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Making agricultural value chains more inclusive through technology and innovation

Reena das Nair and Namhla Landani*

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Abstract: Some entry barriers in agricultural and agro-processing value chains, particularly for smallholder farmers and small/medium-sized processors, can be overcome with innovation and technology adoption. Technologies and innovation in these sectors have been both radical and incremental, ranging widely through biotechnology; production technologies; automation in sorting, grading, and packaging; and digital platforms and data-connected devices for market access. These technologies have enabled farmers in Africa to increase productivity and quality; reduce costs; meet standards; improve access to finance, markets, and information; and facilitate payments. We evaluate the role of technology in South African fresh fruit and selected processed food value chains in facilitating inclusive participation, while highlighting potential adverse effects for certain players. Recommendations for addressing the challenges and building capabilities to adopt new technologies are provided, emphasizing the role for public–private partnerships and an enabling regulatory environment.

Key words: innovation, technology, upgrading, value chains, agriculture, agro-processing, inclusive, capabilities

JEL classification: O13, O14, O30, O31, Q16

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* Centre for Competition, Regulation and Economic Development (CCRED), University of Johannesburg, Johannesburg, South Africa; corresponding author: reenadn@uj.ac.za.

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Information and requests: publications@wider.unu.edu

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Katajanokanlaituri 6 B, 00160 Helsinki, Finland

1 Introduction

In many African countries, agriculture and agro-processing have been identified as priority sectors with the potential to boost regional trade and investments, foster rapid industrialization and economic diversification, create jobs, and eradicate hunger and poverty (Annan et al. 2015; Hussein and Suttie 2016; NEPAD 2013). Given the continent's rapidly expanding urban areas and population, and the availability of arable land, there is potential to increase food production. This could stimulate food exports, especially within the continent, and substitute imports that have increased as the population has grown (Annan et al. 2015). It could also allow for the development of the capabilities of food producers to participate more deeply in global food value chains.

The potential for agri-businesses in food processing and horticulture, as 'industries without smokestacks', to contribute to industrialization and to grow jobs has been argued by Newfarmer et al. (2018: 2) to offer new opportunities for Africa's future growth. Countries in Southern Africa have recognized the need to prioritize the agricultural sector and the role that small and medium-sized enterprises (SME), including small farmers and agro-processors, can play in growing the sector (Department of Trade and Industry 2017, 2018; Ministry of Industry and Commerce, Zimbabwe, 2019; Ministry of Trade and Industry, Namibia, 2015; Republic of Zambia 2018; SADC 2017).

There are, however, high barriers to entry which limit the contestation and participation of new entrants and SMEs in agriculture and agro-processing value chains. High levels of concentration and vertical integration in these markets, particularly in agro-processing, mean a few large firms with market power control most levels of value chains (Paremoer 2018). This creates barriers to entry for new players who are reliant on incumbents to access inputs or markets.

In primary agriculture, the lack of appropriately adaptable seeds and fertilizers, along with limited access to plant chemicals, are among the most fundamental challenges that smallholder farmers face in the region (Annan et al. 2015; Tinsley and Agapitova 2018). Other challenges include limited access to finance, skills, and training, along with the lack of infrastructure such as storage facilities and lack of access to market information (Hussein and Suttie 2016: International Finance Corporation 2017). Linking smallholder farmers and SMEs to key routes to markets such as supermarkets is also a challenge, as suppliers need to meet basic phytosanitary and food quality standards, as well as the private standards of supermarkets (das Nair et al. 2018; Gereffi and Lee 2014; Hussein and Suttie 2016; Reardon et al. 2003). Small farmers and processors are also more exposed than larger players to the negative impacts of the recent occurrences of drought in the Southern Africa region (Davis and Vincent 2017; Nyasimi et al. 2014). There are further vulnerabilities linked with being located in rural areas (Annan et al. 2015; Dlodlo and Kalezhi 2015; Hussein and Suttie 2016).

Innovation in agriculture and agro-processing value chains can play a major role in overcoming some of these barriers, incorporating emerging farmers and agro-processors into regional and global value chains and potentially making these value chains more inclusive. Many challenges and barriers faced by SMEs can be addressed through innovation in technology and digital platforms. For instance, information services can be provided digitally to farmers and processors on the best practices, certifications, and standards required by regional and international supermarket chains. Mobile money platforms can be a way in which emerging farmers and suppliers can be paid instantly to ease cash flow crunches and enabled to access credit and insurance products. Digital profiles can be created for verification purposes, and blockchain technology has developed to be able to provide real-time traceability and certification of products. This improves the transparency of suppliers to supermarket chains, improving the chances for SMEs to sustainably participate in value chains. Digital tools can also greatly improve logistics systems in agro-processing value chains. Cloud computing, computing systems, connectivity, and open-source software have become more commonplace, and more affordable and accessible. But technological innovation is not the only form that innovation can take. Innovation in business models and operations can also contribute to the growth and inclusion of players.

It is important to highlight that innovation and technological advances may have the opposite, and undesirable, effects. They may widen the gap between established incumbents and new entrants or SMEs who cannot access or afford the technologies. Adverse incorporation may be an outcome also where firms are included and integrated on negative terms (Hickey and Du Toit 2007; Ponte and Ewert 2009). For instance, studies on the impact of growing demand for oil palm in Indonesia have found that the way social relations and land ownership in the rural areas worked meant that the potential of the crop may ultimately work against poor smallholder farmers. The outcomes were very dependent on the terms on which the smallholders were included in oil palm production, whether there was institutional support for them, and the role of the state (McCarthy 2010).

This working paper evaluates the use of technology and innovation in agriculture and agro-processing sectors. Lessons are drawn from experiences in food value chains internationally and in other African countries. The lessons offer valuable insights as to how technology and innovation can be incorporated and supported in agro-processing value chains in the Southern Africa region. Following global value chain (GVC) principles, the paper draws on desktop research, as well as primary research undertaken by the Centre for Competition, Regulation and Economic Development (CCRED) that has involved interviews and workshops with relevant stakeholders in agricultural and agro-processing value chains, including for projects undertaken for the South African Department of Trade and Industry (Chisoro-Dube and das Nair 2018) and as part of a project funded by the UK's Global Challenges Research Fund on 'Innovation and Inclusive Industrialization in Agro-Processing'.[1]

Section 2 explains how the GVC framework can be used as the conceptual framework through which to understand how technology and innovation can facilitate upgrading and build dynamic capabilities in value chains. In Section 3, a literature review is undertaken on the types of technologies in agriculture and agro-processing globally. Section 4 assesses how technology has facilitated the inclusion of SMEs in different countries in Africa, especially East Africa. The role of technology and innovation in facilitating participation in fresh and processed food value chains South Africa is evaluated in Section 5. Section 6 concludes, identifying constraints to adopting technology in the region and offering lessons for policy interventions that could facilitate greater inclusion and participation.

2 Conceptual framework

Incorporating emerging farmers and SME agro-processors into global value chains requires significant capability building, as production, standards, and pricing are increasingly shaped by powerful lead firms (Gereffi and Fernandez-Stark 2011; Humphrey and Schimtz 2002; Reardon et al. 2003). The same applies to incorporating them into regional value chains (RVCs), although the requirements for entry and participation are often lower in other African regions than they are in

[1] See https://iiap.info.

GVCs. As such, RVCs are seen as offering stepping-stones into participating in GVCs (Farole 2015; Horner and Nadvi 2018).

Growing urbanization has led to the growth of modern retail formats such as supermarket chains in Africa, particularly in Southern and East Africa. This has made them important routes to market for processed food products and other household consumables. Supermarkets often place pressure on suppliers with regard to the ability to supply the required volumes, maintain consistency, ensure quality, and contain costs of supplying products, among other factors (das Nair and Chisoro-Dube 2015, 2017; das Nair et al. 2018; Ziba and Phiri, 2017). Compliance with legal standards on quality and food safety is absolutely critical for consumer health and safety. Private standards imposed by supermarkets further add to the requirements associated with supplying them, and these, while still possibly desirable from consumers' perspective, may impose barriers to SME participation in food systems. In other export-orientated industries such as fresh fruit, lead firms in key consumer markets which are typically located in developed countries often control terms of trade (Chisoro-Dube et al. 2019). As such, governance and power relationships in interactions between retailers, lead firms, and suppliers have implications for technological learning and the adoption of technologies for the upgrading of emerging farmers and SME agro-processors.

