Disruptive Technologies, Agricultural Productivity and Economic Performance in Kenya

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List of abbreviations and acronyms

AI	Artificial Intelligence
BMI	Business Monitor International
BTV	Botswana Television
COVID-19	Corona Virus Disease 2019
DATs	Disruptive Agricultural Technologies
DTs	Disruptive Technologies
DVA	DigiFarm Village Advisors
GCP	Gross County Product
GDP	Gross Domestic Product
GoK	Government of Kenya
GPS	Geographical Positioning Systems
ICOR	Incremental Capital Output Ratio
ICT	Information and Communications Technology
IoT	Internet of Things
IT	Information Technology
ITES	IT-Enabled Services
KALRO	Kenya Agricultural and Livestock Research Organization
KCC	Kenya Cooperative Creameries
KEPOFA	Kenya Poultry Farmers Association
KFA	Kenya Farmers Association
KIHBS	Kenya Integrated Household Budget Survey
KNBS	Kenya National Bureau of Statistics
KPCU	Kenya Planters Cooperative Union
MTPs	Medium-Term Plans
POPs	Persistent Organic Pollutants
SACCOs	Savings and Credit Co-operatives Societies
TV	Television

Abstract

Kenya is at the forefront of technological innovations and is often referred to as the 'Silicon Savannah' of Africa. Disruptive technologies in Kenya comprise of fast internet connectivity, ICT infrastructure investments, value-added services, mobile money, and mobile banking services, among others. Kenya's ICT sector, therefore, remains a key enabler to economic growth, resilience and overall economic performance across counties. Disruptive technologies in agriculture consisted of digital and technical innovations that enable farmers and agribusiness entrepreneurs to leap from current methods to increase their productivity, efficiency, and competitiveness, thereby facilitating access to markets, improving nutritional outcomes, and enhancing resilience to climate change while contributing to sustained economic growth.

Disruptive technologies have the potential to help address the inequality challenge. Adoption of disruptive technologies, including use of innovations in the context of modern methods of farming, has contributed to improved farm productivity, marketing and incomes. The study established a positive correlation between fertilizer use and agricultural productivity. This is because small scale producers, when exposed to relevant on-farm training, benefit more from the innovation, including use of fertilizers and certified seed. The use of manufactured feed is gaining traction in commercial intensive production systems such as poultry and had a positive and significant effect on productivity.

Key enablers for effective adoption of disruptive technologies include access to power, education and skills, and affordability of disruptive technologies in given sectors. Going forward, to harness the benefits of the disruptive technologies requires strong digital ecosystem and exploiting synergies at the national and county levels and across sectors of ICT, training and agriculture. There is need to leverage public private partnerships to mobilize long-term ICT infrastructure development across all the counties. Further, digital sector investments should be matched with enhanced investments in training, digital literacy, building communities of learning, and innovations.

Acknowledgment

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1.0 Introduction

Various African economies are driven by agricultural development in a mutually reinforcing way. The agricultural sector provides 80% of the livelihoods, creates employment to about 60% of the people, and 63% of the rural households derive their incomes from agriculture (Medium-Term Plan-MTP, II, 2012–2018). In addition, the sector accounts for 65% of the export earnings. The sector is also the main driver of the non-agricultural economy, including manufacturing, providing inputs and markets for non-agricultural operations such as building/construction, transportation, tourism, education, and other social services.[1] These forward and backward linkages of the agricultural sector ensure a linkage between the input and output sectors of the economy. For example, use of agrochemicals creates backward linkages with other sectors, whereas processing and value addition leads to forward linkages.[2]

Smallholder production systems are heterogeneous in terms of production systems and vulnerable to climate variability, land degradation soil erosion and a decline in soil fertility. This heterogeneity leads to district agro-ecological zones, with unique production techniques, challenges, and opportunities for investment. For example, pastoralism is widely practiced in the Kenyan arid and semi-arid lands, whereas most households practice mixed farming (Hunt et al., 2019). Agricultural production in Kenya is dependent on rainfall, with little irrigated production taking place. The agricultural sector is vulnerable to changing climatic conditions including erratic rainfall patterns, increased temperature, drought, and flood. Over 80% of Kenya's agricultural land is arid and semi-arid, making it vulnerable to variability in climatic conditions. Thus, it is difficult to achieve satisfactory productivity when rainfall patterns become more difficult to predict and very few farmers irrigate their farms. Thus, investment in agricultural production systems requires specific and targeted policies and interventions.

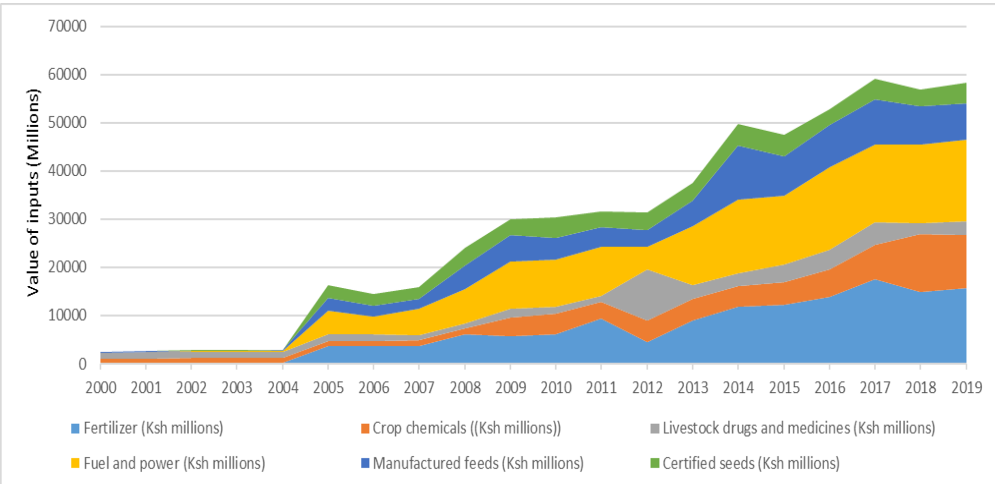
Agricultural productivity depends on the adoption of technological factors like irrigation, fertilizers, pesticide use, improved seed, and agricultural mechanization. These factors are vital for enhanced production. Over the last five years, the yield gap for most crops has been widening, for example, there is an estimated 50% yield gap in maize production and 70% yield gap in legume production. To reduce this yield gap, farmers need to adopt technology in the form of modern farm practices, and input

1 https://www.fao.org/kenya/fao-in-kenya/kenya-at-a-glance/en/

2 https://www.fao.org/3/y4383e/y4383e04.htm

use accounts for 38%, manufactured feeds 22%, crop chemicals 18%, and livestock vaccines and drugs 9% (Figure 1). These are a pointer towards the continuous efforts that the government had made through the fertilizer subsidy programme. However, the gains on this investment are yet to be realized due to various challenges, including weather variability that has resulted in frequent drought and floods episodes, and high pest and disease incidences. Notwithstanding, there are other factors that affect the number of inputs used for production, including production system and technical capabilities.

Figure 1: Proportion of input use (2000-2019)



Source: KNBS, 2016.

To continue supporting the economy, various agricultural research organizations have generated various technologies, but their impact on farmers' livelihood and quality of life has been minimal (World Bank, 2006). Disruptive technologies constitute of innovations that significantly alter the way that consumers, industries, or businesses operate. A disruptive technology sweeps away the systems or habits it replaces because it has attributes that are recognizably superior (Downes et al., 2013). Examples of recent disruptive technologies include e-commerce, mobile money, online news sites, ride-sharing applications, blockchains, and Geographical Positioning Systems (GPS), among others. Previously, automobile technologies, electricity service, and television constituted examples of disruptive technologies (Smith, 2020). With disruptive technologies, new firms may emerge as risk-taking companies recognizing the potential to innovate new products and risk-averse firms may adopt the emerging technologies; new jobs were created while contributing to job creation, better incomes, low poverty, and expansion of economic activities. On the other hand, companies that totally fail to adapt to changing business environment may risk exiting the market while contributing to job destruction, decline in incomes, and/or increased inequalities and, hence, increased population requiring social safety nets.

Further, the disruptive technology concept by Christensen (1997) refers to a phenomenon where a novel technology has lower cost and relative performance as indicated by the ordinary measures and whose ancillary impact is immense. It explains how a product/service originally emanates from the lower segment of the market characterized by lower costs and accessibility, and eventually seeps the upper segments (Downes et al., 2013). For disruptive innovation to be successful, the enabling environment must be well-aligned, starting with enabling technology that avails a more affordable and accessible product to a broad market; and it should deliver a product targeting the least profitable market segment.

Kenya has experienced major developments in technology innovations in the last three decades, and various sectors in the economy have potential to benefit from adopting technology. For example, according to the Business Monitor International (BMI), Kenya's ICT market was valued at US$717 million at the end of 2019 with computer hardware accounting for 60% of the total ICT investments and the remaining balance from ICT services. Kenya is at the forefront of technological innovations and is often referred to as the 'Silicon Savannah' of Africa. The Government of Kenya (GoK) has invested heavily in the broadband sector. There are currently four undersea fibre optic cables that land off the coast of Kenya, namely SEACOM, TEAMS, EASSY, and LION2, which are the core drivers of the heavy fixed internet penetration in the country making it one of the highest, fastest, and most reliable in the region. Kenya is a regional leader in terms of Internet connectivity, general ICT infrastructure investments, value-added services, mobile money, and mobile banking services.

The country's ICT sector was set to contribute up to 8% of the country's GDP through IT-enabled services (ITES) and create 250,000 jobs by the end of 2020 (GoK, 2021). Internet access has continued to spur economic growth and led to the government's launch of the Digital Economy Blueprint (2019), a framework to improve Kenya's and by extension Africa's ability to rebound and attain sustained economic growth. The policy framework is hinged on five pillars, namely, digital government, digital business, infrastructure, innovation-driven entrepreneurship, and digital skills.[3] ICT innovations have also become an important enabler in economic operations and promoted greater efficiency and economic competitiveness, while promoting firm resilience and business continuity amidst the COVID-19 pandemic. In addition, many diverse services that support industries are gradually shifting into the ICT space. These include data acquisition or capture, communication, decision-making, on-job training, and monitoring of production processes. This study focuses on adoption of disruptive technologies in the agriculture sector.

The agriculture sector is large, complex, has various dispersed actors, and constitutes 26% of the GDP. Agriculture sector comprises of livestock and crop farming. Kenya Agricultural and Livestock Research Organization (KALRO) is mandated to carry research to address the constraints in both the livestock and crop sub-sectors through

3 https://www.trade.gov/knowledge-product/kenya-information-communications-and-technology-ict

the development of technologies that: provide livestock of high genetic potential, improved feed availability throughout the year especially dry season feeding, come up with well-suited livestock forage and fodder for the different production systems, and improve value addition on both crop and livestock products.[4] Whereas the sector is complex, development of various value chains and sub-sectors are dependent on different levels of government investment, a varied range of technologies, and a wide range of partnerships.

As a result, this study concentrated on these areas and value chains where technological innovation will result into significant impact to both food and livestock production. Only about 17% of the country's land is high and medium potential agricultural land where most intensive crop and dairy production take place. The rest is arid and semi-arid, not suitable for rainfed agriculture. Thus, increasing agricultural production will rely on intensification of land use in the high and medium potential lands. Resource use and market access was marked by varied efficiency levels. Smallholder farmers struggle to connect with input suppliers whether for seed, machinery, fertilizer, finance, or advisory services, and with farms and farm enterprises. Food production is risky, in part because of limited information about weather patterns, soil characteristics, future market demand, and other variables. With limited information, farmers' decisions are based on intuition, and thus are often less efficient than they could be. In addition, Kenya's food system suffers from inequalities in access to technologies, information, and markets. These inequalities manifest in the form of marginalized groups, such as low skilled farmers, both men and women, based in rural areas with limited connectivity, who traditionally have lower access to information and markets.

Disruptive technologies, therefore, have the potential to help address the inequality challenge. The relationship between technology and inequality is multifaceted. Technology can enhance productivity, accelerate economic growth, enable knowledge and information sharing and increase access to basic services. Disruptive technologies in agriculture, such as use of Internet, can help reduce inequality by making information available to all farmers. They are, therefore, able to have information about market prices for their farm output and farm inputs. Disruptive technologies in agriculture consist of digital and technical innovations that enable farmers and agribusiness entrepreneurs to leap from current methods to increase their productivity, efficiency, and competitiveness, thereby facilitating access to markets, improving nutritional outcomes, and enhancing resilience to climate change, while contributing to sustained economic growth.

Agri-tech solutions range from mobile phone apps to solar applications, portable agriculture devices, and bio-fortified foods (Kim et al., 2020). Other examples include Internet of Things (IoT) which simplifies the work of farmers in the agriculture sector. Sensors are used to gather data on the soil content, rainfall, humidity, temperature, and other factors that enable automation of farming techniques. Satellite imagery

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4 https://www.kalro.org/divisions/livestock/

helps in the early detection of seasonal problems in the farms such as presence of pests and diseases and nutrient deficiencies. The presence of this information enables farmers address their crops to ensure high yields. Big data and Artificial Intelligence (AI) are being used to reach the needy people during emergencies such as COVID-19 pandemic. Geographical positioning system (GPS) technology helps farmers to accurately locate specific area in the field where they can monitor crop conditions and collect soil samples for laboratory analysis.

