Technological Revolution, Sustainability and Development in Africa: Overview, Emerging Issues and Challenges

Abstract

The paper examines the silent technological revolution in sub-Saharan Africa focusing on emerging issues and challenges. In view of the centrality of technology diffusion in fostering local innovations and economic development in developing countries, it is surprising that our understanding of the challenges and opportunities in scaling-up technologies remains limited. This paper capitalises on the ongoing silent technological revolution in sub-Saharan Africa to present an overview of how new technologies have been adopted and utilised to achieve sustainability. The study identified a host of factors such as weak regulatory enforcement systems, lack of financial credit availability and limited banking services, which have created conditions for technological innovations such as mobile-phone-based banking, mPedigree, "cardiopad" and M-PEPEA to emerge. The public policy implications and directions for future research are identified and examined.

Keywords: Africa; technological revolution; new technology; sustainable development; stakeholder engagement; business development.

1 Introduction

One of the distinctive characteristics of 21st century Africa has been the increasing adoption of a multitude of technologies including mobile phones, solar PV and drones to help create the platform for innovation, business development and economic development (see Asongu, 2013; Asongu & Nwachukwu, 2018; Tabrizian, 2019; Lucas, Dagnachew & Hof, 2017; The Economist, 2015a; World Development Report (WDR), 2016). Although the 1950s and 1960s wave of independence witnessed little economic and technological progress, the last two decades have seen a growing willingness among nations to embrace liberalisation reforms (see Taylor, 2003) and the adoption of state-of-the-art technologies to help facilitate business and economic development (Amankwah-Amoah & Sarpong, 2016; Asongu & Odhiambo, 2018; Jackson, 2004; You et al., 2018; WDR, 2016). The continent has

increasingly adopted and digested a range of new technologies to help facilitate indigenous innovations, which represents a shift from the past where the emphasis was on duplication (The Economist, 2015a).

In spite of the doom and gloom often associated with Africa, there are emerging new phenomena and technological revolutions which still remain underexplored (Amankwah-Amoah, 2015; Amankwah-Amoah et al., 2018; Versi, 2014). Anecdotal evidence suggests that the spread of mobile phones coupled with the declining cost of communications have ushered in a new era of innovation (Asongu, 2013; The Economist, 2015a). The internet penetration rate has surged and the number of mobile phones has been projected to increase to around 930m by 2019, around one per person (The Economist, 2015a). Accordingly, contemporary practitioners and academics have referred to Africa as the "sleeping giant" with copious promising opportunities for businesses to flourish and for the continent to eclipse some rivals (World Bank & FAO, 2009). In spite of these positive trends, a number of challenges and barriers exist which often inhibit technology diffusion and indigenous innovation. Although technology diffusion has garnered increasing attention of scholars (for detailed review, see Perkins & Neumayer, 2005), our understanding of constraints and accompanying indigenous innovation remains limited (Mignon and Bergek, 2016). This neglect is rather unfortunate given that technology diffusion has been identified as a backbone in African economic development in the 21st century (see WDR, 2016). With this in mind, the purpose of this paper is to fill the gap in the literature by presenting an overview of the ongoing silent technological revolution in sub-Saharan Africa and the accompanying challenges.

This paper offers key contributions to innovation, strategy and technology research. First, although aspects of technology diffusion have been examined by past studies (Attewell, 1992; Comin & Hobijn, 2004), there is a paucity of scholarly works which examine the embryonic nature of technology revolution in developing countries in general, and Africa, in particular. In so doing, the study deepens our understanding of the opportunities and challenges in adopting and utilising modern technology to

foster economic development. Second, despite the growing research on technology management and technology diffusion (e.g. Ferrier et al., 2016), there has been a dearth of research on the issue of barriers to technology diffusion in an underdeveloped institutional context. The study employs illustrative cases of technological innovation to highlight some of the embryonic issues regarding technology diffusion in sub-Saharan Africa. In addition, in spite of a burgeoning stream of research on technology diffusion (e.g. Desmarchelier & Fang, 2016; Sheng et al., 2018; You et al., 2018), an integrated framework regarding the conditions favourable to the technology diffusion is lacking. In sharp contrast with previous studies, a framework of institution-based and technology-specific factors was developed which shed light on barriers to technological diffusion and scaling-up. Thus, the study adds to the emerging body of research which has emphasised the role of government policy in technology adoption and disseminations (Perkins & Neumayer, 2005). Furthermore, we move beyond mere review to integrate the latecomer advantage and "open" economies' views (Perkins & Neumayer, 2005) of technology diffusion to develop a unified framework which highlights the barriers and challenges inherent in scaling-up new technologies. The remaining sections are organised as follows. In the next section, a review of the literature on technology and technological diffusion is presented. This is followed by an examination of the African context, focusing specifically on technology use, technology utilisation and innovation. Then the barriers to technology diffusion are examined. Finally, the article concludes by setting out the implications for practice and theory.

2 Technological diffusion and scaling-up

Technology diffusion can be viewed as "a process of communication and influence whereby- potential users become informed about the availability of new technology and are persuaded to adopt" (Attewell, 1992, p. 2). In a similar vein, technology diffusion can be defined as the scaling-up or spread of new technology in the marketplace to end users (Loch & Huberman, 1999; Schilling, 2013). Researchers and

practitioners alike have sought to explain technological diffusion by examining the patterns of flow. An accumulated body of research has demonstrated that technologies do not spread simultaneously across all nations but rather diffuse at different pace and scope (Perkins & Neumayer, 2005; Schilling, 2013). Technology diffusion encompasses technology adoption and technology use to improve the living conditions of individuals and the wider society (Lanzolla & Suarez, 2012). Some scholars have asserted that an effective mechanism for technology diffusion is information diffusion using communication channels such as social media platforms (see Sheng et al., 2017) and traditional channels such as radio and television advertising to spread the potential gains/advantages associated with the adoption and use of latest technology (Lanzolla & Suarez, 2012). Some studies have indicated that effective communication channels are essential in spreading information about new technology as well as linking prior users and potential users of the technology (Attewell, 1992). Emerging technologies are those in the embryonic phase in terms of adoption and utilisation (see Mambrey & Tepper, 1999).

