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Assessing Research Collaboration for Technological Innovations in ICT Institutions in Nigeria

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The study purposively selected 340 researchers in the Information and Communications Technology (ICT) Department in Knowledge Institutions in Nigeria. The study aimed to determine the effect of collaboration on innovation outputs. Two forms of collaboration (active and passive) were explored as sources of information in the study. The main research instrument was a questionnaire administered to three hundred researchers in the School of Computing and Informatics across thirty universities in Nigeria and forty other researchers in the Research & Development (R&D) Departments in four ICT-related government research agencies. The study identified eight partners for collaboration. These eight indicators were regressed against indicators of ICT R&D outputs (publications, patents, and prototypes) during the reference period 2016, 2017, and 2018. In addition, the eight indicators were regressed against indicators of ICT innovations (product and process innovations) during the reference period 2016 to 2018, with ICT R&D outputs and innovations as dependent variables and the sources of information and collaborating partners as independent variables. The study found that institutional sources, market sources, and other technical sources of information significantly impacted the ICT R&D outputs. However, market sources of information are the leading significant influencers of ICT innovations. Also, publications written with colleagues in other institutions and patents granted with colleagues in the same institutions through collaborations are critical drivers of ICT R&D outputs in the knowledge institutions. At the same time, market partners such as suppliers and clients are the main drivers of ICT innovations.

Keywords: *Information and Communications Technology, research & development outputs, innovations, knowledge institutions, Nigeria*

Introduction

Information and Communications Technology (ICT) has been the most significant driver of Nigeria's service sector and economy, as far as the nominal gross domestic product (GDP) and employment are concerned (FinIntell, 2015). ICT has impacted Nigeria's GDP regarding employment generation, security, communication, industrialisation, and increased national output (Emmanuel & Adebayo, 2011). The financial intelligence report on ICT shows that Nigeria's ICT sector's contribution to the GDP grew consistently from less than 0.5% in 2001 to 6% in 2012 (FinIntell, 2015). Currently, the ICT sector contributes 10% to Nigeria's GDP (FinIntell, 2015; Nnodim, 2016). According to Adepetun (2017), the Nigerian ICT sector contributed about 500 billion naira to the economy and approximately 2.5 million jobs within a decade. Furthermore, from 2003 to 2014, the sector attracted about $30billion in foreign investment to Nigeria (Adepetun, 2017).

Innovation activities encompassing ICT technologies have yielded exploitable outcomes (Majeed & Ayub, 2018; Haftu, 2019; Haftu, 2019). Other sectors of every economy are now dependent on ICT for operations, progress, and survival. According to Harchaoui (2002), developed nations such as Canada and the United States of America (USA) have significantly benefited from ICT since the late 1990s. Emerging economies such as India, China, South Africa, Korea, and Taiwan have benefited considerably from ICT, especially in their economic growth (Fuss & Waverman, 2005). ICT innovation has been a continuous process over the years, leading to the development of new products and value-added services that proffer solutions to several societal problems such as security issues, buying and selling, and access to various facilities (Aghaei & Rezagholizadeh, 2017; Myovella, Karacuka & Haucap, 2020; Vu, Hanafizadeh & Bohlin, 2020). Progressive advancement in innovation has dramatically influenced the operations and performance of the ICT sector.

There is a need to foster innovation in ICT by involving academics, the private sector, research institutes, and investors. Although, a study on Science, Technology and Innovation (STI) in Nigeria by the African Institute of Technology, USA, showed that innovation in ICT in Nigeria is inadequate. Nigeria was ranked 114 out of 128 countries in the 2016 Global Innovation Index (Elebeke, 2015; Adepetun, 2016) and 118 out of 126 countries in the 2018 Global Innovation Index (GII, 2018).

However, great benefits from innovations in ICT in Nigeria have been reported to be associated with private firms. In contrast, the activities and contributions of tertiary institutions, research institutes, and government agencies towards innovation in ICT have been neglected in studies on the subject (Aderemi, 2010; Jegede & Ojo, 2012; Jegede & Ojo, 2013; Olamade, Oyebisi & Olabode, 2014; Binuyo, Oyebisi, Olayinka & Afolabi, 2015). Moreover, innovation activities in ICT are not limited to only the industry or private sectors, but many of these activities occur in various knowledge institutions (Oluwatobi, Efobi, Olurinola, and Alege, 2015). Knowledge institutions such as universities, polytechnics, and government research agencies play critical roles in knowledge-based economies by allowing individuals to transform practical ideas into beneficial innovations.

