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ARE DIGITAL SPILLOVERS IMPORTANT FOR INNOVATION AND FIRM PRODUCTIVITY? EVIDENCE FROM MALAYSIAN MANUFACTURING SECTOR

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ABSTRACT

Industry 4.0 has prompted Malaysia's manufacturing firms to enhance their innovation and technological capabilities. Digital spillovers are vital in capturing the full impact of digitalization because the externalities created by digital adoption can be spread across the entire economy. However, scarce studies have considered digital spillovers in the analysis. This research uses the sequential CDM model to examine the relationships between firm characteristics, digital spillovers, innovation and productivity of Malaysian manufacturing firms. The firm-level data that comprises 14,723 Malaysian manufacturing firms is used for data analysis. The results reveal that the firm characteristics and horizontal digital spillover positively influence innovation and firm productivity, as opposed to the backward digital spillover. On the other hand, the effects of internal and forward digital spillovers on the innovation output and firm productivity are relatively mixed. It suggests that manufacturing firms respond differently to information flows from various stakeholders on digital platforms, applying them uniquely to their production methods and business operations. The government is encouraged to support manufacturing firms, especially the SMEs, in leveraging digitalization to improve their performance and competitiveness.

INTRODUCTION

In the 21st century, the world has transitioned into the era of Industrial Revolution 4.0 (IR4.0). Concurrently, the concept of "Industry 4.0" was introduced within the manufacturing sector, accompanied by the emerging ideas of smart manufacturing, smart factories and the Internet of Things (IoT) (World Economic Forum, 2019). These concepts have driven the global manufacturing sector to undergo a significant technological transformation because their implementation necessitates the extensive use of disruptive technologies, such as robotics, artificial intelligence (AI) and cloud computing.

The manufacturing sector is the economic backbone of many countries, including Malaysia. According to the Department of Statistics Malaysia [DOSM] (2023a) and World Bank Group (2024), the manufacturing sector has contributed approximately one-quarter of the gross domestic product (GDP) and plays a significant role in job creation. In addition, the manufacturing sector has acted as a crucial buffer for Malaysian economic growth during external shocks, as demonstrated by its quick recovery in both production and employment rates following the COVID-19 pandemic (Economic Planning Unit [EPU], 2023; DOSM, 2023b). The manufacturing sector is also the key exporter in Malaysia, accounting for more than 65% of the merchandise exports (World Bank Group, 2024).

In order to embrace the concept of Industry 4.0, Malaysian manufacturing firms are forced to enhance their innovation and technological capabilities to keep up the sectoral competitiveness (Ministry of International Trade and Industry [MITI], 2018). Innovation capabilities are essential for modifying business operations by integrating disruptive technologies into existing production and management methods. Meanwhile, technological capabilities are needed to leverage information and communication technologies (ICT) to use the disruptive technologies effectively.

PROBLEM STATEMENT

Although innovation and technological capabilities are vital elements in implementing the idea of Industry 4.0, Malaysia's innovation capability is insufficient to support the technological transformation, as evident in Malaysia's declining international innovation ranking (World Intellectual Property Organization [WIPO], 2022; Jamrisko et al., 2021). At the same time, the level of ICT usage that is closely related to the digital technologies essential for Industry 4.0—such as cloud computing, data analytics, and online collaborative platforms—remained lower than expected, despite the manufacturing sector having the highest ICT usage among all economic sectors (DOSM, 2021).

On the other hand, concerns have been raised about measuring the full impact of digitalization. Past studies have predominantly focused on the direct effect of digitalization, but Xu and Cooper (2017) and Marsh et al. (2017) proposed that this approach may underestimate the full impact of digitalization and lead to misleading analysis. They argued that it is essential to also incorporate the indirect effect, which they coined as the "digital spillover effect", in the analysis. The "digital spillover" is defined as the creation of external knowledge or information flow via digital channel or platform (Xu & Cooper, 2017).

RESEARCH OBJECTIVE

This study aims to examine the relationships between digitalization, innovation and firm productivity in the Malaysian manufacturing sector using the Crepon-Duguet-Mairesse (CDM) model proposed by Crépon et al. (1998).

LITERATURE REVIEW

The theoretical foundation of this research lies in the Schumpeter's Theory of Innovation. Schumpeter (1934) perceived that innovation is the outcome of research and development and it is essential for a firm to increase its efficiency and productivity. In turn, it helps a firm to retain its competitive advantage in the market. Past studies have confirmed that innovation has a positive impact on enhancing firm efficiency (Dai & Sun, 2021; Khachoo et al., 2018; Mariev et al., 2022). Collectively, innovation can achieve the long-run industrial growth as well as the national economic growth.