The GVC framework is a useful tool for identifying opportunities and challenges for technological upgrading and the development of capabilities by emerging farmers and agro-processors in the region. The framework considers governance and upgrading to assess global industries, with governance accounting for power relationships and their ability to determine the allocation and flow of resources in the value chain. Specifically, governance describes how powerful lead firms, or groups of lead firms as part of industry associations for instance, form the conditions for inclusion and exclusion in value chains, which subsequently control the terms and location of value addition, distribution, and capture (Dallas et al. 2019; Gereffi and Lee 2014). On the other hand, upgrading—which can be identified as process, product, functional, and chain upgrading—explores how firms can improve competitiveness and change their position in the value chain (Gereffi and Lee 2014; Nkhonjera and das Nair 2018).

The insertion of firms into value chains can facilitate the transfer of knowledge, allowing small firms to upgrade and subsequently gain access to regional and global value chains (Morrison et al. 2008). However, some studies on value chain governance which draw on innovation theory point out that the complexity and codifiability of information for upgrading, along with the existing capability of suppliers, determines the transferability of knowledge The transferability of information influences the nature of the relationships that govern the value chains (Gereffi et al. 2005; Guiliani et al. 2005; Lema et al. 2018). Power asymmetries in the different forms of governance also affect knowledge transfers and upgrading in a value chain (Morrison et al. 2008).

Technology can facilitate access to and inclusion of firms into global or regional value chains by lowering barriers to entry and facilitating upgrading (see Section 3). For technological upgrading, emerging farmers and agro-processors need capabilities. Morrison et al. (2008) define technological capabilities as a set of skills, which can be technical, managerial, and organizational in nature, that enable firms to efficiently use the hardware (equipment) and software of technologies to sustain or improve a firm's competitiveness. Capabilities can also be classified from a functional perspective and by considering the degree of complexity of activities. These include investment, production, and linkage capabilities. 'Investment capabilities' refers to the set of skills required prior to undertaking an investment. 'Production capabilities' refers to the skills necessary for operating a plant with a given technology at the basic level, and its improvement over time. This includes process, product, and industrial engineering capabilities. Lastly, 'linkage capabilities' refers to skills that are required to establish technology linkages between firms, service suppliers, and interact with the science and technology infrastructures (Lall, 1990, 1992, 2001). All three are important for upgrading in agriculture and agro-processing, as discussed in Sections 3 and 4.

Over the years, the literature has expanded to include dynamic capabilities. These are defined as 'the firm's ability to integrate, build and reconfigure internal and external competencies to address rapidly changing environments' (Kay et al. 2018: 516). Dynamic capabilities can be viewed as only existing at an advanced level of complexity, as they emphasize a firm's ability to move beyond ordinary capabilities to partake in higher-level activities that give the firm a competitive advantage and generate long-term Schumpeterian rents (Kay et al. 2018).

The development of technological capabilities and the ability of firms to absorb technological changes is a function of a firm's existing knowledge base and intensity of effort (Kim 2001; Morrison et al. 2008). Given that technology is tacit, and knowledge about technologies is not accessible equally among firms or easy to duplicate and transfer between firms, the absorptive capacity also depends on a firm's ability to convert tacit to explicit knowledge (Kim 2001; Lall 1992; Morrison et al. 2008). The differences in absorptive capacities between firms may strengthen the market power of incumbents, making the gap between large firms and SMEs even larger.

In essence, the fundamental approach of the GVC framework is to analyse how firms can potentially upgrade and acquire capabilities in order to participate or gain positions further up the value chain. However, as noted in Section 1, small players or certain groups can be adversely incorporated into value chains (Hickey and Du Toit 2007; Ponte 2008). This means that firms may upgrade and participate at higher positions along the value chain without necessarily 'reaching a better deal' (Ponte and Ewert 2009: 1, 3). As another example alongside the oil palm one in Section 1, in the wine industry in South Africa, functional and process upgrading to produce better-quality wine that is eligible for export has simultaneously made farmers more vulnerable to risk and limited their rewards, as the costs associated with upgrading are high (Ponte 2008; Ponte and Ewert 2009).

3 Literature review: innovation and technologies in agricultural and food value chains globally

As discussed in Section 2, inclusion and upgrading in agricultural and food value chains can be facilitated by innovation and technology. Innovation can be defined as launching a new product, applying new methods, or acquiring new resources (Baregheh et al. 2012; Pignatti et al. 2015; Santovito et al. 2016). These activities can yield different types of innovation, including product, process, organizational, and market innovation (Caraça et al. 2009; Lefebvre et al. 2015). The key feature of innovation is that it enables the 'successful exploitation of ideas' (Lefebvre et al. 2015; 3), and at a firm level, success means that innovative companies gain competitive advantages and economic benefits (Hagedoom 1996; Schumpeter 1934). In particular, the adoption of technologies[2] resulting from innovation has the potential to generate income, increase productivity, accelerate communication, and much more (Baregheh et al. 2012; Pignatti et al. 2015; Santovito et al. 2016).

Innovation can be classified as either radical or incremental in nature (Lefebvre et al. 2015). Radical innovations result in fundamental changes to the activities of a firm or industry and lead to a clear existing departure from existing practices. On the other hand, incremental innovations introduce

[2] There are many definitions of technologies; however, this paper will hereafter refer to technologies generally as tangible tools and techniques that make production factors more efficient.

relatively minor changes that result in little departure from existing practices (Dewar and Dutton 1986; Ettlie et al. 1984; Lefebvre et al. 2015). Although technology and innovation in agriculture and agro-processing value chains continue to advance, most developments are relatively incremental and characterized by a low degree of novelty (Chisoro-Dube et al. 2019; Salavou and Avlonitis 2008). These technologies can also be adaptations and applications of disruptive technologies in other industries that are adapted to agriculture and agro-processing.

Technology disruptions globally have occurred in areas that directly affect the production of agricultural products, including biotechnology, irrigation, and precision farming methods (Chisoro-Dube et al. 2019). There have also been developments in sorting, packaging, and cold storage; and electronic certification and integrated data-sharing digital platforms (Chisoro-Dube et al. 2019). In addition, information and communication technology (ICT) and digital platforms have played a remarkable role in agricultural value chains, as these are spread into almost all socioeconomic activities and are accessible in most parts of the world—including rural areas with agricultural activities (Lefebvre et al. 2015; Santovito et al. 2016). ICT is also available to the poor, the uneducated, and marginalized groups (Annan et al. 2015; Dlodlo and Kalezhi 2015; Singh et al.). The ways in which technology positively enables agriculture and agro-processing around the world are discussed below.[3] Although there are numerous other technologies in this space (see Krishnan et al. 2020), the ones we discuss below have particular applicability in the Southern Africa context, in terms of the agricultural products produced and the growing conditions and challenges faced.

3.1 Developing new varieties of produce and crops

The use of new breeding technologies including gene editing, targeted epigenetic modifications, and the adoption of synthetic DNA components and artificial chromosomes significantly impacts the quality and productivity of fruit and vegetables (Cell Press 2018). This is because these genetic modifications allow scientists to edit existing genes which control many of a plant's key consumer traits. Given the global challenges of climate change, along with limited food security and sustainability, these technologies are important. They improve the ability of fruit and vegetables to adapt to climate change, as well as enhancing their ability to resist insects and diseases (College of Agriculture and Life Sciences 2012). They also improve sustainability by increasing the yields obtained from a given piece of land, without the use of more inputs such as water, fertilizer, and other agricultural chemicals (Best Food Facts 2015). Such technology is also critical in improving the appearance and taste of food. These technologies can allow farmers and processors to enter into and upgrade in regional or global value chains.

3.2 Crop pest technologies

There have been advances in technologies to control pests (insects, weeds, and pathogens). An example of one such technology is the Integrated Pest Management (IPM) Module, which links farmer weather data to actual pest risk to fight against crop pest damage. In particular, it uses weather technology through solar-powered wireless weather stations to gather real-time temperature, humidity, rain, and leaf wetness data. The software then generates stepped risk levels to warn the farmer when these conditions are most likely to make plants vulnerable to pest development. The software uses the pest configuration and real-time data from orchard weather sensors, along with the updated pest development algorithms, to deliver the most accurate, orchard-specific risk assessment available (Wines Vines Analytics 2011). This technology is being

[3] Unless otherwise referenced, the following discussion is drawn from Chisoro-Dube and das Nair (2018).

used for stone fruits (peaches, apricots, cherries, plums, and prunes) as well as grapes, apples, and pears (Rusnak 2013).

