Economic Horizons, September - December 2023, Volume 25, Number 3, 197 - 211
UDC: 33 ISSN: 1450-863 X

Original scientific paper
UDC: 004:330(669.1)
doi:10.5937/ekonhor2302215A

DIGITAL TRANSFORMATION AND FIRM EFFICIENCY IN THE NIGERIAN MANUFACTURING SECTOR

Foluso Modupe Adeyinka

Nigerian Institute of Social and Economic Research, Ibadan, Nigeria

The effects of a digital technologies uptake on firm efficiency in the Nigerian manufacturing sector were examined. The combined application of data envelopment analysis and the Tobit regression methods were employed to analyze the cross-sectional survey data derived from a sample of manufacturing firms. The research results showed that the uptake of digital technologies was still skewed to the low-end appliances/devices, whereas the uptake of the high-end digital technologies required to forge the digital transformation of firms was still low. Manufacturing firms in Nigeria need to make a quick transition to high-end digital technologies in order for them to increase their efficiency and competitiveness in the global marketplace. Challenges to the uptake of digital technologies need to be addressed as well. The training/retraining of personnel need be scaled up so as to build the digital capacity of the sector, bolster efficiency and improve the productivity of operations. The importation of digital devices may be an option in the short run, but local production should be ramped up in the long run.

Keywords: digital transformation, firm efficiency, manufacturing sector, data envelopment analysis

JEL Classification: O14, O33, Q55

INTRODUCTION

Digital transformation is the process of taking up digital technologies in order to create new or modify the existing business processes, culture, and customer experiences in order to meet changing business and market requirements. It is the "reimagining" of business in the digital age, and transcends traditional roles like sales, marketing, and customer service (Xiao, 2022). Firms' business records are easily and quickly retrievable via the use of digital technologies, providing ample opportunities to engage productively with customers and suppliers in different sectors of the economy (Zapata, Berrah & Tabourot, 2020). The manufacturing sector is one of the key sectors that have greatly been influenced by digital transformation in order to improve labor productivity, increase competitive advantage and provide quality products and services to clients, particularly in developed economies (Molchanova, 2020). The emergence of the fourth industrial revolution has further aided digital transformation in the global economy (Zu, Gu & Lei, 2022). Evidence shows that digital transformation in

* *Correspondence to:* F. M. Adeyinka, Nigerian Institute of Social and Economic Research, Ibadan, Nigeria;
e-mail: folu_adeyinka@yahoo.com

the manufacturing sector is expected to stimulate innovation and competition, create new jobs and, by extension, efficiency gains (Albukhitan, 2020; Zapata *et al*, 2020).

Efficiency gains in the manufacturing sector in the Nigerian economy have remained disturbingly low. The sector is yet to fully transit from a low-skilled labor-intensive activity to a capital-intensive and high-skilled enterprise (Chete, Adeoti, Adeyinka & Ogundele, 2016; Afolabi & Ogunjimi, 2020). There is a considerable validation of the firm-level uptake of digital technologies, and its transformational effects associated with productivity gains, albeit in industrial and emerging economies (Domanovic, 2016; Cariolle & Carroll, 2020; Jakopin, 2020; Lukonga, 2020; Nucci, Puccioni & Ricchi, 2023). A general consensus from these studies is that the uptake of digital technologies as innovations by firms in the manufacturing sector will improve firm efficiency. The hypothesis that this paper brings to the fore is that the uptake of digital technologies may be a mechanism through which efficiency in the Nigerian manufacturing sector can be improved. However, it remains unclear if the configurations of manufacturing firms in Nigeria support this thesis as there is still a considerable gap in the knowledge and paucity of firm-level studies on the effect of digital transformation on the efficiency of Nigerian manufacturing firms, which thus warrants more evidence-based enquiries. In this regard, the following research questions were addressed:

1. What is the structure of the uptake of digital technologies by firms in the Nigerian manufacturing sector?
2. What are the levels of the efficiency of these firms in the pre- and post-uptake of digital technologies?
3. What are the effects of digital transformation on firm efficiency?

The growing importance of digital technologies in the global economy and its transformational effect on different sectors of the economy are also evidenced by an increasing number of empirical and theoretical studies (Mosiashvili & Pareliussen, 2020; Cusolito, Garcia-Marin & Maloney, 2021; Danquah & Owusu, 2021; Afolabi, 2023). The theoretical position is that digital technology is efficiency-enhancing although its effect on employment remains unsettled. The theories underlying the importance and effect of digital technologies include neoclassical growth theory, endogenous growth theory, neo-Schumpeterian theory and innovation diffusion theory. However, this study was guided by the neoclassical growth theory highlighting the productivity paradox, with an extension to the innovation theory so as to connect the diffusion and uptake of digital technologies (Brynjolfsson & McAfee, 2011; van Ark, 2016; Brynjolfsson, Rock & Syverson, 2017).

This paper is organized into five sections. The first section provides the background and introductory elements of the study context which this paper was culled from. The second section contains a review of the relevant and related studies, while the third section provides the methodology adopted for data collection and analysis. In the fourth section, the empirical results are presented and discussed. Finally, the fifth section concludes the paper with policy implications.

REVIEW OF RELATED STUDIES

There is the growing literature on the effect of digital transformation on firm performance, albeit with mixed evidence. For example, W. Zu, G. Gu and S. Lei (2022) investigated how digital transformation in the manufacturing sector affected the trade balance between China and the United States (US). The digital transformation of the US manufacturing sector had a positive and significant effect on the US-China trade, and it is noteworthy that extant manufacturing policies in China played a crucial mediating role. Evaluation of digital technologies in the manufacturing sector and the modalities for improving efficiency in China by Y. Xiao's (2022) revealed that it improved automation and intelligence and also helped firms achieve efficiency and innovation. In their seminal paper, S. Hussain, A. M. A. Hussein and M. H. A. Joma (2021) identified a lack

of digital skills, a global market exposure, capacity building and enduring philosophy as the barriers to digital transformation and readiness to take up digital technologies in the manufacturing sector of any economy. Similarly, S. M. Molchanova (2020) and Y. O. Abdallah, E. Shehab and A. Al-Ashaab (2021) posited that barriers to digital transformation could be classified into four management practices, namely, the skills gap, the adoption of new technologies, the change management process, innovation policies and procedures, and argued for the need to address these barriers.

