments. He used these measurements to compare electronics exporting industries in Malaysia and Thailand. He concluded that the technological capabilities of local firms in Thailand are higher than those in Malaysia. However, the technological capabilities of foreign firms in Malaysia are generally higher than in Thailand (Rasiah, 2003). Furthermore, Rasiah (2007) re-categorised technological capabilities into three distinctive capabilities, namely the human resource capabilities, process capabilities and product capabilities. The product capabilities are similar to the R&D capabilities and it incorporates two measurements, namely the percentage of R&D expenditure (RDE) in total sales and the percentage of the R&D personnel (RDM) in the total workforce. He used these measurements to compare computer and component firms in Johor and Penang, Malaysia. He concluded that computer and component firms in Penang developed better technological capabilities than in Johor. For example, there

was one firm that conducted R&D activities and had some R&D personnel in Johor. By contrast, there were more than fifteen firms which conducted R&D activities and employed R&D personnel in Penang (Rasiah, 2007).

There are two major studies which examined the technological change in the E&E industry in Malaysia (Rasiah, 2013, 2017). Rasiah (2013) investigated whether Malaysia's electronic firms climbed up the technological ladder. He used the trajectory of technological capability deepening from the lowest level of simple manufacturing activities, the complete knock-down (CKD) and the complete built-up unit (CBU), to the highest level of the original brand manufacturing (OBM), through the major improvement of original equipment manufacturing (OEM) and the early R&D activities of the original design manufacturing (ODM). He claimed that there is at least one firm in the E&E industry which developed the highest technological capabilities or OBM capabilities. He also concluded that there are some improvements in capability-building and upgrading in the knowledge intensities in the E&E industry in Malaysia. However, there is also stagnation in the productivity growth in the industry. Furthermore, Rasiah (2017) used the taxonomy of capability deepening to classify the 25 firms in the E&E industry in Malaysia into seven levels of technological capabilities from simple manufacturing activities to frontier production manufacturing activities. He claimed that foreign firms have relatively higher technological capabilities than local firms. There are seven foreign firms in the E&E industry which have original brand manufacturing (OBM) capabilities in Malaysia. However, there is no local firm which has the same level of technological capabilities.

In this context, the fourth industrial revolution (IR4.0) can be differentiated from earlier industrial revolutions by three features. They are increasing automation and digitisation (Brettel et al., 2014; Oesterreich & Teuteberg, 2016), the agglomeration of a collective group of technologies (Hermann et al., 2016; Szalavetz, 2019), and outcomes produced by the transformation expected in production (Kagermann et al., 2013; Pereira & Romero, 2017). In this study, seventeen technologies are observed. These are separated into five major technology groups: infrastructure, tracking and monitoring, production, transport and digitalisation (Yeap & Rasiah, 2023). Some key benefits could be summarised as job creation, sustainability and better resource efficiency, improved decision-making process, increased flexibility and customisability in production, more efficient production, synchronisation of production, better response to customer demands, profitability, and increase in competitiveness of the firm. These benefits are linked to key drivers of technological adoption (Oesterreich & Teuteberg, 2016; Yeap & Rasiah, 2023).

On the other hand, some challenges associated with IR4.0 would embody the risks, concerns and circumstances that make manufacturing technologies more difficult or less attractive to acquire (Moeuf et al., 2019; Rauch et al., 2020; Stock et al., 2018; Vaidya et al., 2018). These issues and challenges include suitability of current production infrastructure (Rojko, 2017), data variation (Brettel et al., 2014), cybersecurity threats (Roblek et al., 2016), lack of technological understanding (Szalavetz, 2019), low-value perception, unfavourable surrounding infrastructure and ecosystem (Brettel et al., 2014), changes in job structures (Oesterreich & Teuteberg, 2016), demand and supply of technologies, lack of technological sophistication, lack of government support, financial

constraints, lack of strategy, and legal concerns (Kagermann et al., 2013). Furthermore, E&E manufacturing has been understood in the literature to be cutting-edge in both product and process development. These are developed both internally through R&D or sourced externally from partners and suppliers. However, there are still limited studies that explore the sources of IR4.0 technological adoption amongst manufacturing firms (Yeap & Rasiah, 2023). This is particularly true in the E&E industry in Malaysia.

3. Methods and Data

A questionnaire was developed by adapting the one used by Rasiah and Yap (2016a, 2016b). The questionnaire, specifically targeted at IR4.0 technologies, uses Likert scale scores to capture E&E firms' rating of critical supporting organisations that are important for the promotion of IR4.0 technologies. The population used for this study was defined by the largest database available from the Malaysian Industrial and Development Authority (MIDA) of 485 companies across all the sub-sectors of the E&E industry (Yeap & Rasiah, 2023).