The agriculture sector faces such challenges as inadequate ICT literacy skills, which hinder uptake of disruptive technologies, inadequate ICT infrastructure, unreliable supply of electricity, and poor network coverage (World Bank, 2020). Cutting across regions, disparities in Internet access characterized by low network coverage across the country, prevalent poverty levels, reduced household income in the face of the pandemic have led to disparities in utilization of disruptive technologies. Various sectors such as ICT and finance have produced competitive and innovative strategies in search of favourable competitive positions in the agriculture sector and industries to adapt to the changes either due to COVID-19 and/or need to advance innovation and attain competitive advantage. Although the country has made substantial achievements in terms of technology in the ICT and financial sectors, more need to be done especially in the ICTs, agri-business, and ICT skills enhancement sectors for enhanced uptake of disruptive technologies. Consequently, the uptake would result into increased sector efficiency and productivity leading to the economic growth and increased opportunities. This study will explore the effect of disruptive technology in agriculture sector, and how disruptive technologies can contribute to poverty reduction and sustained economic growth.

The study, therefore, focused on the nature of disruptive technologies in Kenya with specific focus on agriculture and ICTs; their potential to support emerging industries with specific focus on implications on sustained economic performance. The study addressed the following research questions: What form do disruptive technologies take in agriculture? To what extent do disruptive technologies support agricultural productivity? To what extent do disruptive technologies contribute to economic performance? What infrastructure and enabling environment is required to take full advantage of the disruptive technologies?

The broad objective of the study was to understand the nature of disruptive technologies in Kenya with specific focus on the agriculture sector. The specific objectives include to:

(i) Assess the nature of disruptive technologies in Kenya, and their potential to support emerging industries with specific focus on agriculture and related ICTs.

(ii) Determine the impacts of disruptive technologies on agricultural productivity and economic performance.

(iii) Establish infrastructure and enabling environments (including skills and training) required to take full advantage of the digital revolution.

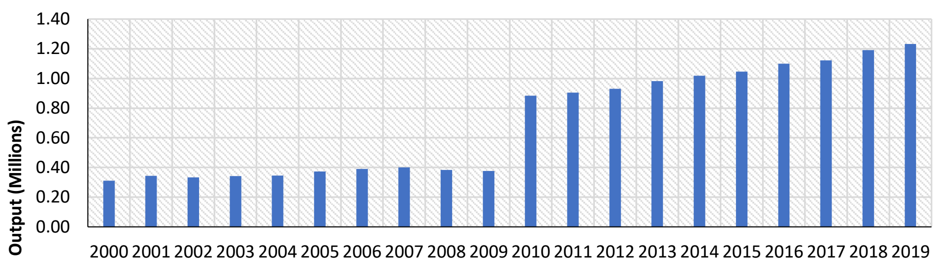
(iv) Provide policy steps needed to be taken to help Kenya harness the benefits of digitalization and mitigate its risks; and identify sectors in which additional policy actions are needed.

2.0 Agriculture development in Kenya

Agricultural output growth (2000-2019)

There has been a gradual increase in the total aggregate agricultural output over the period under review. There has been increase in agricultural output from the year 2000 where the agricultural output was estimated at Ksh310,716 million through the year 2019 in which agricultural output increased to Ksh1,232,714 million (see Figure 2). Increase in agricultural output is attributed to government policies targeting the agriculture sector. A sharp increase in the years 2018 and 2019 was specifically attributed to Government Kenya Vision 2030 commitments and its Medium-Term Plans (MTPs), including the Big 4 Agenda where food nutrition and security is one of the priority areas.

Figure 2: Agricultural output growth (2000–2019)



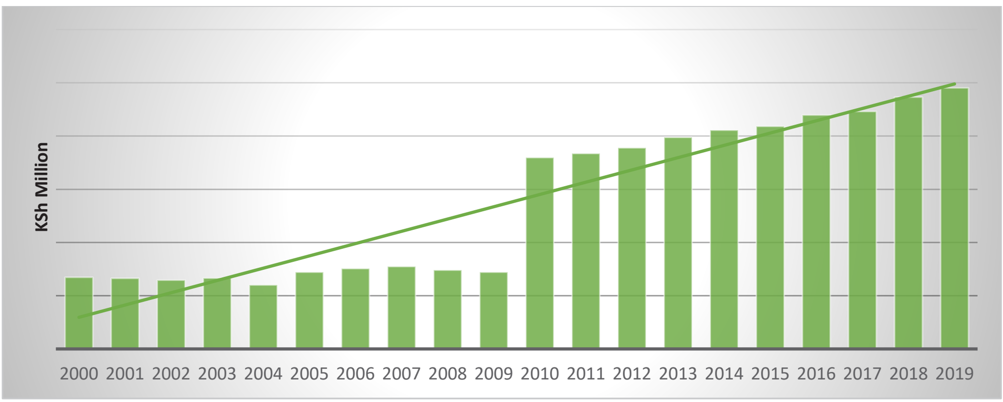
Source: KNBS, 2019

Agricultural value addition

Kenya's agriculture sector has been experiencing growth characterized by an increase in value addition activities. Tremendous growth was experienced from the year 2010 to 2019, where the gross value addition in millions increased from Ksh718,727 to Ksh981087 at current prices (Figure 3). This was attributed to the Kenya Vision 2030 which underscores value addition and marketing efficiency as one of the priority areas under the economic pillar. This was implemented under MTP II leading to increased value addition of the agricultural products. Various agricultural cooperatives that had collapsed were revived during this period, hence played a critical role in the production, processing and marketing of major agricultural commodities and services and mobilization of savings through Savings and Credit Co-operatives Societies (SACCOs). This process started in 2002, and it started by the revitalization of Kenya Cooperative Creameries (KCC) in 2003 (Atieno & Kanyinga, 2008). Other cooperatives include the Kenya Planters Cooperative Union (KPCU), Kenya Farmers Association (KFA), and textile industries like Rivatex and Kicomi

Currently, the country has a total of 25,050 cooperatives, employing a substantial number of the Kenyan population either directly or indirectly.[5] Moreover, the Kenyan cooperatives have been ranked as the top movement in Africa and fastest growing sub-sector in the world.[6] Value addition to agricultural commodities implies increased net returns to farmers and improvement of other multiplier benefits from further processing into higher value products and by-products such as employment in processing, forward and backward linkages with other services and complementary raw material suppliers. Value promotes technology transfer, especially to the rural economy where further processing occurs, hence improving households' livelihoods. Promotion of value addition has received immense government support, including establishment of export processing zones. Value addition also plays a critical role in food loss reduction and an overall reduction to greenhouse gas emissions (FAO, 2014).

Figure3: Gross value addition in the agricultural sector (2000-2019)



Source: KNBS Abstract, 2019.

It is worth noting that the average productivity of major crops in Kenya has not increased at a significant rate annually. For example, the maize productivity increased by 17% over the last ten years resulting in an annual increase of about 1.7%. There

5 https://coops4dev.coop/sites/default/files/2021-04/Kenya%20Key%20Mapping%20Data.pdf

6 https://www.industrialization.go.ke/images/downloads/history-and-organization-of-cooperative-development-and-marketing-sub-sector-in-kenya.pdf

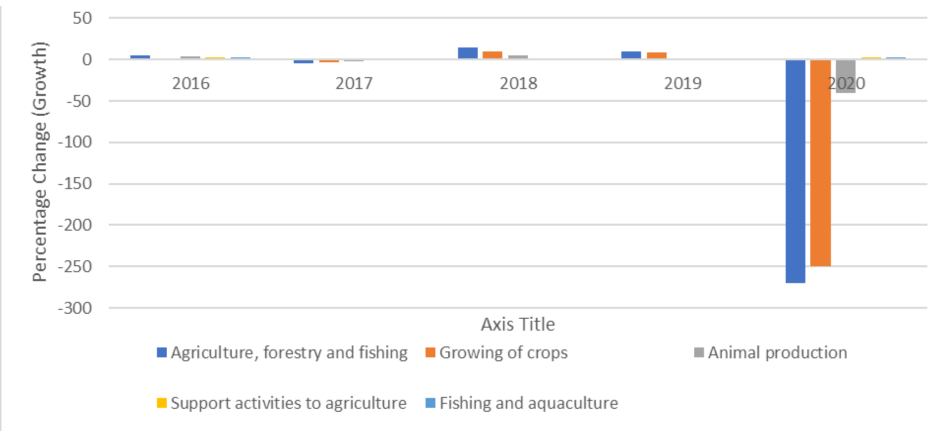
are multiple reasons why growth in productivity has been slow. These include low access to extension and advisory services, including digitally enabled agripreneurs, and lack of inputs and quality data. To reach their full potential, farmers need to have access to the latest technologies and data.[7]

Agriculture and economic performance

Agriculture contributes to the satisfactory performance of the Kenyan economy. In the year 2020, agricultural activities were more vibrant than in 2019, but the sector's exports were negatively impacted on by contraction in global demand. Gross value-added of the sector grew by 4.8% in 2020 compared to a revised growth of 2.6% in 2019. This was on account of favourable weather conditions in 2020 which improved production of food crops such as beans, rice, sorghum, and millet, and livestock and related products such as milk and meat. There was mixed performance in the production of cash crops during the review period. Tea production increased by 24.1% from 458,800 tonnes in 2019 to 569,500 tonnes in 2020. The volume of cane deliveries, in tonnes, increased from 4.4 million in 2019 to 6.0 million in 2020. Coffee production and horticultural exports declined by 18.0% and 4.5% to stand at 36.9 and 313.6 thousand tonnes, respectively, in 2020. However, earnings from horticultural produce increased by 3.9% to stand at Ksh150.2 billion in 2020. The increase in the earnings was attributed to better international export prices for the horticultural products in the review period (GOK, 2021).

In 2020, there was a shift in the sectors contributing to economic growth because of the COVID-19 pandemic. Major sectors supporting the economy were affected hence leading to the contraction of the economy. However, growths in Agriculture cushioned the economy from deeper contraction (Figure 4).

Figure 4: Agriculture as a source of growth (2016–2020)



Source: KNBS, 2021.

7 https://www.worldbank.org/en/events/2019/04/05/disruptive-agricultural-technology-challenge-and-conference

Disruptive technologies in agriculture

The steady growth of Kenya' agriculture sector in the past three decades is evidence of a success story. Kenya's agriculture sector has grown by 4.8% annually since 2012, with its share of GDP at 33% as of 2016 and 26% in 2019. However, the agriculture sector still faces significant challenges that range from effects of climate change and poor farming technologies to poor prices for agricultural products.

Recognizing that technology has a critical role to play in the agricultural sector, the Ministry of Agriculture has formulated various policies and strategies to improve the sector. For example, the agriculture sector has put in place a 10-year Agricultural Sector Transformation and Growth Strategy (2019–2029). One of the priorities is on the transformation of smallholder agriculture from subsistence to an innovative, commercially oriented, and modern agricultural sector. Smart agriculture can be part of the solution to reactivate the growth in the agriculture sector. It was observed that the right application of technology can be leveraged to address the challenges like food security in current times and the future. For example, the use of computing devices and precision agriculture can allow agriculture businesses to be more profitable, efficient, safer, and more environmentally friendly. The Internet of Things (IoT) is one of the disruptive technologies that can offer innovative solutions to support the agricultural sector to achieve inclusive agricultural growth, nutrition, and food security in the country.

Disruptive technologies, such as the IoT, enhance the agricultural productivity by meeting food demand. Food security is a key part of Kenya's Big 4 Agenda by the government. The IoT based technologies supports the development of smart agriculture to boost operational efficiency, maximize yields, and minimize wastage due to real-time field data collection, data analysis and deployment of control mechanisms. Kenya is home to about 25% of agriculture tech start-ups in sub–Saharan Africa. Description of the key start-ups supporting the agricultural sector in Kenya is provided here below.

The IoT solutions such as the sensors assist in establishing accurate real-time weather conditions such as rainfall, humidity and temperature which have an impact in the quality and quantity of crop production. The use of sensors helps farmers increase their productivity and reap massive agricultural benefits. Using generated soil fertility map, the agricultural extension officers can recommend the right amount of fertilizer to be used by farmers. Wireless sensor network where sensors are positioned both inside and outside agricultural fields can be used in collecting data from the environment which can be used to determine the right crops that can be grown and sustained in the established climatic conditions. Precision agriculture/satellite farming/site specific crop management which is a farming concept of improving crop yields and the use of technology such as sensors, robots, drones, GPS guidance, control systems, among others can be used as data and analysis tools to manage and make smart and quick decisions. Precision agriculture has aided in the analysis of the soil condition and other farming parameters to increase efficiency in the daily operations. Smart Greenhouse using IoT greenhouses can adjust climate conditions automatically based on defined set of instructions. They have made the farming process to be cost-effective and increase accuracy by eliminating human interference. Sensors assist in monitoring the consumption of water and the state of a greenhouse by sending alerts via SMS and emails. Examples of disruptive technologies (DTs) in agriculture are presented in Box 1.