2.1 Competing schools of thought on technological diffusion in developing countries

Decades of research have demonstrated that there are competing schools of thought on the conditions favourable to the technology diffusion (Perkins & Neumayer, 2005). The first theoretical lens is the latecomer advantage hypothesis which argues that because developing countries often lag behind their developed-country counterparts, they often adopt many technologies at a later stage after cost has declined and efficiency improved (Sharif, 1989). Consequently, the diffusion of new technology tends to be faster than advanced nations (Perkins & Neumayer, 2005). In addition, it has also been demonstrated that developing or industrialising nations in the infant stage can leap directly to the next generations of technologies in areas such as mobile phones (Asongu, 2013; Liikanen, Stoneman & Toivanen, 2004) and solar panels (Amankwah-Amoah & Sarpong, 2016). Indeed, emerging economies can obtain modern technology that originated in advanced economies at a fraction of the original

research and development costs to skip decades of incremental false steps and leap directly into the latest and most advanced technologies in the field (Mathews & Cho, 2007; Perkins & Neumayer, 2005). They are also often unconstrained by past resources and expertise commitments or the high cost of technical change (Ferrier, Reyes & Zhu, 2016), referred to as latecomer advantages (Sharif, 1989). Prominent examples of nations include the Asian economies of South Korea and Taiwan which managed to achieve fast industrialisation by imitating and utilising some of the technologies developed in the West (Mathews, 2002; Mathews & Cho, 2007).

Another school of thought contends that new technologies diffuse more rapidly in "open" economies which create conditions for trade, and investments (Ferrier et al., 2016; Perkins & Neumayer, 2005). The crux of this argument is rooted in the neoliberal assertion that liberalisation is an effective mechanism for accelerating the technology diffusion (Ferrier et al., 2016; Perkins & Neumayer, 2005). By creating a more open economy through trade, liberalisation and deregulations, countries create conditions for the demand and supply of new technology (Perkins & Neumayer, 2005). It has been shown that cross-border trade facilitates technology diffusion through imitation as well as enables nations to capture the benefits of innovation and technologies developed elsewhere (Ferrier et al., 2016). A growing strand of this stream of research has concentrated on how trade openness can create conditions for the exchange of ideas, introduction of new technologies and ultimately contribution to technology adoption and technology use (Perkins & Neumayer, 2005). Thus, international trade and FDI have been identified as channels of technology diffusion (Ferrier et al., 2016).

Another relevant school of thought is anchored in the Northian perspective of institutions (North, 1990). By institutions, we are referring specifically to "the rules of the game in a society" (North, 1990, p. 3). These include formal and informal institutions such as government, norms, culture and language (Peng, 2014; Peng, Sun, Pinkham & Chen, 2009). Rooted in this line of argument is the suggestion that

developed and developing countries differ in terms of economic development, regulations and stages of economic development, which need to be taken into consideration when examining factors that influence technological diffusion (see Amankwah-Amoah, 2015). One strand of research has indicated that the nature of governments, policy regime, science and technology policy, regulations and laws can play a pivotal role in scaling-up or creating conditions for diffusion of new technologies (Lanzolla & Suarez, 2012; Lücke, 1993). Governments can also offer incentives such as tax relief and subsidies to help facilitate the spread and adoption of the new technology (Amankwah-Amoah, 2015). Such actions are more likely to incentivise consumers to switch to capture the potential cost and efficiency savings associated with the new technology.

Insert Figure 1 about here

Another suggestion is that government capabilities can moderate the pace of technology diffusion. By government capabilities, we are referring to "the differential ability that some governments have to devise policies that promote new resource accumulation, accompanied by credible mechanisms to monitor the outcomes of policies that curb dysfunctional political interference" (Musacchio, Lazzarini & Aguilera, 2015, p. 126). Therefore, government interference and influence in technology diffusion may tend to differ across nations. Related to this are country-specific factors; studies indicate that high levels of educational attainment in countries influence technology diffusion success, as highly educated individuals are more likely to become aware of the existence of new technology (e.g. Caselli and Coleman 2001). Indeed, there is an accumulated body of research to indicate that quality of human capital (i.e. knowledge, skills and abilities (KSAs) influences the dissemination of knowledge about a technology and technology diffusion (Perkins & Neumayer, 2005). Human capital development through education and public investment appear essential in countries' ability to capture value for state-of-the-art technologies. Indeed, past studies have demonstrated that a country's type of government and human

capital endowment are primary determinants of the point at which a given technology is adopted (Comin & Hobijn, 2004). Another line of research has demonstrated that technology diffusion is predicated on the distinctive features and functionalities of the technology itself (Loch & Huberman, 1999), perceptions of the technology (Rogers, 2003), and its complementarity and compatibility with existing technologies or products (Katz & Shapiro, 1994; Shy, 2001). Therefore, the ability to disseminate relevant information about a technology eventually influences firms', individuals' and nations' decisions to switch to a more efficient, state-of-the-art technology. Based on the above, it can be deduced that technological diffusion is predicated on external environmental (institution-based, trade and FDI) factors, technology-specific factors and knowledge diffusion (human capital and effective communication channels), as depicted in Figure 1. Notwithstanding these informative lines of research, our understanding of technological diffusion and ensuing challenges and effects remains unclear. In light of the foregoing, we now turn our attention to the African context.