There are two main criteria for the selection of firms, namely the size of firms and the location of firms. Based on these criteria, a stratified sampling technique, in consultation with the E&E industry association, was used to identify 10 firms in the E&E industry for a pilot study. After the implementation of the pilot study, the full-scale research was conducted through a non-discriminative snowball sampling method. Based on the two selection criteria, 55 companies were selected for the full-scale research. These firms were directly approached and eventually, 50 firms joined the survey. The face-to-face semi-structured interviews conducted for all these firms lasted between 45 to 90 minutes each and took place across two years, throughout 2019 and 2020. The response rate was 90.9% of the sample of firms identified (Yeap & Rasiah, 2023).

Among the 50 firms in the sample, 33 firms are owned by foreign multinational corporations (MNCs). Concerning employment size, 24 firms employed less than 1,000 employees and only 11 firms employed more than 3,000 employees (Yeap & Rasiah, 2023). The location of the firm is an important factor in influencing the level of technological adaptation. These 50 firms are spread over 8 states in Malaysia, namely Johor (3), Kedah (3), Melaka (1), Negeri Sembilan (1), Penang (30), Perak (1), Sarawak (1), and Selangor (10). Among these selected E&E firms, 30 firms are in Penang which is commonly considered the Malaysian hub of the E&E industry. There are five main sub-sectors among these 50 E&E firms: electronic components, consumer electronics, industrial electronics, electronic machinery and equipment, and electric appliances (Yeap & Rasiah, 2023).

As Figure 1 indicates, this research delves into the driving internal and external forces that encourage, deter and enable the process advancement and adoption of IR4.0 technologies in Malaysia's E&E manufacturing industry. These drivers and challenges are drawn from literature and touch on both the internal capabilities of the firm and the external influences of its surrounding ecosystem. E&E manufacturing firms operate in a highly competitive environment and under unique circumstances that make acquisition of new process technologies varied. These internal and external sources enable firms to implement process changes within their operations after a decision is

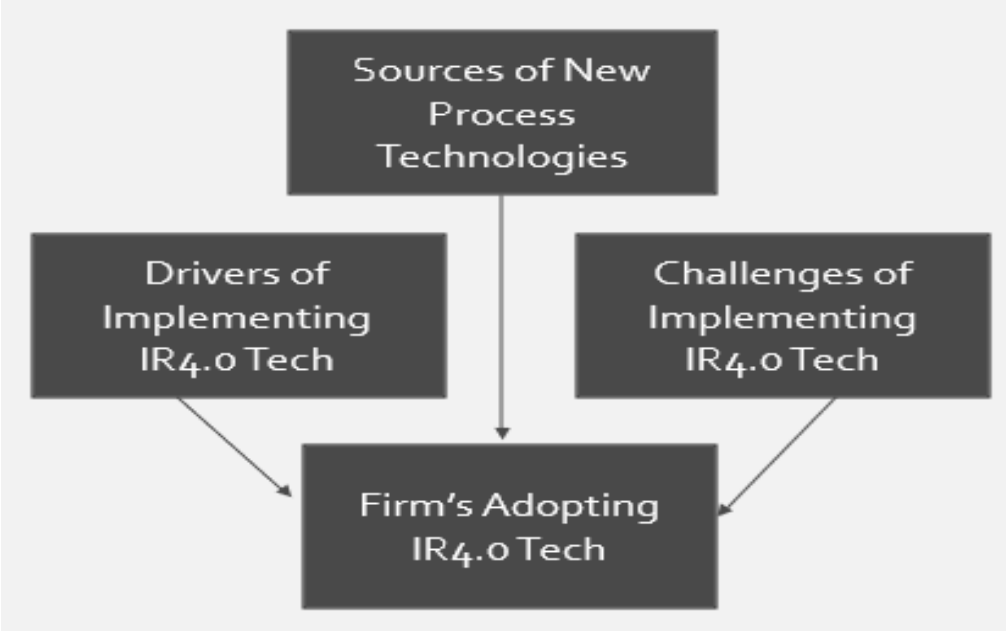

Figure 1. Analytical framework

made. This analytical framework describes the rationale behind the findings established in this study.

4. Empirical Findings

From the literature review, eleven factors were found to influence firm's decisions to adopt IR4.0 technologies in their production processes. These factors were included in the questionnaire and the respondents were asked to rate their importance on a Likert scale of 0 (least important) to 5 (most important). As Figure 2 shows, the primary drivers behind the adoption of IR4.0 technologies are internal benefits, particularly improvements in production efficiency and cost reduction. External factors such as shifts in customer demand and heightened global competition serve as additional drivers for embracing Industry 4.0. The least influential drivers encompass changes in regulations, the aspiration to decentralise decision-making processes, and fluctuations in labour availability.