Therefore, innovation is a collaborative activity between businesses, universities, research centers, and other establishments that generate knowledge. Collaboration enables the transfer of knowledge and information among stakeholders. In addition, stakeholders can access sufficient resources, assets, or new sources of innovation, produce economies of scale and improve the authority of their undertaking (Kramer *et al*., 2007). Moreover, collaboration helps create new abilities, transform market environments and generate new strategic opportunities. Hence, one cannot overemphasize the importance of R&D collaboration to productivity. The ability to innovate transcends the innovating firm and includes the exchanges between a plethora of private and public actors (BIS, 2011).

Therefore, focusing on collaborations in ICT firms is limited because partnerships in knowledge institutions are essential to determine the final output value. According to Adu, Emunemu, and Oshati (2014), ICT is currently highly rated due to numerous R&D and innovations that have emerged from it. Even though the potential of R&D results from ICT knowledge institutions towards innovation breakthroughs are required for economic growth and national development, very little attention is currently paid to these institutions in Nigeria. Universities, research institutes, and other tertiary institutions are the primary sources of knowledge at the highest level. Therefore, there is a need to determine the extent of collaboration required for these institutions' R&D outputs and innovations. However, poor collaborations within the knowledge institutions towards the implementation of R&D results may be connected to the low level of innovative orientation.

A few studies from Nigeria have been identified in the literature to assess information and collaboration sources in the ICT knowledge institutions. In Nigeria, most studies identified in the literature on collaboration for innovation seem to have focused on collaboration towards innovation in the firms (Adelowo, Akinwale & Olaopa, 2017; Jegede, 2017a; Jegede, 2017b; Akinwale, Akinbami & Akarakiri, 2018; Salisu & Bakar, 2018; Olufemi, 2018; Karakara & Osabuohien, 2020). Alaba (2014) and Longe, Bolaji, and Boateng (2017) studies examined collaboration in the ICT industry. However, studies that assessed collaboration between institutions and industry include that of Oyelaran-Oyeyinka & Adebowale (2017). Hence, literature on innovation in public institutions in Nigeria is very scant, while the literature on collaboration for innovation in tertiary institutions in Nigeria is missing. This study intends to fill the gap in the literature.

Innovation is a collaborative activity between businesses, universities, research centers, and other public establishments that generate knowledge. Nevertheless, government regulations and laws can shape the innovative dynamism and strength of the economy (BIS, 2011). A central facet of the innovation process is knowledge infrastructure, consisting of two fundamental parts: the science infrastructure of academic institutions and research centers; and the information infrastructure. The latter comprises organisations producing and disseminating knowledge frameworks, such as measurement techniques and methods, geophysical data, the principles and elements of design, or intellectual property laws.

According to a 2011 study by NACETEM, researchers tend to cooperate more with colleagues in local research organisations than other participants in the National Innovation System (NIS). Based on the study's samples, only 29% of researchers partnered with industrial companies. The rationale for such collaboration varies from financial support for workshops and conferences, travel awards, S&T grants, provision and transfer of R&D amenities, to staff exchange programmes. Likewise, a significant portion of research performed in industrial firms and partnership with public research is about presenting a foundation to enhance pre-existing products and processes. For an efficient transfer of know-how, there is a need for direct interactions and dialogue between industry and public research organisations. The underlying assumption of such interactions is that organisations have adequate expertise to identify suitable partners and forge the right connections. Organisations often rely on a current knowledge base to solve the difficulties of developing innovation.

Furthermore, companies conduct new research when the current knowledge base is insufficient. Similarly, innovating firms primarily draw on existing internal expertise, and where this strategy proves inadequate, they turn to an external knowledge base from collaborators. Lack of expertise with the necessary technology spurs firms towards external sources, such as government-sponsored programmes or the service of consultants. An in-depth research frame shows an interaction or dialogue consisting of far more multiplex and reciprocal layers than the use of research findings for "commercialization."

The use of academic research, particularly towards business development, is far more comprehensive than the invention of new product ideas or new technology-based firms (Jacobsson & Perez, 2011). Thus, the primary role of academia in this process is to inform scientifically trained persons; such education helps them maneuver the existing knowledge base and identify research gaps that need further improvement. Besides, academic researchers are better equipped with the skills necessary to identify sources of resolutions to difficulties arising during the development stage. In the initial stages, academic researchers can participate as dialogue partners in a commercial enterprise's quest for knowledge. This type of collaboration utilises the researchers' overall skills and connections, providing a synopsis of their discipline but not necessarily their research findings. Also, such collaboration offers a more extensive viewpoint on technology capability. Thus, it underlines new approaches to existing challenges and new business prospects. Furthermore, through research collaboration, companies are better suited to understand customers' preferences and recognise sources of solutions to technical difficulties. Collaboration also unlocks business opportunities for firms that trade academic expertise (consultancies), which are equally important.