3.3 Smart water technologies and precision agriculture

The impacts of climate change and water scarcity have resulted in the introduction of smart irrigation technologies to save water. Such technologies include the adoption of fully automated drip irrigation systems, irrigation scheduling, and information on evapotranspiration rates and soil moisture (Zappa 2014). 'Precision agriculture' refers to farming management based on observing (and responding to) intra-field variations. Farmers globally are adopting satellite imagery and advanced sensors, in order to optimize returns on inputs while preserving resources. High-resolution crop sensors can be used to inform the application of the right amounts of irrigation or fertilizer, while optical sensors or drones can be used to identify crop health across the field (for example, by using infrared light). An understanding of crop variability, geolocated weather data, and precise sensors enables improved automated decision-making and complementary planting techniques (Zappa 2014).

3.4 Agricultural robots

Many firms are increasingly automating agricultural processes at the growing and processing level using agricultural robots also known as 'agbots'. At the growing level, agricultural processes such as harvesting, fruit picking, ploughing, soil maintenance, weeding, planting, and irrigation are being automated (Zappa 2014). At the processing level, production and packaging are also increasingly being automated.

3.5 Cold storage technologies and materials

The ability to preserve the shelf-life and quality of fruit and vegetables, along with perishable agro-processing products, until they reach supermarket shelves requires specific cooling technology. Innovation in cold chain logistics and technology enables growers, processors, and retailers to build faster and more flexible, precise, and transparent food supply chains. Increasing the speed of the supply chain enhances the freshness of the produce.

Globally, companies are developing mobile cold chain technologies with lower installation expenses than traditional refrigeration systems. These are highly adaptable energy-efficient refrigerated storage solutions for smallholder farmers aimed at reducing post-harvest losses, improving energy reliability, and enabling access to markets. Cold chain technologies have key benefits such as ensuring a fresh product, longer shelf-life, improved income stream, and enabling the farmer to harvest over a few days and deliver a large shipment rather than on a daily basis, resulting in less wasted time away from the farm. A UK-based firm, InspiraFarms,[4] for instance, has developed automated, controlled, and remotely monitored refrigeration storage units that can be adapted in both size and specific layout to suit the needs of any farmer (interview with InspiraFarms). Data services, enabled by a remote sensing device and a centralized data management system, support customers with customer-specific configuration and optimization of their facility. They also enable remote supply chain data aggregation that is supplied to clients to support improved performance and predictive maintenance. Similarly, a USA-based company, Coolbot,[5] has developed a walk-in cooler, which is an electronic controller that converts a standard

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[4] See www.inspirafarms.com.

[5] See www.storeitcold.com/build-walk-cooler-small-farm-free-download.

air conditioner into a chilling unit. These and other innovations in cold storage and the cold chain have extended shelf-life and reduced wastage in fruit value chains.

3.6 Smart materials in cold chain infrastructure

Aside from the actual cold storage infrastructure, the materials used in the construction of this infrastructure are also improving with technological developments. InspiraFarms, for instance, uses materials for structures that are lightweight, expandable, and fast and easy to install. Their cold storage and processing facilities are built with a laser-cut galvanized steel framework and high-quality insulated panels to ensure superior durability and energy efficiency in any climatic conditions. All units are shipped as turn-key solutions, designed to be operational and certification-ready immediately after installation with regard to food safety (interview with InspiraFarms).

3.7 Sensor technologies

Sensor technologies are playing a vital role in food monitoring and detecting the freshness of produce. Examples of such technologies include electronic noses, hyperspectral and multispectral imaging, RGB (red, green, and blue) cameras, microwave imaging, near infrared spectrometer, electrochemical sensors, and calorimetric sensors. Apart from remotely monitoring food, sensor technologies are used for determining fruit ripeness and predicting the shelf-life of fruits and vegetables during transportation. Ethylene is a key sensing parameter suitable for detecting volatile organic compounds in order to indicate ripening or decay of fruits and vegetables, and also to indicate if a commodity is near the end of its shelf-life (Wyman 2018). Such technologies are increasingly important to fruit growers who are exporting their produce across the world.

3.8 Delayed ripening technology (DRT) and ripening chambers

There has been significant innovation in delaying the ripening of fruit so that farmers have the flexibility in marketing their goods and consumers are guaranteed 'fresh-from-the-garden' produce. This means that farmers can ensure the best quality by waiting until the fruit fully matures on the vine before plucking, and can access wider markets over greater distances. It also reduces post-harvest loss and provides greater resilience during handling and transportation. The technology involved in delaying ripening includes the regulation of ethylene production (which causes ripening) by the fruit by 'switching off' or decreasing ethylene production through gene manipulation (CropLife International 2016).

Conversely, ripening chambers can be configured to speed up ripening at the desired time, and at the destination market, as well as to ripen the fruit to the point that it has the right colour, taste, and flavour. This can happen in chambers in which the atmosphere is controlled in terms of temperature; humidity; and ethylene, oxygen, and carbon dioxide content. Again, this contributes to reductions in post-harvest loss and ensures quality for the customer, all critical to effective participation in GVCs.

3.9 Process automation, machine learning, and artificial intelligence (AI)

The automation of processes in the supply chain helps to make supply more reliable. Warehouse automation boosts service-level consistency and conformity to industry standards in areas such as pallet and carton quality, while machine learning and artificial intelligence improve forecasting and automatic stock replenishment, among other uses (Wyman 2018).

3.10 ICT, the Internet of Things, digital platforms, and big data

ICT allows the communication and transmission, electronic capture, and processing of information (Osterwalder 2002). It includes physical software and hardware as well as electronic technologies, resources, and techniques used to acquire, manage, store, and share information and knowledge, and it is useful in developing online resources for effective task performance and to simplify the sharing of electronic data (Boohene et al. 2015; Dlodlo and Kalezhi 2015; Singh et al. 2015). Digital platforms, along with the Internet of Things (IoT), allow for the real-time sharing of data. This involves various innovation techniques, such as the use of applications, blockchain technology, and Global Positioning Systems (GPS), as discussed below.

Blockchain

Blockchain technologies enable end-to-end data transparency for fresh products, allowing all players in the chain to respond to customers' demands. They can allow for players in the value chain to access historical and real-time data linked to the product, such as timing (time of harvest, time in transport), location (its origin and the history of its journey from farm to fork), or data on farming, labour, environmental, and ethical practices and verifying standards (Kamilaris et al. 2018; Chisoro-Dube et al. 2019). Such technologies address the challenges related to limited data availability, the often poor quality of data in Africa, and the lack of interoperability resulting in high levels of manual intervention and paperwork.

The decentralized nature and location of blockchain technology on a cloud database enables retailers to share data with customers on individual produce items. For instance, the consumer can scan a simple quick-response code on their smartphone, and then use an app to view every step of the purchased product along the supply chain. A producer can collect and upload data on field location, growing conditions, soil and fertilizer use, harvest details, cold chain initiation, and the transportation history of their product (Chisoro-Dube et al. 2019). Start-ups like Provenance, Arc-Net, Bart. Digital, and Bext360 sell such traceability products for end customers (Kamilaris et al. 2018).

Central to the use of blockchain technology is its ability to improve transparency from growers to the consumer, which empowers producers to make better commercial decisions and fairly assess value and risks. At the grower level, a transparency system could capture and verify batch-level quality differentiators such as cold storage conditions, cultivars, and flow of goods through the value chain. Particularly relevant to value-added products, a transparent value chain enables the documenting of people and processes, which may help to humanize the story of the supplier, especially if it is an SME. Retailers also increasingly demand that producers provide transparency and new data such as carbon reporting. At an industry level, the decentralized aspect of blockchain technology may also create the trust environment for carbon intensity information to be shared across the chain while maintaining the confidentiality of production information.