The questionnaire also sought information on the barriers to IR4.0 technology adoption. As Figure 3 indicates, the top three challenges faced are a shortage of necessary talents and skills, limited funds available for technology upgrading, and a lack of business case justifying such investment. Although less severe, other barriers include the lack of a unified vision for innovation within the firm, concerns over cybersecurity, and a lack of understanding of these IR4.0 technologies.

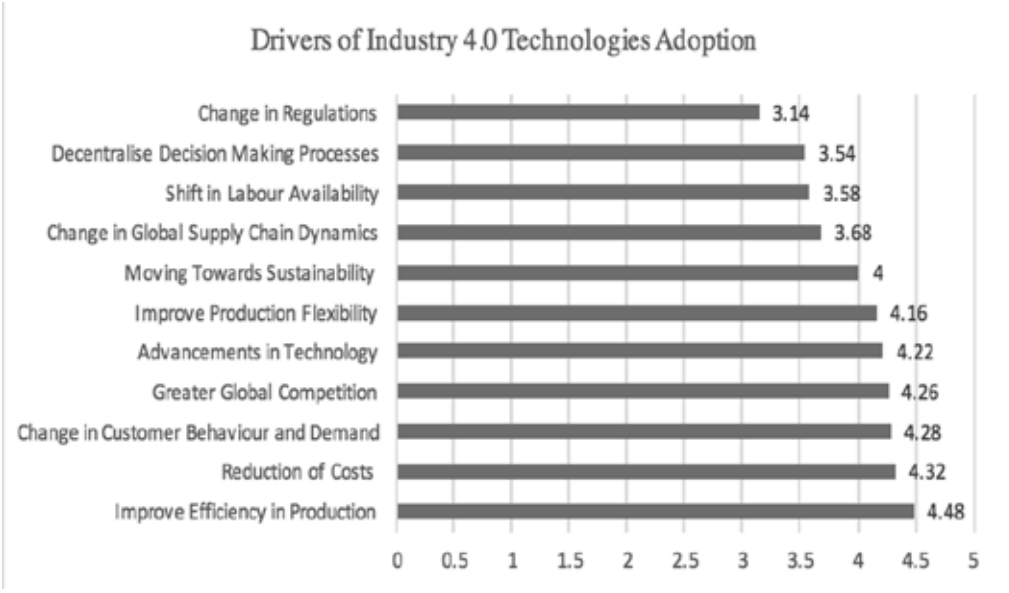

Figure 2. Drivers of the IR4.0 technology adoption

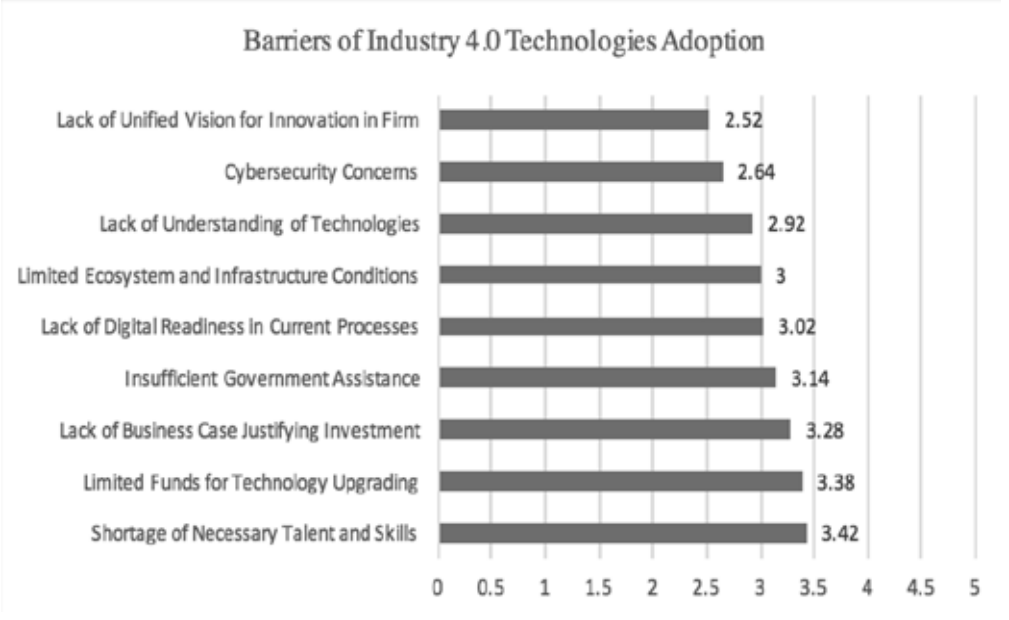

Figure 3. Barriers of the IR4.0 technology adoption

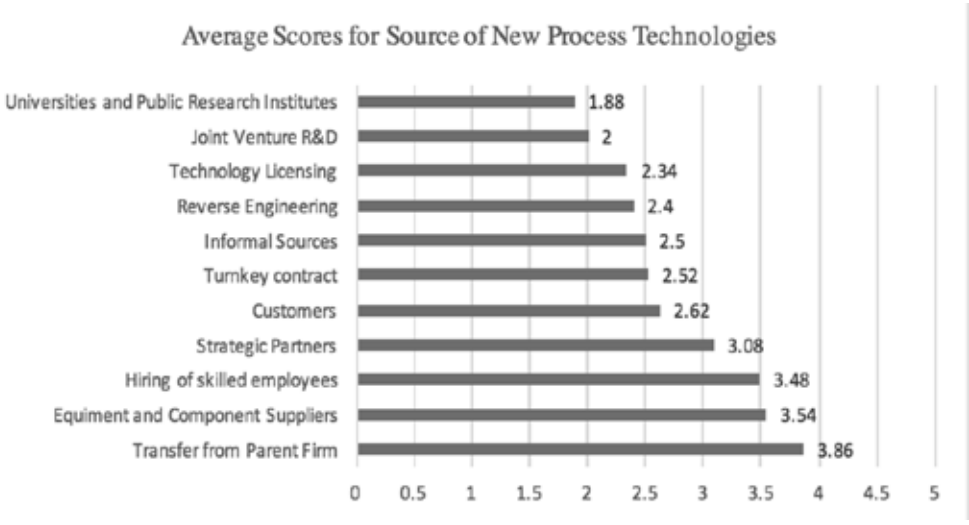

Figure 4. Average scores for source of new process technology

In order to understand the shifting motivations of technological adoption, firms were asked about their primary source of new process technologies. Figure 4 shows that the sources with the highest average scores are through transfer from the parent firm, equipment and component suppliers, and the hiring of skilled employees. The lowest scoring sources were universities and public research institutes, joint venture R&D, and technology licencing.

5. Discussion

The main internal drivers for the adoption of IR4.0 technologies in the E&E manufacturing industry in Malaysia are production efficiency and cost reduction (Figure 2). Organisations are increasingly drawn towards integrating IR4.0 technologies when they demonstrate the potential to enhance overall production performance. This not only elevates the quality of products but also boosts competitiveness in the market. External drivers like changing customer demands and increased global competition also encourage its adoption. These factors underscore the necessity for companies to stay responsive to evolving market dynamics, encouraging them to leverage advanced technologies for sustained growth and adaptability. The least impactful drivers in the context of IR4.0 adoption are changes in regulations, the desire to decentralise decision-making processes, and labour availability. While the Malaysian government has prioritised incentivising and providing financial support to encourage IR4.0 technology adoption within the manufacturing industry, the impact of these initiatives is limited by a lack of significant changes in legal regulations that effectively mandate alterations in firms' production processes and technological upgrades. In contrast to the more direct benefits of efficiency improvements, the decentralisation of decision-making processes