Examples of DTs in agriculture in Kenya

DigiFarm is an integrated mobile platform that offers farmers convenient, one-stop access to a variety of services including discounted inputs and advice on input use, financing, and information on crops and animals[8] . The platform also improves collection of agricultural data by registering farmers and allowing them to key in information such as the size of their farms and nature of farming activities. Other value-add services provided through DigiFarm include insurance yield cover and extension services through remote agronomists located at the DigiFarm call centre or on ground DigiFarm Village Advisors (DVA). Registered farmers have access to discounted farm inputs from DigiFarm Master Agents located nearest to them in different counties across the country. Registered farmers will be able to access learning information on livestock and crops to educate them on best farming practices that will help them maximize their yield[9] . Registered farmers will have access to a credit voucher which they can redeem to receive farm inputs such as feeds, seeds and fertilizers from the DigiFarm Master Agent. Registered farmers will be provided with access to market services where they will have an opportunity to sell their produce at competitive rates.

M-Farm is a transparency tool for Kenyan farmers where they simply short messages (SMS) the number 3555 to get information pertaining to the retail price of their products, buy their farm inputs directly from manufacturers at favourable prices, and find buyers for their produce. M-Farm gives farmers up-to-date market information, links farmers to buyers through the marketplace and current agri-trends. M-Farm offers smallholder farmer with three services: price information, collective crop selling, and collective input buying. The application is currently used in collecting wholesale market price information on 42 crops in five markets in Kenya. Pricing information is collected daily through independent data collectors using geocoding to ensure that the prices are being collected from wholesale traders located in each market. M-Farm Services is available on Android platforms. A study by Baumüller (2015) found that survey of M-Farm users confirms that m-services offering

8 https://www.safaricom.co.ke/faqs/faq/810

9 https://mercycorpsagrifin.org/wp-content/uploads/2019/05/DigiFarm-Platform-Case_Final_.pdf

price information can help farmers plan production processes better. The study also showed that the radio can be an effective dissemination channel especially at the early stages of production.

SunCulture is a mobile enabled, solar-powered irrigation system for Kenyan smallholder farmers. SunCulture uses pay-as-you-go technology to ensure rural communities can afford and have access to water pumping solutions. The best feature of SunCulture in agri-tech is that it allows for flexibility and reliability through remote monitoring, predictive maintenance, and performance optimization features.

SolarFreeze uses an integrated approach to post-harvest management to help smallholder's farmers in Kenya deal with post-harvest losses. SolarFreeze's mobile app and Internet of Things (IoT) platform helps to monitor Cold-Chain distribution networks and fresh produce being delivered to clients in solar powered cold rooms and energy efficient trucks.

iProcure's supply chain platform offers complete procurement and last mile distribution services, providing businesses with intelligent and data-driven stock management across supply chains. Operating in rural Kenya, with its storage facilities strategically located to ensure extensive reach to their consumers, iProcure uses a predictive algorithm to ensure the most popular goods are always available.

Waziup is an Internet of things (IoT) and big data platform for farm management. It extends Internet connectivity beyond conventional computing platforms and into a range of non-internet-enabled everyday devices. The platform's smart farming applications include ways of monitoring soil moisture, water storage tanks, cattle, and field conditions. It can also track agro-management decisions such as date of sowing, irrigation, fertilizing and tilling. Waziup's technology is adept at delivering in tough conditions, particularly in low power and long-distance applications.

Twiga Foods is a food supply chain platform that allows grocers to access quality products, at cheaper prices, delivered directly to their shops. Providing vendors with a simple mobile-based ordering platform to purchase stock, and farmers with predictable pricing for their crops. Twiga works with more than 8,000 Kenyan farmers and over 5,000 vendors, linking smallholders in rural areas to retail vendors in cities.

Twiga Foods is supported by Liquid Intelligent Technologies to deploy a complete precision agriculture IoT system to improve farm productivity at Twiga's Takuwa farm. The system includes four different types of agriculture sensors: a comprehensive weather station, soil moisture and temperature probes, borehole water meters, and sensors for measuring irrigation water acidity and salinity. The system takes advantage of Liquid Intelligent Technologies' extensive low-power wide area IoT network using 0G Sigfox technology covering 85% of the population in Kenya at lower costs than other technologies. The IoT sensors provide critical information to the Twiga agronomy team, helping to measure temperature, humidity, rainfall and wind speed to give real-time data at the farm site. This helps the farm managers know the right farming approach to be applied, such as when to irrigate or apply pesticides. Further, the water quality sensors provide specific metrics that help the team to optimize their fertilizer application. Liquid Intelligent Technologies has installed soil probes that measure moisture levels and temperature at six different depths into the soil, giving precise information of soil quality and irrigation needs at the roots of specific crops. This is set to improve farming methods at Takuwa farm and contribute towards increase of crop yield for Twiga Foods.

Source: Online resources.

Other examples of disruptive technology in agriculture include data analytics where agriculturalists use sensors to collect data on a large scale. Data analytics assist in the analysis of crop conditions, weather conditions, and livestock conditions, thus assisting in making better decisions. Use of aerial and ground sensors to increase yields and reduce costs by assessing crop health, crop spraying, planting and performing field analysis and use of renewable energy such as wind, biomass and solar provides farmers with a long-term source of income. This also helps in preventing dependency on imported fuels, reduces pollution and global warming. Disruptive technologies have revolutionized farming over the few decades leading to higher productivity, effective use of water, fertilizer, and pesticides thus reducing cost of production as well as reduced impact on natural ecosystem. The use of new and innovative technologies in agriculture will attract youth to farming, thereby helping reduce unemployment and migration to cities. Further, disruptive technologies will allow farmers and their families to be more economically, socially, and environmentally sustainable.

The effects of COVID-19 pandemic, including the movement restrictions imposed by the government, had disrupted the food production and distribution chains. Technology and new digital tools played and continue to play a significant role in the agricultural sector by offering timely information and tools to farmers. For example, technology-based tools help farmers use precise amounts of inputs, detect issues with their crop and better manage their farm operations. It is evident that digital products are facilitating various businesses to make better decisions in reducing operational inefficiencies and widening access to local and global markets.

Disruptive technologies in agriculture related ICTs

Digitization supports the IT industry in several ways. Some of the innovations include cloud computing which involves the provision of computing services such as databases, servers, analytics, storage, networking, software, and intelligence over the Internet. In the modern business world, access to information was especially important to both business owners and their employees. Cloud computing offers the flexibility of data access if one has Internet connection. This has brought about immense change such as availability of file storage, data backups and disaster recovery as compared to the traditional IT infrastructure. The impacts of cloud computing include cost reduction on the purchase of computer resources where large files can be shared among employees seamlessly in real-time through emails without having to use the external storage devices such as flash drives. It has also offered flexibility to small/medium business owners who are always mobile and need to access their data from anywhere, and management of businesses and project collaboration has become simpler as employees can work remotely.

Automating business processes has helped reduce repetitive tasks in organizations and facilitated more time for creativity and accomplishment of complex tasks that cannot be automated has been created. In addition, Internet of Things (IoT) which refers to a collection of physical devices that have sensors and other technologies embedded in them to connect and exchange data in real-time with systems and other devices over the Internet without human intervention (Ranger, 2020) has contributed to the digitization of the ICT sector. Any physical device/object can be converted to an IoT device once it has been connected to the Internet for the purpose of exchanging information. Examples of IoT devices include a lightbulb that can be switched on and off using a smartphone app, smart home security systems, wearable health monitors, voice assistants such a Siri and Alexa. Some of the impacts of Internet of Things include provision of a real-time outlook into how business systems work by providing insights for machine performances and operations. Deployment of the IoT ends up automating processes and reducing labour costs and service delivery improvement, thus lowering costs of goods delivery, and offering transparency on customer transactions.

Financial Technology (FinTech) involves the use of technology to offer financial services that lead to customer satisfaction. Some examples of FinTech include digital lending and credit, mobile banking, mobile payment, and cryptocurrency and blockchain. Impacts of FinTech in agriculture include use of FinTech has led to increased levels of transparency in the finance sector, financial institutions are using the latest security techniques to ensure that many customers are confident using their financial services and that the customer data is secure (GOK, 2021). FinTech optimizes efficiency and boosts productivity, thus creates competition with the traditional financial institutions. Through improved and modern financial services, the customer retention rate grows resulting to increased profits in the FinTech companies. Lastly, FinTech companies have increased number of people who use their services since the financial services are accessed through mobile connectivity.

Education, skills training, and use

Effective adoption of disruptive technologies in all sectors, agriculture included, requires that the population has adequate ICT skills and devices and are enabled to use the devices though Internet and power connectivity. On the other hand, digitization supports education through e-readers and tablets which bridge the education divide around the globe by enabling learners become computer literate. The use of tablets improves the delivery of education curriculum through the innovation of games, quizzes, and videos to supplement the text material which enables students better understand the learning material. Online learning/ virtual lessons make it possible for remote learning and has enabled students gain control on their learning and an opportunity to reflect on what they learn, while later applying the same in the workspaces. Custom e-learning platforms have business intelligence tools integrated in them making it easy for tutors to analyse student data and monitor the education progress of a specific learner. Artificial Intelligence, which is the ability of computers and machines to perform tasks that are associated with human intelligence, has potential to enable educational materials to be recorded and shared efficiently, student progress evaluation, efficient generation of students' reports, performance analysis and grading. Virtual reality and augmented reality have the possibility of transforming the educational sector but unfortunately the tools have not been fully utilized in education sector save in the gaming industry. Virtual reality has a high potential for growth in the education sector as it allows the recreation of cheap and realistic scenarios for students studying medicine, physics, and archaeology. In Kenya, virtual reality devices used in education are minimal due to its cost and skills gaps.

Christensen (1997) argues that an innovation only qualifies as disruptive innovation if it can balance the various interests of the stakeholder such as consumers, suppliers, and other partners upon its proliferation. Under the disruptive innovation, firms that make the right strategic choices are likely to have competitive advantage. The main assumption is that the firms have perfect access to information about disruptive trends in the environment. The preposition also ignores the influence of firm heterogeneity in its postulation on the influences of disruption to the state of firm competitiveness (Constance et al, 2007). Further, there are limited empirical studies on status of disruptive technologies in the country, and available infrastructure and enabling environments required to take full advantage of the digital revolution. The current study will attempt to fill this gap while focusing on agriculture and the country's economic performance.

3.0 Related literature

Disruptive technologies in agriculture

Disruptive technologies in the agriculture industry have potential in improving the decisions being made in the industry. According to Mahant et al. (2012), E-Agriculture involves the use of ICT to exchange information and ideas around the globe in order to improve the agriculture sector and promote the development of rural areas. A study was conducted by Namisiko and Aballo (2013), and a quantitative technique used to gather data to investigate the awareness, usage and farmers perception on the use of E-agriculture techniques such as M-agriculture and E-commerce in Trans Nzoia county in Kenya. The results proved that majority of the farmers had an idea of E-agriculture but were reluctant to use the technologies.

Farmers lacked sufficient information on the market prices of their produce. This causes them to make losses in their sales and increases food insecurity. The implementation and use of agricultural disruptive technologies would assist farmers sell their produce at competitive and market based prices (Namisiko & Aballo, 2013).The Kenya Vision 2030 economic blue print aims to ensure that farmers in the agricultural sector get quality and reliable information that will enable them access markets to sell their produce at competitive prices (Ministry of Planning and Devolution, 2007). Countries that have taken up the use of E-agriculture have recorded an increase in the sale of market produce leading to economic growth and promotion of food security. In India, the government set measures to ensure that farmers used E-agriculture which led to increase in economic growth by 3% (Namisiko & Aballo, 2013).

In Kenya, there are limited policies that encourage the use of E-agriculture by the farmers, albeit the increase in the use of mobile phones in both urban and rural areas. Krell et al. (2020) noted that, as of March 2018, 95.1% of Kenya's adult population owned phones while 42.9% of the population had access to the Internet. Internet access had become affordable thus M-services had immerged to assist farmers become aware of crop prices and connect to both buyers and sellers. Examples of the M-services were mkulima (farmer) online, M-Farm that offer marketing and price service and Twiga Foods that connects farmers to buyers through a mobile platform (Namisiko & Aballo, 2013).

The use of green house agriculture seems to be the preferred alternative since crops can be grown throughout the year and are restrained from experiencing the harsh weather conditions (Antony et al., 2020). Green houses, however, do face challenges such as lack of climate control in the green houses, difficulty in crop growth monitoring, crop harvesting, among others. These challenges can be addressed through using smart greenhouses. Smart greenhouses include the application of Internet of Things technologies such as smart sensors, big data analytics which aid in decision-making and network topologies to the farms. In Kenya, researchers at Dedan Kimathi University of Technology developed an IoT temperature, relative humidity, and soil moisture sensor which were connected to Internet gateway to assist farmers in making proper adjustments to the greenhouses. The use of IoT proved to be successful as it improved the tomatoes output in the greenhouses (Antony et al., 2020).