Blockchain technology in value chains also brings about other efficiencies. First, digitizing and sharing existing information removes the use of paper-based processes and enhances full value chain visibility. Second, digitalized supply chains also create new financial opportunities by improving access to preferential lending rates. Decentralized technology supporting the availability of granular, verified transparency data stored on a blockchain-backed system could stimulate financial innovations and lending. Because risk can be assessed at a more granular level, the existing financial mechanisms within the value chain can operate more efficiently. This creates potential for preferential financing based on verified farming practices and outcomes such as reduced carbon systems and land rights data. Third, blockchain technology can bring about dynamic insurance due to increased visibility of crop risks. Fourth, there are improved quality signals through the use of product passports containing a complete history, from growing to export market, using the IoT. Blockchain can also enable the verification of audits and certifiers. Lastly, blockchain technology creates social proof by facilitating the collection of new data points.

The benefits of blockchain technology for small farmers and processors can be illustrated through services provided by companies like UK-based Provenance. Provenance has linked small players in developing countries with large retailers and brands such as the Co-op supermarket—the UK's largest consumer co-operative. The technology has, for instance, helped to link South-East Asia's fishing industry to retailers by allowing the smart tagging of fish caught by fishermen providing verified social sustainability claims for export markets. The social and environmental conditions at the point of capture are verified through trusted local non-governmental organizations (NGOs) whose audit systems validate their compliance to an external standard. These standards include Fair Trade USA, Pole and Line Foundation Association membership, and GPS (working with Seatracker data) (Provenance 2019). Similarly, the Co-op has used Provenance software to track fresh produce and product claims from origin to supermarket. The Provenance app showcases the journey of fresh produce and its data through the supply chain, and links this with systems data at a Co-op depot and retail outlet, building a real-time digital history for the fresh produce. The shopper can, by scanning the product label, access product information, journeys, and stories that have been verified by the Provenance app.

As part of the research for this study, CCRED engaged with Provenance UK to identify what opportunities there are for South Africa to use this technology in the agriculture space. This is discussed in Section 5 below.

However, there are also concerns around the use of such technology. Key challenges relate to issues of data protection, the standardization of data exchange, and the standardization of certification. We discuss some of these concerns below in the context of big data.

Big data

Retailers and consumer goods manufacturers are using large volumes of consumer data to better analyse and forecast changing demand patterns. This includes the growing use of platforms such as Google Cloud, Google Analytics, and Amazon Web services. These platforms enable better analytics, fact-based decision-making, and greater automation, resulting in more efficiencies in value chains (Goga and Paelo 2019a, 2019b).

There are, however, concerns about how big firms access and use the data, and the anti-competitive effects that may result. The use of big data can reinforce dominance due to network effects. Network effects imply that the value of a product or service increases as the number of users increases (Autorite de la Concurrence and Bundeskartellamt 2016). In a market with dominant players, the additional value creates a positive feedback loop whereby the biggest networks become even bigger. Eventually, users instinctively favour the dominant player, thus strengthening the position of dominant players in the market and increasing barriers to entry (Clark and Chatterjee 1999).

Analytics platforms make use of valuable information collated from various sources, such as customers, company websites, and loyalty cards, which often require a range of demographic data upon sign-up. A dominant firm is likely to have more website traffic and more customers who sign up for loyalty points. As such, they have more data, which allows them to generate more accurate analysis of market trends than their smaller counterparts. In so doing, the dominant firm may offer greater value and higher-quality products and services to customers. This added competitive advantage may increase the market share of the dominant player, resulting in a more concentrated market with greater barriers to entry (Autorite de la Concurrence and Bundeskartellamt 2016; Goga and Paelo 2019a). In addition, the extraction and use of customer data raises ethical concerns about consumer exploitation and infringement of data privacy (Goga and Paelo 2019a, 2019b).

The dominance of vertically integrated platforms also raises concerns about abuse of power, as these platforms may exercise their market power and control over a key route to market, to the exclusion of smaller players. Large companies such as Amazon, Alibaba, and Takealot South Africa are retailers that sell their own brands of goods while also acting as a route to market for third-party suppliers to sell their goods (Goga and Paelo 2019a). These companies may use the data generated from their website traffic to inform their strategy for supplying goods, often leveraging their large integrated manufacturing and logistics base, which at times excludes SME suppliers. For instance, the European Commission has opened a case to probe whether Amazon's dual role as a retailer and merchant has anti-competitive effects (European Commission 2019).

Platforms active in several markets may also leverage their dominance in one market to distort competition in another market where they do not have dominance (Pietro 2008). For instance, the European Commission has convicted Google for using its dominance in general search to promote its comparison shopping services, getting an undue advantage over rivals instead of competing on merits (European Commission 2017). Further, platforms such as Amazon which have significant market share in the automated assistant market as well as in online retail may leverage their positions to gain an advantage. Currently, Amazon's Alexa—which is a voice-controlled assistant—prioritizes Amazon-owned brands when making suggestions to users (Goga and Paelo 2019a).

4 How technology has facilitated the inclusion of SMEs in food value chains in Africa

There have been technological developments and innovations in agriculture and agro-processing value chains in Africa, especially in East Africa. These developments address some of the challenges in entering and staying competitive in agriculture and agro-processing value chains, along with the inclusion of previously disadvantaged and marginalized groups, such as SMEs and women. The discussion below considers some of these developments. For a comprehensive, recent publication on insights from East Africa into disruptive technologies in agricultural value chains, see Krishnan et al. (2020).

4.1 ICT technologies to provide financing solutions

Limited access to finance for smallholder farmers and SME agro-processors remains one of the biggest challenges to participation and growth in food value chains, particularly those situated in rural areas (International Finance Corporation 2017; Tinsley and Agapitova 2018). Although agriculture employs approximately 65 per cent of Africa's population, and makes up 32 per cent of its GDP, less than 6 per cent of bank lending in Africa goes to agriculture (FAO 2018). Formal sources of debt financing, including local and national banks and microcredit institutions, find it difficult and costly to penetrate into the rural agriculture sectors due to distance from bricks-and-mortar branch offices (Annan et al. 2015). Agriculture in Africa is also prone to market risk, as prices fluctuate depending on productivity yields at particular times (Deichmann et al. 2016; Samboko et al. 2018). Agricultural SMEs are often unable to provide the appropriate business and financial management documents as collateral. They also often lack financial reporting capabilities and cannot afford to outsource services to get regular annual reports, business plans, and forecasts (Deichmann et al. 2016; Samboko et al. 2018).

There have been a number of innovative solutions in Africa that address some of these barriers to entry and improve access to finance for smallholder farmers and rural-based agricultural business. Nigeria's eWallet service, for example, allows registered smallholder farmers to transact with service providers and purchase agricultural inputs. Here, farmers use eWallet vouchers (through a mobile phone or a unique identification code) to purchase fertilizers, seeds, and other agricultural inputs from agro-dealers at half the cost, the other half being borne by the federal government of Nigeria through input subsidies. This system makes it easier to ensure that inputs are supplied on time and into the right hands, as the identification codes limit corruption (Annan et al. 2015).

Kenya's FarmDrive is a mobile platform which uses mobile technology and analytics to assess farmers' risk profiles (Deichmann et al. 2016; GSMA 2018b). The farmers can access this technology by using the short message service (SMS) to register; thereafter, a comprehensive profile of a farm's financial stability is created which is drawn from satellite images, weather forecasts, produce buyers, agricultural dealers, and the farmers themselves.[6] Financial institutions can then view the data and approve loans, and farmers receive the loan via M-Pesa, the ubiquitous mobile money transfer service in Kenya (Robb and Vilakazi 2015). This particular technology has had a significant impact for female farmers, who typically have less access to financial services than male farmers in Kenya (GSMA 2018b).

Mobile penetration has been growing rapidly in Africa. In 2018, Sub-Saharan Africa had an estimated 456 million unique mobile subscribers, increasing by 20 million from 2017. Also in 2018, 239 million people, or 23 per cent of the population, used mobile internet regularly. It is estimated that by 2025, half of the population in Sub-Saharan Africa will subscribe to mobile services (GSMA 2019). There is therefore great potential for technologies leveraging this infrastructure to be introduced to address some of the barriers in agriculture in Africa.

However, the availability and affordability of broadband coverage in all areas, particularly rural areas, is critical in ensuring that some of these technologies can be adopted. This is discussed in the context of South Africa in Section 5 below. Related to this, the adoption of digital platforms and IoT technologies is also constrained by the high data prices that prevail in the region (Nhundu and Chin'anga 2017).