Table 2.1 illustrates the anticipated results of cooperation with public research. Concerning the first factor (the direct outcomes of R&D co-operation), firms deemed "soft" outcomes to be of equal significance as "directly usable results." Lennart (2014) argues that various factors motivate companies to collaborate with academic institutions. Examples of such motivations include R&D capabilities for product and process innovation, connection to academics, capacity enhancement, business prospects, sponsorships through national R&D funding agencies, EU funding schemes, etc.

Theoretical Background

This study draws insight from concepts of collaboration in literature. The conceptual framework used in this study was developed based on a blend of different established theories in the literature. For instance, the theory of economic development advanced by Schumpeter (1942; 54), the theory of planned behaviour put forward by Ajzen (1991), the network theory of social capital by Lin (1999), the knowledge spillover theory of entrepreneurship by Acs et al. (2009) and the innovation system theory by Lundvall (2007). Innovation sourcing is the acquisition and integration, rather than internal development, of critical knowledge from external providers. This fundamental strategy has emerged as a necessity for survival in many markets.

Consequently, sourcing processes complement internal design capabilities with external knowledge to improve innovation performance. Firms use external knowledge to enhance products and services, gain market share, and improve profits. Acquiring new knowledge through external sources makes it possible to develop and deploy new products and knowledge faster. However, the far-driven strategy of outsourcing can also decrease the ability of firms to maintain and upgrade their internal capabilities. The institutional sources include universities, colleges, and federal and provincial governments. Other available sources are business associations, conferences, and trade fairs.

National Innovation System

Countries that have effectively changed their economies to contend and flourish in innovation and information concentrated segments have made and reinforced their National Innovation System (NIS). Finland was the first country to embrace the idea as an essential part of its science and innovation policy; also, Sweden has given the concept genuine status in its own right by naming another focal government institution, the "Systems of Innovation Authority" (Sharif, 2006). In addition, there have been a few endeavours to advance a compact definition for NIS. An instance of such initiatives was the one provided by Metcalfe (1995), which portrayed NIS as a "set of institutions that (jointly and individually) contribute to the development and diffusion of new technologies. These foundations give the system inside which governments structure and actualise arrangements to impact innovation. Sharif (2006) indicated that NIS is an arrangement of interconnected organisations that make, store, and transfer the knowledge, skills, and artifacts that characterise new technologies.

As indicated by Kuhlmann and Matamaros (2017), NIS is an arrangement of cooperating private and public firms, colleges, and government agencies focusing on producing science and innovation within national borders. The collaborations among these units might be technical, business, lawful, social and financial, even though the communication objective is the advancement, insurance, financing, or guideline of modern science and innovation. One of the earliest and most well-known definitions, given by Freeman (1987), is that NIS contains a system of organisations in public and private sectors whose activities and collaborations start, import, change and diffuse new technologies. Furthermore, Freeman (1987) underscored that NIS is a system or joint effort of open and private foundations or associations with the end goal of advancement. This depiction likewise concurs with a prior definition by Adeoti (2002), which also characterised NIS as an incorporated arrangement of financial and institutional specialists legitimately advancing the age and utilisation of innovation in a national economy.

NIS comprises four principal components: government, academia, the private sector or industry, and the finance element (Kuhlmann & Matamaros, 2017; Foxon, 2006). Each of these has its unique roles, which rely upon the usefulness of the others for progress. It has been observed that the innovative performance of an economy depends upon how the individual institutions and actors act in detachment and how they communicate with one another as components of an aggregate arrangement of knowledge creation and use and on their interchange with social establishments (OECD, 1997). Without sufficient development of these actors and establishments in the domestic and regional settings, the innovation framework stays immature and weak. Furthermore, Egbetokun *et al*. (2007) noted that the achievement accomplished by any country in exploiting new, particularly logical knowledge for development and growth relies upon the adequacy of the country's National Innovation System (NIS). Therefore, NIS gives a system that comprehensively assesses a country's endeavour to create and apply the knowledge needed to address the necessities of its society (Egbetokun *et al*., 2007).