is anticipated to be an indirect advantage resulting from a more interconnected production system. Lastly, the Malaysian E&E manufacturing industry has historically heavily relied on foreign low-skilled labourers for labour-intensive tasks and operator roles. This dependence presents a unique challenge amid the IR4.0 transition, requiring thoughtful strategies to address shifts in labour dynamics while ensuring a smooth technological upgrade.

The most prominent challenges are a shortage of necessary talents and skills, limited funds available for technology upgrading, and a lack of business case justifying such investment (Figure 3). Many companies expressed the need for upskilling within the firm's workforce in order to handle new technologies and the incompatibility of the educational qualifications of fresh graduates with that of the firm's changing needs. Companies insist that there are limited funds available for spending on process technology upgrading, either due to tight financial control by parent firms or unwilling senior management. As many of these IR4.0 technologies are not associated with short-term profitability, companies are not convinced to make large investments in significant changes in production systems. Other barriers include the lack of a unified vision for innovation within the firm, concerns over cybersecurity, and a lack of understanding of these IR4.0 technologies. Although firms find that there are insufficient funds to invest in Industry 4.0, they do not equate that with a lack of unified vision for innovation. Physically embedded technologies that transmit data and an Internet enabled cloud computing and storage system poses a threat to cyber security attacks from external agents. However, electronics firms have acknowledged that cybersecurity is in itself a necessary investment to support the productivity and bolster the potential of other IR 4.0 related technologies.