3 Technology diffusion, innovations and scaling-up in sub-Saharan Africa: Trends, challenges and opportunities

Throughout the second half of the 20th century, sub-Saharan Africa nations especially those in West Africa remained largely stagnant in terms of innovations whilst other countries surpassed and accelerated ahead. One of the main barriers to Africa's development during that era was the historical underutilisation of existing technologies to foster development (see Fabayo, 1996; WDR, 2016). Starting in the 1950s, many African governments started moving toward self-governance and in the process ushered in a host of reforms aimed at powering industrialisation and economic development. For instance, in Ghana, Kwame Nkrumah focused on science and technology as one of the cornerstones of his wider policies (Amankwah-Amoah, 2016a). As many countries gained independence by the 1960s, they also began adopting technology and science-based national policies. Over time, attention to power

science through education and effective national policies faltered as a result of conflicts and political instabilities in countries such as Ghana and Nigeria. Over two decades ago, Fabayo (1996) attributed Africa's over-reliance on the West and slow-paced industrialisation to the lack of robust indigenous scientific and technological capabilities. Since then, progress has been made in capturing the benefits of many technologies and utilising them to foster indigenous innovations (Demombynes & Thegeya, 2012). In recent years, largely due to the digital revolution and technological breakthroughs, many countries have leapfrogged to the latest technologies, accompanied by local innovations (African Business, 2014). The technology revolutions have occurred in sectors such as mobile, solar and broadband which have all unleashed opportunities and challenges for nations. The information and communication technology (ICT) industry encapsulates telecommunications, internet service and internet cafes, ICT education providers, data operators, and software development (African Business, 2016). There has also been a growing emphasis on technology and science-based national policies by many nations. In recent years, many countries, including Kenya and Ghana, have established tech hubs (African Business, 2014). An example of technological leapfrogging has been skipping of fixed-line telecommunications to embrace mobile technology across the continent (Toesland & Cross, 2015). It has been suggested that this has helped to bypass the prohibitive infrastructure costs associated with landline and fixed-line telecoms (Toesland & Cross, 2015).

In 2014, around 600 million people – about 56% of Africa's population – owned a mobile phone, which was surprising given that only 1% of Africans owned a mobile in 2000 (Wall, 2014). Partly due to liberalisation and market reforms, there are over 35 major mobile network operators expanding the scope and pace of their operations (Wall, 2014). Another source of technological leapfrogging has been the skipping of traditional computing technologies by using mobile phones to access the internet (Espiner, 2014). Recently, 3D printing has also appeared as a route for the continent to join the leading Asian nations at the manufacturing frontier. Before proceeding to shed light on the major barriers to technology

diffusion, we first outline some of the technological innovations and development that have transformed the business landscape. Recently, many technology-based start-up firms have seized the opportunities provided by emerging technologies to equip them to enter new markets. The recent growth of service-based enterprises and jobs is unsurprising given that Africa accounts for a mere 1.5% share of global manufacturing outputs (Soni, 2017). Besides helping to reduce the cost of serving consumers across an array of industries such as finance and banking, technology has also paved the way for "services that were traditionally only accessed by the privileged few to reach a wide pool of new customers" (Soni, 2017, pp. 22–23). New technologies have also altered the nature of competition by creating conditions for firms to provide services which differ from those offered by incumbents. By being blindsided start-ups which culminates in some loss of market share, incumbent firms have been forced to improve or adjust their offerings to maintain or develop new sources of competitive advantage.

One noteworthy observation is that the overreliance of natural resource-intensive industries has often diverted attention from harnessing technology to improving the competitiveness of African industries and firms. In a recent insightful piece, The Economist (2017, p. 7) noted that "the world's most valuable resource is no longer oil, but data". This represented a fundamental shift, given that a century ago oil was regarded indisputably as the most valuable resource. In the light, nations have to develop national digital capacity and encourage technology adoption and development of data and technology-based enterprises. Harnessing technology and utilising data has the potential to help Africa leap into the 21st century. To illustrate the technological innovations we turn to the following examples.

3.1 Healthcare and social innovations

In the face of weak regulatory enforcement systems (Acquaah, 2007), poverty and growing need among consumers for effective medication, the fake pharmaceutical product market has flourished. This problem has besieged the pharmaceutical and healthcare sectors for decades and has had a profound

effect on lives. For instance, in 2011, 64% of antimalarial drugs in Nigeria, Africa's largest market for medicines, were found to be counterfeits (The Economist, 2012b). Some anecdotal evidence indicates that around 700,000 deaths in Africa can be attributed to fake malaria and tuberculosis drugs (Allafrica.com, 2009). By siphoning sales from authentic products and brands, product counterfeiting undercut the intellectual property rights as well as the reputation of well-established organisations (Staake, Thiesse & Fleisch, 2012). Against this backdrop, some technologies such as radio-frequency identification tags are increasingly being used to tackle the problem. This has provide the conditions which has begun to reverse this trend. One Ghanaian start-up enterprise, mPedigree, utilises mobile phone technology to help consumers to identify counterfeit drugs (Greenwood, 2011; The Economist, 2010). The "M-Pedigree" mobile phone app works by encouraging drug companies to imprint a special code onto the product packages which can be revealed by customers scratching off the coating (The Economist, 2010). Consumers would be able to determine whether the package is genuine or fake by sending a free text with that code (The Economist, 2010). Given that the drug industry in Ghana is worth around $750m a year, fake medicines not only endanger human lives (Greenwood, 2011) but also lead to misallocation of national resources (The Economist, 2012b). From the government's perspective, tackling or reducing counterfeit products in the marketplace has helped to minimise tax evasion and money laundering, which has been a drain on national resources. Despite its shortcomings in terms of limited use within the wider populations, the technology has been impactful in curtailing the activities of criminals in the drug industry supply chain. It has also helped to tackle the issues of counterfeit drugs and illegal trade in fake medicines.