In a qualitative study, K. Vogelsang, K. Liere-Netheler, S. Packmohr and U. Hoppe (2018) highlighted the factors that could foster digital transformation in the manufacturing sector. The factors include collaboration with clients, suppliers and other firms, cultural dynamics and a technology type. The study also outlined the three dimensions through which digital transformation could occur - environment, organization and technology. The study concluded that taking these three dimensions into consideration was a sure path to engendering digital transformation. In a later study, K. Vogelsang, S. Packmohr and U. Hoppe (2019) showed that the bottlenecks to the achievement of digital transformation in the manufacturing sector could be leveraged to develop research agendas. G. Gaffley and T. G. Pelser (2021) demystified how leaders' transformative skills powered digital transformation in South Africa. A total of 2064 manufacturing firms were included in a survey using the clustered sampling technique. The findings revealed that digital transformation in the manufacturing sector was low, but also that it could be fostered if leaders in the sector deployed their innovative skills. S. Albukhitan (2020) argued that digital transformation transcended the adoption of new technologies, but also encompassed being proactive in the development of technological innovation. Thus, manufacturing firms would need to plan ahead and actively engage in generating new innovation to foster digital transformation. M. L. Zapata, L. Berrah and L. Tabourot (2020) proposed digital models as critical in helping manufacturing firms navigate through their digital transformation journey.

UNIDO (2019) as well as the OECD (2021) reported that the uptake of advanced digital technologies was positively associated with firm productivity. Both studies identified the age of the firm, investment in research and development (R&D), and machinery, human capital, the global value chain participation as intervening variables. The countries and firms actively engaged in advanced digital production technologies grew manufacturing value added faster than the rest that were not (UNIDO, 2019). The rapid growth in manufacturing value added was explained in terms of the dynamic nature of employment creation, higher productivity gains, or both. The UNIDO report maintained that the adoption of advanced digital manufacturing production was buoyed by the knowledge-intensive services driven by information technology and the digital solutions that sparked smart production. The interaction with knowledge-intensive services potentially expands the multiplier effects of manufacturing on jobs creation, poverty reduction and, by extension, productivity. J. Zhang, W. Zhao, B. Cheng, A. Li, Y. Wang, N. Yang and Y. Tian, (2022) opined that one of the productivity effects of digital technologies was that demand for more products and services expanded, thereby increasing demand for labor. Thus, the goods and services whose production is increasingly automated become cheaper and improve in their quality. Digital technologies allow enterprises to rationalize costs, reorganize supply chains and market products and services globally. Expansion in trade at reduced costs would have positive spillover effects on the economy through competition, productivity, and innovation (UNCTAD, 2017).

R. Evangelista, P. Guerrieri and V. Meliciani (2014) investigated the economic impact of digital technologies on labor productivity, economic growth, and employment in 27 EU countries using the generalized least square (GLS) method between 2004 and 2008. The results of the study revealed that digital technologies were the major drivers of labor productivity, economic growth, and employment growth. The authors revealed that inclusive policies may effectively contribute to bridge digital divide in the EU countries. P. Gal, G. Nicoletti, T. Renault, S. Sorbe and C. Timiliotis (2019) applied ordinary least

square (OLS) regression analysis on the industry-level data about the digital technology uptake and the cross-country firm level data about the productivity of the 20 OECD countries. The results demonstrated the fact that the digital technology uptake in an industry had positive impacts on productivity at the firm level, particularly so in routine-intensive and manufacturing activities. They concluded that productivity gains were often more significant among highly productive firms, and less significant in the presence of skill shortages. This relationship is explained by the complementarities between digital technologies and other capital forms including skills, intangibles, and organization. Building on and extending the work of P. Gal *et al* (2019), N. Mosiashvili and J. Pareliussen (2020) revealed robust connections between the adoption of digital technologies, the use of digital skills and the firm-level productivity. Additionally, the results obtained from the sectoral split analysis indicated higher firm-level productivity effects because of the adoption of advanced digital technologies in the services sector than in the manufacturing sector.

Similarly, M. Danquah and S. Owusu (2021) found that digital technology had more impact on the labor productivity of adopters than non-adopters. The study also established higher benefits from the adoption of digital technologies for larger enterprises in the upper echelon of the informal sector in Nigeria. In a similar study, Cusolito *et al* (2021) examined the impact of digital technology adoption, such as the website and the e-mail, coupled with other firm-level variables such as managerial experience and exporting status, on the revenue-based total factor productivity of firms in 82 developing countries from 2003 to 2018. The results showed that the adoption of digital technology had positive effects on the productivity of manufacturing firms in developing countries, although the magnitude of the effects varied across firms depending on the type of the adopted digital technology.