Griliches (1979) explained that innovation is a double-edged knife to a firm. If the innovation is succeeded, the firm productivity can be enhanced. Otherwise, the opportunity cost for innovation is the high sunk cost which is irrecoverable. Thus, the decision to invest in innovation highly depends on the potential marginal return obtained by the firm. Empirical studies have proven the positive relationship between innovation input and innovation output, both in developed countries (Audretsch & Belitski, 2020; Giotopoulos et al., 2023) and developing countries (Khachoo et al., 2018; Younas & ul-Husnain, 2022; Zhu et al., 2021).

Organisation for Economic Cooperation and Development [OECD] (2018) refers innovation activities as the full spectrum of actions, starting from the early phase of innovation investment until the last stage of implementing the innovation output. Past researchers have found a significant relationship between firm characteristics and innovation activities, for example, the firm size, role of an exporter, market share etc (Giotopoulos et al., 2023; Mariev et al., 2022; Montégu et al., 2022). It is observed that the firm characteristics factors that driving a firm's involvement in the innovation activities can be categorised into two aspects, i.e. its access to innovation resources and its desire to maintain competitiveness in the market.

Firm size and industry group secure a firm's accessibility to the resources needed for innovation activities. Giotopoulos et al., (2023), Ma et al., (2022) and Ouyang et al. (2022) discovered that large firms have stronger financial foundations and better access to financing channels, making them have high innovation investment and greater resilience in managing innovation activities. Nonetheless, some researchers revealed that SMEs tend to invest in research and development because they want to leverage the innovation to get a higher market share even if they may face limited resources and have a higher chance of failing the innovation (Edeh & Acedo, 2021; Viglioni & Calegario, 2021).

Similar evidence is shown by the industry group. A firm located in high-technological industries or high-productive industries has a higher intention to carry out research and development due to the industry requirement where they need to apply the latest technology in their operation (Audretsch & Belitski, 2020; Mariev et al., 2022). Alike to Malaysian manufacturing firms which belong to high-technological industries, they abound with resources and talents that are required for innovation (Ong et al., 2019; Shafi'I & Ismail, 2015).

Based on the Theory of Innovation, a firm's market share is the main driver of innovation because it grants a firm market position and influential power (Schumpeter, 1934). Aghion et al. (2018) and Montégu et al. (2022) have proven the positive relationship between market share and innovation output. Aghion et al. (2018) even discovered that productive firms have a higher tendency to innovate as compared to non-productive firms as the former is dealing with tough competition. Likewise, Ong et al. (2019) and Shafi'I and Ismail (2015) reached the same conclusion when they studied the impact of market share on innovation among Malaysian manufacturing firms.

On the other hand, past studies proposed that an exporting firm is likely to undertake innovative tasks to sustain its international competitiveness, see Jitsutthiphakorn (2021), Fedyunina and Radosevic (2022) and Zabłocka and Tomaszewski (2024). In addition, Santana et al. (2011) commented that the positive impact of innovation output on the firm productivity is even stronger among exporters and importers. However, Ong et al.(2019) found that the exporting firms in developing countries have no motivation for innovation when rules and regulations imposed on the exported goods are strict.

The main difference between this study and the previous innovation literature is the inclusion of "digital spillover effects". Based on the categorisation of Xu and Cooper (2017), internal digital spillover refers to knowledge sharing within a firm through the use of internal digital channels, such as intranet, email, and online collaboration platforms. It represents the direct effect of a firm's digitalization. Meanwhile, external digital spillovers refer to external knowledge shared by the firm's competitors (horizontal spillover), suppliers (backward spillover) and retailers (forward spillover) via the digital platforms. They represent the indirect effects of a firm's digitalization.

OECD (2018) and Silva (2021) agreed with Marsh et al. (2017) and Xu and Cooper (2017), saying that the information flowing within and beyond the firm can be the catalyst for a firm to conduct innovation activities. Empirically, Khalifa (2023) and Zhu et al. (2021) confirmed the complementary effects between R&D and ICT investment in fostering innovation. From a broader perspective, the regional digital spillover effects facilitate knowledge diffusion and contribute to the formation of an innovation system in a country (Yang & Wang, 2022).

The backward and forward digital spillovers propel innovation activities because the information flow generated helps the firm understand its suppliers' requirements and customers' demands better, as found by Karhade and Dong (2021) and Mendoza (2024).