Table 1 provides a summary of examples of healthcare and other sectorial innovations across the continent including the "cardiopad", solar kiosk, M-PEPEA and the "Inye computer tablet". The table also provides details of the void in the marketplace filled by the innovation, for example mobile insurance services targeted at farmers and delivered via mobile technological developments (BBC,

2016b). This is particularly impactful given that a large number of Africans work in agriculture, but only 6% of the total population in Africa and the Middle East actually have any kind of agricultural insurance (BBC, 2016b). One of the outcomes of this has been that affordability has helped to attract farmers to indemnify themselves against extreme weather events such as droughts and floods which often destroy many individuals' livelihoods in rural areas.

Insert Table 1 about here

3.2 Mobile-phone-based banking

Largely due to "institutional voids" such as limited infrastructure development, weak contract enforcement regimes, lack of adequate disclosure and weak governance regimes which permeate the developing world (Khanna & Palepu, 1999), many entrepreneurial firms are motivated to develop innovative products by bypassing the weak market-supporting mechanisms to fulfil market demand (Radjou et al., 2012; Cunha et al., 2014). In the face of resource-constrained environments, frugal innovations have flourished. By frugal innovation, we are referring to firms' ability to utilise technologies to develop innovative products quickly and cheaply (Radjou, Prabhu & Ahuja, 2012). For frugal innovators, resource scarcity is a fact and an opportunity to generate new ways of utilising and producing products that can tap into potentially hidden markets (Cunha et al., 2014). One of the local innovations in Africa stemming from technological advancements and scaling-up of technology towards addressing well-noted problems is the "mobile money", e.g. M-Pesa in Kenya, which refers to financial transactions on mobile phones (Asongu, 2013). The M-Pesa is a phone-based money transfer and banking facility which was launched in 2007 by Safaricom, Kenya's largest mobile operator, in partnership with Vodafone, to help overcome some of the institutional voids in the marketplace (Morawczynski, 2009). The financial transactions over time have come to include deposits and

withdrawals, payments for goods and services, and money transfers. This mobile-phone-based banking has brought millions of people into the formal financial system (Chironga, Leke, Lund & van Wamelen, 2011; Morawczynski, 2009). Kenya is one of the African nations characterised by nepotism, corruption and inefficiency of the state-owned enterprises which affects business development (Mutiga, 2014). Besides creating jobs, it has also curtailed the activities of criminals by substituting cash for pin-secured virtual accounts, which could hold around $1,000 at a time (Mutiga, 2014; see also Morawczynski, 2009). By offering subscribers pin-secured virtual bank accounts on their mobile phones, it was possible to eliminate the security issues such as armed robbery associated with transferring physical money to rural areas in Africa (Mutiga, 2014). By 2012, the M-Pesa handled transactions accounting for about 31% of the nation's GDP, and by the end of 2013 the country had around 65,000 M-Pesa agents each providing jobs in the local community (Mutiga, 2014). In 2014, the M-Pesa mobile payments' system handled an estimated 1.15 trillion Kenyan Shillings (£7.72bn) a year, which is equivalent to 35% of Kenya's gross domestic product (Wall, 2014). Over time, the popularity and innovativeness of M-Pesa has meant that many Kenyans increasingly use it to transfer money and make payments (Shaffer, 2013), with over 18 million users worldwide (Wall, 2014).

In recent years, India, Bangladesh and Pakistan have become the largest region providing mobile money services with an estimated 3.8 million users compared with 805,000 in the whole of Africa (Shaffer, 2013). India has now been projected to handle over $350 billion mobile money transfers, which would further eclipse the progress we have seen in much of sub-Saharan Africa (Shaffer, 2013). In recent years, similar businesses or business models have emerged in countries such as India (e.g. MoneyOnMobile), Bangladesh (e.g. bKash) and Pakistan (Shaffer, 2013). Developments in mobile technology such as smartphones have also helped to accelerate the growth of this sector.

3.3 Solar technology and solar PV

In recent years, it has become apparent that the transition to low-carbon energy systems in Africa and elsewhere in the developing world is partially predicated on the widespread diffusion of renewable energy technologies (RETs) such as solar photovoltaic (PV) and wind turbines (Amankwah-Amoah, 2015; Amankwah-Amoah et al., 2018; Szabó, Bódis, Huld, & Moner-Girona, 2013; see also Mignon & Bergek, 2016). A widely noted development is the adoption of solar technology and solar PV. Pay-as-you-go models for solar panels have also emerged (Browne, 2009). Historically, scaling-up solar PV in Africa has often been curtailed by factors such as high upfront costs, lack of clear government policies, lack of absorptive capacity of local firms, and underdeveloped and underutilised human capital (Amankwah-Amoah, 2015). Past studies indicates that low-income households able to overcome the initial financial cost huddles associated with acquiring the small solar light benefits in long term due to cost savings and access to better quality light (Harrison, Scott & Hogarth, 2016). To an extent, pay-as-you-go models for solar panels in tandem with the mobile money-transfer system have in many ways revolutionised the way businesses conduct their operations in terms of receiving payments and communicating with customers. Indeed, it is long established that given the right environment entrepreneurs can innovate to help foster economic development (Schumpeter, 1934). For instance, the scaling-up of solar PV in rural areas can provide opportunities for new repair and installation businesses to emerge.