DATA AND METHODOLOGY

Research design

The survey approach was used to generate primary data from manufacturing firms in Nigeria. The study covered the six geo-political zones of Nigeria and the Federal Capital Territory (FCT), with a purposive selection of one state in each region, and two states from the southwestern region - Abuja (FCT), Anambra (southeastern), Bauchi (northeastern), Kano (northwestern), Plateau (north-central), Rivers (south-south), Lagos (southwestern) and Ogun (south-western). The choice of the states from each region was based on the relative level of the economic and business activities in the state and, by extension, the likelihood that the firms in the state would adopt digital technologies. Two states were selected in the southwestern region due to the heavy concentration of economic and business activities in the Lagos-Ogun axis, which is broadly regarded as the commercial hub of the country. A sample of the manufacturing firms were randomly selected from the national frame of the firms categorized by the states obtained from the National Bureau of Statistics (NBS). The inclusion criteria for the firms in this study was on the basis that a firm must have at least five employees, which effectively excludes the microenterprises or informal sector enterprises from the sample. The sample consisted of the formally organized small, medium-sized and big firms in Nigeria in line with the SMEDAN (2010) approved classification.

Research instrument, data sources and description

In each of the eight selected locations, 25 copies of a semi-structured questionnaire were administered, totaling 200 copies. A total of 165 copies were retrieved, representing an 83 percent retrieval rate, and they were found usable at the end of the fieldwork in February 2022. The questionnaire captured pieces of information on the firm characteristics and the profile of the digital technologies uptake in order to enable the assessment of the effects of digital

transformation on the efficiency of the manufacturing firms. Precisely, the data were collected on the estimated sales value of the firms' pre- and post-adoption of digital technologies and they were used as a proxy for the efficiency of each firm. The estimated value of the fixed assets of each firm's pre- and post-adoption of digital technologies was used as a proxy for the capital input of each firm, while the number of the employees' pre- and post-adoption of digital technologies was used to mirror the labor inputs. The respondents filling out the questionnaire included the human resource managers, the information technology managers, the production managers and the accountants of those firms.

Analytical procedures and techniques

The study employed the data envelopment analysis (DEA) two-stage approach so as to determine the efficiency scores of the manufacturing firms. The DEA is a nonparametric approach based on linear programming techniques, through which an efficient frontier is derived. The best-performing firms in the sample were used to generate the efficiency frontier. The efficiency of the firms found at the frontier were considered to operate at full potential by either producing the maximum level of the output for the inputs they use or operating with the least amount of the input in order to obtain the given level of the output. The DEA approach provides the index numbers that tell how far each firm is from the efficiency frontier. The indices range from zero (the zero output and the non-zero input) to one (the highest level of efficiency).

In mathematical terms, the basic DEA model that illustrates the relative efficiency score of the decision-making unit (DMU) is as follows:

$$\text{Maximize: } G_0 : \frac{\sum_{j=1}^{s} B_j T_{jo}}{\sum_{i=1}^{r} P_i Q_{io}} \tag{1}$$

$$\text{Subject to: } \frac{\sum_{j=1}^{s} B_j T_{jm}}{\sum_{i=1}^{r} P_j Q_{im}} \leq 1 \quad m = 1, 2, \ldots, n \tag{2}$$

$$B_j \geq 0; j = 1, 2, \ldots, S$$
$$P_i \geq 0; i = 1, 2, \ldots r \tag{3}$$

where the used symbols have the following meanings: T_{jo} is the output j of the DMU o; Q_{io} is the input i of the DMU o; B_j represents the weight for the output j; P_i denotes the weight for the input j; n is the number of the DMUs; s is the number of the inputs, and r is the number of the outputs.

From the above expressions, the DEA computed the unknown weighted parameters B_j and P_i in order to obtain a relative efficiency measure for each DMU. This then allows the arrangement of the optimization contingent on the efficiency of each DMU to convert the inputs into the outputs in relation to the efficiency of all the other DMUs. The weights for each DMU are separately estimated so that the efficiency level can be the maximum attainable. The DEA is mostly carried out in two ways:

- the input-oriented approach (the given level of the outputs is achieved with the minimum amount of the inputs) and
- the output-oriented approach (i.e. the output is maximized for the given level of the input).

In this study, the input and the output variables reflected the use of digital technology in maximizing the efficiency of the manufacturing firms. The input variables considered in the efficiency analysis include the estimated value of the fixed assets, while the output variable used is the estimated sales value of the sampled firms.

The digital technology (DT) uptake is dichotomous in nature (measured by 0 and 1), and depends on whether each sampled enterprise has adopted digital technologies or not. After having computed the efficiency score, the analysis further determined the

influence of digital transformation on the efficiency of the manufacturing firms in Nigeria, which was done with the aid of the regression analysis using the Tobit estimation method. The rationale for this technique is due to the nature of the dependent variable ranging between 0 and 1. The Tobit model is an econometric regression model mostly used in the case of censored data (Tobin, 1958). The framework of the Tobit model requires that the observations of the efficiency score be clustered at a threshold value of zero. This is characterized as left-censored in the standard Tobit model literature, whereas the inefficient score can be kept as continuous data to represent the magnitude of inefficiency.

The Tobit model is expressed as follows:

$$y^* = X'\beta+\varepsilon, \text{ with } \varepsilon|X \sim N(0:\sigma^2), \text{ with } y = y^* \text{ if } y^* = 0, \text{ and } y = 0 \text{ if otherwise} \quad (4)$$

where y, y^*, X, β and ε are the observed variable of interest, the latent variable, the vector of the explanatory variables, the vector of the parameters, and the error term (with the zero mean and the constant variance σ^2), respectively.

According to equation (4), the expected effect of X on y^* is monotonic; the residuals follow a normal distribution and the dependent variable is left-censored.

In the context of this study, y^* is the dependent variable (the efficiency score generated from the DEA).

The Tobit regression model to be used to examine the effect of digital transformation on the efficiency of the firms in Nigeria is specified as follows:

$$EFF_i = \beta_0 + \beta_1 LCAPLAB_i + \beta_2 FAG_i + \beta_3 OWN_i + \beta_4 DTI_i + \beta_5 RIRC_i + \varepsilon_i \quad (5)$$

The definitions of the variables are accounted for in Table 1.