Lundvall (1988) and (1992) focused on interactions among clients and makers, encouraging a progression of knowledge and information connecting technological capabilities to client needs. Due to the significant vulnerability of development, Lundvall (1988) contended that these communications are beyond pure market instruments and depend on joint trust and commonly regarded codes of conduct. Further insight originated from Nelson's (1993) investigation of an experimental examination and correlation of the national advancement frameworks of 15 nations. To a significant degree, the examiner reasoned that differences in innovation systems reflect disparities in nations' economic and political conditions and needs. These distinctions mirrored the institutional set-ups between various countries, including frameworks of university research, training and industrial R&D, money-related organisations, management skills, public infrastructure, and national financial, monetary, and exchange strategies (Nelson, 1993). Given these early studies, the national innovation systems approach to dealing with innovation theory has been widely utilised by the Organisation for Economic Co-operation and Development (OECD). The innovation process is portrayed by the various actors and organisations (small and large firms, users, legislative and administrative bodies, universities, and research bodies), the connections and streams of information, funding and influence, and the motivating forces for innovation by the institutional set-up. The NIS approach lays on the intelligent innovation process model that accentuates market and non-market information exchanges among firms, organisations, and human resources (OECD, 1999). The OECD work with NIS recognises firms as the establishing unit of the innovation system. It proceeds to draw vigorously on the idea of clusters of advancing firms and included entities, which is similar to other innovation conceptualisations, especially National Innovative Capacity (Speirs *et al*., 2008).

Methodology

The study was assessed based on a direct collection of information from ICT researchers in the knowledge institutions through a questionnaire, carefully designed and structured after the sample used in the community innovation surveys by the Eurostat/OECD. A multi-stage sampling technique was adopted for this study. Three zones were purposively selected out of the six geopolitical zones in Nigeria: South-South, North-Central, and South-East. Ten universities were randomly selected from each of the three zones focusing on the School of Computing and Informatics. Those universities were purposively selected from each of the selected universities. In addition, four ICT-related government research agencies were purposively selected. The ICT R&D units of the government research agencies were also purposively selected. Ten lecturers were randomly selected from each university within the relevant departments, specifically, Professors, Associate Professors, Senior Lecturers, Lecturer I, Lecturer II, and Assistant Lecturers. Also, ten scientific researchers and engineers were randomly selected from each government research agency. Three hundred and forty (340) respondents were selected to participate in the survey. The reference period was 2016, 2017, and 2018. The questionnaire was administered to 300 lecturers in the universities and 40 scientific researchers in the government agencies. Secondary data were sourced from relevant journals, textbooks, institutions' annual reports, and published sources.

The questionnaire was designed to obtain information on the breadth of collaborations with actors in the innovation system. Actors considered were colleagues within the same institution, colleagues in other institutions, suppliers of equipment, materials, software, clients, Government research institutes, universities or higher educational institutions, consultants & commercial labs or private R&D institutes, and the industry or private firms. In addition, the sources of information contributing to the final output were explored. Sources considered were conferences or trade fairs/exhibitions, scientific journals or technical publications, national/international bodies, professional and industry associations, sources within the department or institution, suppliers, clients, consultants & commercial labs or private R&D institutes, government or public research institutes and universities or other higher educational institutions.

The dependent variables, the prevalence of ICT innovation: product innovation, and process innovation, were measured on a binary scale, while the R&D outputs (Publication, Patent, and Prototype) were measured as continuous variables. The independent variables (sources of information and collaboration) were measured on a 5-point Likert rating scale. The field survey was conducted in 2019.

Study Variables:

Table 1: Independent Variables (Collaborating Partner Indicators)

Dependent Variables	Measurement
R&D Outputs: Number of Publications	Continuous Variable
R&D Outputs: Number of Patents	Continuous Variable
R&D Outputs: Number of Prototypes	Continuous Variable
Innovations: Product (New hardware or software)	"Yes" = 1, "No" = 0
Innovations: Process (New Algorithms)	"Yes" = 1, "No" = 0
Independent Variables: Collaborating Partners	
Colleagues within your institution	"0 = Not used; 1 = Low; 2 = Medium; 3 = High; 4 = Very high"
Suppliers of equipment, materials, components, or software	"0 = Not used; 1 = Low; 2 = Medium; 3 = High; 4 = Very high"
Clients or customers	"0 = Not used; 1 = Low; 2 = Medium; 3 = High; 4 = Very high"
Colleagues in other institutions	"0 = Not used; 1 = Low; 2 = Medium; 3 = High; 4 = Very high"
Colleagues in other institutions	"0 = Not used; 1 = Low; 2 = Medium; 3 = High; 4 = Very high"
Consultants, commercial labs, or private R&D institutes	"0 = Not used; 1 = Low; 2 = Medium; 3 = High; 4 = Very high"
Universities or other higher education institutions	"0 = Not used; 1 = Low; 2 = Medium; 3 = High; 4 = Very high"
Government research institutes	"0 = Not used; 1 = Low; 2 = Medium; 3 = High; 4 = Very high"
Industry or private firms	"0 = Not used; 1 = Low; 2 = Medium; 3 = High; 4 = Very high"