Beuürmann (2015) conducted a study about telecommunications technologies, agricultural profitability, and child labour in rural Peru. The study established that the introduction of mobile phones had raised agricultural profitability by increasing the value that farmers received for each kilogram of agricultural production and by reducing agricultural costs.

Baumüller (2015) conducted a case study in Kenya to examine the impact of the price information and marketing m-service M- Farm on Kenyan farmers' decision to adopt agricultural technologies and generate income from their use. The study found that price information had helped them in their production planning and thereby adapting their cropping patterns by expanding lucrative crops. It also examined the relative role of mobile phones in delivering the price information service vis-à-vis other information channels. The radio was found to be an equally useful source of price information in the initial stages of production, but M-Farm gained in importance towards the sales stage when farmers required timely information. Thus, disseminating price information both through the radio and the mobile phone appeared to be the best strategy to reach many farmers. The study used data from one region only when examining the impact of M-farm.

In Uganda, Martin & Abbott (2011) conducted a study about mobile phones and rural livelihoods (diffusion, uses, and perceived impacts among farmers in rural Uganda). The study established that farmers used their phones for a range of farming activities, especially: to coordinate access to agricultural inputs such as training, seeds or pesticides (87% of farmers), accessing market information (70%), requesting agricultural emergency assistance (57%), monitoring financial transactions (54%), and consulting with expert advice (52%).

Krishnan et al. (2020) established that The Eastern Africa Farmers Federation is running the e-Granary mobile platform to increase access to market information and e-extension services for farmers to mitigate the lack of access to conventional extension services in Kenya. The project meets the needs of farmers by using mobile phones to increase their access to real-time market information, which helps inform food production and trade within the region. The e-Granary platform enables farmers to decide when, where and at what price to sell their products. This information helps them make more informed production and marketing decisions. The project began in 2018 and currently has 250,000 registered farmers. It sends targeted voice messages to registered farmers based on location and crop. The most common crops are maize and sorghum in Meru and Trans-Nzoia counties in Kenya.

Kim et al. (2020) established that challenges in agriculture (for example, irrigation, access to inputs, among others) remain pressing and the adoption of Digital Action Tracking Systems disruptive agricultural technologies (DATs) is low in sub-Saharan Africa. However, evidence shows that DATs can amplify the impact of "analogue" investments. Regarding scale of operations, from 1,000 farmers to more than 600,000 farmers make use of particular DATs, depending on the delivery model, indicating the successful adoption of DATs within the agri-food system.

Disruptive technologies in related ICTs

Moriro (2018) conducted a survey on disruptive innovation and competitive advantage of large telecommunication firms in Nairobi County. The study established that Kenya technological dynamism of the telecommunication firms in Nairobi County was characterized by innovative disruptions from various players. Whenever such disruptions occur from small players in the industry, it normally attracts retaliation from big players leading to multiplier effect in the industry.

Nyambura et al. (2019) examined the state of ICT in Kenya. The study concluded that there is substantial growth in the ICT sector in Kenya. With devolved governance, the counties have been competing on effective and efficient service delivery to the citizenry through innovations, a number of which use digital technologies. The positive growth witnessed in the mobile money services market has been driven by the widespread use of mobile money solutions, and Kenya's commitment to advancing financial inclusion.

The ICT sector is expected to continue expanding and catalyse growth in financial services, health, housing, transportation, and agribusiness sectors. Robust growth of the ICT sector over the medium term was driven by growing access to 4G mobile technology and mobile money services, E-commerce, and Internet penetration.[10]

Disruptive technologies in education and use

Nchunge et al. (2012) found that, although ICT plays a crucial role in effectiveness, efficiency, and service delivery in education, its adoption in Kenya has remained limited. The study found that the pace of ICT adoption was slowed by a perception among users that ICT was complex, by the fact that many potential users had inadequate technological literacy, by the lack of psychological and technical readiness, and by insufficient policy guidelines. They argued that inadequate technical and psychological preparedness impeded attitudinal and behaviour changes, which, in turn, hampered technology use.

10 https://documents1.worldbank.org/curated/en/968481572468094731/pdf/Kenya-Economic-Update-Securing-Future-Growth-Policies-to-Support-Kenya-s-Digital-Transformation.pdf

Njoroge and Kibaru (2012) established that there are various challenges that have hindered the integration of instructional change and ICT. One difficulty is the personnel who ICT improvement would affect. While classroom teachers are the main agents of innovation and diffusion of skills and ideas at the school level, the role of head teachers in ICT programme implementation cannot be underestimated.

Piper et al. (2015) conducted a study on Kenya's ICT policy in practice (the effectiveness of tablets and e-readers in improving student outcomes). The study established the need to integrating ICT not as a panacea to instructional challenges but should be designed in ways that can support effective pedagogical improvement. The current ICT policy resulted in the teaching of computer science or information technology as discrete subjects both in secondary schools and in teacher training colleges, rather than embedding the use of ICT into larger reform processes. The study, however, did not highlight the success achieved by integration of the ICT in the education sector and implications on the productive sectors.

Kirimi (2014) investigated the impact of information communication technology on education in Kenya. The results showed that, at the policy level, the Ministry of Education had not produced ICT policy, nor encouraged secondary schools to come up with the same in support of ICT use in school management, a shortcoming that for some time led to ad hoc acquisition of computers by the schools for lack of a proper strategy. The study showed that a high proportion of the teachers and administrators lacked training in essential ICT skills in database applications and administrative software needed for the effective application of ICT to school administration, thus leading to limited use of computers for administrative purposes. The situation could have changed given the adoption of digital devices in learning institutions across the country.

Overview of the literature

Disruptive technologies are important within the agri-food systems (Antony et al., 2020) and effective adoption of disruptive technologies requires that the population has adequate ICT skills and devices and are enabled to use the devices though reliable Internet and power connectivity. Although some studies have focused on importance of ICTs in education (Piper et al., 2015), there is limited evidence on implications on disruptive technologies in the productive sectors such as agriculture; and level of readiness across counties to benefit from digitization. The current study provides an understanding of the nature of disruptive technologies in Kenya with specific focus on the agriculture sector and related ICTs; estimates the impact of disruptive technologies on agricultural productivity and economic performance; and identifies the requisite infrastructure and enabling environments to take full advantage of the digital revolution while mitigating its potential risks.

Theoretical literature review

Basic growth model

The most fundamental model of economic performance is based on the following equations. Production function relates total output to the size of capital stock and labour force.

$Y = f(K, L)Y = f(K, L)$..(1)

In this framework, economic growth occurs by increasing either capital stock or the size of labour force or both.

$S = \Delta Y S = \Delta Y$...(2)

Where saving is a fixed share of income in a closed economy with no trade or foreign investment

$S = IS = I$.. (3)

Equation 4 shows how capital stock changes with time. Capital stock II increases each year by the amount of new investment. dk shows capital stock decreases each year

$\Delta K = I - dK\Delta K = I - dK$...(4)

$d ==$ rate of depreciation

Supply of labour equation

$\Delta L = nL\Delta L = nL$... (5)

Labour grows exactly as total population, where nn is growth rate of labour force. Combining equations 2, 3 and 4, we get Equation 6. Change in capital stock = savings less deprecation:

ΔK=ΔY-dK... (6)

Harrod–Domar growth model

This growth model is based on fixed coefficient production function which exhibits constant return to scale in labour and capital. This model is credited to Roy Harrod of England and S.E Domar of MIT and their main focus was to establish relationship between growth and unemployment in capitalist societies. Their ultimate attention was the rate of capital accumulation on growth process. On this model output was assumed to be a linear function of capital.

$Y = \frac{1}{v} + K$ .... (7)

$V =.$ Capital output ratio.

It captures capital intensity and efficiency, so that a more capital-intensive process will display a larger v than a more labour-intensive process.

Policy makers are, however, concerned with incremental capital output ratio (ICOR) because in studying growth, one is interested in the impact of the output of additional or incremental capital. ICOR measures the productivity of additional capital while the average capital output ratio refers to the relationship between the country's total stock of capital and its total national products. Equation 1 can be rearranged so that we have change in output due to change in capital stock.

$\Delta Y = \Delta K/V\Delta Y = \Delta K/V$ ……………………………………………………………… (8)

Growth rate of output denoted by gg is increment in the output divided by total amount of output $\Delta Y/Y\Delta Y/Y$ so that dividing both sides of Equation 2 by Y

$g = \frac{\Delta Y}{Y} = \Delta K/YV$ ……………………………………………………………… (9)

Change in capital can be written as: $\Delta K = \Delta Y - dK$; substituting this equation into Equation 3 and simplifying it gives us the basic Harrod–Domar relationship for the economy:

$g = \frac{s}{v} - d$ ……………………………………………………………… (10)

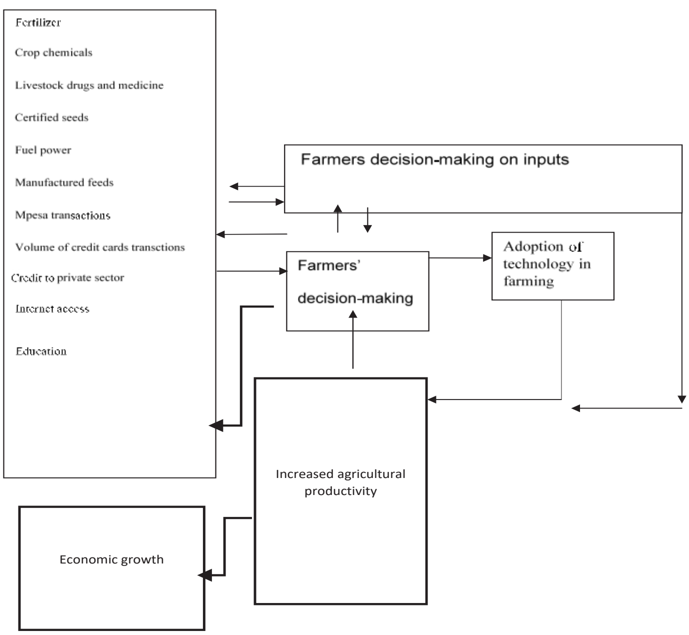
Equation 10 shows that capital created by investment in plant and equipment is the main determinant of growth, and that savings by people and plants make investment possible. The key aspects of economic growth are savings and the efficiency of which capital is used in production. The weakness of this model is that it assumes the capital–labour ratio is fixed which is not the case in real sense, it doesn't consider the effect of technological change which plays a key role in growth and development; finally, the model assumes that the economy remains in equilibrium with full employment only if labour and capital ratio remains constant and this can only occur if labour and capital grow at the same rate which is not always the case.

4.0 Methodological approach

Conceptual framework

With disruptive technologies, new firms may emerge as risk-taking companies recognizing the potential to innovate new products and risk-averse firms may adopt the emerging technologies. Adoption of innovative technology contributes to increased productivity hence increasing the individual and firm's income. This contributes to the growth of countries GDP hence increased economic growth. Figure 5 presents the conceptual framework on link between disruptive technologies, agricultural productivity, and economic performance in the context of Kenya.

Figure 5: Conceptual framework on disruptive technologies, agricultural productivity and economic performance in Kenya



Source: Adapted from Madhur (1999).

From the conceptual framework, adoption of disruptive technologies in agriculture takes the form of utilizing modern methods of agriculture and utilizing ICT in production, marketing and access to information processes. This then enables the technologies and innovations to affect agricultural productivity and, the country's economic performance.

Analytical framework for measuring effect of disruptive technologies of economic growth

The study applied mixed-method whereby both quantitative and qualitative approaches were utilized. To assess the nature of disruptive technologies in Kenya, and their potential to support emerging industries with specific focus on agriculture and related ICTs, the research team undertook desk and document review. The study investigated the effects disruptive technologies through measuring the impact of ICT indicators and technology driven agricultural techniques on economic performance in Kenya for the period 2000–2021. A common model used in previous studies investigating the effects of ICT investments on output growth is the neoclassical model Hagemann, (2019).

This model was credited to Robert Solow (1956). He recognizes the problems that arose from rigid production function in the H-D which did not allow for substitution between the factors of production. He dropped coefficient production function and considered neo-classical production function which allows flexibility and substitution; K/Y and K/L are no longer fixed but vary depending on the relative endowment of capital and labour in the economy and production process.