4 Technology diffusion in Africa: Barriers and challenges

In spite of the progress, a number of barriers to technology diffusion remain. These have not only curtailed the pace of technology adoption, but also economic development. As shown in Figure 2, the challenges and opportunities stem from a host of individual, national, technology, industry and organisation-level factors.

Insert Figure 2 about here

4.1 Institutional barriers

One of the main challenges in facilitating technology diffusion is institutional barriers. By institution, we are referring to the challenges stemming from the formal "rules of the game" such as laws and regulations, and informal institutions encompassing norms and values which can hinder the adoption of new technology (see Peng, 2014). In view of the centrality of the role of governments in laying the foundations for local innovations to flourish through adequate funding of education and skills developments, it is unsurprising that African nations and firms continue to lag behind their counterparts in Asia and elsewhere in the developing world. Historically, poor governance, corruption and lack of clear government policies have created obstacles to investors and businesses in Africa (Amankwah-Amoah & Hinson, 2019; Jackson, 2004). Indeed, lack of effective government regulations and support has been identified as a factor curtailing renewable entrepreneurial activities in the developing world (Gabriel, 2016). Although many African countries are democratic in nature, political interference and bureaucracy have often undermined business formation activities. Another factor is that, historically, technology has not always been at the forefront of many national government policies. There has been a general underinvestment in science and technology, which often limited nations' ability to adopt, assimilate and utilise technologies developed in developed countries (Afuah, 2003). As a consequence, Africa's ability to capture value from the abundance of natural resources or utilise existing technologies has often been curtailed by lack of skilled personnel (Afuah, 2010). Anecdotal evidence regarding the issue in Africa indicates that national policy towards research and development in less profitable areas is either weak or entirely absent (Afuah, 2010). As African Business (2012, p. 18–22) noted:

> "The importance of innovation is something which African governments are slowly waking up to: they are showing a greater willingness to explore concrete policies and strategies to stimulate innovation in a range of areas, particularly the ICT industry but also in other sectors like biotechnology and agriculture."

One possible explanation is that historically, the telecommunication sector, like the airline industry, has been dominated by state monopolies. Consequently, these sectors were governed by strict regulatory environments aimed at protecting the market share of state-owned enterprises. Since the 1990s, progress has been made by countries to open the sector to private competition. From 1995 to 2004, the share of African countries maintaining a state monopoly in the mobile segment dropped from 70% to less than 10% (Djiofack-Zebaze & Keck, 2009). As more of the mobile market on the continent becomes more attractive, major telecom operators in Europe and the US such as Vodafone, Telefónica and T-Mobile have established a foothold. In spite of recent accomplishments in scaling-up technologies with mobile-phone penetration to around 70% of the population, more needs to be done. This is exemplified by the fact that in one of Africa's largest markets, Ethiopia, the penetration rate is around 25% with only 2.5% of Ethiopians having access to the internet in contrast with 40% in neighbouring Kenya (The Economist, 2013c).

Another of the challenges revolves around telecommunications' (mobile and internet access) infrastructural development. A case in point is Nigeria, where around 42% of the population has some form of internet access with broadband costing about 30% of a household's income (Wall, 2014). This means that this market remains underserved with more than half of the people in Africa's most populous nation remaining unconnected and take-up of high-speed services remaining slow (Wall, 2014). In addition, poor connectivity and unreliable source of power continue to pose challenges to users and firms in many countries including Nigeria (Soni, 2017). As previously noted, technology adoption is

often predicated on the nature of market reforms and openness of nations to trade and foreign investments**.** It has been suggested that grid-based electrification is more an attractive option for heavily populated territories and areas with high demand for electricity coupled with shorter distance to high voltage power lines (Quak, 2018). However, for many developing economies including those in sub-Sahara Africa tend to have sparsely populated rural areas and therefore off-grid technologies and powers sources such as solar, present an enticing opportunities for nations to develop a different platform for economic development (Amankwah-Amoah, 2015; Quak, 2018).

4.2 Convergence of banking and mobile services

The advent of mobile banking services including mobile money transfers and mobile payments in countries such as Nigeria, Kenya and Ghana have ushered in a new era where countries no longer have to develop the expensive traditional brick-and-mortar outlets and branches required to run banking services. Another observation is that largely due to the increasing coverage and wider adoption, mobile phones have also evolved from being regarded as mere "communication tools into service delivery platforms" including banking and money transfer (Aker & Mbiti, 2010, p. 208). The convergence of banking and mobile services has also had an impact on public policy. For instance, some governments, including Tanzania, now require mobile money operators to have both banking and mobile operating licences (Ford, 2016). Following the revolutionary mobile services, Ghana's central bank has also granted mobile operators permission to offer money transfer services, thereby further exerting competition among firms in the money transfer sector (African Business, 2014).

4.3 Organisation level of analysis

At an organisational level, there is a need to explore both public- and private-sector organisations as mechanisms for technology diffusion. Adoption of new technology for private-sector organisations may

stem from the efficiency gains and profitability associated with the new technology. For many small and medium-sized enterprises in Africa, they are often locked into inferior technologies such as inefficient appliances, rudimentary information and technology, and inefficient machinery and facilities, which limit their ability to embrace new technology (see Jackson, 2004). Indeed, adoption and use of obsolete technologies adds to their cost base, coupled with lack of innovation which often precipitates their premature demise. One of the driving forces behind many industries' decline in Africa has been reliance on or adoption of obsolete technologies and failure to upgrade technological capabilities (Amankwah-Amoah, 2015). This often means that the cost of production, errors and defects is higher which can make many producers uncompetitive relative to rivals originating from other emerging economies. Besides these positive effects, technology has also provided opportunities for many small-business owners to conduct their operations by reducing costs of communication and banking. Accordingly, new technology adoptions can lead to the development of sustainable sources of competitive advantage. This is also predicated on firms being informed of the existence and benefits of the technology. Cumulatively, these are factors which did not portend well for technology adoption and utilisation, or for capturing value from resources to innovate. As evident in the proposed framework, a multilayer effort would be required to tackle the challenges outlined here.