Results and Discussion

Table 2 shows that an average number (57%) of the universities' lecturers had 0 to 10 years of work experience in an ICT background, followed by lecturers (31.1%) with work experience between 11 to 20 years. Lecturers with years of work experience above 20 years in the ICT field only constituted 12% of the respondents. This statistic could be related to the late adoption of ICT studies in most universities' curricula, which was not earlier than 1988. Only the first-generation universities embraced the importance of ICT awareness and teaching in Nigeria until 1988, when the National Policy on Computer Education was published. There was still no effective implementation of ICT studies in most Nigerian universities due to a noticeable dearth of sufficiently qualified lecturers (Modum, 1998). Due to a lack of exposure to ICT before the tertiary level, not many Nigerians knew the professional opportunities involved with computing-related programs. Therefore, it was not fully embraced until the 21st century, when ICT studies were introduced at various stages of the Nigerian academic system, which led to an increase in the number of computing and informatics graduates across several universities (Modum, 1988; Dasuki, Ogedebe, Kanya, Ndume and Makinde, 2015). This explains why most ICT lecturers in Nigerian universities have work experience between 0 to 15 years. Currently, 124 universities officially (federal, state, and private) produce computing and informatics graduates based on the accreditation of the Nigeria University Commission (NUC, 2019).

Table 2 also shows that the majority (51%) of the scientific researchers at the ICT government agencies had 6 to 10 years of experience in ICT jobs and researchers (18.4%) had 11 to 15 years of experience. Furthermore, only a few (16.3%) of the researchers had 0 to 5 years of work experience, while a few (14.3%) had 16 to 20 years of experience. Studies conducted by Igbokwe *et al.* (2015) and Ajayi (2017) support this result because most of the very active civil service workforce in Nigeria usually have 6-15 years of work experience. In summary, the majority (58.9%) of the ICT lecturers and researchers in the knowledge institutions had years of work experience between 0 to 10 years. In comparison, only a few (17.4%) had 16 to 20 years of experience and 14% with 11 to 15 years of experience, and the least was 9.8% with more than 20 years of experience.

Table 2: Years of Work Experience and Educational Qualification of the Respondents

Respondents' Characteristics	Respondents' categories					
	Universities' lecturers		Government agencies' researchers		Gross Total	
	Frequency	%	Frequency	%	Frequency	%
Work Experience (Years)						
0-5	58	26.9	8	16.3	66	24.9
6-10	65	30.1	25	51.0	90	34.0
11-15	28	13.0	9	18.4	37	14.0
16-20	39	18.1	7	14.3	46	17.4
Above 20	26	12.0	-	-	26	9.8
Total	**216**	**100.00**	**49**	**100.00**	**265**	**100.00**
Educational Qualification (Degree)						
Bachelors	13	6.0	14	28.6	27	10.1
Masters	93	42.7	28	57.1	121	45.3
Ph.D.	112	51.4	7	14.3	119	44.6
Total	**218**	**100.00**	**49**	**100.00**	**267**	**100.00**

As shown in Table 2, only a few (6%) of the universities' ICT lecturers had B.Sc. (bachelors) degrees, and 43% of the lecturers had M.Sc. degrees. In comparison, the majority (51.4%) of the lecturers possessed a Ph.D. degree as their highest educational qualification. This reveals the level of education required for a research or lecturing job by most universities in Nigeria, i.e., candidates with a Ph.D. degree or an M.Sc. degree are considered for such employment. Only very few universities in Nigeria employ lecturers with only a BSc degree. According to Oloruntoba and Ajayi (2006), a Ph.D. degree is a pre-requisite for lecturing positions in most Nigerian universities.