4.2 Digital and ICT technologies to improve market access

Market access is critical for suppliers of agricultural and processed products. The modernization of supermarket procurement systems and trading requirements in the region has placed pressure on smallholders to invest in and acquire capabilities that match those systems, as supermarkets grow and become an important route to market (das Nair and Chisoro-Dube 2015; Gereffi and Lee 2016; Reardon et al. 2003). In most emerging economies, the shortage of critical agriculture infrastructure for storage, transportation, and warehousing of agriculture produce constrains small producers from reaching markets (Annan et al. 2015; Hussein and Suttie 2016; Tinsley and Agapitova 2018). Agriculture SMEs also often do not have the production, processing, and packaging technologies to meet the standards of international markets. Similarly, agriculture SMEs struggle with consistent quality, reliable, and timely distribution. SMEs, especially if remotely located, often do not have access to relevant information about the demand and pricing of their products in national and international markets, limiting their reach to lower-margin and low-volume local and regional markets (Hussein and Suttie 2016; Tinsley and Agapitova 2018).

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[6] See www.ewb.ca/en/venture/farmdrive/#how.

The application of appropriate digital technologies can help to address the lack of access to market information, including in terms of the ability of smaller enterprises to absorb and respond to market information. The web-based platform Esoko is an example of technology that has been used to facilitate the flow of market data. In Africa this company operates in Ghana, Kenya, Mauritius, Malawi, Uganda, Mozambique, and Benin (van Schalkwyk et al. 2017). SMS messaging is offered in multiple languages[7] to gather and disseminate market data, including pricing data, through mobile devices among farmers and traders in Africa (Narsalay et al. 2012). The platform also provides weather forecasts and crop production protocols (van Schalkwyk et al. 2017). Subscribers pay a small fee to receive up to 10 SMS alerts per month and to upload buy and sell offers directly to the system. In addition, institutional users, such as agri-businesses, NGOs, and government agencies, can purchase a subscription and use the information to advise and train their local beneficiaries.

Kenyan-based platform Sokopepe provides timely information about the price of commodities and farming practices, along with geolocations for storage facilities, suppliers of inputs, and extension services providers. This platform facilitates the trading of agricultural commodities. It is accessible online but can also be used through SMS via basic mobile phones.[8]

Twiga Foods in Kenya is another mobile-based platform enabling market access and information that links fruit and vegetable farmers in rural Kenya to small- and medium-sized vendors, outlets, and kiosks in urban Nairobi. This platform is able offer higher prices and a guaranteed market to farmers, and provides a reliable supply to vendors. It also helps to reduce post-harvest losses and waste, as it better matches demand with supply. Consumers also benefit, as they are able to buy fresher products at lower prices due to a more efficient supply chain. Farmers only need a feature phone to receive harvest receipts, and they simply have to deliver their products to Twiga Foods collection centres. Thereafter they get an SMS receipt and settlement is completed within 24 hours using mobile money (GSMA 2018a). Vendors can place orders and pay using mobile money.

Through their subsidiary platform Mergdata, Ghana-based company Farmerline provides traceability and farmer profile services, certification tracking, farm mapping, input distribution, and farmer education.[9] Through this platform, users can track produce from the farm all the way through the value chain by using a custom barcode that the platform creates. Users can also track the certification status of farmers, while farmers are able to save and send voice messages that reinforce their knowledge on generally accepted practices, global sustainability standards, weather forecasts, prices, and agronomics tips. The platform also tracks where and when farming inputs are needed and how effective they are.

Multinational companies also offer similar platforms in Africa. In 2017, Mastercard launched a mobile marketplace for the East African region called 2Kuze that incorporates payment systems (Sishuba 2017). The platform allows small farmers to co-ordinate sales, payments, and the distribution of crops. Buyers place orders in the app and farmers are able to notify buyers if they can fulfil the order. Thereafter an agent picks up the produce and records its weight to the app via Bluetooth. The agent then delivers the produce, and the farmer is paid through a mobile money platform.

[7] For instance, in Ghana messaging is in English and 12 other local dialects (van Schalkwyk et al. 2017).

[8] See www.fao.org/fileadmin/templates/dimitra/pdf/dim_24_e_p18.pdf.

[9] See https://mergdata.com/industry.

Such mobile-based platforms and apps are an easy way to greatly enhance the ability of smallholder farmers and agro-processors to access wider markets in Africa. These platforms, particularly the locally developed ones, are very responsive to local needs and challenges, and serve to reduce the information asymmetry in agricultural value chains. The barriers to establishing such platforms for local service providers in regions like East Africa appear to be surmountable, as evidenced by the multiple platforms that are emerging. The regulatory and competitive environment is important to ensure this and to encourage the entry and participation of such service providers. These environments are less open in countries like South Africa, where a very few mobile network operators and banks dominate, and where regulations are not favourable to new entrants. This is discussed in Section 6.

4.3 Climate-smart technologies

The research on climate change has identified several avenues through which climate variability will affect agriculture. These include rising temperatures, rising sea levels, increased snow-melt, change in the volume and timing of water use for irrigation, and increased probability of extreme events. Since the SADC region is a semi-arid area, climate change has meant that it is often plagued by droughts (Davis and Vincent 2017). The frequency of weather- and climate-related disasters has increased since the 1970s, and Southern Africa has become drier during the twentieth century (Davis and Vincent 2017), with several areas facing severe, debilitating drought.

These droughts have meant that farmers have to change production mechanisms to include appropriate irrigation (where affordable), adopt drought-resistant seeds, and use more plant chemicals. Small farmers have inadequate capabilities to respond to and mitigate the risks of climate change. This is often because they have limited information about weather trends and patterns, are reliant on rainfall, and have limited access to irrigation facilities or resources to purchase these inputs (Mwangi and Kariuki 2015; Nyasimi et al. 2014). Small farmers may also have limited access to drought-resistant seeds, as the majority in the region tend to use seeds retained from the previous years' produce given that they cannot afford to buy new seeds (Mwangi and Kiriuki 2015).

There have been multiple mechanisms and technologies employed to mitigate some of the risks associated with climate change (Bucci et al. 2018; Nyasimi et al. 2014; Tinsley and Agapitova 2018). For instance, in Kenya a small start-up called Illuminum Greenhouses supplies greenhouses and drip irrigation kits equipped with SMS-controlled solar-powered sensors (GSMA 2018a). The system allows smallholder farmers and farm owners to monitor and regulate conditions remotely via SMS. The start-up claims that by controlling water via irrigation schedules, farmers using their greenhouses can reduce water usage by up to 60 per cent (GSMA 2018a). The reported impact has been significant—for 300 farmers using the technology, production increased by 70 per cent while incomes increased by 60 per cent. Expansion into Uganda and Tanzania was also being considered (Bett, no date).

An agricultural technologies company in Kenya, Ujuzi Kilimo, assists small farmers with precision farming and data analytics, as well as climate-smart farming.[10] Ujuzi Kilimo uses sensor technologies to capture soil and farm data, which are subsequently used to advise on fertilizer, seeds, and best practice to maximize yields and for sustainable farming. The platform also provides insight on crop cycles and weather patterns. In 2017, the start-up helped 200 rural farmers to increase productivity by 36 per cent over one year through its US$20 package for complete soil

[10] See https://www.ujuzikilimo.com/index.html#home.

analysis and $6 annual subscription. Flexible payment options through mobile money platform M-Pesa make it more accessible to farmers in rural areas.[11]

Ethiopia's Agricultural Transformation Agency has developed the Ethiopian Soil Information System or EthioSIS. This system is a digital soil map analysing the country's soils down to a resolution of 10 km by 10 km which is updated regularly (Annan et al. 2015). The system enables small farmers to obtain valuable information to improve their investment capabilities, in that they are able to assess and identify which fertilizers, seeds, and other technological inputs would be the most profitable to invest in given the soil characteristics. Results in the early stages of the implementation of the system suggested that the soil mapping resulted in yield improvements of up to 65 per cent as a result of more informed use of fertilizers and better soil management (ATA 2016).