4.4 Individual level of analysis

From the individual level of analysis, some of the barriers to technology adoption are knowledge of the benefits and cost of using the technology. In recent times, lack of highly skilled individuals to manage government and formulate effective national policies has often resulted in inefficiency and bureaucracy which stifles business development and the ability of local firms to utilise knowledge and technology developed elsewhere (see Asongu & Le Roux, 2017; Budhwar & Debrah, 2001; Debrah & Ofori, 2006). Indeed, the ability of individuals to adopt a new technology might be curtailed by lack of knowledge

and limited ability to capitalise on the technology (WDR, 2016). Many countries in sub-Saharan Africa are characterised by low levels of quality education. It must be pointed out that lack of education also limits individuals' ability to obtain knowledge about latest technologies. Accordingly, national policy to boost quality of education will ultimately have an effect on the spread and adoption of new technology. For some time now, there has been a recognition that cost of data poses a major challenge in diffusing technology across the developing world (WDR, 2016). Although a number of countries, including Angola and South Africa, have adopted the 4G revolution, data prices across the continent are often exorbitantly high, which deters many of the poor from accessing data and technology (Padmore, 2014; Ford, 2016). In light of the slow reduction in data costs, the East African community, including Kenya and Uganda, has introduced the "roam like home" policy, geared towards reducing cross-border roaming charges among its members (Ford, 2016). This was unsurprising given that one of the main objective of the economic bloc has been to eliminate barriers to trade between members. Beyond helping to reduce costs for users, the lower costs as a result of the policy have helped to encourage more users to user mobile phones, thereby helping operators to largely maintain their revenue streams (Ford, 2016). In addition to the above, low levels of education and low entrepreneurial skills have also stifled small and medium-sized enterprises' adoption of new technologies. This is important given that indigenous firms often lack the high-quality human capital and stabile institutional environment for business transactions to occur (Jackson, 2004). Table 2 provides a summary of the barriers to the technological revolution and industrial development in Africa.

Insert Table 2 about here

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5 Conclusion and implications

The main objective of this study was to provide an overview of the ongoing silent technological revolution in sub-Saharan Africa and the accompanying challenges it faces. The analysis revealed that institutional voids such as weak regulatory enforcement systems, lack of financial credit availability and limited banking services have created conditions which have precipitated new technological innovations such as the mobile-phone-based banking, mPedigree, "cardiopad", solar kiosk, M-PEPEA and the "Inye computer tablet". In spite of resource scarcity, these innovations have merged into potentially unexploited markets across the continent. The preceding analysis indicates that the fast pace of technological adoption including mobile phones and mPedigree have been buttressed by government policies, creation of business-friendly environments and opening up of some markets to competition. The increasing and faster pace of technology adoption means that African nations can no longer afford to delink themselves from adoption of new technologies emerging on the global stage. Isolationist policies are likely to retard new technology adoption and consequently local innovation and economic development (see also Mishra, 1992). Despite this progress, barriers to technology diffusion such as poor governance, corruption and lack of clear government policies remain, which curtails technological development and pace of innovation. Regarding the challenges in scaling-up technologies, government bureaucracy and lack of or limited government investment in research and development continues to pose barriers. Skill development and utilisation, and dissemination of technology-specific knowledge have the potential of help to boost scaling-up efforts. Regarding contributions to theory, our analysis further contributes to technology-diffusion literature (Asongu, 2013; Perkins & Neumayer, 2005) by examining how institutional barriers such as weak legal enforcement and poor governance mechanisms for economic development can help to foster local innovations. These findings reinforce the assertion that quality of institutions plays a pivotal role in African countries' ability to adopt and utilise new technology. In addition, the paper moves beyond the existing streams of research on technology and

innovation (Afuah, 2009; Schilling, 2013) by identifying factors which curtail technology diffusion and underserved markets. The paper articulates how some "institutional voids" can create conditions for frugal innovation to occur. In particular, we highlight the conditions which aided the development of M-PESA.

5.1 Contributions to public policy

There are some public policy implications which must be noted. First, in spite of the technological developments, Africa's economy is still primarily based on extracting natural resources such as gold, diamonds and oil rather than industrial productivity (Khumbah & Foote, 2014). In this direction, a more robust national industrialisation policy anchored in harnessing these and other technologies is essential in helping countries to diversify their economies. More importantly, it would help more African nations to diversify their economies and reduce their reliance on mainly natural resources. In addition, in light of the growing technological trends and breakthroughs, it may be necessary for nations to update their regulatory and digital code of conducts in timely manners to keep pace with new practices. Beyond embracing a science-led development agenda as advocated in Ghana by Kwame Nkrumah in the 1950s (see Amankwah-Amoah, 2016a, 2018), nations lacking human capital can turn to the diaspora as a source of untapped talent. Given that most African countries have ineffective or non-existing strategies to leverage the social, human and financial capital of their diaspora to power economic development (Chand, 2016), diaspora-country-of-origin knowledge-exchange forums and conferencing might be useful in fostering positive knowledge diffusion. By and large, Africa's diaspora talent and expertise remains "grossly underutilised" by many emerging economies (African Development Bank, 2011; Chand, 2016). This is important given that potential knowledge that can be tapped by the country of origin to power technological innovations.