RESULTS AND DISCUSSION

Characteristics of the firms

The description of the features of the sampled manufacturing firms is presented in Table 2. According

Table 1 The definitions of variables and measurement

Variable name	Definition	Measurement	Expected sign
EFF	Efficiency	Efficiency score generated from DEA	
LCAPLAB	The ratio of capital to the labor used in the production of the firm	The total amount incurred on the fixed assets divided by the number of the employees per firm	+
FAG	The firm's age	The year of the establishment of the firm	+
OWN	The ownership structure of the firm	Sole proprietorship = 1 Partnership = 2 Cooperative society = 3 Shareholding company with shares traded in the stock market = 4 Shareholding company with non-traded shares or shares traded privately = 5	+
DTI	The adoption of digital technology	Construct an index to aggregate the various types of the digital technologies adopted by the sampled firms	+
RIRC	Registration with an internationally recognized certification	Yes/ No	+

Source: Author

to the sectoral classification, the survey returns show that a large proportion of the firms (28.5%) are in the food, beverage and tobacco subsectors, only to be followed by the basic metal, iron and steel subsector (20%), and the least represented is thepulp, paper and paper products subsector (1.2%). The modal age range of the firms is from 1 to 10 years, the youngest firms accounting for 40.6% of the sample, whereas only 6.1% of the employees are over 40 years of age. The majority of the firms (75.8%) are not older than 20 years. This indicates that most sampled firms are young, with the likely implications for their adoption and use of digital technologies and its consequential lag effect on productivity and employment. The firm size in this study is proxied by the number of the employees based on the SMEDAN (2010) classification of firms as small, medium-sized, and large. The results show that 85.4% of the sampled firms are small, whereas about 13.4% and 1.2% are medium-sized and large firms, respectively. The largest number of the sampled firms (84.8%) are owned by sole proprietors, whereas 12.1% are partnership businesses. The high proportion of sole owners is not surprising as most firms are small enterprises. The ownership structure of the firm is the likely determinant of the level of the adoption of digital technologies.

Table 2 The characteristics of the firms

Sectoral classification of firms	Frequency	Percent
Cement	11	6.7
Food, Beverages, and Tobacco	43	28.5
Textile, Apparel and Footwear	11	6.7
Wood and Wood Products	14	8.5
Pulp, Paper and Paper Products	1	1.2
Chemical and Pharmaceutical Products	16	10.9
Non-Metallic Products	18	12.1
Electrical and Electronics	4	2.4
Basic metal, Iron and Steel	33	20
Motor vehicles & assembly	5	3
The age of the firms		
1-10 years of age	67	40.6
11-20 years of age	58	35.2
21-30 years of age	18	10.9
31-40 years of age	12	7.3
Above 40 years of age	10	6.1
The firm size / The number of employees		
Small	140	85.4
Medium-sized	22	13.4
Large	3	1.2
Ownership		
Sole Proprietorship	140	84.8
Partnership	20	12.1
Cooperative Society	5	3.0

Source: Author

Types of digital technologies

The types of the digital technologies adopted by the sampled firms are given in Table 3. The results reveal that, to a certain extent, the four strands of digital technology within the SMAC classification, namely social media, mobile, analytics and cloud computing, are used by the sampled firms. More than half of the firms adopted social media applications such as Facebook (58.7%), e-mail marketing (63.6%) and WhatsApp (56.4%), which require no sophistication to operate. The uptake of these broad ranges of access technologies support e-commerce, e-marketing and online banking activities, bolstered by low search and transportation costs (Atiyas & Dutz, 2021). There are both upstream and downstream dimensions of these transactions and interactions related to products and services. For instance, the Internet is used to locate suppliers or market and sell goods and services to customers, whereas mobile money platforms (which do not necessarily require an Internet-enabled smartphone) and online banking are used to pay vendors or receive payments from clients (Atiyas & Dutz, 2021).

Digital technologies in the second strand of the SMAC framework - mobile devices - are also prominently used by the firms, especially laptops (55.8%) and smart phones (62.4%). It is instructive to note that most other digital technologies are typically operated on mobile devices, indicating their indispensability in the digital space. The uptake of the third component of the SMAC framework - analytics - is still nascent as

only a few firms (3.6%) have integrated this technology in their operations. The low-level uptake of analytics, which is a sophisticated digital technology, shows that for the largest part firms included in this survey are yet to acquire high-end digital technologies and the required expertise to deploy them for their operations. The scenario is not dissimilar for the fourth strand, comprising also high digital technologies such as cloud computing, which has only been adopted by 3.0% of the firms. Robot/cobot, 3D printing, artificial intelligence and block chain technologies are grossly underutilized given the fact that less than 10% of the total sampled firms employ these technologies. In sum, the pattern of the uptake of digital technologies by the manufacturing firm in Nigeria is still skewed to low-end digital technologies (particularly social media and mobile phones), the uptake of high-end digital technologies (analytics and cloud computing) still being at a low ebb.

Table 3 The types of the digital technologies adopted by the firms

SMAC	Digital Technologies	Frequency	%
Social Media	Facebook	97	58.7
	Twitter	68	41.2
	E-mail Marketing	104	63.6
	WhatsApp	93	56.4
	Telegram	32	19.3
	Instagram	41	24.8
	Snapchat	42	25.5
Mobile	Smart Phones	103	62.4
	Laptop	92	55.8
	iPad	26	15.8
	Tablet	23	13.9
	CCTV	35	21.8
Analytics	Big Data Analytics	6	3.6
Cloud Computing	Robot/Cabot	2	1.2
	Internet of Things (IoT)	28	16.9
	Cloud Computing	5	3.0
	Machine Learning	18	10.9
	3D Printing	8	4.8
	Artificial Intelligence	2	1.2
	Blockchain technology	2	1.2