These innovations have helped participating small farmers to more effectively integrate into agricultural value chains and have increased their productivity and their income. Although a comprehensive assessment of the full extent of such platforms is beyond the scope of this paper, a preliminary scoping suggests that many of these are in East African countries where there are a large number of smallholder farmers. Several, although not all, of these innovations are spearheaded by small tech start-ups and appear not to be widely adopted at a national level by governments. Governments in the Southern Africa region in particular are for the most part still focused on early-stage technologies, including primary mechanization and inputs to the growing process (such as fertilizer and seeds subsidies). There are lessons to be learnt in order that governments can also actively support the agricultural sector through enabling the use of such technologies or, at the very least, creating a conducive environment for start-ups to offer these services more widely.

5 Technologies used in agriculture and agro-processing in South Africa

Unlike East Africa, agricultural markets in South Africa and in other Southern African countries are typically highly concentrated and dominated by large, commercial farmers. A fringe of smallholder farmers mainly serves very narrow localized markets or communities. Markets in agro-processing value chains are also highly concentrated (Mtombeni et al. 2019), in which a few, often multinational firms dominate. It is generally these large firms develop and adopt innovative systems and technologies. This section assesses some of the technologies adopted in fresh fruit and selected processed food industries in South Africa and the drivers behind them.

5.1 Technologies in fresh fruit value chains

Digitalization of value chains

Several industry and government systems and procedures in the agricultural sector in South Africa are still largely paper-based. The Department of Agriculture, Forestry and Fisheries (DAFF) (now the Department of Agriculture, Land Reform and Rural Development—DALRRD), has been slow in adopting and implementing electronic systems of capturing data. Although there are developments as we discuss below,[12] most processes remain paper-based, and on email and spreadsheet systems. The delays in digital migration are exacerbated by the department's

[11] See https://startup.info/ujuzikilimo.

[12] Unless otherwise referenced, this discussion is drawn from Chisoro-Dube and das Nair (2018).

constraints around capacity in terms of human resources, skills, and lack of implementation of policies (Chisoro-Dube et al. 2019).

In the case of fresh fruit, reliance on paperwork and manual processes of capturing data on the registration of orchards, phytosanitary records of growers, and shipping information results in considerable time wasted and human errors. The paper-based process of exporting fruit and acquiring phytosanitary certification requires that growers physically frequent government offices to sign paperwork (Chisoro-Dube et al. 2019).

In response to the challenges of manual intervention and paper-based systems, the industry association in the fruit sector, Fruit South Africa (FSA), and specifically the Citrus Growers' Association (CGA), in conjunction with DAFF developed a platform for electronic data interchange (EDI) called Phytclean in 2016. Phytclean is an electronic digital platform used to capture, store, and report data for export phytosanitary certification (Hardman 2016). The platform captures information on the registration of orchards, enables instant updates and verification of orchards and phytosanitary records of growers, and ultimately issues electronic certificates. As such, Phytclean provides electronic evidence as an alternative to the paper-based system for all the requisite steps in the certification process. All relevant parties in the value chain, including importing-country authorities, can access these data. With the new digital platform, after a product is cleared and the sanitary and phytosanitary (SPS) requirements are met, the product is signed off electronically without the growers having to visit government offices and sign paperwork. The electronic certification (e-cert) of phytosanitary standards was successfully piloted in the citrus industry in September 2018 from South Africa to the Netherlands (Chisoro-Dube et al. 2019).

Estimates are that the Phytclean platform will save the fruit industry ZAR250 million over five years. The success of the platform was evidenced when EU legislation required compliance in relation to the false codling moth in 2018. This necessitated specific and special management processes through the value chain to ensure market access in the EU. Through Phytclean, this was possible and South Africa was able to continue exporting to the EU. The platform is owned by FSA. As of 2018, there were 3,000 registered users in the citrus, apple, pear, peach, nectarine, table grape, and pomegranate markets. Other players in the value chain, such as growers, packhouses, exporters, and other service providers, are also connected to it.

There are questions, however, about who is able to access this system and at what costs. The availability and affordability of accessing the platform for non-FSA industry association members, who are likely to be smaller and black farmers, may be limited. From a governance perspective, the power wielded by the industry association in controlling such platforms determines the conditions for inclusion and exclusion in value chains. There is a role for government support in such circumstances, to enable outsiders to access these platforms on fair terms—or to access similar platforms, as we discuss in Section 6.

The adoption of digital systems like EDI improves process efficiency along the value chain. To complement and realize the benefits of industry-wide initiatives towards electronic certification and data-sharing systems, individual firms in South Africa, particularly large producers, are implementing EDI systems within their own supply chains. Such systems integrate information in the packhouse and cold chain facilities rather than using paper-based systems. This technology allows for the seamless monitoring of supply chain processes as the system synchronizes the information from the packhouse and cold storage facility and then produces comprehensive reports and documentation. Tablet devices installed with apps that use cloud storage are used to conduct at the source (i.e. at the farms) the audits and inspections necessary to acquire accreditation in export markets (Chisoro-Dube et al. 2019).

Blockchain

Similarly to the above, the fruit industry is also adopting blockchain-powered data systems to create new value exchanges. Currently, blockchain technology is being used in limited cases to process payments in fruit trading, which has drastically reduced the speed with which payments are processed. For example, some producers use a company called Traderly, which utilizes blockchain to fast-track trade payments by converting US dollars into cryptocurrency in South Africa. In comparison with the traditional 'SWIFT' payment method, this technology has sped up the payment process from 3–5 days to 15 minutes (Chisoro-Dube et al. 2019).

As highlighted in Section 3, there are numerous opportunities to use blockchain more widely in agriculture and agro-processing value chains. As also noted, CCRED engaged Provenance UK on what opportunities there are for blockchain in the South African horticulture sector. In early 2019, a preliminary workshop was held with stakeholders in the avocado industry to explore the potential applications of blockchain. This involved exploring the opportunities for digitally enabled avocado supply chains focusing on value-add and efficiency. Several opportunities were identified,[13] including allowing for the sharing of richer data points in the chain to support sales—for instance, providing data on carbon footprint and living wage proof; tracking the impact of retailer-funded community programmes; sharing the authentic origin stories of avocados across the value chain, which is something that is important for small growers; and creating operational efficiencies by improving existing processes and decision-making.

Despite these benefits, several challenges were also highlighted that limit the adoption of digitally enabled supply chains in South Africa. These include long technology investment cycles in established value chains which mean that returns are only likely to occur several years after the investment is made. To overcome this, especially for SME growers, there needs to be some financial support to encourage adoption. Switching costs from incumbent systems also remain high partly because of a lack of trust in new platforms like blockchain. Training and workshops on the features and benefits of such platforms are needed to increase awareness. External regulation and audits are part of the costs to operate such systems to maintain their integrity. These challenges can be extended to products other than avocados. In the case of avocados, there was low appetite to disrupt the status quo among growers without significant change in pull from the market, including through supermarket outlets. Given the nature of traded fresh produce, which has relatively low customer loyalty, there may not be sufficient motivation for supermarket chains to co-invest over a longer term.

There have also been local applications of blockchain in the citrus industry in South Africa. For example, a grower and producer of citrus fruits, Katlego Sitrus, is exporting fruits with stickers which have a quick-response barcode. Consumers can scan the barcode with their smartphones, then access video clips about Katlego's production and packaging processes. Such platforms address the historic challenges related to limited data, often of poor quality, difficult to verify, and recorded in different formats at different stages of the value chain, resulting in high levels of manual intervention and paperwork.

Overall, although decentralized blockchain technology is expected to bring about a number of digital efficiencies in the value chain, it is important to note that this is a relatively nascent technology and as such the benefits are not yet well established. There are still a number of challenges associated with the use of blockchain technology. As a decentralized data system, it is slower to process large transactions, especially if it is a public platform and there are various

[13] Provenance post-workshop report for CCRED, University of Johannesburg, April 2019.

efficient systems currently available. Another challenge regarding blockchain technology relates to issues of scalability.

Automated sensing, grading, and sorting technologies

The use of automated grading technology and high-resolution cameras taking pictures of fruit and identifying defects has dramatically improved the quality and speed of sorting in packhouses (Tru-News, no date [a]). This has resulted in efficiency improvements in exporting and higher prices. For example, Tru-Cape Fruit Marketing, one of South Africa's largest marketing companies of apples and pears installed a new 10-lane sorting equipment that can process eight fruits per second per lane. This technology is combined with the new iFA light technology to determine any internal irregularities and is installed with camera-scanning equipment (Tru-News, no date [b]).