However, the horizontal digital spillover is found to be insignificant in affecting a firm's innovation activities because competitors tend to avoid disclosing too much information on publicly accessible online platforms, as they prefer to protect their business secrets to maintain their market position (Paunov & Rollo, 2016).

In terms of firm productivity, empirical evidence showed that the internal digital spillover improves the firm productivity by a firm (Khalifa, 2023;Lee et al., 2020; Yap et al.,2020). Nonetheless, the concept of the "Solow Paradox" suggests that the impact of digital technology on productivity can initially be minimal. Han et al. (2017) explained that the relationship between digital assets and productivity exhibits a dynamic U-shaped relationship, signalling that firms require time to realize the benefits of their digital investments. The recent study by Zhu et al (2021) also proved that even though the ICT investment positively affects innovation the positive effect was not captured in the firm productivity.

Similarly, the effect of external digital spillovers on the firm productivity is relatively mixed. Paunov and Rollo (2016) supported that the horizontal digital spillover helps boost the firm productivity, especially the SMEs, because it facilitates the manufacturing SMEs to absorb the knowledge that relates to the latest technology at a lower cost. Nonetheless, the significance of the backward and forward digital spillover depends on the "knowledge network" applied by the firm (Paunov & Rollo, 2016). The negative and insignificant relationships between external digital spillover effects and firm productivity are detected by Marsh et al. (2017) and Mendoza (2024).

METHODOLOGY

The Crepon-Duguet-Mairesse (CDM) model was founded by Crépon et al. (1998) to study the relationship between innovation and firm productivity using firm-level data, instead of sectoral and national data. In addition, the CDM model allows the incorporation of firm characteristics and a broader set of interested variables, making it a popular method in the field of innovation studies. In this study, the digital spillover effects are added to the CDM model as the model extension.

The CDM model is a recursive system consisting of three stages: innovation input, innovation output, and productivity. Three stages are treated with different estimation techniques due to the different nature of the data (Crépon et al., 1998).

Stage 1: Innovation Input

The innovation input stage is estimated using Heckman's two-step model (Crépon et al., 1998). It begins with the estimation of the selection equation via the Probit model, examining the intention of a firm in investing in R&D expenditure (r^*_{ij}). Then, the response equation is used to estimate the level of R&D expenditure (rd_{ij}) via the Least Square method.

Selection function:

$$r^*_{ij} = \alpha_1 + \alpha_2 dbig_{ij} + \alpha_3 dmed_{ij} + \alpha_4 dind_{ij} + \alpha_5 log(ex_{ij}) + \alpha_6 log(rms_{ij}) + \alpha_7 log(it_{ij}) + \alpha_8 log(soi_{ij}) + \alpha_9 log(sob_{ij}) + \alpha_{10} log(sof_{ij}) + \upsilon_{ij} \text{--(Eq1)}$$

Response function:

$$log(rd_{ij}) = \beta_1 + \beta_2 dind_{ij} + \beta_3 log(ex_{ij}) + \beta_4 log(rms_{ij}) + \beta_5 log(it_{ij}) + \beta_6 log(soi_{ij}) + \beta_7 log(sob_{ij}) + \beta_8 log(sof_{ij}) + \varepsilon_{ij} \text{--(Eq2)}$$

Both equations share the same variables of firm characteristics, including the industry group (ind_{ij}), export volume (ex_{ij}), and firm market share(rms_{ij}). Nevertheless, the firm size (big_{ij} and $dmed_{ij}$) is included only in the selection equation as the exclusion restriction for the identification purpose because the scale of R&D investment is implied by the firm size (Gujarati, 2021; Khachoo et al., 2018; Zhang & Islam, 2022). Meanwhile, the internal digital spillover is proxy by the digital expenditure(it_{ij}). The external digital spillovers are represented by horizontal spillover (soi_{ij}), backward spillover (sob_{ij}) and forward spillover (sof_{ij}).

The selection equation is essential for the researchers to determine whether to include those non-reporting R&D firms in the data estimation. Heckman (2013) explained that even though a firm does not formally report any R&D expenditure in the innovation survey, it does not mean that the firm does not have the intention to carry out R&D activities in the future or was not involved in some R&D activities in prior time. If the researchers excluded these firms from the sample, it would raise the issue of selection bias, which could produce inaccurate estimates and biased analysis.