The majority (57.1%) of the scientific researchers in ICT government agencies had M.Sc. degrees (Table 4). On the other hand, only a few (28.6%) of the researchers had B.Sc. degrees; this reveals that the research agencies encourage and support researchers to earn higher degrees as active employees or placed on study leave. Therefore, some researchers might have acquired an M.Sc. degree while working in the agencies, while others could have been employed with an M.Sc. degree. However, table 4 also reveals that the least (14.3%) of the researchers have a Ph.D. degree as their highest qualification, implying that many researchers do not have a Ph.D. The result could be associated with the long years and dedication required to earn a Ph.D. while striving to gain work experience alongside. In addition, some agencies do not support their staff training to Ph.D. level, as there might not be any added value to the institution compared to actual work experience. In summary, the majority (89.9%) of the lecturers and researchers in the knowledge institutions had M.Sc. or Ph.D. degree as their highest educational qualification. This is reasonably expected of researchers in knowledge institutions because the main aim is to acquire more knowledge through degree earnings and training. Moreover, enhancing lecturers' and researchers' educational qualifications is a worthy goal of knowledge expansion.

Over 80.3 % of the lecturers were from the Schools of Computing & Informatics, while only a few (19.7%) were from the Department of Electrical & Electronics Engineering. This result reveals that not all universities in Nigeria have Electrical & Electronics engineering Departments, while Computing and Informatics Departments are in most universities. Furthermore, only 59 universities (public and private) offer Electrical & Electronics engineering as a course. In comparison, 124 universities offer computing and informatics courses based on the Nigeria University Commission’s approval and accreditation (NUC, 2021).

Overall, the majority (65.5%) of the respondents in knowledge institutions were lecturers of the Schools of Computing & Informatics (Table 4.5). Very few (18.4%) were scientific researchers in the R&D Departments of government agencies, while the least (16.1%) were lecturers in the other cognate departments. Data for this study were retrieved from R&D Departments of only four government agencies compared to data from two departments across thirty universities. A few (8.2%) of the researchers were Principal Manager/ Assistant Director/ Deputy Director, while only 2% of the respondent worked as Directors.

Table 3: Distribution of Respondents by Working Status and Departments

Respondents' Characteristics	Respondents' categories					
	Universities' lecturers		Government agencies' researchers		Gross Total	
	Frequency	%	Frequency	%	Frequency	%
Department						
Computer Science and Engineering	175	80.3	-	-	175	65.5
Electronics/Electrical Engineering	43	19.7	-	-	43	16.1
R&D Department	-	-	49	100%	49	18.4
Total	**218**	**100.00**	**49**	**100.00**	**267**	**100.00**
Working Status						
Assistant Lecturer/ROI	54	24.8	7	14.3	61	22.8
Lecturer II / SRO/PRO/M	56	25.7	25	51.0	81	30.3
Lecturer I/CRO/SM	43	19.7	8	16.3	51	19.1
Senior Lecturer/ PM/AD	34	15.6	4	8.2	38	14.2
Associate Professor/DD(R)	17	7.8	4	8.2	21	7.9
Professor/D(R)	**14**	**6.4**	**1**	**2.0**	**15**	**5.6**
Total	**218**	**100.00**	**49**	**100.00**	**267**	**100.00**

Legend:

RO: Research Officer, **SRO:** Senior Research Officer, **M:** Manager,

PRO: Principal Research Officer, **CRO:** Chief Research Officer,

SM: Senior Manager, **PM:** Principal Manager, **AD:** Assistant Director,

DD(R): Deputy Director, Research, **D(R):** Director, Research.

ICT R&D outputs & innovation of the Nigerian knowledge institutions

Three types of ICT R&D outputs, including publication, patent, and prototype in the knowledge institutions in Nigeria, are shown in Table 4. R&D outputs in the knowledge institutions were measured for the year 2018. The study explored three R&D outputs viz: publications, patents and prototypes. According to Table 4, the average publication per researcher/lecturer was 2.33. The number of patents granted to researchers in the ICT field was low, representing 7% of the researcher. However, seven out of every ten ICT department researchers were able to develop prototypes in 2018. Table 5 shows the innovations by the researchers in the ICT Department that have been made available to potential users. Table 5 indicates that more than half of the product innovations coming from the ICT Departments have been made available to potential users of the research outputs. On the contrary, slightly less than the process innovation from the ICT researcher has been made available to potential users of the research output.