The primary sources to acquire new production technologies in the E&E manufacturing industry in Malaysia are through transfer from the parent firm, equipment and component suppliers, and the hiring of skilled employees (Figure 4). The firms interviewed are either subsidiaries of large parent companies or overseas factory sites of MNCs. This finding implies that they have upgraded or integrated new process technologies under the instruction of their parent firm. There is limited evidence that these E&E firms do not have sufficient technological capabilities to innovate internally at the technological frontier. Similarly, when companies look for new technologies, they also turn to existing equipment and component suppliers to provide recommendations. To introduce new process technologies, firms look to continuously hire skilled employees from competitor firms who might assist in knowledge transfer and expertise in handling different technologies. The less relevant sources were universities and public research institutes, joint venture R&D, and technology licencing. Domestic research institutions are less active in process technology development, and few have collaborative relationships with firms. Joint venture R&D is rare domestically due to the nature of the products manufactured in Malaysia. Furthermore, as most firms serve lower value-added functions within the E&E value chain, the types of production processes do not require cutting-edge technologies. This reasoning also explains the lower dependence on technology licencing.

The adoption of automation and digitisation technologies is an appropriate way forward for the Malaysian E&E industry. However, it faces a serious problem

of labour shortage and reliance on employment of foreign unskilled workers. Thus, the main policy implication highlighted by this empirical study is the importance of the promotion of such IR4.0 technologies in Malaysia. The right policies can support institutional drivers and simultaneously address fundamental challenges that companies face when considering technological advancement. These involve developing the human capital availability for high skilled workers, providing targeted support for specific clusters including SMEs, setting clear regulations that incentivise improved production processes, and enhancing the capabilities of our universities and public research institutions. In particular, more needs to be done to improve the quality of the science, technology and information (STI) infrastructure in Malaysia. It is hindering the potential for manufacturers to improve production capabilities up the value chain and overall competitiveness. Additionally, this has previously and will continue to discourage investors from considering the nation as a potential destination for higher value-added production and product technologies in the highly competitive E&E industry. Universities and technical training institutes have room for quality improvement to increase relevance in curriculum and to become more active contributors to innovation within the domestic ecosystem.

Other policy approaches include targeted support for high performing and emerging domestic firms that can provide related technical services for the development of such infrastructure. This can include financial and other policy incentives for research and development activity to deserving firms and institutions that are tied to stringent performance standards. For public education and training, the focus should be on producing more industry relevant content through collaboration with the private sector to conduct regular syllabus review and source funding. Malaysia can learn from and adapt innovative and compatible case studies based on other successful models, such as Taiwan, for human capital development, especially for vocational training and reskilling and upskilling programmes. Finally, the topic of IR4.0 should be promoted more widely amongst the general population because a more informed labour force and customer base will be both ready and also demand higher quality products linked to better production processes.

6. Conclusion

In conclusion, there are significant internal and external drivers and challenges that determine the adoption of new process technologies, particularly IR4.0 technologies amongst the Malaysian E&E firms. Different types of firms consider different factors to be drivers and challenges when implementing new process technologies. However, we have established that a large proportion of the E&E firms are driven to adopt new technologies if they are perceived to have clear internal benefits to profitability and production efficiency, as well as external influences from the market. As domestic regulations are not considered to be as impactful, there is great potential for effective policy to assist firms in tackling their biggest challenges in regards to human capital, financial incentives and high technology ecosystem development. Lastly, a clear understanding of where E&E firms in Malaysia are positioned in the global supply chain is important to determine their sources of new technologies. Operating as subsidiaries

of MNCs, many firms will obtain technological transfer from their parent firm. Ensuring that domestic firms can innovate at the technological frontier is essential in order to attain Malaysia's ambitions to move up the technological ladder.

There are some limitations in this study. Although in-depth interviews were conducted with 50 firms in the E&E industry, the sample size may not be sufficiently representative of the whole industry in Malaysia, considering its complexity. Furthermore, the face-to-face interviews did not sufficiently cover some adjacent issues, such as the comparatives of skilled versus unskilled workers and the exact role of AI. The lack of information on these matters could be considered a limitation of the study's applicability. Lastly, future research may consider using more advanced statistical methods, such as multiple regression methods for a more robust empirical analysis. Overall, future research may consider expanding the sample size, including wider thematic issues, and adopting different empirical methods to supplement the findings of this study.

References

Amsden, A.O. (1989). *Asia's next giant: South Korea and late industrialization*. Oxford University Press. https://doi.org/10.1093/0195076036.001.0001

Anderl, R. (2015). Industrie 4.0 – Technological approaches, use cases, and implementation. *Automatisierungstechnik, 63*(10), 753–765. https://doi.org/10.1515/auto-2015-0025

Ashton, K. (2009). That 'internet of things' thing: In the real world things matter more than ideas. *RFID Journal, 22*(7), 97–114.