It is essential to deal with the selectivity issue in the context of the Malaysian manufacturing sector because small and medium enterprises (SMEs) have accounted for more than 97% of the manufacturing sector but a majority of them are not involved in innovation activities due to the difficulties in recruiting high-performing talents and securing funding (EPU, 2021; MITI, 2018). Moreover, Shafi'i and Ismail (2015) also mentioned that not all Malaysian manufacturing firms, including large firms, which are involved in innovation activities have formally reported their involvement in R&D.

Stage 2: Innovation Output

The innovation output stage examines whether a firm successfully realizes an innovation output via the Probit Model. Following the practice of Crépon et al., (1998) and Khachoo et al. (2018), "patent" is used as the proxy of innovation output. To alleviate the problem of endogeneity, the dependent variable in Eq3 is the forecasted R&D expenditure from Eq2, as suggested by Khachoo et al. (2018) and Shafi'l and Ismail (2015).

Innovation output function:

$$p_{ij} = \chi_1 + \chi_2 1og(rd^*_{ij}) + \chi_3 dbig_{ij} + \chi_4 dmed_{ij} + \chi_5 dind_{ij} + \chi_6 log(ex_{ij}) + \chi_7 log(rms)_{ij} + \chi_8 \, log(lhs_{ij}) + \chi_9 log(it_{ij}) + \chi_{10} log(soi_{ij}) + \chi_{11} log(sob_{ij}) + \chi_{12} log(sof_{ij}) + \omega_{ij} \text{----------(Eq3)}$$

In Eq3, the same vector of firm characteristics used in the innovation input is applied. Moreover, the high-skilled labourers (lhs_{ij}) are included in Eq3 because it is believed that they are important in achieving innovation outcomes.

Stage 3: Firm Productivity

The final stage of the CDM model involves the estimation of firm productivity via the Ordinary Least Square (OLS) estimator. The production function is an augmented Schumpeterian endogenous growth model that is structured in the Cobb-Douglas general form, as demonstrated by Udeogu et al. (2021). The forecasted innovation output (dpt_{ij}*) is derived from the second stage, while the capital intensity of the firm (kw_{ij}) and the ratio of high-skilled labour ($lhsw_{ij}$) are the two main variables in the Cobb-Douglas production function. All independent variables in the production function are in per-labour form except the forecasted innovation output.

Production function:

$$logy_{ij} = \eta_1 + \eta_2 dpt_{ij}^* + \eta_3 log(kw_{ij}) + \eta_4 log(lhsw_{ij}) + \eta_5 log(itw_{ij}) + \eta_6 log(soiw_{ij}) + \eta_7 log(sobw_{ij}) + \eta_8 log(sofw_{ij}) + \omega_{it} \text{--(Eq4)}$$

Measurement of Digital Spillovers

The measurement of internal digital spillover is straightforward by using the ICT expenditure spent by a firm, adopting Xu and Coopeer's (2017) practice. Meanwhile, the measurement of external digital spillovers follows the procedures of Marsh et al. (2017). The horizontal spillover is calculated by dividing the total ICT expenditure by the total labour at the industry level. In contrast, the measurement of backward and forward digital spillover is relatively complex as it depends on the transaction intensity between industries. The spillover effect happens when there is an inter-industry intermediate buying and selling transaction carried out between industries *i* and *j*, otherwise, the weightage of and become zero.

Horizontal digital spillover effect: $SOI = \frac{\sum_{i \epsilon j} ICT_{ij}}{\sum_{i \epsilon j} L_{ij}}$

Backward digital spillover effect: $SOB = \sum_{j \neq i} \frac{\alpha_{ij}}{x_i} \, ICT_j$

Forward digital spillover effect: $SOF = \sum_{j \neq i} \frac{\beta_{ij}}{x_i} \, ICT_j$

Where represent the ICT expenditure spent in industry *j* meanwhile the is the total employment in industry *j*. The is the total amount of intermediate input that industry *i* bought from their suppliers (industry *j*), while is the total amount of intermediate output that industry *i* sold to their customers (industry *j*). The total amount of inter-industry transactions of industry *i* is represented by.

DATA SOURCE

The CDM model needs a large amount of firm-level data for estimation, but the availability of the firm-level data remains the main challenge in the study. This issue causes a period gap between the year of study and the sample period, see Audrestch and Belitski (2020), Khachoo et al. (2018), Shafi'I and Ismail (2015), Xu and Cooper (2017) and Zhu et al. (2021). The same difficulty arises in this study.