Source: Author

Expenditure on digital technologies

Table 4 shows the expenditures on digital technologies and their share of the total expenditure of the firm. The largest number of the sampled firms spent less than ₦500,000 (approximately 600 euros) on digital technologies between 2017 and 2021. Specifically, the percentage of the firms that procured digital technologies paying for them less than ₦500,000 trended downward over the period, whereas the percentage of the firms that spent between ₦1 million and ₦5 million on digital technologies ranges between 16% and 20.7%. Meanwhile, the proportion of the firms that spent more than ₦5 million on digital technologies annually is less than 10%. Between 2017 and 2021, the share of the digital technology expenditure in the total spending peaked at 20% as reported by 48.7% to 51.8% of the sampled firms. The percentage of the firms that spent between 21% and 80% on digital technologies was less than 10%. About 16% of the firms spent between 81% and 100% of their total expenditure on digital technologies in 2017, but the number of the firms in this category declined to 13% by 2021. The generally low expenditure on digital technologies could be attributed to the large number of sole proprietorship businesses in the sample. The characteristic of the sole proprietorship businesses is the low capital base to expansively deploy digital technologies for the firms' operations. Overall, this indicates that expenditure on digital technologies is relatively low among the sampled firms.

Expenditure for training/skills development on digital technologies

The expenditure for training/skills development on digital technologies and its share in the firms' total expenditure are accounted for in Table 5. The table shows that more than 53% of the sampled firms spent

Table 4 Expenditure on digital technologies

Expenditure on digital technologies (expressed in ₦' Million)	2017	2018	2019	2020	2021
< 0.5	-	41.2	39.2	38.7	34.7
0.5 - 0.9	7.8	10.6	9.8	6.2	10.1
1 - 5	17.9	16	19.3	18.5	20.7
6 - 10	5.6	7.3	7.6	2.5	7.6
> 10	3.9	4.2	3.4	2	3.4
The share of the total spending on digital technologies (%)	2017	2018	2019	2020	2021
0-20	51.8	50.7	50.4	48.5	48.7
21-40	3.9	7.3	5.6	2.8	6.2
41-60	5	2.5	3.9	3.6	4.5
61-80	2.8	2.8	4.5	3.6	2.2
81-100	16	14.3	14	8.1	13.4

Source: Author

less than ₦500,000 on the digital technology training or skills development of their workers between 2017 and 2021, whereas no more than 16.2% of the firms spent between ₦1 million and ₦5 million. Moreover, less than 7% of the firms spent between ₦500,000 and ₦1 million, whereas less than 6% of the firms spent more than ₦5 million on digital training and skills development between 2017 and 2021. This indicates the fact that digital training and skill empowerment were all but prioritized by the biggest number of the sampled firms. Table 5 further shows the share of the cost of digital training and skills development in the total expenditure shows that, between 2017 and 2021, an average of about 56.9% of the sampled firms spent up to 20% on the digital training and skills development of their workforce. The percentage of the firms that spent between 81% to 100% ranged between 11.2% and 18.2%. Less than 5% of the sampled firms spent between 21% and 80% on the training and development of digital skills of their workforce. This indicates that, while some firms prioritize the training of their staff, the others spent a meagre percentage of their expenditure on digital training and skills development. In sum, spending on digital training and skills development is still at a low ebb among the sampled firms.

Table 5 Expenditure for training/skills development on digital technologies

The cost of training /skills development on digital technologies (₦' Million)	2017	2018	2019	2020	2021
< 0.5	56.3	54.9	53.8	56	54.1
0.5 - 0.9	4.2	5.9	5.6	4.8	6.2
1 - 5	14.3	15.1	15.4	12.3	16.2
6 - 10	3.4	4.2	5.6	1.7	5.6
> 10	0.6	0.6	0.6	0.3	0.8
The proportion of the total spending on training/skills development on digital technologies (%)	2017	2018	2019	2020	2021
0-20	56	58.3	57.4	57.4	55.7
21-40	3.4	3.4	2.8	2.8	4.2
41-60	1.4	1.1	2	1.4	3.6
61-80	1.4	1.1	1.4	0.6	0.8
81-100	15.7	16.2	16.2	11.2	18.2

Source: Author

Data Envelopment Analysis (DEA)

Table 6 shows the efficiency scores of the Nigerian manufacturing firms sampled in this study. The results show that the majority of the firms lie below the frontier both before and after the adoption of digital technologies. Prior to the adoption, 163 (98.8 %) of the sampled firms had had the efficiency scores ranging from 0 to 0.49, whereas only three (3) of these firms accounting for 1.82% of the sample are at the frontier with the efficiency scores at 1. However, none of the sampled manufacturing firms had the efficiency scores between 0.5 and 0.99, which signifies

that an overwhelming majority of the Nigerian manufacturing firms (98.8%) were inefficient prior to the adoption of digital technologies. Comparing the efficiency dynamics pre- versus post-uptake of digital technologies in the manufacturing sector, the results show a mild improvement as the total number of the efficient manufacturing firms slightly increased to 3% relative to 1.82% prior to the uptake of digital technologies. Post-uptake, 96.4% of the sampled firms had the efficiency scores ranging between 0 and 0.49, whereas 0.6% of the firms had the efficiency scores ranging between 0.5 and 0.99. Interestingly, the number of the manufacturing firms operating at full capacity (efficiency) after the digital technology uptake increased to five, accounting for 3% of the sampled manufacturing firms. Evidently, the uptake of digital technologies had slightly improved the efficiency of more manufacturing firms relative to the pre-uptake scenario.

The overall low efficiency gains from the uptake of digital technologies imitate the predominant types adopted, which are low-end digital tools, namely mobile/smartphones, computer, the website and social media (mainly Twitter, Facebook, and WhatsApp, among others). It has been established in the literature that efficiency gains are mostly associated with sophisticated digital technology and the other high-end digital technologies that have enormous cost-reducing properties (Borowiecki, Pareliussen, Glocker, Kim, Polder & Rud, 2021). It has also been argued that digital transformation requires integration with other technologies within each firm, along with corresponding investments in skills, data and the business model adjustments as part of the firm's intangible assets (Mosiashvili & Pareliussen, 2020).