Babiceanu, R.F., & Seker, R. (2016). Big data and virtualization for manufacturing cyber-physical systems: A survey of the current status and future outlook. *Computers in Industry, 81*, 128–137. https://doi.org/10.1016/j.compind.2016.02.004

Bauer, W., Schlund, S., Hornung, T., & Schuler, S. (2018). Digitalization of industrial value chains – a review and evaluation of existing use cases of industry 4.0 in Germany. *LogForum, 14*(3), 331–340. https://doi.org/10.17270/J.LOG.2018.288

Benitez, G.B., Ayala, N.F., & Frank, A.G. (2020). Industry 4.0 innovation ecosystems: An evolutionary perspective on value cocreation. *International Journal of Production Economics, 228*, Article 107735. https://doi.org/10.1016/j.ijpe.2020.107735

Brettel, M., Friederichsen, N., Keller, M., & Rosenberg, M. (2014). How virtualization, decentralization and network building change the manufacturing landscape: An Industry 4.0 perspective. *International Journal of Information and Communication Engineering, 8*(1), 37–44. https://doi.org/10.5281/zenodo.1336426

Brödner, P. (2018). "Super-intelligent" machine: Technological exuberance or the road to subjection. *AI and Society, 33*, 335–346. https://doi.org/10.1007/s00146-017-0731-6

Cooper, J., & James, A. (2009). Challenges for database management in the Internet of things. *IETE Technical Review, 26*(5), 320–329.

Dahlman, C.J., Ross-Larson, B., & Westphal, L.E. (1987). Managing technological development: Lessons from the newly industrializing countries. *World Development, 15*(6), 759–775. https://doi.org/10.1016/0305-750X(87)90058-1

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

Gilchrist, A. (2016). *Industry 4.0: Industrial internet of things*. Apress. https://doi.org/10.1007/978-1-4842-2047-4

Hermann, M., Pentek, T., & Otto, B. (2016). Design principles for Industrie 4.0 scenarios. In *2016 49th Hawaii International Conference on System Sciences* (*HICSS*). IEEE. https://doi.org/10.1109/HICSS.2016.488

Huong, T. (2023, February 22). Big demand for skilled workers in E&E sector. *The Star*. https://www.thestar.com.my/business/business-news/2023/02/22/big-demand-for-skilled-workers-in-ee-sector

Johnson, C. (1982). *MITI and the Japanese miracle: The growth of industrial policy, 1925–1975*. Stanford University Press. https://doi.org/10.1515/9780804765602

Jomo, K.S. (2019). *Southeast Asia's misunderstood miracle: Industrial policy and economic development in Thailand, Malaysia and Indonesia*. Routledge. https://doi.org/10.4324/9780429306822

Jomo, K.S., & Edward, C. (1993). Malaysian industrialisation in historical perspective. In K.S. Jomo (Ed.), *Industrializing Malaysia: Policy, performance, prospects* (pp. 14–39). Routledge. https://doi.org/10.4324/9780203021910

Kagermann, H., Wahlster, W., & Helbig, J. (2013). *Securing the future of German manufacturing: Recommendations for implementing the strategic initiative Industrie 4.0: Final report of the Industrie 4.0 Working Group*. https://www.ups.com/assets/resources/media/knowledge-center/Final_report__Industrie_4.0_accessible.pdf

Kaldor, N. (1957). A model of economic growth. *Economic Journal, 67*(268), 591–624. https://doi.org/10.2307/2227704

Lall, S. (1992). Technological capabilities and industrialization. *World Development, 20*(2), 165–186. https://doi.org/10.1016/0305-750X(92)90097-F

Lall, S. (1994). The East Asian miracle: Does the bell toll for industrial strategy? *World Development, 22*(4), 645–654. https://doi.org/10.1016/0305-750X(94)90119-8

Lall, S. (1995). Malaysia: Industrial success and the role of the government. *Journal of International Development, 7*(5), 759–773. https://doi.org/10.1002/jid.3380070506

Lall, S. (1996). *Learning from the Asian Tigers: Studies in technology and industrial policy*. Palgrave Macmillan. https://doi.org/10.1057/9780230389892

Lasi, H., Fettke, P., Kemper, H.G., Feld, T., & Hoffmann, M. (2014). Industry 4.0. *Business Information Systems Engineering, 6*, 239–242. https://doi.org/10.1007/s12599-014-0334-4

Lee, I., & Lee, K. (2015). The internet of things (IoT): Applications, investments, and challenges for enterprises. *Business Horizons, 58*(4), 431–440. https://doi.org/10.1016/j.bushor.2015.03.008

Lee, J., Bagheri, B., & Kao, H.A. (2015). A cyber-physical systems architecture for Industry 4.0-based manufacturing systems. *Manufacturing Letters, 3*, 18–23. https://doi.org/10.1016/j.mfglet.2014.12.001

Ministry of Economy, Malaysia (2023). *Mid-term review, 12th Malaysia Plan*. https://rmke12.ekonomi.gov.my/ksp/bm/dokumen/mid-term-review-twelfth-malaysia-plan-by-chapter