Moreover, government financial and non-financial supports are essential in fostering further development and boosting technology adoption. Governments need to provide necessary institutional support in establishing technology hubs for entrepreneurs and local firms to develop and expand. Although many have adopted the array of new technologies, digital literacy and language skills appear essential in disseminating knowledge about new technology and encouraging individuals and firms to adopt them. A national and local strategy around these would provide the necessarily fuel to boost the spread of these and other technologies across the continent and foster utilisation of digital applications. To sustain and accelerate the past successes noted above, high-tech investments coupled with closer alignments between universities and governments are necessary to create an environment for future innovations to be nurtured and flourish.

5.2 Contributions to practice

The analysis presented here also has practical implications. First of all, for African nations seeking to leap directly into rapid industrialisation, knowledge diffusion and innovation across industries, firms and government is essential. By knowledge diffusion, we are referring to the mechanisms by which technology knowledge is disseminated to the wider society (see Davenport & Prusak, 1998). Effective technology diffusion channels may encompass linkages between foreign and local firms in areas such as research and development, and training of workers (Blomström & Kokko 1998). For nascent entrepreneurs, the ability to utilise technology to manage and run their business operations is essential not only to reduce costs but also to turn their businesses into major players on the global scene. For indigenous firms, early technology adoption and utilisation can constitute a pivotal source of competitive advantage, thereby enabling them to establish first-mover advantage. Given that local innovations often stem from local knowledge development through research and development activities, firm-level human

capital development through training and research will go a long way in powering new innovations and building on technologies developed elsewhere.

Promising avenues for future inquiry exist including a need to delve into relationships between technology diffusion and exporting of obsolete technologies to developing countries and whether they have any potential effects on innovation. Although some scholars have long suggested that Africa represents "the last frontier" of the global economy, many firms and investors still overlook its potential (Quelch & Austin, 1993). There is a need to examine the effects of technological revolution on foreign firms' motives to invest in Africa. Concerning limitations, the analysis was limited to Africa as a region but there are variations within countries which have largely been overlooked. This represents a potentially fruitful avenue for scholars to examine the within-country adoption rates. The study provides a preliminary analysis of an emerging trend and a fast-developing region of the world. In closing, it is hoped that some of the issues outlined here would ignite new streams of research.

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Figure 1: A framework of barriers to technology diffusion