Table 6 The distribution of the firms by the efficiency score

Efficiency score	Pre-DT adoption (%)	Post-DT adoption (%)
1.0	3 (1.82%)	5 (3.0%)
0.5 - 0.99	0 (0%)	1 (0.6%)
0.0 - 0.49	163 (98.8%)	160 (96.4%)

Source: Author

The digital transformation effect on the efficiency of the Nigerian manufacturing sector

The estimations presented in Table 7 show that the Wald test for determining whether the correlation between the residuals from the main equation (predicting the firm age) and the residuals from the auxiliary equation (predicting the efficiency score) is 0. The existence of the endogeneity issue was confirmed in the model, necessitating the use of the instrumental variable Tobit (IV Tobit) model. The empirical analysis exploring the effect of digital technologies and the efficiency of Nigerian manufacturing firms for the pre- and post- uptake of digital technologies are presented in Table 7. The models 1 and 2 show the estimates of the Tobit model with the continuous endogenous covariates (i.e. the Tobit model with the endogenous regressors). The estimates of the Tobit regression model are presented in the models 3 and 4. In line with the standard literature, this study only discusses the statistically significant variables in the model of focus. Considering the IV Tobit regression model, the estimates for the pre-digital technologies uptake (the model 1 of the table 3) show that the firm age, firm ownership and recognized certification significantly determine the efficiency of the Nigerian manufacturing firms. The estimates in the model 2 reveal that the firm age and digital technology adoption, firm ownership and recognized certification significantly promote the efficiency of the Nigerian manufacturing firms. Some of these results do not conform with their expected signs, except for recognized certification. However, the ratio of capital to labor used in production is not statistically significant under the two models. Checking the robustness of the analysis, the Tobit regression model was also used, and the results show that, prior to the digital technologies uptake, the efficiency of the Nigerian manufacturing firms had only been determined by the firm age. With digital technologies, the estimated results reveal that the efficiency of the Nigerian manufacturing firms is mainly determined by the firm age and digital technology adoption, whereas the ratio of capital to labor used in production, the firm ownership and recognized certification are not statistically significant.

Table 7 The digital transformation effect on the efficiency of the Nigerian manufacturing sector

Independent variables	The Tobit model with endogenous regressors (IV Tobit)		The Tobit model	
	Model 1 Pre-DT adoption model	Model 2 Post-DT adoption model	Model 3 Pre-DT adoption model	Model 4 Post-DT adoption model
LCAPLAB	-0.023 (0.016)	-0.013 (0.014)	-0.001 (0.005)	0.001 (0.005)
FAG	-0.473*** (0.170)	-0.459*** 0.152	-0.025* (0.013)	-0.029** (0.013)
OWN	-0.201** (0.092)	-0.194** (0.083)	0.019 (.015)	0.017 (0.015)
DTI	-	-0.036** (0.016)	-	-0.009* (0.005)
RIRC	0.226* (0.122)	0.226** (0.114)	0.027 (0.034)	0.031 (0.033)
Constant	2.113*** (0.796)	2.111*** (0.731)	0.108 (0.099)	0.142 (0.100)
Observations	165	165	165	165
No of left censored obs.	1	1	0	0
Pseudo R^2	-	-	0.082	0.113
Prob > X^2			0.0533	0.0253
Log likelihood	-127.4536	-122.02484	61.114458	62.848593
Wald test of exogeneity (corr = 0): chi2(1)	31.08 (0.0000)	34.92 (0.0000)	-	-

Note: *The standard errors are in parentheses.* ***, ** and * imply significance at 1%, 5% and 10%.

Source: Author

Discussion of the findings

Digital technologies have a significant negative effect on the efficiency of the Nigerian manufacturing firms after their adoption, as is shown in the models 2 and 4 of Table 7. The result shows that a unit increase in the use of digital technologies will retard the efficiency of the Nigerian manufacturing firms by 0.01 and 0.04 points. This result does not follow *a priori* expectation and is therefore inconsistent with theory. This result is explained by the fact that the majority of the sampled manufacturing firms have only adopted low-end digital tools, namely mobile/smartphones, the computer, the website and social media (mainly Telegram, Twitter, Facebook, and WhatsApp, among others). These low-end digital tools will hardly produce high efficiency gains for the manufacturing sector. Nevertheless, the results of this study corroborate the findings of M. Borowiecki *et al* (2021), who noticed that efficiency gains were generally associated with the uptake of the sophisticated nature of digital technology, such as big data, cloud computing and the other related high-end digital technologies that had enormous cost-reducing properties.

The negative but significant effect of the firm age on the efficiency of the Nigerian manufacturing firms suggests that the older firms accustomed to the crude methods or analogue modes of operation might have a difficulty in adopting and using digital technologies due to the cost considerations and adaptability. The results also indicate that the efficiency effects of adopting and using digital technologies might not show up for younger firms in the short run but could only be evident after a lag period. Consequently,

the efficiency of these firms may be impaired in the short run. The significant but negative effects of the firm ownership on the firms' efficiency can be traced to the preponderance of the sole ownership structure of the sampled firms, which by implication undermines the efficiency of the firms. With respect to registration with an internationally recognized certification, the estimates for pre- and post-digital technology adoption show a significant positive effect on the efficiency of the Nigerian manufacturing firms, which implies that the importance of possessing an internationally recognized certification, particularly so the ISO 9001 certification, could improve or promote efficiency, and the assurance of quality for international markets. A related finding was reported by N. Zahoor and O. Al-Tabbaa (2021), who claimed that firms with internationally recognized certification had the tendency to embrace digital technologies and thus promote the efficiency of their operations.