The data applied in this study is the unpublished firm-level data provided by the DOSM upon official request. There are a total of 14,723 firms in the sample size, accounting for 30% of microdata in Malaysia's manufacturing sector based on the 2016 Economic Census (the fourth economic census). Although the data collection of the 2023 Economic Census (the fifth economic census) was completed in 2023, the firm-level data is not available to the public.[1] As a result, the data extracted from the 2016 Economic Census is the best sample that can be applied to this study. In order to tally with the period of firm-level data, the industry-level data used in the study was extracted from the Annual Economic Statistics Manufacturing 2015 and the Report on Annual Survey of Manufacturing Industries 2015. Meanwhile, the 2015 Input-Output Tables are used for the calculation of digital spillovers.

FINDINGS

Table 1 shows the estimation results of both innovation input and innovation output functions. The z-statistics are reported for Eq1 and Eq3 because both equations are estimated using the Probit Model. Meanwhile, the t-statistic is reported for Eq2 as the Least Square Method is applied.

1 For more information on the Economic Census, the reader may refer to the website http://economiccensus.dosm.gov.my/ec2/index.php/en/info-banci-ekonomi/sejarah-banci

Table 1. Results of the Innovation Input and Innovation Output

	Innovation Input			Innovation Output
	Eq1 z-statistic	**Eq2** t-statistic		**Eq3** z-statistic
Firm characteristics				
$dbig_{ij}$	0.5562***	-		0.7774***
$dmed_{ij}$	0.2978***	-		0.1420
$dind_{ij}$	0.2869***	0.9084***		0.4384***
ex_{ij}	0.0499***	0.0867***		0.0171*
rms_{ij}	0.2001***	0.6304***		0.2819***
rd^*_{ij}	-	-		0.1578***
lhs_{ij}	-	-		0.0555
Digital spillover effects				
it_{ij}	0.08132***	0.1950***		0.1393***
soi_{ij}	0.3380***	0.8467**		0.122***
sob_{ij}	-0.0702	-0.1767		-0.3448***
sof_{ij}	-0.1295***	-0.2239**		-0.2771**

*The denotation of ***/**/* represents the 1%, 5% and 10% significance level respectively.*

The results show the firm size, industry type and firm's market share positively affect the innovation input and innovation output. These findings are consistent with Giotopoulos et al. (2023), Mariev et al. (2022), and Zabłocka and Tomaszewski (2024). The significance of the industry type and market share demonstrates the validity of Schumpeter's Theory of Innovation in the context of Malaysia's manufacturing sector. However, even if the medium-sized firm positively affect a firm's intention in R&D investment and the R&D intensity, the positive effect discontinues in realizing the patent issuance. Yang and Wang (2022) argued that the high prices of innovation resources induced by the competition might restrict the less advantaged firms from continuously participating in the innovation wave.

On the other hand, the results of digital spillovers are consistent across the innovation input and innovation output estimations. The internal digital spillover has a positive impact on innovation activities as expected because it drives knowledge sharing within firms which fosters brainstorming and new idea generation (Silva, 2021; Xu and Cooper, 2017). In addition, the result reveals that the horizontal digital spillover carries the highest influential power on innovation activities, implying a potential mimicking behaviour in Malaysia's manufacturing sector where firms tend to follow the competitors' innovation strategies.

Nevertheless, the forward spillover negatively influences the R&D investment and patent issuance, which is inconsistent with the conclusion reached by Karhade and Dong (2021) and Paunov and Rollo (2016). This result may indicate that when Malaysian manufacturing firms receive customer feedback quickly via digital platforms at almost zero cost, they can directly modify their products accordingly without the need for innovation (MOSTI & MASTIC, 2020). Moreover, manufacturing firms can bypass the trial-and-error process and reduce concerns over the significant costs of failed innovations.

In addition, the backward digital spillover is found to negatively affect the innovation output even though the negative impact is not significant on the innovation input. Mendoza (2024) and Marsh et al. (2017) explained that there might be a technology gap between the manufacturing firm and its suppliers, which causes the information flow from the upstream industries to be a barrier for the manufacturing firm. Thus, it discouraged the firm from carrying out innovation activities by applying the knowledge transferred by its suppliers via digital platforms.

For the production function, it is found to suffer from the heteroskedasticity issue, thus the OLS estimator is adjusted with the Huber-White covariance method and the result is presented in Table 2. The result reflects that the patent issuance, capital intensity and ratio of high-skilled labour are found to affect firm productivity positively, consistent with the findings of Dai and Sun (2021), Khachoo et al. (2018), and Mariev et al. (2022). It is an encouraging finding that the innovation output has the highest influential power in boosting the firm productivity.