Solow model was understood more easily by expressing the variables in per worker terms:

$$Y = F(K, L) \qquad (11)$$

Both sides of the equation are divided by L to get per worker terms

$$\frac{Y}{L} = F\left(\frac{K}{L}, \frac{L}{L}\right) \qquad (12)$$

Output per worker is a function of capital per worker. Using small letters to represent quantities in per worker term $y = \frac{Y}{L}$ $and\ k = K/L$.then we get first Solow equation.

$$y = f(k) \qquad (13)$$

This function displays diminishing returns to capital. Capital per worker is fundamental to the growth process. The second key equation of the model focuses on the determinants of the change per worker

$$\Delta K = sY - dK$$

Dividing both sides by K gives us

$$\frac{\Delta K}{K} = \frac{sY}{K} - \frac{dK}{K}$$

$$\frac{\Delta K}{K} = \frac{sY}{K} - d \quad \text{.....} (14)$$

Then we focus on capital per worker ratio $= \frac{K}{L} = \frac{K}{L}$; it can be shown that growth rate of k is equal to growth of K-L so that

$$\frac{\Delta k}{k} = \frac{\Delta K}{K} - \frac{\Delta L}{L} \quad \text{.....} (15)$$

Re arranging the equation, we have

$$\frac{\Delta K}{K} = \frac{\Delta k}{k} - \frac{\Delta L}{L} \quad \text{.....} (16)$$

We assume that growth rate of population is given by n so that $\frac{\Delta L}{L} = n$ then the equation becomes:

$$\frac{\Delta K}{K} = \frac{\Delta k}{k} + n \quad \text{.....} (17)$$

From Equation 4,

$$\frac{\Delta k}{k} + n = \frac{sY}{K} - d \quad \text{.....} (18)$$

Recall y=Y/K.

$$\frac{\Delta k}{k} + n = sy - d \quad \text{.....} (19)$$

Subtracting n in both sides of Equation 19 we get:

$$\Delta k = sy - (n + d)k \quad \text{.....} (20)$$

This is the second equation of Solow model which denotes that the capital accumulation depends on savings, population growth, and depreciation. Savings and investment add to capital per worker while labour force growth and depreciation reduce it.

The two equations of Solow model can be summarized as

$y = f(k)y = f(k)$ (capital per worker depends on initial capital per worker)

$\Delta k = sy - (n + d)k$ (capital per capita depends on savings, investment, population growth, and depreciation)

Where: y=income per capita

k=capita per worker
n=rate of population growth
d=depreciation.

In this model, the technological factor, or Solow residual parameter is important. It includes all other factors of production that cannot be explained by capital and labour alone. Since growth is influenced by technology, which often is determined by factors such as new innovations, externalities, human capital and investment decisions, there are reasons to believe upon a positive relationship between the Solow residual and the capital variable for ICT (Stiroh, 2002), making the neoclassical model suitable to use in this context. Although Stiroh (2002) finds little evidence of the positive relationship, he argues that one should not drop the framework of the neoclassical concept since there are strong reasons to believe GDP growth in the digital era is in favour of technological factors. The production function outlined by Solow includes the three following factors of production: $Y = AK^{\alpha}L^{1-\alpha}$ where Y is output stock, K and L is the stocks of capital and labor, respectively. A is the technological parameter affecting the productivity of K and L. In addition, the function represents constant returns to scale, implying that 1-unit increase in both capital and labour will contribute to 1 unit increase in the level of output. The values of α and $(1 - \alpha)$ will, therefore, sum up to one.

ICT investment is used in many studies as one of the main technological changes during the current and last decades. Accordingly, the capital measure in Solow's model can be divided into ICT and non-ICT capital. In this research, a modified version of this production function is used by inserting additional measures for ICT usage (S) as some of the technological changes (Table 1) in order to assess the impact of using ICT services on economic growth as well as a lag indicator for GDP to accommodate for highly persistent series of output (Bond et al., 2001). Accordingly, the following econometric model was used:

$$GDP = f(VTCD, MPS, INT, DCR) GDP = f(VTCD, MPS, INT, DCR) \quad \ldots (21)$$

$$LogGDP = \beta_0 + \beta_1 LogVCD + \beta_2 LogMPS + \beta_3 LogINT + \beta_4 LogDCR + \beta_5 LogEDUC + \varepsilon_{it} \quad \ldots\ldots (22)$$

Table 1: Variables and data sources for the growth model (Model 1)

Variable	Description	Source
GDP	Gross domestic product	World Bank
VTCD	Volume of transactions by card; ATM Cards, POS machines	Central Bank of Kenya
MPS	Mobile access	Central Bank of Kenya
INT	Internet access and usage	World Bank
DCR	Domestic credit to private sector	World Bank
EDUC	Formal education	KNBS

Framework of the decision to adopt agricultural technologies

The theoretical basis for capital accumulation and higher output is based on the classical, neoclassical (better exemplified in the Cobb–Douglas and malleable capital growth theory), and endogenous growth theory. According to the classical economists, increases in output and productivity are seen as a direct consequence of specialization, which lead to more tools and machinery made available for production. This point was well explained in Adedeji and Bamidele (2003), when he observed that the process of capital formation is "cumulative" and "self-feeding", and this involves three interrelated stages, thus the existence and rise of real savings, the existence of credit, and lastly the existence of financial institution to mobilize savings and development for appropriate investment in capital goods. The neoclassical growth theory is an extension of the classical theory of growth, which assumed variable input substitution in production and a constant return to scale in productive activities; this implies that the capital/labour ratio is constant and capital stock must be expanding at the same rate as labour forces. The basic framework of their analysis is contained in the neoclassical malleable capital model of Prescott (1988) and in the Cobb–Douglas production function.

The Cobb–Douglas equation relates production function to capital and labour input. An accepted view on the theoretical foundation on the analysis of agricultural productivity is the Cobb–Douglas production function. The Cobb–Douglas functional form of production function is extensively used in economic works to denote the relationship of an output to input. The equation was advanced by Wicksell (1851–1926) and tested statistically by Charles Cobb and Paul Douglas in 1928 (Cobb & Douglas, 1928). The model exhibits striking mathematical features, such as highlighting diminishing marginal returns to either factor of production. This paper adopted a model similar to the one by Enaami et al. (2011).

The Cobb–Douglas equation relates production function to capital and labour input.

Thus,

$$Y = AK^{\alpha} L^{\beta} \quad \text{......} \quad (23)$$

Where: Y is output; K, L are capital stock and labour input, respectively; A is index for technical change. In Equation 21, an increase in labour input raise output. Recall the neoclassical growth equation by Solow (1957) which states that:

$$Y = f(K, L) \quad \text{......} \quad (24)$$

Equation 21 shows that production function is a non-linear and, therefore, had to be transformed to linear model using logs which converted non-linear Cobb–Douglas function into linear function as seen in Equation 23 and using variables in Table 2.

$$LogAOUTPUT = \beta_0 + \beta_1 LogFERT + \beta_2 logCCHEM + \beta_3 LogLDRUGSMED + \beta_4 CSEED + \beta_6 logMFEED + \beta_7 EDUC + \varepsilon_{it}$$
..........(25)

Table 2: Variables and data sources for output model (Model 2)

Variable	Description	Source
LogAOUTPUT	log of Agricultural output	KNBS
LogFERT	log of price of fertilizer	KNBS
LogCCHEM	log of Crop chemicals	KNBS
LogFPOWER	Log of fuel power	KNBS
LogLDRUGMED	log of Livestock drugs and medicines	KNBS
LogMFEED	log of manufactured feeds	KNBS
LogCSEED	log of certified seeds	KNBS
LogEDUC	Log of education	KNBS

Establishing infrastructure and enabling environments (including skills and training) required to take full advantage of the digital revolution

In addressing this objective, the focus included analysis of infrastructure and enabling environments (including skills and training) required to take full advantage of the digital revolution. This included analysis of indicators on ICT infrastructure by county, ICT skills and ICT uptake. The KIHBS 2015/16 and Kenya Housing and Population Census 2019 data was utilized. Some of the ICT infrastructure indicators analysed include: percentage distribution of households by ownership of ICT assets by county using 2019-census data; desk top computer/laptop/tablet; Internet ownership by county; distribution of population age three years and above owning a mobile phone by county; household Internet connection and type (using KIHBS, 2015/16); and access to electricity by county in 2019.

ICT skills indicators analysed in this study include highest level of education attainment (no education, primary, secondary, and tertiary education) and level of digital literacy; average years of schooling by county; activities in use of the Internet such as getting information from any government website; reading newspaper online; selling goods or services; doing a formal online course; writing online articles such as blogs, online forums; watching a movie or listening to music or playing games via Internet; and reasons for not using the Internet.

ICT uptake indicators included distribution of population age 15 years and above who searched and bought goods and services online by area of residence by county; distribution of population subscription to mobile money transfer platform by county; distribution of population subscription to mobile money banking platform by county; average money spent on airtime in a week (talk time) by county (Ksh); reasons for not using Internet connection; and place of Internet usage by county.

The next section focuses on the findings from the study, including the effect of disruptive technologies on agriculture productivity; correlates of disruptive technologies adaptation in agriculture; and enabling environments required to take full advantage of the digital revolution.

5.0 Findings

Descriptive statistics

In this section, we present descriptive statistics on digital technologies. Table 3 shows the various sources of fertilizer among farmers. Under the Big 4 Agenda, for 100% food security in Kenya, there is a goal to have 50% of fertilizers blended. Blending fertilizer enable the production of fertilizer that is specific to certain areas and provides the needed nutrients according to the soil types. The most common fertilizers used in dry blends include urea, triple super phosphate (TSP), diammonium phosphate (DAP), and potassium chloride (KCl) (GoK, 2018). Most the farmers apply only DAP with low level of secondary micronutrients. This makes soil acidity, due to inherent soil factors, fertilizer acidification, and lack of corrective liming, a challenge in various parts of the country (Roobroeck et al., 2015).

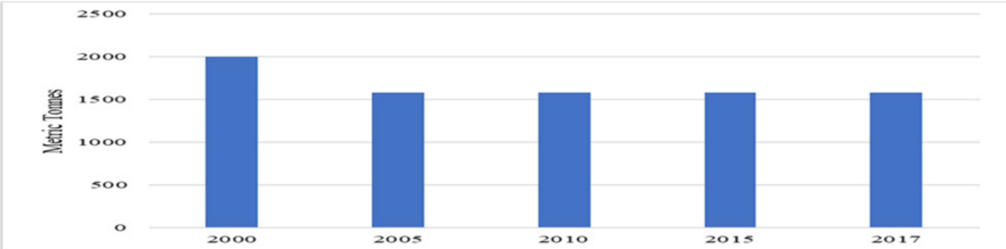
Table 3: Source of fertilizer at household level by type (%)

Source/ Type	Private stockists and companies	Other farmers	Societies/ Farmers associations	Government subsidized	Faith based organization	Commodity grants	Own production
Inorganic	12	43	75	30	97	80	0
Organic	11	51	2	3	2	17	49
Both organic and inorganic	72	4	22	66	0	2	46
None	3	2	1	0	1	1	4
NA	2	0	0	1	0	0	1

Source: KIHBS 2015/16.

About 25-35% loss in agricultural produce was caused by pests and diseases which can be controlled by use of pesticides. It is well known that over-use of pesticides can lead to dangerous levels of hazardous chemicals entering the food chain. Fresh fruit and vegetables are being consumed in increasing quantities and it is this fresh produce that is most susceptible to pesticide residues. Figure 6 shows that the most commonly used pesticide are insecticides, implying that insect pest is a challenge.

Figure 6: Amount of pesticide use in agriculture



Source: FAOSTAT, 2019[11]

Provision of livestock drugs is based on the Stockholm Convention, a global agreement whose objective is to protect human health and the environment from Persistent Organic Pollutants (POPs). POPs are a group of organic chemicals which have been inadvertently produced and introduced into the environment. Due to their stability and transport properties, they are now widely distributed around the world, and are even found in places where they had not been used and are known to effect toxicity. Given their long half-lives and fat solubility, they tend to be biomagnified along the food chain in living organisms, particularly in long-lived species at the top of the food chain. POPs appear at higher concentrations in fat-containing foods, including fish, meat, eggs, and milk (Kinyamu et al., 1998).

Improved seeds can contribute to higher yields, disease and pest resistance, climate change adaptation, and improved nutrition. Farmers who participate in multiple seed systems, depending on the crop or animal that they intend to produce, in most cases participate in both formal and informal seed systems. The formal seed system has most of the activities such as breeding, seed production, and distribution organized and undertaken by public institutions and large corporate entities; and in most cases, the seed was classified as certified (Munyi & De Jonge, 2015). The seeds are guaranteed to produce higher yield when compared to the other seeds type. Certified seeds represent improved technology. We find that an estimated 89% of certified seeds were sourced from a stockiest, an indication that farmers rely on certified seeds for crop production. Interestingly, we also find that cuttings and suckers were sourced from other producers, which could explain higher disease prevalence in various crops including bananas and cassavas.

11 https://www.fao.org/faostat/en/#data

Table 4: Source of seed used by households by type (%)

Type ofseed	Stockist/ Retailer	Other farmers	Nursery	Cooperative society	Government	NGO /FBO	Own Production	Direct Import	Under contract	Other
Certified seed	89.8	1.8	0.1	1.2	2.2	1.8	1.4	0.0	0.6	1.0
Uncertified seed	20.86	35.44	0.05	0.05	0.07	0.06	40.07	0.01	0.05	3.33
Seedlings	12.65	29.24	24.00	3.53	0.76	0.32	26.85	0.04	0.00	2.60
Cuttings	1.64	53.97	0.19	0.39	0.52	0.03	38.70	0.03	0.75	3.78
Suckers	1.34	51.18	0.91	0.65	0.21	0.26	44.98	0.00	0.00	0.48
Do not Know	15.07	49.32	0.00	0.00	0.00	0.00	25.90	0.00	0.00	9.71

Source: KIHBS 2015/16.