There have been public–private collaborative efforts, other than Phytclean, in the fruit sector in South Africa. Through the Post-Harvest Innovation Programme, a public–private partnership between the Department of Science and Technology (DST) and the Fresh Produce Exporters Forum, a range of technological solutions related to logistics, transport, and packaging, is being developed. These include validation of time and temperature tolerances, cooling efficiency, and the maintenance of product quality, modified atmosphere packaging, air freight cold chain management and traceability systems.[14]

Biotechnology

The impacts of climate change and weather variability in the Southern Africa region are driving investments in advanced breeding technologies to grow varieties that are adaptable to climate change, with improved resistance to diseases and pests (insects, weeds, and pathogens). For example, the citrus industry in South Africa has been successful in developing new local varieties of soft citrus such as mandarins. These include a branded mandarin variety called ClemenGold, successfully launched into the world markets, and the Tango mandarin variety. The ClemenGold mandarin brand is being rolled out to include other branded citrus products such as the LemonGold, HoneyGold, and NavelGold. Tango's plant breeders' rights were granted in South Africa in March 2016, confirming that it is now registered as an individual variety in its own right (Meintjes 2017).

Although the South African fruit industry has access to locally bred varieties (through the Agricultural Research Council) and open (typically older) varieties, the industry relies largely on imported varieties. The stone fruit industry has imported more than 4,000 stone fruit varieties since 1994. In 2017, of the planted plum trees, 870,000 were 'open' varieties that are freely accessible without conditions while 915,000 were 'protected' varieties with producer limitations and marketing conditions. Importing new varieties into South Africa involves an extended period of time in quarantine (currently two years) before the varieties can be used for commercial production, causing major delays for growers in planting new varieties. The quarantine process involves laboratory testing to ensure that the imported varieties are free of pests and diseases. The length of time it takes for imported varieties to pass through quarantine could be greatly reduced to improve the local growing of new varieties. In response to the lengthy processes involved in importing new varieties, Citrus Research International (CRI), under the Citrus Growers' Association of Southern Africa (CGA), conducts evaluations of new citrus cultivars focusing on the cultivar's characteristics, its climatic suitability, and its commercial potential in the market.

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[14] See https://postharvestinnovation.org.za.

The ownership of cultivars and plant genetics is also an important aspect for participation in fruit value chains. In the berries industry, for instance, imported varieties in South Africa are owned by three leading producers globally (BerryWorld, United Exports, and Haygrove). These producers have the breeding licences to produce new plants/seedlings from the parent plant and have contracts with universities and Costco to disseminate the tree seedlings. As such, any new farmer planning to produce blueberries would have to buy plants from the incumbents who own the licences to the plant genetics. New farmers are also required to sell their produce through the incumbent in exchange for payment of royalties and commission for marketing services. This means that intellectual property (IP) holders possess considerable market power and are able to extract rents at each level of the value chain from growing to the marketing of the product in export markets. The development of quality varieties or genetic material is critical in the berries industry (Chisoro-Dube et al. 2019).

Crop pest and disease technologies

While biotechnology contributes to producing more pest- and disease-resistant varieties, technological advances in software can link fruit growers' weather data to actual pest risk. This involves using weather technology through solar-powered wireless weather stations to gather real-time temperature, humidity, rain, and leaf wetness data which is used to generate stepped risk levels to warn the farmer about when conditions are most susceptible to pest development. For example, Katlego Sitrus has developed a scouting smartphone app designed to speed up and improve pest and disease identification and treatment. Using the app, a scout can take a photograph of the pest or disease on the tree or plant, then upload the image to a database in real time for immediate identification and treatment (den Hartigh 2016).

At an industry level, CRI and River BioScience, a commercial subsidiary of the CGA, conduct extensive research on pre- and post-harvest diseases of citrus, crop protection products, and pest monitoring products. The association has an integrated pest and disease management division focusing on both indigenous and introduced pests.

Irrigation technologies

Increased weather variability and water scarcity are driving key disruptions at the growing level through the application of irrigation technologies and precision farming methods. Satellite imagery and high-resolution crop sensors are used to inform the application of the right amounts of irrigation or fertilizer, while optical sensors or drones are used to identify crop health across the field. For example, avocado growing companies such as Westfalia are adopting the use of low-flow drip irrigation technologies in their farming methods, controlled by mobile phones. The recent droughts in South Africa are increasingly forcing growers to adopt irrigation and precision farming technologies to maintain and improve production. In response to water challenges, the Western Cape Department of Agriculture developed an online application called FruitLook in May 2016 to provide farmers with accurate and reliable information on the water needs of crops.[15] At an industry level, CRI conducts long-term research on how to improve water use efficacy in citrus orchards. A key part of the research focuses on understanding the basic principles involved in different fruit physiology and irrigation scheduling, which are critical to increasing production and fruit quality.

The above discussion highlights how the fruit sector has been at the forefront of innovation and adopting technologies in agriculture in South Africa. Many of these initiatives are driven by the

[15] See www.fruitlook.co.za.

private sector. Powerful industry associations backed by large lead firms have been at the forefront of developing and adopting these technologies. These associations have, in certain cases, joined forced with government to roll out certain technologies. Especially in citrus, this has served to propel and maintain South Africa's strong global position in citrus exports (as the second-largest exporter globally). Creating greater access and lowering the cost of access to these or similar technologies is important to ensuring that more players in these value chains, and not just those that are part of industry associations, are able to benefit from them.

5.2 Technologies in selected processed food product value chains

While the previous section evaluates the role that innovation and technology play in fresh produce value chains, an ongoing project funded by the UK's Global Challenges Research Fund on 'Innovation and Inclusive Industrialization in Agro-Processing' provides insights on the role of innovation and technology in selected processed food value chains. This project, which will be completed by mid-2021, is undertaken by CCRED at the University of Johannesburg, the Centre for African Studies at the University of Edinburgh, and the Economic and Social Research Foundation of Tanzania. Below we discuss some preliminary findings on technologies from over 50 field interviews with small and medium-sized maize millers and dairy processors in South Africa as part of this project. These findings have implications for the inclusion of SMEs in these value chains.

Maize milling

Although the maize milling or mealie meal production process has fundamentally remained the same for many generations, and the industry is relatively mature, some SME milling companies in South Africa have upgraded their products and production processes through the adoption of technologies. Various technologies have been employed at different levels of the value chain in response to changing market conditions.

Milling companies typically make use of ICT technologies as part of their procurement of maize from the upstream level of the value chain. Industry association Grain SA makes market information on pricing and usage of grain commodities available to its members through ICT (Sihlobo et al. 2014). Millers typically use the internet to keep track of prices, and the industry trades maize and hedges trades using prices and differentials published daily and annually by Grain SA. In addition, millers also use the internet to keep track of market trends and conditions associated with the supply of maize. This allows millers to speculate on whether or not to buy maize in advance in anticipation of an increase in prices. Given the impacts of climate change on crop production since the 2014/15 drought in the region, this is particularly important.

Prior to processing, grading and testing technologies are necessary to meet food safety requirements and product specifications. For instance, in South Africa, white mealie meal made from white grade 1 maize is generally preferred by consumers, while other products such as grits and animal feed allow for the use of yellow maize at different grades. Grading technologies allow the maize to be sorted into these different grades. There is limited public sector support for testing facilities, making it difficult for SMEs, which then have to rely on more expensive private testing labs.

In terms of processing technologies, some SME millers use cleaning and conditioning machinery to improve the quality of the maize products they make. The cleaning machinery washes the maize prior to milling in an attempt to get rid of as much foreign material as possible, while the conditioning machinery adds moisture to the maize to ensure that the bran peels off easily during milling. This technology results in better-quality maize products. Larger milling companies have invested in optical technologies to get rid of black specks in mealie meal, producing higher-quality maize meal that can be sold at higher prices. However, this machinery was found to be too expensive for small and medium-sized millers. This has implications for the quality of the products that smaller millers are able produce relative to larger players, and negatively affects their competitiveness.

Processors also employ technologies to make value-added products fortified with minerals and vitamins, such as flavoured maize meal and porridges. Such product upgrading requires new processes and equipment, which relatively small and medium-sized players appear to be investing in.