Similarly, the horizontal and forward digital spillovers reveal positive associations with firm productivity, as supported by Khalifa (2023), Lee et al. (2020) and Yap et al.(2020). The horizontal spillover is found to be the most significant channel in enhancing firm productivity, proving that manufacturing firms gain valuable insights from analysing their competitors' production methods and business practices through digital platforms, which enable them to adjust their strategies effectively. The same conclusion can be drawn regarding the information flow from the retailers.

Table 2. Result of the Production Function Estimation

	Eq4 t-statistic
Firm characteristics	
dpt_{ij}*	0.3613***
kw_{ij}	0.3492***
$lhsw_{ij}$	0.0092***
Digital spillover effects	
itw_{ij}	-0.0191***
$soiw_{ij}$	0.2721***
$sobw_{ij}$	-0.4074***
$sofw_{ij}$	0.1372***

*The denotation of ***/**/* represents the 1%, 5% and 10% significance level respectively.*

In contrast, the internal and backward digital spillovers have negative influences on the firm productivity. The result indicates that the "Solow Paradox" was present among Malaysian manufacturing firms, suggesting the possibility that the relationship follows a U-shaped pattern (Han et al, 2017). Meanwhile, the negative backward digital spillover suggests that Malaysian manufacturing firms might rely more on offline knowledge networks, such as face-to-face meetings or physical visits, to obtain information that can be integrated into their business operations, as suggested by Paunov and Rollo (2016). Meanwhile, Mendoza (2024) explained that the knowledge shared by suppliers on digital platforms might be complex, causing manufacturing firms to take time to internalize this external knowledge for its use.

CONCLUSION

This study has validated the relationships between firm characteristics, digital spillovers, innovation and firm production via the CDM model. The results of the data analyses have confirmed the significance of both direct and indirect effects of digitalization on innovation activities and firm productivity. It highlights the importance of including digital spillover effects in the study of digitalization, as its exclusion may lead to misleading conclusions and ineffective policy recommendations.

Given the importance of digitalization in fostering innovation, the policymakers are recommended to support the firms to leverage their digital capabilities in boosting firm productivity. With higher digital readiness, manufacturing firms can better utilize the effects of digitalization, enabling them to respond more strategically and agilely to evolving market dynamics. On the other hand, the management team of the manufacturing firm should consider increasing their investment in digitalization to enhance operational efficiency and remain competitive in a rapidly changing market.

Similar to other CDM studies, this research is constrained by limitation in data availability. The sample size required for the CDM model is huge but the firm-level innovation and digital data available in Malaysia are mostly unpublished and they can only be obtained upon approval from the authority parties. Future researchers are recommended to re-run the CDM model when the latest firm-level data is available.

REFERENCES

Aghion, P., Bergeaud, A., Lequien, M., & Melitz, M. J. (2018). *The impact of exports on innovation: Theory and evidence* (p. 678). Cambridge, MA: National Bureau of Economic Research.

Audretsch, D. B., & Belitski, M. (2020). The role of R&D and knowledge spillovers in innovation and productivity. *European economic review*, *123*, 103391.

Crépon, B., Duguet, E., & Mairessec, J. (1998). Research, Innovation and Productivi [Ty: An Econometric Analysis at The Firm Level. *Economics of Innovation and new Technology*, *7*(2), 115-158.

Dai, X., & Sun, Z. (2021). Does firm innovation improve aggregate industry productivity? Evidence from Chinese manufacturing firms. *Structural Change and Economic Dynamics*, *56*, 1-9.

Department of Statistics Malaysia (DOSM). (2021). *Malaysia Digital Economy*. Retrieved April 20, 2022, from https://v2.dosm.gov.my/portal-main/release-content/malaysia-e-commerce-income-soared-17.1-per-cent-to-rm279.0-billion-in-the-third-quarter-2021.

Department of Statistics Malaysia (DOSM). (2023a). *Employment Statistics 2023*. Retrieved Jan 14, 2024, from https://newss.statistics.gov.my/newss-portalx/ep/epFreeDownloadContentSearch.seam?cid=343133.

Department of Statistics Malaysia (DOSM). (2023b). *Labour Productivity First Quarter 2023*. Retrieved August 18, 2023, from https://newss.statistics.gov.my/newss-portalx/ep/epDownloadContentSearch.seam?cid=1466.

Department of Statistics Malaysia (DOSM). (2024). *Economic Census History*. Retrieved Jan 18, 2024, from https http://economiccensus.dosm.gov.my/ec2/index.php/en/info-banci-ekonomi/sejarah-banci.