Moeuf, A., Lamouri, S., Pellerin, R., Tamayo-Giraldo, S., Tobon-Valencia, E., & Eburdy, R. (2019). Identification of critical success factors, risks and opportunities of Industry 4.0 in SMEs. *International Journal of Production Research, 58*(5), 1384–1400. https://doi.org/10.1080/00207543.2019.1636323

Mosconi, F. (2015). *The New European industrial policy: Global competitiveness and the manufacturing renaissance*. Routledge. https://doi.org/10.4324/9781315761756

Nazeer, N., Rasiah, R., & Furuoka, F. (2021). Technology transfer, technological capability, absorptive capacity and firm performance: An investigation of the textile and clothing firms in Pakistan. *Malaysian Journal of Economic Studies, 58*(1), 99–124. https://doi.org/10.22452/MJES.vol58no1.6

North, D.C. (1990). *Institutions, institutional change and economic performance*. Cambridge University Press. https://doi.org/10.1017/CBO9780511808678

Oesterreich, T.D., & Teuteberg, F. (2016). Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Computer Industries, 83*, 121–139. https://doi.org/10.1016/j.compind.2016.09.006

Oqubay, A., Cramer, C., Chang, H.J., & Kozul-Wright, R. (2020). Introduction to industrial policy and development. In A. Oqubay, C. Cramer, H.J. Chang, & R. Kozul-Wright (Eds.), *The Oxford handbook of industrial policy* (pp. 2–16). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780198862420.013.1

Pereira, A.C., & Romero, F. (2017). A review of the meanings and the implications of the Industry 4.0 concept. *Procedia Manufacturing, 13*, 1206–1214. https://doi.org/10.1016/j.promfg.2017.09.032

Rasiah, R. (2003). Foreign ownership, technology and electronics exports from Malaysia and Thailand. *Journal of Asian Economics, 14*(5), 785–811. https://doi.org/10.1016/j.asieco.2003.10.006

Rasiah, R. (2007). The systemic quad: technological capabilities and economic performance of computer and component firms in Penang and Johor, Malaysia. *International Journal of Technological Learning, Innovation and Development, 1*(2), 179–203. https://doi.org/10.1504/IJTLID.2007.015403

Rasiah, R. (2011). *Industrialization and export-led growth in Malaysia: Policies and issues in economic development*. Institute of Strategic and International Studies (ISIS) Malaysia.

Rasiah, R. (2013). Are electronics firms in Malaysia catching up in the technology ladder? In R. Rasiah, Y. Lin, & Y. Sadoi (Eds.), *Innovation and Industrialization in Asia* (pp. 82–100). Routledge.

Rasiah, R. (2017). The industrial policy experience of the electronics industry in Malaysia. In J. Page, & F. Tarp (Eds.), *The practice of industrial policy: Government-business coordination in Africa and East Asia* (pp. 123–144). Oxford University Press. https://doi.org/10.1093/acprof:oso/9780198796954.003.0007

Rasiah, R. (2020). Industry policy and industrialization in Southeast Asia. In A. Oqubay, C. Cramer, H.J. Chang, & R. Kozul-Wright (Eds.), *Oxford handbook of industrial policy* (pp. 680–715). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780198862420.013.25

Rasiah, R. (2022). Manufacturing transformation. In R. Rasiah, K. Salih, & K.C. Cheong (Eds.), *Malaysia's leap into the future: Dynamics of Asian development*. Springer. https://doi.org/10.1007/978-981-16-7045-9_6

Rasiah, R., & Jomo, K.S. (2013). Introduction. In G. Felker, Jomo, K.S., & R. Rasiah (Eds.), *Industrial technology development in Malaysia: Industry and firm studies* (pp. 1–20). Routledge.

Rasiah, R., & Nazeer, N. (2016). Comparing industrialization in Pakistan and the East Asian economies. *Lahore Journal of Economics, 21*, 167–192. https://doi.org/10.35536/lje.2016.v21.isp.a7

Rasiah, R., Shahrivar, R.B., & Yap, X.S. (2016). Institutional support, innovation capabilities and exports: Evidence from the semiconductor industry in Taiwan. *Technological Forecasting and Social Change, 109*, 69–75. https://doi.org/10.1016/j.techfore.2016.05.015

Rasiah, R., & Yap, X.S. (2016a). Institutional support, technological capabilities and domestic linkages in the semiconductor industry in Singapore. *Asia Pacific Business Review, 22*(1), 180–192. https://doi.org/10.1080/13602381.2014.990213

Rasiah, R., & Yap, X.S. (2016b). Institutional support, regional trade linkages and technological capabilities in the semiconductor industry in Malaysia. *Asia Pacific Business Review, 22*(1), 165–179. https://doi.org/10.1080/13602381.2014.990210