The correlation between agricultural productivity and disruptive technologies

From the results in Table 5, the F-statistics recorded a high significance level, implying the model is well specified. The t-statistics gives the significance levels of the variables. These combined with our hypothesized signs, shows that most of the variables' results are significant apart from crop chemicals and livestock drugs and medicine. Overall, fertilizer, certified seeds, manufactured feeds, and education attainment had a positive and significant effect on agricultural productivity. The variables are significant at 1% or 5% or 10% level of significance. The discussion of the results follows.

The use of fertilizer showed a positive relationship with agricultural productivity and highly noteworthy results at 10%. Use of fertilizer is treated as adoption of technology. Thus, the use of productivity enhancing inputs has positive and significant impact on agricultural productivity. In particular, use of fertilizer is positively correlated with productivity. The findings collaborates those of Reardon et al. (1997) who studied profitability due to fertilizer use both in Senegal and Burkina Faso. This is expected since areas where farmers have moved into modern farming practices will be those who have knowledge on the benefits of using modern agricultural methods. In this case, farmers who have been exposed to relevant on-farm training are expected to benefit more from the innovation, including use of fertilizers. Further, since formal education has a significant effect on farm productivity, it is possible that even those with limited education are likely to have copied the productive practices from the skilled farmers in the neighbourhood. It has been established in India that education spillovers are substantial. An additional year in mean level of education of neighbours increased household's farm productivity by 3% (Gille, 2012).

A review of Reardon (1997) reveals some variations in fertilizer use just because of the distribution systems. For example, Reardon found that in higher rainfall areas, there was high usage of fertilizer because parastatal agencies managed distribution in the four countries of Senegal, Burkina Faso, Zimbabwe, and Rwanda. The high rainfall areas were also the areas where cash crops were grown, and fertilizer prices were subsidized. On the other hand, when there was a switch to private sector distribution and elimination of subsidies, Reardon's study observed reduced fertilizer use in all the study countries. This highlights a key factor for consideration in enhancing usage of fertilizer including enhancing government distribution coupled with subsidies.

Manufactured feeds were used as proxy for modern technology used by farmers to feed the livestock. The results show a positive relationship between manufactured feed and agricultural productivity. The use of manufacture feed is gaining traction in commercial intensive production systems such as poultry. This is because these feeds assure uniformity of quality thus giving the nutrient balance needed for optimal growth. Empirical literature shows that poultry is among affordable livestock for the poor and improving their production level can improve the livelihood of the village farmers, and thus serve as an avenue out of extreme poverty[12]. Indigenous poultry are the most popular and common farm species. According to the Kenya Poultry Farmers Association (KEPOFA), the poultry population stands at 32 million, of which six million are commercial hybrids and the rest are indigenous birds. They contribute significantly to the socioeconomic and nutritional needs of an estimated 21 million people, many living in rural areas.

From the results presented in Table 5, the use of certified seed has a positive and significant effect on agricultural productivity. This implies that an increase in use of certified seeds by farmers increase output per acre. Therefore, certified seed has been identified as one of the important determinants of agricultural productivity with a potential of higher yields. High yielding seeds results from investments in research and development. Thus, in highlighting the importance of promotion of certified seeds, it is not possible to separate the issue of research and development. This is because certified seeds imply quality, and the quality is guaranteed by research. Research itself is a function of several factors including resources. In Kenya for example, Odhiambo et al. (2014) highlight several constraints that affect the use of certified seeds. They include insufficient funding for basic research, inadequate resources to enforce seed quality and the tendency to retain and use own seeds particularly by small-scale farmers.

Another dimension to the use of certified seeds is distribution mechanisms. Like fertilizer and other farm inputs, seed distribution has worked better when a single entity is in charge. In Senegal, Reardon et al. (1997) found that government seed distribution led to lower prices and hence affordability. However, during the structural adjustment programme, the role of the government was reduced, which marked the use of certified seeds. Therefore, seed distribution is key in ensuring increased usage of high-quality seeds. In the presence of constraints like unavailability, and unaffordability, farmers are likely to use lower quality seeds from previous harvest, which would negate our findings on positive contribution of seeds to farm productivity.

Table 5: Regression results on the effects of technology on agricultural productivity

Variable	Marginal Effect of Agricultural Production
Fertilizer	1.13*** (1.05)
Crop chemicals	-0.57 (0.556)
Livestock drugs and medicine	0.87 (1.63)
Manufactured feeds	0.78* (2.87)
Certified seeds	0.78** (1.6)
Fuel power	-2.3* (1.4)
Education	5.97*** (2.65)

12 https://www.cabdirect.org/cabdirect/abstract/20133184474

Constant	0.254*** (1.65)
R2	0.90
R2 Adjusted	0.85
F (7,12)	26.22
Prob>F	0.0001
Observations (years)	20

Note: * Significant at 1%; **significant at 5%; *** significant at 10%.

The effect of disruptive technologies on economic growth

From the results, the F-statistics recorded a high significance level, implying the model is well specified. The t-statistics gives the significance levels of the variables. These combined with our hypothesised signs, shows that most of the variables' results are as expected apart from the direct credits to the private sector which has a negative relationship with the economic growth. The test of the variables shows a positive relationship with the economic growth with some being significant at the 1% or 5% or 10% level of significance (see Table 6).

Table 6: Regression results showing effects of ICT on economic growth

Variable	Marginal Effects on Economic Growth
M-PESA transactions	0.16*** (0.88)
Volume of tractions using credit cards	0.01 (0.20)
Direct credit to private sector	-0.44 (-1.43)
Internet	0.43* (1.09)
Education	0.38*** (0.95)
Constant	0.254*** (1.65)
R2	0.98
R2 Adjusted	0.97
F (7,12)	59.6
Prob>F	0.0008
Observations	20

Mobile money

M-PESA transactions have gained a lot of traction in Kenya with majority using it as means of payment. As seen from the Table 6, M-PESA transactions have positive relationship with GDP. This means that the more the M-PESA transactions the more the country will experience economic growth. The massive transaction count makes mobile transactions key aspect in the economic wheel, equivalent in importance to banking and other formal financial systems. Increased popularity and easy access to mobile loans have also fuelled the growth. Major sectors of the economy, including financial institutions, retail and wholesale traders and agriculture, have integrated mobile money platforms such as M-PESA into their payment systems owing to their convenience and speed. The results obtained are similar to the qualitative evidence from Morawczynski and Pickens (2009), which suggested that M-PESA is used as a saving instrument.

The study finds that the volume of transactions by cards have a positive and insignificant influence on the growth of GDP. This means that the more transactions are done in the country the more the GDP will increase leading to the general growth of the economy but the effect was insignificant. This is because of the low number of individuals using credit cards in financial transactions. Domestic credit, on the other hand, was found to have a negative relationship with the GDP which was insignificant. This means that the credit extended to the people including farmers might depict detrimental impact on the country's GDP. Another argument could be that not many people are willing to borrow the loans from the credit facilities due to the various demands by the banks before the credit is given. This discourages people especially the farmers who do not have guarantors as the farming sector is vulnerable. In addition to this, we find that the correlation with the Internet has a positive and significant impact on economic growth.

The overall state of ICT infrastructure penetration in Kenya is good and includes Base Transmitter Stations for Mobile Networks often loosely called Transmission Towers, Fibre Optic cables, Fixed Broadband, and International Internet landing stations. The speed of current mobile network connection in Kenya is estimated at 13.7 megabits per second. Kenya has been ranked 28th globally with an average Internet speed of 10.7 mbps. As of 30 June 2020, total broadband subscriptions stood at 22.6 million from 22.3 million subscriptions posted in the last quarter. Mobile broadband subscriptions remained high at 97.3% of total broadband subscriptions. However, total fixed broadband subscriptions registered a remarkable growth of 14.7% to stand at 609,611 due to high demand of broadband services, as most consumers worked from home and learners continued to attend online lessons and access E-content during the COVID-19 pandemic.[13] This demonstrates that Kenyans have adopted technology which facilitates agricultural production through information flow about the inputs and markets. A study by Mercy Corps (2016)[14] among farmers in Kenya shows that, "While the number of basic phones owned is still increasing, smart phones have taken over from feature phones and become more widespread. This is supported by a growing network coverage with a 3G population coverage of 85% and 4G penetration of 25% in 2017, making Kenya the leader in Internet penetration in sub-Sahara Africa with total Internet penetration of 86% in 2017."[15]

13 https://www.ca.go.ke/wp-content/uploads/2020/10/Sector-Statistics-Report-Q4-2019-2020-1.pdf

14 https://www.mercycorps.org/sites/default/files/2021/Youth_Impact_Labs_Kenya_Gig_Economy_Report_2019_0_0.pdf

15 https://www.rvo.nl/sites/default/files/2019/12/Digital-Farming-in-Kenya.pdf

Infrastructure and enabling environments required to take full advantage of the digital revolution

Figure 7 shows the correlation between household assets, particularly desktops/laptops/tablets, and mobile phones by county. According to the correlation data, urban counties such as Nairobi, Mombasa, Kiambu, and Kajiado have a high correlation between the ownership of mobile phones and desktops. On the other hand, counties in the arid and semi-arid lands showed low correlation between the ownership of mobile phones and desktops. This indicates that there exists a positive relationship between owning a mobile phone and owning a desktop. Also, urban counties compared to their rural and arid counties could be having persons with higher disposable income enabling them to acquire certain household assets that facilitate them in performance of their duties while away from the office while effectively adopting to emerging sectors in the country.

Figure 7: Correlation between mobile phone (horizontal) and desktop (vertical) ownership (%)

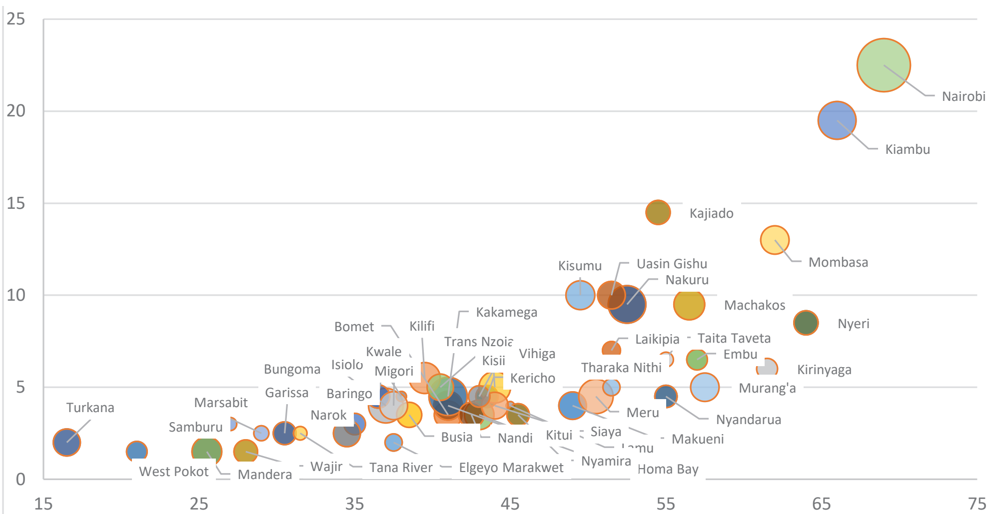


Figure 8 shows the distribution of households connected to the different Internet connection types by county. According to the data, mobile phone was identified as the most common method of connecting to the Internet. This is attributed to the high ownership of the mobile phones thus providing an easy connection method without the need of other additional devices.

Figure 8: Percentage distribution of Internet connection by type and county (%)

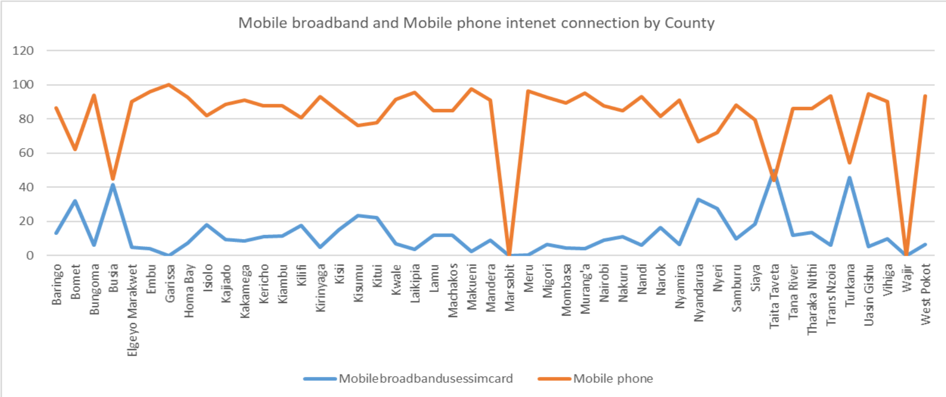


Figure 9 shows the correlation between access to electricity and Internet connection. Analysis of the correlation between Internet connectivity shows that counties with high electricity connectivity also have high Internet connection. This is because usage of Internet requires connection to a power source. As a result, adoption and adaptation of disruptive technologies will be affected by the distribution of the Internet connection and to a considerable extent the electricity distribution.