Economic Planning Unit (EPU). (2021). *National Fourth Industrial Revolution (4IR) Policy*. Putrajaya: EPU, Prime Minister's Department.

Economic Planning Unit (EPU). (2023). *Socio Economic Statistics-National Accounts*. Retrieved April 25 2023, from https://www.epu.gov.my/en/socio-economic-statistics/socio-economic/national-accounts.

Edeh, J. N., & Acedo, F. J. (2021). External supports, innovation efforts and productivity: Estimation of a CDM model for small firms in developing countries. *Technological Forecasting and Social Change*, *173*, 121189.

Fedyunina, A., & Radosevic, S. (2022). The relationship between R&D, innovation and productivity in emerging economies: CDM model and alternatives. *Economic Systems*, *46*(3), 100998.

Giotopoulos, I., Kritikos, A. S., & Tsakanikas, A. (2023). A lasting crisis affects R&D decisions of smaller firms: the Greek experience. *The Journal of Technology Transfer*, *48*(4), 1161-1175.

Griffith, R., Huergo, E., Mairesse, J., & Peters, B. (2006). Innovation and productivity across four European countries. *Oxford review of economic policy*, *22*(4), 483-498.

Griliches, Z. (1979). Issues in assessing the contribution of research and development to productivity growth. *Bell Journal of economics*, *10*(1), 92-116

Gujarati, D. N. (2021). *Essentials of econometrics*. Sage Publications.

Han, Z., Liu, M., & Rui M. (2017). Direct and indirect effects of informatization on productivity: Mediation role of labor's skill structure. Technology and Economy, *36*(07), 56–65.

Heckman, J. (2013). Sample selection bias as a specification error. *Applied Econometrics*, *31*(3), 129-137.

Jamrisko, M., Lu, W., & Tanzi.A., (2021, February 4). *South Korea leads world in innovation as US exits top ten*. Retrieved May 8, 2022, from https://themalaysianreserve.com/2021/02/04/south-korea-leads-world-in-innovation-as-us-exits-top-ten/.

Jitsutthiphakorn, U. (2021). Innovation, firm productivity, and export survival: firm-level evidence from ASEAN developing countries. *Journal of Economic Structures*, *10*(1), 1-17.

Karhade, P., & Dong, J. Q. (2021). Information technology investment and commercialized innovation -performance: Dynamic adjustment costs and curvilinear impacts. *MIS Quarterly*, *45*(3),1007-1024.

Khachoo, Q., Sharma, R., & Dhanora, M. (2018). Does proximity to the frontier facilitate FDI-spawned spillovers on innovation and productivity? *Journal of Economics and Business*, *97*, 39-49.

Khalifa, A.B. (2023). Impact of research and development (R&D) and information, and communication technology (ICT) on innovation and productivity evidence from Tunisian manufacturing firms. *Economics of Transition and Institutional Change*, *31*(2), 341-361.

Lee, J. W., & Song, E. (2020). Aging labor, ICT capital, and productivity in Japan and Korea. Journal of the Japanese and International Economies, 58, 101095.

Ma, C. A., Xiao, R., Chang, H. Y., & Song, G. R. (2022). Founder management and innovation: An empirical analysis based on the theory of planned behavior and fuzzy-set qualitative comparative analysis. Frontiers in Psychology, 13, 827448.

Mariev, O., Nagieva, K., Pushkarev, A., Davidson, N., & Sohag, K. (2022). Effects of R&D spending on productivity of the Russian firms: does technological intensity matter? *Empirical Economics*, 1-25.

Marsh, I. W., Rincon-Aznar, A., Vecchi, M., & Venturini, F. (2017). We see ICT spillovers everywhere but in the econometric evidence: a reassessment. *Industrial and Corporate Change*, *26*(6), 1067-1088.

Mendoza, A. R. (2024). Technological Innovation, Productivity, and Global Value Chains Participation of Philippine Manufacturers. *The Developing Economies*.

Ministry of Investment, Trade and Industry (MITI). (2018). *National Industry 4.0 Policy Framework*. Kuala Lumpur: MITI.

Montégu, J. P., Pertuze, J. A., & Calvo, C. (2022). The effects of importing activities on technological and non-technological innovation: evidence from Chilean firms. *International Journal of Emerging Markets*, *17*(7), 1659-1678.