CONCLUSION

The digital technologies uptake pattern adopted by Nigerian firms is still skewed to low-end digital technologies such as WhatsApp, Twitter, Smart Phones, and Laptops. The high-end digital technologies (Data Analytics, 3D Printing, Cloud Computing, IoTs, Blockchain) uptake, those being required to forge the digital transformation of firms, is still low. The overwhelming majority of the Nigerian manufacturing firms confirmed to be inefficient prior to the adoption of digital technologies, nevertheless the uptake of digital technologies slightly improved the efficiency of the manufacturing firms relative to the pre-uptake scenario. A fact has been established in the literature that efficiency gains are mostly associated with digital technologies, especially the high-end ones that have enormous cost-reducing properties (Borowiecki *et al*, 2021). Therefore, digital transformation can be considered as an emerging phenomenon in the Nigerian manufacturing sector. The transformation and efficiency effects of the digital technologies uptake might not appear in the short run, and it only becomes evident after a lag period. Consequently, the efficiency of these firms may be impaired in the short run. To engender a positive transformational effect of digital technologies on the firms' efficiency, it is imperative that the manufacturing firms should make a quick transition to the uptake of high-end digital technologies. There is, however, a strong requirement for making substantial investments in skills, data and the business model adjustments as part of the firm's intangible assets (Mosiashvili & Pareliussen, 2020).

Some of the limitations of this paper, as well as the implications of the findings of the study, are as follows:

- the data collected are a one-time measurement of both the apparent cause and the effect, making long-term trends difficult to prove;
- the number of the questionnaire responses cannot be compared to using the database that was unavailable at the time of inquiry; there were also a few questions in the research instrument (the questionnaire) that went unanswered;
- despite these limitations, the findings of the study are still valid and valuable.

This paper has focused on the digital transformation prior to and after the digital uptake and firm efficiency in the manufacturing sector. A further research attempt on this issue of enquiry may wish to focus on the other two major sectors of the economy, namely agriculture and services, to come up with the comparative analysis of the subject matter across the sectors. Also, subject to the availability of the secondary data, a comparative study across African countries across sectors could also be embarked upon.

REFERENCES

Abdallah, Y. O., Shehab, E., & Al-Ashaab, A. (2021). Understanding digital transformation in the manufacturing industry: A systematic literature review and future trends. *Product, Management & Development*, *19*(1), e20200021. doi:10.4322/pmd.2021.001

Afolabi, J. A. (2023) Employment effects of technological innovation: Evidence from Nigeria's economic sectors. *Economic Horizons*, *25*(1), 3-17. doi:10.5937/ekonhor2301003A

Afolabi, J., & Ogunjimi, J. A. (2020). Industrialization: A roadmap to inclusive growth in Nigeria. *Economics and Policy Review Journal*, *18*(1), 20-28.

Albukhitan, S. (2020). Developing digital transformation strategy for manufacturing. *Procedia Computer Science*, *170*, 664-671. doi:10.1016/j.procs.2020.03.173

Atiyas, İ., & Dutz, M. A. (2021). Digital technology uses among informal micro-sized firms: Productivity and jobs outcomes in Senegal. *Policy Research Working Paper No. 9573*. Washington, DC: World Bank. doi:10.1596/1813-9450-9573

Borowiecki, M., Pareliussen, J., Glocker, D., Kim, E. J., Polder, M., & Rud, I. (2021). The impact of digitalisation on productivity: Firm-level evidence from the Netherlands. *OECD Economics Department Working Papers No. 1680*. Paris, FR: OECD Publishing. doi:10.1787/e800ee1d-en.

Brynjolfsson, E., & McAfee, A. (2011). *Race Against the Machine: How the Digital Revolution is Accelerating Innovation, Driving Productivity, and Irreversibly Transforming Employment and the Economy*. Lexington, MA: Digital Frontier Press.

Brynjolfsson, E., Rock, D., & Syverson, C. (2017). Artificial intelligence and the modern productivity paradox: A clash of expectations and statistics. *Working Paper No. 24001*. Cambridge, MA: National Bureau of Economic Research. doi:10.3386/w24001

Cariolle, J., & Carroll, D. (2020). Digital technologies for small and medium enterprises and job creation in Sub-Saharan Africa. FERDI Report. Clermont-Ferrand, FR: Fondation pour les études et recherches sur le développement international.

Chete, L. N., Adeoti, J. O., Adeyinka, F. M., & Ogundele, F. O. (2016). Industrial policy in Nigeria: Opportunities and challenges in a resource-rich country. In C. Newman, J. Page, J. Rand, A. Shimeles, M. Söderbom, & F. Tarp (Eds.), *Manufacturing Transformation: Comparative Studies of Development in Africa and Emerging Asia* (pp. 115-135). Oxford, UK: Oxford University Press. doi:10.1093/acprof:oso/9780198776987.001.0001

Cusolito, A. P., Garcia-Marin, A., & Maloney, W. F. (2021). Proximity to the frontier, markups and the response of innovation to foreign competition: Evidence from matched production-innovation surveys in Chile. *Policy Research Working Paper No. 9757*. Washington, DC: World Bank Group.

Danquah, M., & Owusu, S. (2021). Digital technology and productivity of informal enterprises: Empirical evidence from Nigeria. *WIDER Working Paper No. 2021/114*. Helsinki, FI: World Institute for Development Economic Research. doi:10.35188/UNU-WIDER/2021/054

Domanovic, V. (2016). The effects of the integrated application of BSC and ABM to enterprise strategy and efficiency. *Economic Horizons*, *18*(2), 149-163. doi:10.5937/ekonhor1602153D

Evangelista, R., Guerrieri, P., & Meliciani, V. (2014). The economic impact of digital technologies in Europe. *Economics of Innovation and New Technology*, *23*(8), 802-824. doi:10.1080/10438599.2014.918438

Gaffley, G. & Pelser, T. G. (2021, September). *Digital transformation in the manufacturing sectors of South Africa*. Paper presented at the 14th International Business Conference, South Africa.