Figure 9: Correlation between Internet connection ('000' horizontal) and electricity connectivity (vertical) (%)

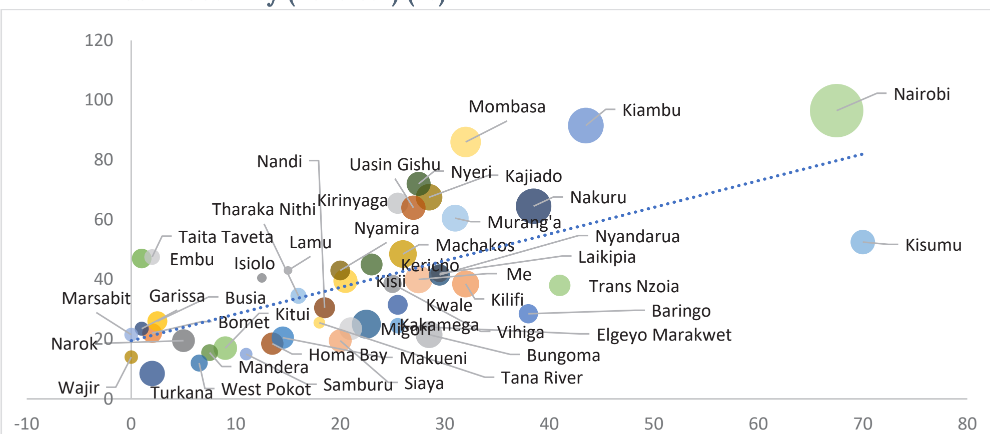


Figure 10 shows the correlation between gross county product (GCP) per capita and the cost of Internet connectivity equipment. According to the results, the correlation between GCP per capita and cost of Internet connectivity equipment was high in counties in the arid and semi-arid lands, though not distributed across the counties while urban counties had the advantage of access to equipment and varied suppliers thus lower equipment cost.

Figure 10: Correlation between GCP per capita ('000', horizontal) and cost of ICT (vertical (%)

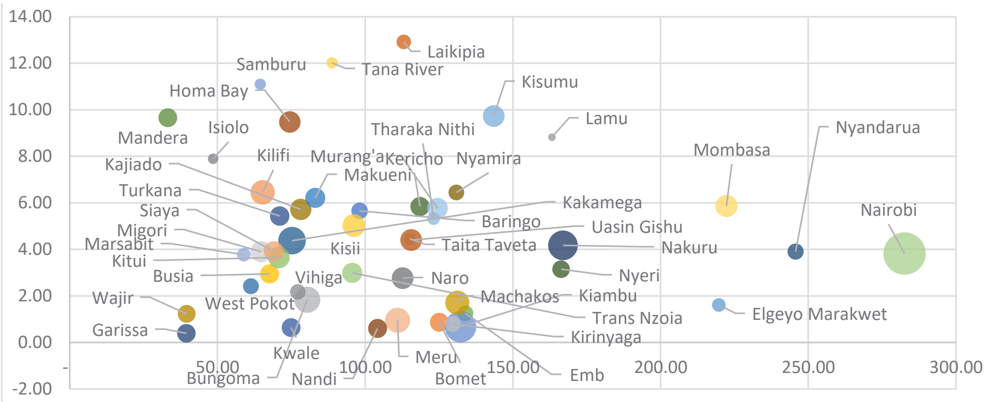
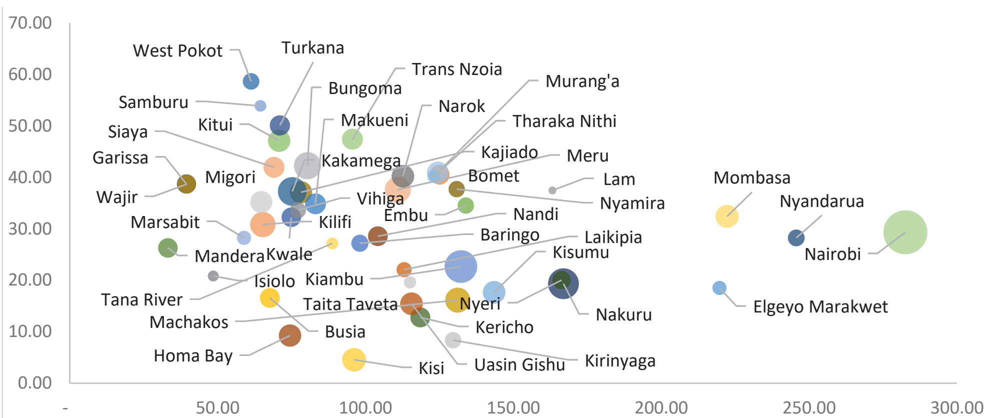


Figure 11 shows the correlation between GCP per capita and lack of knowledge in Internet usage. According to the results, the correlation between GCP per capita and lack of knowledge in Internet usage was inverse in that counties in the arid and semi-arid lands (with low GCP per capita) had moderate knowledge in Internet usage while urban counties (with slightly higher GCP per capita) had the advantage of access to training colleges and Internet equipment thus access to training and improved knowledge in Internet usage.

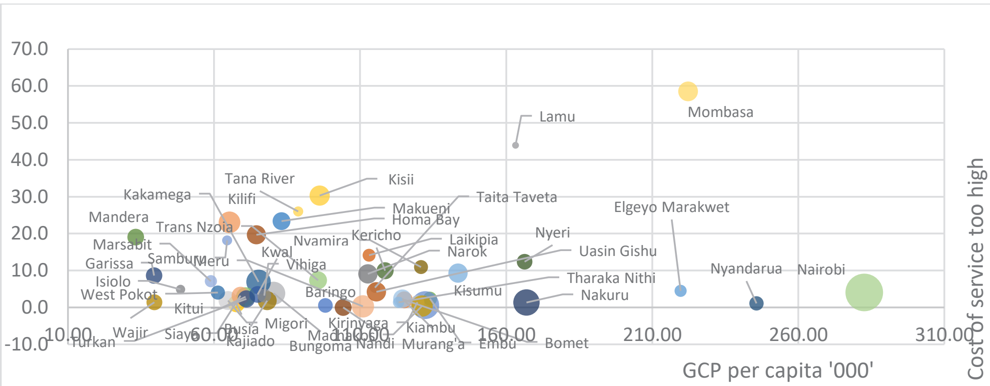
Figure 11: Correlation between GCP per capita ('000', horizontal) and knowledge in Internet use (vertical) (%)



Uptake of ICT was evidenced by the use of the ICT devices and related software to undertake activities that contribute to economic development. We find that Nairobi, Kiambu, Mombasa and Kajiado have higher GCP per capita levels and moderate activities in searching and buying goods and services from the Internet. The identified counties enjoy the benefit of high population, high investment in telecommunication devices and proximity to the capital city. Most of the counties with low GCP per capita levels had limited knowledge and skills for Internet connection. Only four counties had high GCP per capita levels of above Ksh200,000 but these counties had diverse levels of knowledge and skills in Internet connection types. The results show that lack of knowledge and skills affect the installation of any type of Internet connection. Addressing this aspect will play a critical role in ensuring adoption of technologies, and thus support diverse forms of economic activities.

Figure 12 shows the correlation between GCP per capita levels and cost of services in Internet connection. Majority of the counties had low GCP per capita levels and low levels of cost of the service. Only one county (Mombasa) had high GCP per capita levels and high levels of the cost of services. Therefore, high cost of the service is not a great hindrance to the installation of any type of Internet connection across the counties.

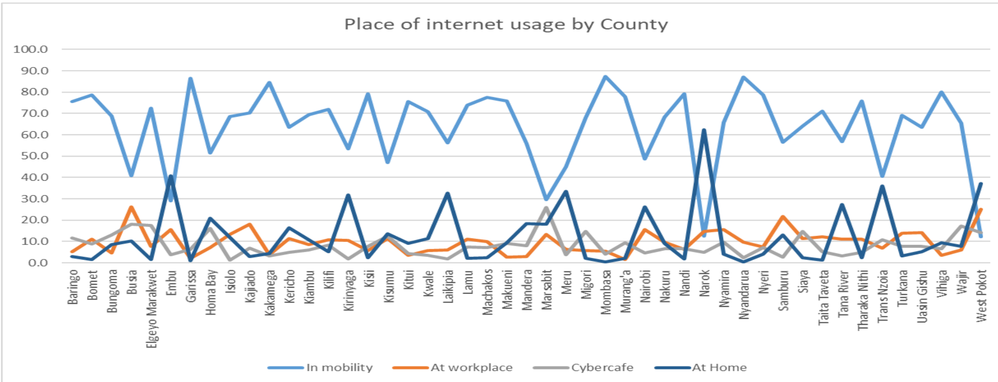
Figure 12: Correlation between GCP per capita ('000') and cost of Internet service (%)



In addition, majority of the counties had low GCP per capita levels and low levels of cost of the equipment. Nairobi County had low poverty levels and slightly high levels of the cost of equipment. Therefore, high cost of the equipment is not a great hindrance to the installation of any type of Internet connection. This indicates that apart from cost of installing the equipment (which is majorly met by government) there might be other factors such as skills and knowledge that hinder adoption of the ICT.

We also find that most of the counties with low GCP per capita levels had high levels of population who had not used Internet. The results indicate that limited activities that require ICT play a critical role in the failure by persons to install Internet connections. Expansion in the online space to increase the number of activities that can be carried online was considered a driver in the adoption and adaptation of ICT. Most people in various counties use internet while mobile. Usage of Internet in mobility correlates with the fact that most people access Internet from mobile phones which are portable. Other places where people use Internet was at work, cybercafé, and at home though this was not evenly distributed across the counties (see Figure 13). As evidenced from the analysis, nation-wide distribution of the Internet signal plays a pivotal role in the usage of the Internet. Capitalizing on this fact is therefore crucial in enhancing ICT usage for economic development through supporting income generating activities.

Figure 13: Distribution of places of Internet usage by county



Education attainment and uptake of technology

To be able to effectively use the ICT infrastructure, ICT skills are required. Using the level of educational attainment as a proxy for skill development, the study evaluated education attainment distribution by county. Figure 14 shows the correlation between GCP per capita and secondary education by county. According to the correlation data, counties with lower GCP per capita levels had lower number of persons who had completed secondary education, while counties with high GCP per capita levels had higher levels of persons who had completed secondary education. The correlation results also show that most counties with GCP per capita of less than Ksh150,000 had at least 25% of the population having completed secondary education. The results on low secondary education attainment indicate low specialization in ICT skills.

Figure 14: Correlation between GCP per capita ('000, horizontal) and secondary education (vertical, %)

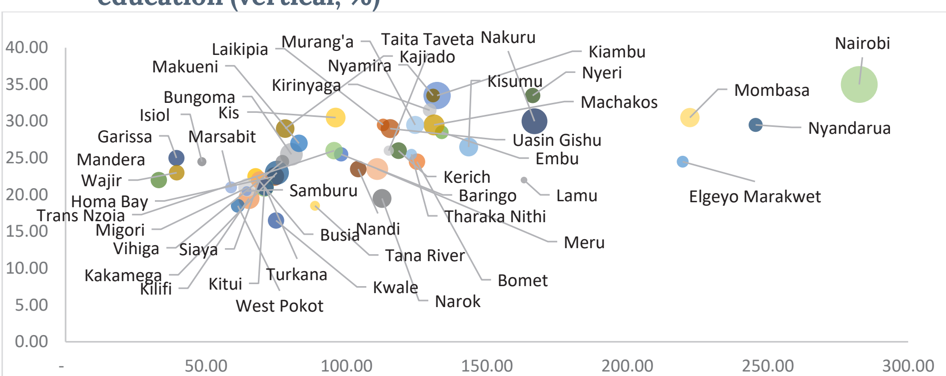


Figure 15 shows the correlation between GCP per capita and middle level college education by county. According to the correlation data, lower GCP per capita level counties have a lower number of persons who had completed middle level or college education, while counties with high GCP per capita had moderate levels of persons who had completed middle level or college education. The results on middle level or college education indicate low specialization in ICT skills.