Ministry of Science, Technology and Innovation (MOSTI), & Malaysian Science and Technology Information Centre (MASTIC). (2020). National Survey of Innovation 2018: Manufacturing and Services Sectors in Malaysia. Putrajaya: Federal Government Administrative Centre.

Ong, C. H., Tan, M. K., Lim. L. P., Tan. O. K. & Goh, C. F., (2019). Determinants of Innovative Performance in the Manufacturing Industry in Malaysia. *International Journal of Academic Research in Business & Social Sciences*, *9*(1), 380-387.

Organization for Economic Co-operation and Development, OECD (2018). *Oslo manual: Guidelines for collecting and interpreting innovation data*. Committee for Scientific and Technological Policy, OECD-OCDE, Paris.

Ouyang, X., Liu, Z., & Zhang, Y. (2022). Firm Size, Radical and Incremental Innovation: A Meta-Analysis Based on The Awareness-Motivation-Capability Perspective. *International Journal of Innovation Management*, *26*(06). https://doi-org.libezp2.utar.edu.my/10.1142/S1363919622500438.

Paunov, C., & Rollo, V. (2016). Has the internet fostered inclusive innovation in the developing world? *World Development*, *78*, 587-609.

Santana, S. K. S., Cavalcanti, S., & Bezerra, J. (2011). "*The role of innovation in industry productivity: a sectoral approach*." Foz do Iguacu: Anaisdo 39th National Meeting of Economics, ANPEC.

Schumpeter, J. (1934). *The Theory of Economic Development*. Oxford University Press, New York.

Shafi'I, M., & Ismail, N. W. (2015). Innovation and Productivity: Evidence from Firms Level Data on Malaysian Manufacturing Sector. *International Journal of Economics & Management*, *9*(1).

Silva, A. L. (2021). Innovation in development cooperation: emerging trajectories and implications for inclusive sustainable development in the 21st century. *Innovation and Development*, *11*(1), 151-171.

Skorupinska, A. A., & Torrent Sellens, J. (2014). *ICT, innovation and productivity: evidence from Eastern European manufacturing firms* (No. DWP14-003). IN3 Working Paper Series.

Udeogu, E., Amakom, U., & Roy-Mukherjee, S. (2021). Empirical Analysis of an Augmented Schumpeterian Endogenous Growth Model. *Journal of Economic Development*, *46*(1), 53-84.

Viglioni, M. T. D., & Calegario, C. L. L. (2021). How firm size moderates the knowledge and affects the innovation performance? Evidence from Brazilian manufacturing firms. *Revista Ibero-Americana de Estratégia, 20*, 15567.

World Bank Group. (2024). *World Development Indicators (Malaysia)*. Retrieved January 12, 2024, from https://databank.worldbank.org/source/world-development-indicators#

World Economic Forum (WEF). (2019). *Fourth Industrial Revolution*. Retrieved December 3, 2019, from https://www.weforum.org/focus/fourth-industrial-revolution.

World Intellectual Property Organization (WIPO). (2022). *Global Innovation Index 2022: What is the future of innovation-driven growth?* Geneva: Switzerland.

Xu, W., & Cooper, A. (2017). Digital Spillover: Measuring the True Impact of the Digital Economy. *A Report by Huawei and Oxford Economics, Oxford, United Kingdom, https://www. oxfordeconomics. com/recentreleases/digital-spillover*.

Yang, L., & Wang, S. (2022). Do fintech applications promote regional innovation efficiency? Empirical evidence from China. *Socio-Economic Planning Sciences*, 101258.

Yap, L. H., Ahmad, S. B., & Hoe, C. H. (2020). Organisational capability on ICT support and SMEs' performances in malaysia. *Utopia y Praxis Latinoamericana*, *25*(10), 271-282.

Younas, M. Z., & ul-Husnain, M. I. (2022). Role of market structure in firm-level innovation: an extended CDM model for a developing economy. *Decision*, *49*(1), 91-104.

Zabłocka-Abi Yaghi, A., & Tomaszewski, T. (2024). The interdependence of R&D, innovations, and productivity: case of Polish manufacturing companies. *Ekonomia i Prawo. Economics and Law*, *23*(1), 195-212.

Zhang, J., & Islam, M. S. (2022). The role of market power in driving innovation and productivity: a firm-level study of emerging ASEAN. *International Journal of Emerging Markets*, *17*(8), 1865-1888.

Zhu, F., Li, Q., Yang, S., & Balezentis, T. (2021). How ICT and R&D affect productivity? Firm level evidence for China. Economic Research-Ekonomska Istraživanja,1-19.