Table 4: Extent of R&D Outputs in the Nigerian Knowledge Institutions

R&D OUTPUTS	Total number	Mean	Standard Deviation
PUBLICATIONS			
Number of Publications in 2018	575	2.33	2.772
PATENTS GRANTED			
Number of patents granted in 2018	18	0.07	0.328
PROTOTYPES			
Number of prototypes developed in 2018	163	0.68	1.301

Table 5: Extent of Innovations in the Nigerian Knowledge Institutions

New Product and Process (2016 to 2018)	N	Prevalence (%)
Product Innovation	51	58.0
Process Innovation	39	45.9

The breadth of Collaborating Partners

Table 6 shows that the most crucial collaborating partner to ICT researchers in the knowledge institutions between 2016 and 2018 was "colleagues within the same institution" (2.57), which has the highest mean value. Researchers have reported that they often collaborate with their colleagues in the same institution due to proximity, easy access, and communication (Nwone & Mutula, 2018; Fari & Ocholla, 2016). However, the depth of collaboration with collaborating partners such as "colleagues in other institutions" (2.07), "universities" (2.03), and "suppliers" (1.54) was relatively low (Table 6). While the depth of collaboration with other collaborating partners, such as "clients" (1.42), "consultants" (1.42), and "government research institutes" (1.37), were reported to be very low.

More recent studies (Love, Roper & Vahter, 2014; Kobarg, Stumpf-Wollersheim & Welpe, 2019; Brenk, 2020; Xu, 2021) have also highlighted the importance of leveraging on a broad range of collaborating partners. For instance, the study by Kobarg, Stumpf-Wollersheim & Welpe (2019) showed high sensitivity of innovation projects (radical and incremental) to the extent/breadth of collaboration, while the study by Brenk (2020) stressed that firms could leverage on breadth, depth of freedom of collaboration to improve their business model innovations.

The results also reveal the very low prevalence of collaboration and weak interactions between the variables capturing knowledge institutions and the industry's variables. The result supports earlier studies that proved the existence of a low level of collaboration between industry and universities in the Nigerian innovation systems (Fadeyi *et al.*, 2019; Osakwe & Moussa, 2017). Furthermore, universities are primarily driven to create new knowledge and educate, while private firms focus on capturing valuable knowledge that can be leveraged for competitive advantage.

Bruneel, d'Este & Salter (2010) study provided insights into the barriers to University-Industry Interaction. Their study examined two possible barriers: (i) those associated with variances in the orientations of industry and universities - orientation-related barriers and (ii) those connected to conflicts over intellectual property and dealing with university authority - 'transaction-related barriers. Their study showed that while many barriers inhibit collaboration between industry and universities, the major limitation to university-industry collaboration is the orientation-related barrier, especially on the part of the university. Transaction-related barriers relating to IP and administrative procedures remain secondary. Bruneel, d'Este & Salter (2010) also showed that transaction-related barriers are much more challenging to manage than orientation-related barriers. The inter-organisational trust would be one of the most robust mechanisms for lowering the barriers to interaction between universities and industry. Trust is built through long-term investment in interactions based on a shared perception of the collaboration's overall goal and the reward system.

Table 6: Extent of collaboration in ICT Knowledge Institutions

Collaborating Partners (2016 to 2018)	Mean	Standard Deviation
Colleagues within the same institution	2.57	1.153
Colleagues in other institutions	2.07	1.141
Universities or other Higher Education Institutions	2.03	1.253
Suppliers of equipment, materials, components, or software	1.54	1.132
Clients or Customers	1.42	1.241
Consultants, commercial laboratories, or private R&D institutes	1.42	1.226
Government research institutes	1.37	1.205
Industry or private firms	1.33	1.164

Correlation analysis of collaboration in the Nigerian knowledge institutions

According to Table 7, there was a positive and significant correlation between publications and colleagues in other institutions (r = 0.221, p. This is in tandem with literature (Endersby, 1996; Morrison, Dobbie & McDonald, 2003; Freshwater, Sherwood & Drury, 2006; Gazni & Didegah, 2011; Onyancha, 2011; Cheng, Hen, Tan & Fok, 2013; Fari & Ocholla, 2016; Abodunde & Jegede, 2020). For instance, Gazni & Didegah (2011) researched different types of research collaboration and citation impact using Harvard University's publications. Their study showed that only 12% of Harvard publications were single-authored, while as much as 60% of all publications had multiple authors. Their results showed a significant positive correlation between the number of authors and the frequency of citations. Their study further showed that publications with more institutions had more citations, but publications with more foreign collaborators were not highly cited. Morrison, Dobbie & McDonald (2003) showed that research collaboration among university researchers is fast changing from horizontal collaboration to vertical collaboration. Hence, a significant collaboration currently occurs across different levels in the hierarchy, that is, among peers; this could be why research collaboration is flourishing. Cheng, Hen, Tan & Fok's (2013) study in Malaysia showed that while researchers generally collaborate beyond work-related activities, collaboration is more rampant among science researchers than among social science researchers. Disciplines with significant international collaboration are essentially science and engineering-based subjects. Their study found little collaboration with researchers from public research institutes or industries.