Figure 15: Correlation between GCP per capita and middle level/college education

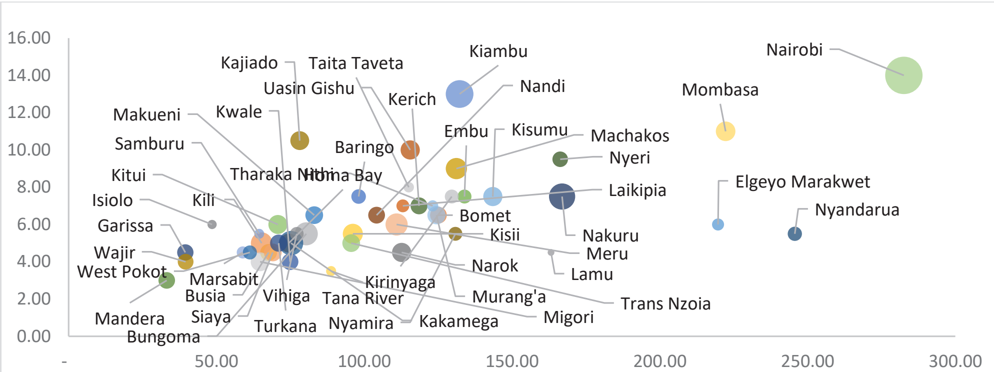
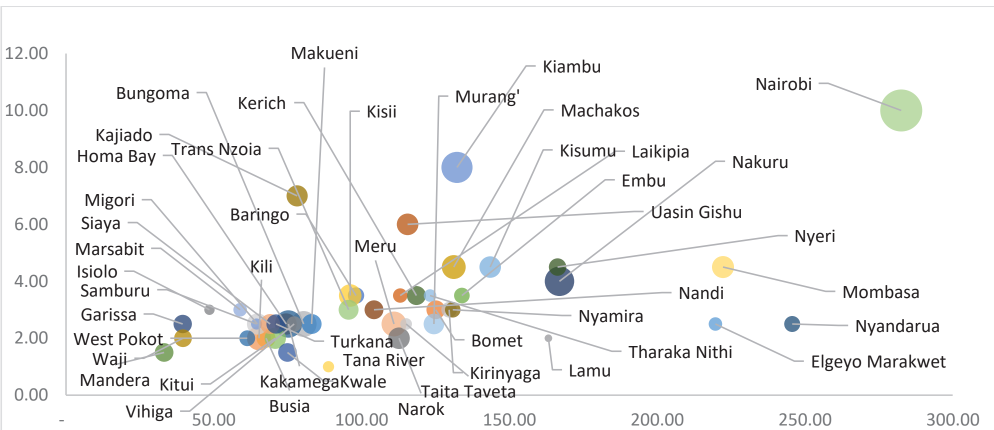


Figure 16 shows the correlation between GCP per capita and university education by county. According to the correlation data, per cent of population with university degree was low across the counties. However, urban counties outperformed the rural and arid counties in terms of population with university education. The results indicate that university education was embraced by few persons across the counties. In order to strengthen the human capital and skills required to adapt to the disruptive technologies, there is need to focus on higher education, particularly on technical and ICT skills.

Figure 16: Correlation between GCP per capita and university education



Further, augmented reality, which is the technology that uses a smartphone or tablet to add a new layer of information to objects in the physical reality, helps learners understand different concepts in their studies due to the use of 3D models. Lecturers and teachers are able to prepare attractive presentations that help capture the students' attention. Augmented reality enables minimal use of hard copy notes which can easily get either damaged or misplaced. Chat-based collaboration platforms, such as web-based video chatting applications, simplify the learning process and make it more social through real-time presentations. Video communication has an enormous impact in the education sector as it allows users worldwide take part in the education process. Through online learning, education has become accessible to the population across the globe. The use of screen-sharing feature in chatting applications has made it possible for lecturers and teachers to present learning content to the students. The content presented remains accessible for future reference. Cloud storage has enabled learners at all levels of education and training to extend their studies at home by accessing textbooks online while minimizing the use of hardcopy books. Teachers are able to easily access and review students' assignments through the cloud storage.

The coronavirus pandemic has grossly disrupted the interconnected global economy and has far-reaching social economic effects on developing countries. The education sector is one of the key sectors worst hit by the effects of the pandemic. It is estimated that 90% of the world's students—from pre-primary to higher education—were out of school in 2020, and millions lacked access to instruction hence contributing to potential loss of human capital and diminished economic opportunities in the long term. Fortunately, most countries, Kenya included, invested in distance education infrastructure and digital resources to ensure educational continuity during the pandemic and beyond. However, the education sector still experiences gaps that include affordability of digital tools and content, adequacy and coverage of digital learning content as well as vast number of learners live in the unserved and underserved areas as depicted by the census data for 2019. At the global scene, various countries are relying heavily on Radio, TV and Internet to support learning and training. With high penetration of radio, TV and Internet across the country, it is possible that access to capacity building and training services can further be enhanced to enhance uptake of digital technologies.

Despite high Internet and mobile penetration in Kenya, radio is still the most commonly available and accessed technology across the globe. According to the Kenya National Bureau of Statistics (May 2020), only less than 15% of learners are using radio despite Kenya having an average of 57% of households owning a radio. Turkana, Marsabit, Tana River, Samburu, and West Pokot counties had the lowest ownership of radio per households. Interestingly, Kenya is almost achieving universal knowledge on information about COVID-19 where radio and television are the main sources of information on COVID-19 at 82% and 60%, respectively, in both May and June 2020. Implementing interactive broadcasting radio lessons would be the quickest option to continued learning and deepening ICT skills.

Despite high production costs, television has tremendous reach and enjoys the advantage of being a familiar and engaging visual medium. There is a long tradition of television as a distance education medium in countries that have well-developed broadcasting or satellite infrastructure (Cuba and the United Kingdom) and that covers a large geographical expanse (Canada, Australia, China, Brazil, Indonesia, and the United States). According to the Kenya National Bureau of Statistics (May 2020), only less than 19% of learners are using television despite Kenya having an average of 41% of households owning a television. The counties that have the lowest ownership of television per households are Wajir, Turkana, Mandera, West Pokot, and Garissa. TV is proving to be one of the best and most direct ways to continue schooling, and several countries, including Kenya, are doing so via state-run broadcasting services. However, there is need to develop more content targeting all learners and avail it across various channels. Botswana Television (BTV) offers daily educational programming, primarily in mathematics and science, which reaches 90% of the country through its terrestrial transmitter and 100% of the country through satellite.

Desktop computers, laptop, tablets, and other mobile devices were considered important educational tools to provide continued schooling during both the pandemic and in the future. The tools provide educational opportunities to access digital content, education applications, social media and educational programming. Online learning offers tremendous benefits but also requires massive infrastructure, design and instructional requirements. According to the Kenya National Bureau of Statistics (June 2020), only about 13% of learners were using online learning despite Kenya having an average of 18% of households owning an Internet and mobile telephone gadget. The counties that had the lowest ownership of Internet services per households were Wajir, Mandera, West Pokot, Marsabit, and Turkana. Similarly, the average household ownership of desktop computer/laptop/tablet in Kenya stands at 8.8%, with lowest percentages reported in Wajir, West Pokot, Mandera, Elgeyo Marakwet, and Turkana counties. However, Kenya enjoys high mobile phone penetration. While appreciating the various initiatives that support digital learning, such as achievement of 97.7% of primary schools with digital devices installed (as of 19 September 2019), development of digital content on Kenya Education Cloud and the recent launch of Telkom and Google Loon Internet services, a huge percentage of learners still cannot access and afford Internet services.

6.0 Conclusion and policy recommendations

Conclusions

The study examined the disruptive technologies adaptation and economic performance in Kenya with focus on Agriculture and ICT sectors. The study sought to assess nature of disruptive technologies in Kenya, and their potential to support emerging industries with specific focus on agriculture and related ICTs. The study also determined the impacts of disruptive technologies on agricultural productivity and effect of ICT technology on economic growth. In addition, the study established infrastructure and enabling environments (including skills and training) required to take full advantage of the digital revolution in Kenya. Finally, the study provided policy steps needed to be taken to help Kenya harness the benefits of digitalization and mitigate its risks; and identify sectors in which additional policy actions were needed.

The study established that farm inputs such as fertilizer, certified seeds, chemicals/ pesticide use, manufactured feeds and fuel power contributes to increase in agricultural productivity. The modern agricultural inputs were found to be statistically significant at 1% significance level. Fertilizer was significant at 1%, 5%, and 10% level, indicating its significant effect on agricultural productivity. With increased productivity in the agricultural sector, it was accompanied by the expansion of the sector hence leading to increased food nutrition and security as set out in the government Big 4 Agenda.

Other crucial factors that increase farm productivity are use of irrigation techniques and on-farm training or extension services. Extension services enhances farm productivity through the expected improvement in farm operations and management practices; improved adoption to any innovative technology and innovation, better crop varieties, changing technologies, ecological and economic environment; and contributes to improving the quality of farm labour. This, however, needs to be supported with low transaction costs and appropriate transport to market centres. In addition, high farm profits, low transaction costs would increase rural farmers' ability to obtain purchased inputs including fertilizer and certified seed at competitive prices.

On assessing information communication technology (ICT) use, the volume of transactions by cards had a positive and considerable influence on the growth of gross domestic product (GDP). This means that the more transactions were done in the country the more the GDP will increase leading to the general growth of the economy. Mobile phone was identified as the most common method of connecting to the Internet. This was attributed to the high ownership of the mobile phones thus providing an easy connection method without the need of other additional devices. A spatial analysis shows that urban counties such as Nairobi, Mombasa, Kiambu, and Kajiado have a high correlation between the ownership of mobile phones and desktops. On the other hand, counties in the arid and semi-arid lands showed low correlation between the ownership of mobile phones and desktops.

Correlation analysis between skill development and gross county product (GCP) shows that counties with lower GCP per capita levels have lower number of persons who had completed secondary education, while counties with high GCP per capita levels had higher share of persons who had completed secondary education. The correlation results also show that most counties with GCP per capita of less than Ksh150,000 had at least 25% of the population having completed secondary education. The results on secondary education indicate low specialization in ICT skills. Lower GCP per capita level counties have a lower number of persons who had completed middle level or college education, while counties with high GCP per capita had moderate levels of persons who had completed middle level or college education. Share of population with university degree was low across the counties. However, urban counties outperformed the rural and arid counties in terms of population with university education.

Policy implications

Disruptive technologies are highly interdependent. They constitute a dynamic ecosystem which includes communication infrastructure, digital platforms, acquisition of appropriate digital skills, local ICT connectivity, and strong regulatory institutions. Harnessing the benefits of the disruptive technologies requires strong digital ecosystem and exploiting synergies at the national and county levels and across sectors of ICT, training, and agriculture.

It is important to pursue partnerships with private sector and non-state actors to mobilize long-term ICT infrastructure development across all the counties. Further, digital sector investments should be matched with enhanced investments in training, digital literacy, building communities of learning, and innovations. Policy measures for agribusiness transformation include affordable and reliable access to the Internet, digital technologies, mobile finance, internet-supported training, E-marketing and strong local ICT services that support innovations and transformative ecosystems. In particular, adaptation of disruptive technologies can be enhanced by:

i) Given the fact that the vast land of Kenya is either arid and or semi-arid, government through the Ministry of Agriculture, Livestock and Fisheries need to offer sustainable provision of extension services to the farmers and training on adoption of appropriate technology in agriculture related activities.

ii) Government through the Ministry of Agriculture, Livestock and Fisheries to ensure use of modern farming methods, key among them use of fertilizers, certified seed and irrigation.

iii) Through collaboration between Ministry of Agriculture, Livestock and Fisheries and that of ICT, youths need to be trained and supported to come up with innovations promoting modern agricultural farming technologies.

iv) Government through the National Treasury and National Planning and that of Agriculture, Livestock and Fisheries to give more credits to the farmers and business-persons so that it can support their farming activities and businesses.

v) The government will need to work towards creating awareness of farmers on the disruptive technologies in agriculture. This will have a huge impact on the economic growth and ensure food security.

While the use of educational technologies is often associated with ability to open up greater possibilities for all learners, in practice it could widen the digital divide and benefit only a small number of learners. The following are key considerations centring on access to the radio, television and Internet: the right technology; and the skills to use the technology that the Ministries of ICT and Education will need to consider in order to bridge the learning gaps during the pandemic.

In order to sustain the use of E-learning platforms in Kenya, the following needs to be taken into consideration. There needs to be frequent trainings on the use of the E-learning technology. This will aid some students and faculty members who are not “Tech-Savvy” to embrace the innovative technology and maximize its application. An efficient changeover strategy needs to be considered. This includes either fully adopting the E-learning as a form of online learning or blending the traditional model of learning with the new E-learning model. A progressive approach needs to be applied to assist the institutions adopt and embrace the change in technology. The institutions need to ensure that critical resources that support the E-learning technology are available. This includes the availability of technology systems and equipment such as computers, Internet connection, student learning centres, E-learning trainers, and IT support, among others. Implementation of the E-learning system requires progressive maintenance of the resources.

Cloud computing involves the outsourcing of computing services which are accessed over the Internet rather than heavily investing on the IT Infrastructure. Cloud computing has provided an avenue to venture into innovative technologies as it aims to automate operations in the institutions. Cloud computing technology has brought about immense change such as availability of file storage, data integrity and confidentiality, data backups and disaster recovery as compared to the traditional IT infrastructure.

Potential areas to respond to job losses from technology and policy choice include: i) developing system for identifying workers who are dislocated due to disruptive technologies using data on occupational change; ii) providing support for workers in training; retraining workers in programmes in emerging sectors or provide required assistance to access jobs with their prior skills; iii) Developing new sectoral training programmes linked to emerging sectors for job creation following disruptive technologies; iv) providing targeted social protection for the poor and vulnerable groups, v) Providing stop-gap income for workers who are close to retirement before pension and social security benefits. The implementation would involve policy discussions with relevant policy makers to enable uptake of proposed feasible social safety nets.

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