Gal, P., Nicoletti, G., Renault, T., Sorbe, S., & Timiliotis, C. (2019). Digitalisation and productivity: In search of the holy grail-Firm-level empirical evidence from European countries. *OECD Economics Department Working Papers No. 1533*. Paris, FR: OECD. doi:10.1787/5080f4b6-en

Hussain, S., Hussein, A. M. A., & Joma, M. H. A. (2021). Digital transformation implementation in the manufacturing enterprises. *Academy of Entrepreneurship Journal*, *27*(5), 1-18.

Jakopin, E. (2020). Effects of structural changes in the economy of the Republic of Serbia: Old problems, new reform challenges. *Economic Horizons*, *22*(3), 179-196. doi:10.5937/ekonhor2003191J

Lukonga, I. (2020). Harnessing digital technologies to promote SMEs and inclusive growth in the MENAP region. *IMF Working Paper WP/20/135*. Washington, DC: International Monetary Fund.

Molchanova, S. M. (2020). Digital transformation in manufacturing, infrastructure and public services. In I. V. Kovalev, A. A. Voroshilova, G. Herwig, U. Umbetov, A. S. Budagov, & Y. Y. Bocharova (Eds.), *Proceedings of the International Conference on Economic and Social Trends for Sustainability of Modern Society (ICEST 2020)*, (pp. 1285-1294). London, UK: European Publisher. doi:10.15405/epsbs.2020.10.03.148

Mosiashvili, N., & Pareliussen, J. (2020). Digital technology adoption, productivity gains in adopting firms and sectoral spill-overs: Firm-level evidence from Estonia. *OECD Economics Department Working Papers No. 1638*. Paris, FR: OECD Publishing. doi:10.1787/ba9d00be-en

SMEDAN. (2010). *National Policy on Micro, Small and Medium Enterprises in Nigeria*. Abuja, NG: Small & Medium Enterprises Development Agency of Nigeria.

Nucci, F., Puccioni, C., Ricchi, O. (2023). Digital technologies and productivity: A firm-level investigation. *Economic Modelling*, *128*, 106524. doi:10.1016/j.econmod.2023.106524

OECD. (2021). OECD digital for SMEs global initiative. Retrieved April 15, 2023, from https://www.oecd.org/going-digital/sme/

Tobin, J. (1958). Estimation of relationships for limited dependent variables. *Econometrica*, *26*(1), 24-36. doi:10.2307/1907382

UNCTAD. (2017). *The 'New' Digital Economy and Development*. UNCTAD Technical Notes on ICT for Development No 8. Geneva, CH: United Nations Conference on Trade and Development.

UNIDO. (2019). *Industrial Development Report 2020: Industrializing in the Digital Age*. Overview. Vienna, AT: United Nations Industrial Development Organization.

van Ark, B. (2016). The productivity paradox of the new digital economy. *International Productivity Monitor*, *31*, 3-18.

Vogelsang, K., Liere-Netheler, K., Packmohr, S., & Hoppe, U. (2018). Success factors for fostering a digital transformation in manufacturing companies. *Journal of Enterprise Transformation*, *8*(1-2), 121-142. doi:10.1080/19488289.2019.1578839

Vogelsang, K., Packmohr, S., & Hoppe, U. (2019). Barriers to digital transformation in manufacturing: Development of a research agenda. In T. Bui (Ed.), *Proceedings of the 52nd Hawaii International Conference on System Sciences*, (pp. 4937-4946). Retrieved on March 15, 2023, from: https://www.unido.org/resources-publications-flagship-publications-industrial-development-report-series/idr2020

Xiao, Y. (2022). Effect and influencing factors of digital transformation of manufacturing industry. In Z. P. Xu, & J. D. Bi (Eds.), *Proceedings of the 7th International Conference on Social Sciences and Economic Development (ICSSED 2022)*, (pp. 441-445). Dordrecht, NL: Atlantis Press. doi:10.2991/aebmr.k.220405.072

Zahoor N., & Al-Tabbaa O. (2021). Post-entry internalization speed of SMEs. The role of relational mechanisms and foreign markets knowledge. *International Business Review*, *30*(1). doi:10.1016/j.ibusrev.2020.101761

Zapata, M. L., Berrah, L., & Tabourot, L. (2020). Is a digital transformation framework enough for manufacturing smart products? The case of small and medium enterprises. *Procedia Manufacturing*, *42*, 70-75. doi:10.1016/j.promfg.2020.02.024

Zhang, J., Zhao, W., Cheng, B., Li, A., Wang, Y., Yang, N., & Tian, Y. (2022). The impact of digital economy on the economic growth and the development strategies in the post-COVID-19 era: Evidence from countries along the "belt and road". *Frontier in Public Health, 10*, 1-17. doi:10.3389/fpubh.2022.856142

Zu, W., Gu, G., & Lei, S. (2022). Does digital transformation in manufacturing affect trade imbalances? Evidence from US-China trade. *Sustainability, 14*(14), 1-14. doi:10.3390/su14148381

Received on 8th May 2023,
after revision,
accepted for publication on 29th November 2023.
Published online on 12th December 2023.

Foluso Modupe Adeyinka is an associate research professor at the Innovation and Technology Policy Department, Nigerian Institute of Social and Economic Research (NISER), Ibadan, Nigeria. She obtained her PhD in Information Science from the African Regional Centre for Information Science (ARCIS). Her research interests are related to the Science, Technology, and Innovation (STI) Policy field.