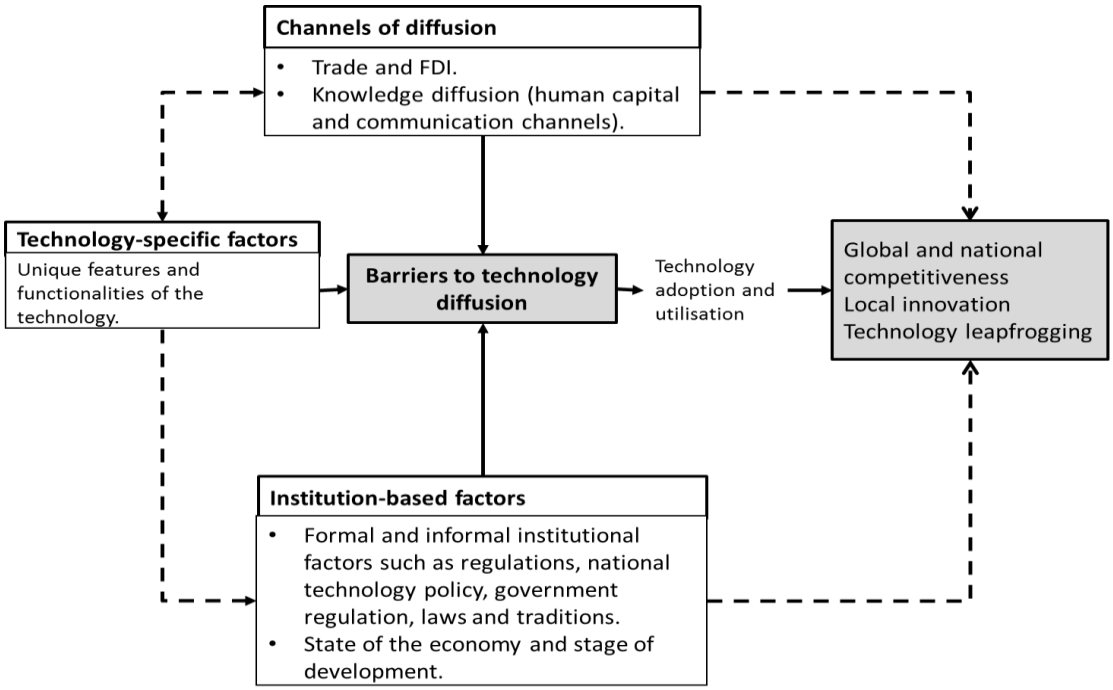

Figure 2: Barriers to Africa's technological revolution model

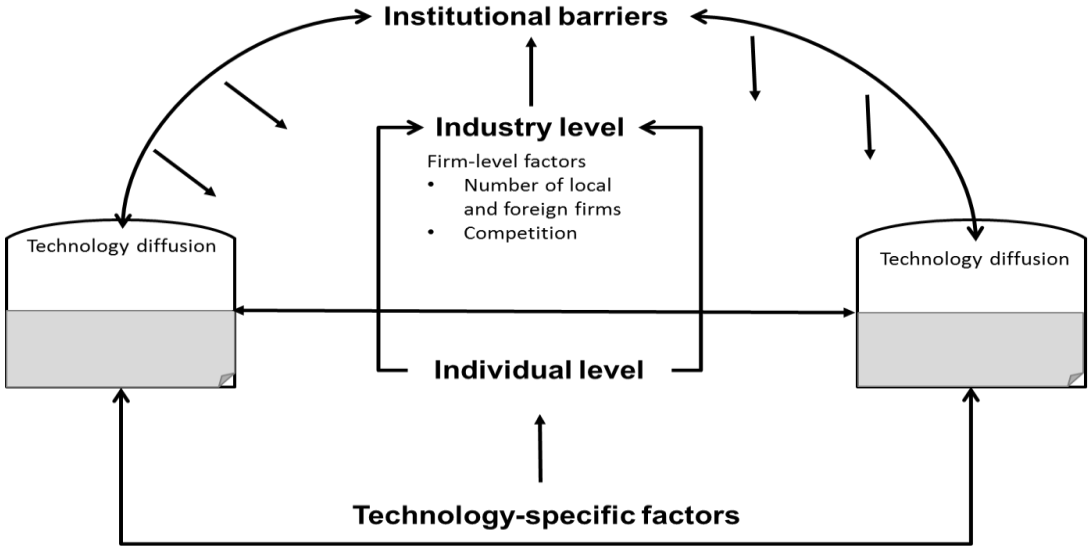

Table 1: Technology, innovations and emerging trends

Name	Nature of innovation	Nations	Application/uses	Gaps in the marketplace
mPedigree	Healthcare and social innovation	Ghana. Similar technology in use in Kenya, Tanzania and Zambia.	Technology utilises the mobile phone to help consumers to identify counterfeit drugs.	The new "tag and trace" technology is helping consumers to outfox criminals.
M-Kopa Solar	Solar technology	Kenya and Uganda	This combines off-grid solar technology and mobile micro-payments (i.e. M-Pesa mobile payment system) to scale-up solar technology (Espiner, 2014). In Kenya, 70,000 households have opted into the scheme.	Provides energy independence and reduces reliance on kerosene-powered generators which are expensive and pose risk to human health.
Hei Julor!	Private security	Ghana	Private security services and technology in Ghana.	Physical infrastructure, poor police response to emergency calls, and deficit in law and order.
The cardiopad	Healthcare innovation – targeting cardiovascular diseases	Cameroon	A computer tablet which diagnoses heart disease in rural households with limited or no access to heart specialists or medical services.	It enables examinations such as electrocardiograms to be conducted in remote areas and reduces unnecessary journeys to hospitals (Itnewsafrica, 2013; Holland et al., 2012). It was an attempt to tackle the sharp increase in the number of cases in the country.
Econet	Healthcare innovation	Zimbabwe	Remotely monitoring patients in Zimbabwe.	Physical infrastructure and cost of travelling to rural areas.
Solar kiosk	Solar-powered panels	Kenya	Provides an opportunity for individuals to pay to charge electronic devices including mobile phones and laptops.	This enables individuals to overcome the lack of limited availability of charging points inherent in many African cities.
The Inye computer tablet	Technological/ Communication innovation	Nigeria	The tablet can connect to the internet via a dongle rather than wireless – pay-as-you-go internet "dongle".	This circumvents the price and infrastructure constraints that have curtailed availability of the internet in many rural areas. To an extent, Africa has also been able to skip the desktop internet era and leap directly into mobile tech. (Holland et al., 2012).
The iCow app	Agriculture innovation	Kenya	The iCow app works by registering animals and then providing useful information to farmers such as immunisation dates, milking schedules and nutrition (Holland et al., 2012). This is a particularly important innovation given that around 80% of sub-Saharan Africa's population engage in some kind of farming (Jackson, 2015).	Fills the information vacuum by providing latest market product and pricing information (Holland et al., 2012).

The Tutu Van	Healthcare innovation	South Africa	A mobile clinic which offers services such as screening for tuberculosis, HIV and general health check-ups (Holland et al., 2012).	The service helps to circumvent some of the cultural and social barriers around TB and HIV screenings.
M-PEPEA	Financial innovations	Kenya	Customers would then be able to access financial credit through cash machines or branches of Safaricom using a special code delivered through their mobile phone (Holland et al., 2012).	To offer emergency credit through mobile phones to individuals without access to credit cards or bank loans. Mobile banking and mobile money transfers – this fills a void given that very few Africans have access to the formal banking system. This sidesteps the inertia of legacy systems.
"Cashless payment system"	Financial transaction innovation	Rwanda	Utilises pre-paid smart cards for some bus services in Kigali.	This reduces bus service delays and often protracted arguments about change which often disrupts public transport in many African cities.

Sources: synthesised from: Amankwah-Amoah, 2016b; BBC, 2016a, 2016b; Wachira, 2015; Wall, 2014; Holland et al., 2012; Wallis, 2016; WDR, 2016.

Table 2: Barriers to the technological revolution and industrial development in Africa

Level	Barriers to innovation and technological development
Technology-specific factors	• Information deficit about new technology. • Lack of awareness among potential users of the technology. • High upfront cost and uncertainty about the benefits and potential costs. This is a major barrier as regards solar PV.
Industry-specific factors	• Limited liberalisation and deregulation which curtails competition and consequently introduction of new technology. • Underdeveloped industrial and telecom infrastructure in countries such as Ghana and Nigeria.
Government level	• Government bureaucracy and political interference of business activities. • Lack of government investment in innovation, research and development. • Weak intellectual property protection. • Political instabilities in countries such as South Sudan and Guinea.
Firm-level factors	• Local firms often lack the ability to assimilate and utilise new technology to boost their competitiveness.

Sources: synthesised from: African Business, 2014; Versi, 2014; WDR, 2016.