Rauch, E., Unterhofer, M., Rojas, R.A., Gualtieri, L., Woschank, M., & Matt, D.T. (2020). A maturity level-based assessment tool to enhance the implementation of Industry 4.0 in small and medium-sized enterprises. *Sustainability, 12*(9), Article 12093559. https://doi.org/10.3390/su12093559

Roblek, V., Meško, M., & Krapež, A. (2016). A complex view of industry 4.0. *Sage Open, 6*(2), 1–11. https://doi.org/10.1177/2158244016653987

Romer, P.M. (1986). Increasing returns and long-run growth. *Journal of Political Economy, 94*(5), 1002–1037. https://doi.org/10.1086/261420

Rojko, A. (2017). Industry 4.0 concept: Background and overview. *International Journal of Interactive Mobile Technologies, 11*(5), 77–90. https://doi.org/10.3991/ijim.v11i5.7072

Rosenberg, N. (1976). *Perspectives on technology*. Cambridge University Press. https://doi.org/10.1017/CBO9780511561313

Santos, M.Y., Sá, J.O., Costa, C., Galvão, J., Andrade, C., Martinho, B., Lima, F.V., & Costa, E. (2017). A big data analytics architecture for industry 4.0. In Á. Rocha, A. Correia, H. Adeli, L. Reis, & S. Costanzo (Eds.), *Recent advances in information systems and technologies* (pp. 175–184). Springer. https://doi.org/10.1007/978-3-319-56538-5_19

Schuh, G., Anderl, R., Gausemeier, J., Ten Hompel, M., & Wahlster, W. (Eds.). (2017). *Industry 4.0 Maturity index*. Herbert Utz Verlag.

Schumpeter, J. (1927). The explanation of the business cycle. *Economica, 21*, 286–311. https://doi.org/10.2307/2548401

Schumpeter, J. (1928). The instability of capitalism. *Economic Journal, 38*(151), 361–386. https://doi.org/10.2307/2224315

Solow, R.M. (1956). A contribution to the theory of economic growth. *Quarterly Journal of Economics, 70*(1), 65–94. https://doi.org/10.2307/1884513

Stock, T., Obenaus, M., Kunz, S., & Kohl, H. (2018). Industry 4.0 as enabler for a sustainable development: A qualitative assessment of its ecological and social potential. *Process Safety and Environmental Protection, 118*, 254–267. https://doi.org/10.1016/j.psep.2018.06.026

Suffian, F. (2021). *Political economy of Malaysia's industrial policy: Institutional capacity and the automotive industry*. Springer. https://doi.org/10.1007/978-981-33-6901-6

Szalavetz, A. (2019). Industry 4.0 and capability development in manufacturing subsidiaries. *Technological Forecasting and Social Change, 145*, 384–395. https://doi.org/10.1016/j.techfore.2018.06.027

Vaidya, S., Ambad, P., & Bhosle, S. (2018). Industry 4.0: A glimpse. *Procedia Manufacturing, 20*, 233–238. https://doi.org/10.1016/j.promfg.2018.02.034

Wade, R. (1990). *Governing the market: Economic theory and the role of government in East Asian industrialization*. Princeton University Press. https://doi.org/10.2307/j.ctv346sp7

Wan, J., Tang, S., Li, D., Wang, S., Liu, C., & Abbas, H., & Vasilakos, A.V. (2017). A manufacturing big data solution for active preventive maintenance. *IEEE Transactions on Industrial Informatics, 13*(4), 2039–2047. https://doi.org/10.1109/TII.2017.2670505

Wang, L., Törngren, M., & Onori, M. (2015). Current status and advancement of cyber-physical systems in manufacturing. *Journal of Manufacturing Systems, 37*(2), 517–527. https://doi.org/10.1016/j.jmsy.2015.04.008

Williamson, O.E. (1985). *The economic institutions of capitalism: Firms, market, relational contracting*. Free Press.

Yao, X., Zhou, J., Zhang, J., & Boer, C.R. (2017). From intelligent manufacturing to smart manufacturing for industry 4.0 driven by next generation artificial intelligence and further on. In *2017 5th International Conference on Enterprise Systems* (*ES*) (pp. 311–318). IEEE. https://doi.org/10.1109/ES.2017.58

Yeap, K.L., & Rasiah, R. (2023). Diffusion of IR4.0 technologies in electronics manufacturing: The role of the embedding ecosystem. In R. Rasiah, W.Y. Low, & N. Kamaruddin (Eds.), *Digitalization and development* (pp. 49–67). Routledge.

Zhong, R.Y., Xu, X., Klotz, E., & Newman, S.T. (2017). Intelligent manufacturing in the context of industry 4.0: A review. *Engineering, 3*(5), 616–630. https://doi.org/10.1016/J.ENG.2017.05.015