None of the collaborating partners had a significant positive relationship with the number of patents granted. Instead, it had a significant negative relationship with colleagues within the same institution (r = -0.257, p0.01) and suppliers of equipment, components, and software (r = -0.159, p0.05). Significant negative correlations implied that each independent variable lessened the researchers' R&D outputs in Nigerian knowledge institutions. Alliances formed by university researchers through collaboration can become problematic. The researchers are likely to have different interests, and since patents have hidden economic value, the tendency for conflict could be high. Therefore, it may be difficult to quantify the knowledge that each researcher or partner contributes. It may also be challenging to appropriately share the profit from commercialising the patent. Hence, collaborating for patent development is not yet common or effective in public institutions in Nigeria and other developing countries. Zhang, Duan & Zhou's (2015) study on small worldliness and firms' innovation within the Chinese culture posits that a more clustered patent collaboration network negatively impacts firms' innovation performance. Their study further showed that patent collaboration networks with greater small worldliness would have a negative impact on firm innovation performance.

There were significant positive correlations between product innovation and suppliers of equipment, components, and software (r = 0.001, p, colleagues in other institutions (r = 0.046, p), and government or public research institutes (r = 0.076, p. In like manner, there were positive and significant correlations between ICT process innovation and suppliers of equipment, materials, components, and software (r = 0.062, p and government or public research institutes (r = 0.1, p). The importance and contribution of the different actors and stakeholders within the innovation system have been stressed in the literature. For instance, studies (Handfield, Ragatz, Petersen & Monczka, 1999; Wynstra, Axelsson & Van Weele, 2000; Wynstra, Van Weele & Weggemann, 2001; Keizer, Vos & Halman, 2005; Hao & Zhun, 2011) have stressed the vital role of suppliers in the development and diffusion of innovations (product and process). Studies by Fritsch & Schwirten (1999) and Moon, Mariadoss & Johnson (2019) also highlighted the importance of other institutions collaborating for innovation. In contrast to literature (Jegede, 2017), researchers in public institutes collaborate with the government (research institutes) to innovate. This may be connected to the fact that government is the main source of funding for universities and research institutes used in the present study.

Table 7: Correlation Analysis of Collaborating Partners and Innovation Outputs

	Publications	Patents granted	Prototypes developed	Product Innovation	Process Innovation
Colleagues within your Institution	0.078	0.257**	-0.087	3.483[a]	1.925[a]
Suppliers of equipment, materials, components, or software	0.039	-0.159*	0.107	14.188a ***	8.957[a*]
Clients or Customers	0.007	-0.061	0.131	3.984[a]	4.185[a]
Colleagues in other institutions	0.221**	0.144	0.022	9.170[a] *	3.970[a]
Consultants, commercial laboratories, or private R&D institutes	0.009	0.126	-0.07	2.516[a]	5.822[a]
Universities or other Higher Education Institutions	0.115	0.099	-0.112	3.228[a]	2.318[a]
Government or public research institutes	0.035	-0.144	-0.129	14.706[a] ***	7.458[a]*
Industry or private firms	-0.056	-0.049	-0.009	1.002[a]	2.019[a]

*. Significant at 90 percent confidence level ($p \leq 0.1$)
**. Significant at 95 percent confidence level ($p \leq 0.05$)
***. Significant at 99 percent confidence level ($p \leq 0.01$)

Conclusion

ICT researchers in the knowledge institutions tend to collaborate mainly with their colleagues within the same institution, colleagues in other institutions, universities, or higher education institutions. However, collaborations with suppliers of equipment, materials, components, or software, government or public research institutes, and colleagues in other institutions were significantly associated with product innovations. In contrast, collaborations with colleagues in the same institution and colleagues in other institutions are significantly associated with research outputs (publications and patents). This is because the common agenda of researchers in tertiary institutions is research outputs. Research is the tool for generating knowledge, while innovation is the channel for generating wealth from knowledge. Therefore, researchers need to collaborate with other actors within the innovation system to generate wealth and solve socio-economic problems from the knowledge produced. They must rely on the support of the technology transfer offices in the university and other market agents to avoid deviating from their primary teaching and research roles. Collaborating with other actors (especially market sources) will also expose them to the various available opportunities to commercialize their research outputs.

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