At the packaging level, medium-sized firms are starting to use technologies to automate packaging, while, as would be expected, this is commonplace with large firms. Automating packaging results in less waste and more consistent product, as it eliminates the variability in how much product is in each package. In addition, automated packaging allows for a cleaner and safer product, as the product is not subjected to contamination while it is packaged. Food safety standards are more likely to be met through automated packaging, allowing access to RVCs and GVCs, especially through supermarkets.

Cloud computing and integrated reporting systems further allow for the generation of better and more accurate records for meeting food safety requirements. Some millers make use of cloud computing and integration software to sync maize grading records with information collected at the processing plant, such as moisture and protein content. This information can often be accessed at different locations, as it is typically stored using cloud computing. Furthermore, millers use ICT and computer systems to conduct e-business. This includes marketing and communicating with customers. Some millers use social media platforms such as Facebook and LinkedIn to market their products and interact with their customers; other millers take orders from customer using platforms such as WhatsApp. In addition, some millers are aiming to completely do away with cash transactions for safety purposes, using electronic or digital payment methods instead.

Overall, the technologies in milling are fairly basic and aside from automated packaging and optical sorting, it appears that SME millers are able to adapt to other technologies relatively easily—although a lack of skilled workers and access to finance were still highlighted in interviews as major constraints. However, the cost of the data, which continues to be a problem in South Africa (although there have been recent interventions), hampers access to even the most basic technology. We discuss this in Section 6.

Milk production and dairy processing

At the upstream raw milk production level, feed technologies have been used to ensure that cattle yield enough good-quality milk to supply the dairy processing industry. These technologies are particularly relevant given climate change implications for the quantity and quality of grass available, along with the availability of water for cattle. At the primary level, farmers also optimize the breed of dairy cows that they use. For instance, Jersey cows produce milk with a high fat content and consume less water than Holstein-Friesland cows. Biotechnology and genetic manipulation are important to ensure that the desired characteristics are achieved. Cloud computing and integrated software systems are also used to monitor the milking of the cows, along with keeping records of the milk quality. Good record-keeping regarding milk quality can greatly assist milk producers and ensure better quality of milk.

Critically, at the dairy processing level technology is needed to ensure that dairy products such as milk, cheese, yoghurt, cream, and others are safe for human consumption. Dairy products are prone to contamination that results in severe adverse health effects. Most dairy products are temperature-sensitive and need to remain refrigerated to stay safe to consume. Throughout the value chain, products need to be stored and transported in temperature-controlled equipment and refrigerated trucks. At the processing level, there are basic processes that milk must undergo in order to be ready for consumption. The basic pasteurization of milk is a mandatory health and safety requirement for milk used in products for human consumption, although there are emerging market trends of consumers now seeking to consume raw milk for wellness-related purposes. This requires good testing facilities, which again is difficult and expensive for SMEs, with a lack of publicly available and reliable labs, especially in rural areas. There have been efforts to create mobile labs and testing facilities to reach farmers in rural areas, but these initiatives are still in early phases of development (interview with Council for Scientific and Industrial Research, CSIR).

In South Africa, consumers prefer homogenized dairy products. The process of homogenizing involves breaking down the fat molecules in milk such that they remain integrated and do not separate as cream when the milk is resting. Many small dairy producers utilize homogenizing machinery and processes to enhance their fresh milk to suit consumer tastes. Some medium-sized processors further invest in separating machinery, which allows cream and fat to be extracted from milk. The growing demand for ultra-high-temperature (UHT) milk has also led to investments in technologies to produce this, although because this equipment is expensive, SME processors often do not invest in it. To produce other value-added products like cheese, butter, yoghurt, and amasi (sour milk), biotechnology is needed to produce cultures, and incubators with temperature sensors are crucial.

At the packaging level, processors use automated machinery to perform specific functions. For instance, cheese-making companies use slicing and grating machinery to package cheese in different sizes, and milk processors use automated bottling machinery.

Given the challenges with maintaining constant and affordable electricity supply, many small processors are using or looking to use renewable energy technology like solar power to perform functions such as warming water for cleaning machinery and powering cold storage infrastructure.

The use of technology and innovation is more significant in dairy than in milling, largely because of the nature and perishability of dairy products, and the degree of value addition possible. Greater use of even basic technology can grow production, lower costs, and increase domestic and export opportunities in both of these value chains. Unlike some of the examples in fruit in the previous section, most technologies in dairy and milling are fairly standard, and with support they can be made easily accessible to SME processors. These technologies are important for SME processors to access formal supermarket shelf space. Given food safety requirements and the escalating private standards of supermarket chains, technology can assist SMEs in product and process upgrading to access supermarket networks in the Southern Africa region. While some technologies such as automated packaging may have implications for employment in these sectors, the potential to grow volumes and access new markets can result in overall employment gain. A lack of skills and the high cost of finance for SMEs need to be addressed across these and many other processed food product markets in South Africa.

6 Conclusions: challenges and constraints to adopting technology and policy recommendations

In this paper we have discussed a wide, albeit non-exhaustive, range of innovations and technologies in agriculture and agro-processing in Africa. The innovation and adoption of technologies can play a powerful role in the upgrading of players in these value chains in Southern Africa. This has the potential to facilitate the inclusion of SMEs into local, regional, or global value chains in a number of ways, including through improving productivity, lowering costs, improving quality, enabling access to finance, providing transparency and traceability, allowing adaptation to climate change, and meeting retail and export standards. The impact on other forms of inclusion, such as inclusion of women, has not been evaluated in this paper.

Innovation and technology, however, also have the potential to exclude players who cannot access them on favourable terms, either for financial reasons or because the technology is controlled by lead firms or groupings of lead firms. This can perpetuate the existing high levels of concentration in agricultural and agro-processing value chains in the region. The governance and power dynamics in such situations determine who can access the technology. As highlighted, this may be the case when lead firms or industry associations develop, own, and control the technology. This may lead to the exclusion of non-industry members, or small and often black farmers in the case of South Africa. Creating greater access and lowering the cost of access to these or similar technologies is important to ensure that more players in these value chains are able to benefit from them. There is a role for government support in this regard. While adopting new technologies has been driven primarily by the private sector, where large firms have substantial existing capabilities in research and technology development, partnerships and the alignment of priorities between government and the private sector are necessary to ensure greater inclusivity and participation.

Similarly, advances in biotechnology, for instance, can increase the market power of firms which own the licenses for plant or animal genetics. These firms then control who participates and the terms of participation, including through the payment of royalties and commissions for marketing services. This control can extend to how much is produced and marketed by licensees. Such IP holders possess considerable market power and are able to extract rents at each level, from the growing to the marketing of the product. This is essentially a form of captive governance of the value chain. While the incorporation of other players may occur through licencing, this may be on adverse terms. Appropriate regulation, including competition regulation, is important to identify and address concerns about the potential abuse of power in such circumstances.

The widespread use of mobile and internet-related technology to incorporate smallholder farmers in the agricultural sector in East Africa has been illustrated in this and other studies. Krishnan et al. (2020), for instance, find that in the East African Community (EAC) the most prevalent use of technology in agriculture—with between 66 and 86 per cent of sampled firms using it—was in the data-connected devices category. Within this category, marketplaces (platforms) were the most important. In South Africa, however, the high cost of data has been a long-standing concern, severely limiting the affordability of using such (and other internet-related) technologies in agriculture. The costs of data of the major mobile operators in South Africa were found to be about three times higher than in countries such as Kenya. Contributing to these high costs is the South African government's delay in releasing available spectrum, which would allow for greater competition and lower costs (Roberts and Zalk 2019). There has, however, very recently (10 March 2020) been a landmark settlement agreement between the Competition Commission of South Africa and the largest mobile network operator, Vodacom, to reduce data prices by over 30 per cent. This followed a market inquiry on high data costs in the country. The other main mobile network operators are likely to soon announce similar reductions in data costs. This will have far-reaching, positive implications for the use of several data-connected technologies in the country. However, the matter of releasing additional spectrum to encourage competition, improve connectivity to rural farming areas, and reduce costs still needs urgent regulatory and political will to materialize.

The power of mobile money platforms to support smallholder farmers is also clearly evident in East Africa, particularly in Kenya. In South Africa, the barriers to entry for providing mobile money products are high. This includes the regulatory barriers which require banking licences for mobile offerings or partnering with existing banks. This has made it difficult for mobile network operators to innovate and react quickly to market needs (Finmark Trust 2017). The regulatory framework needs to change to facilitate more easy entry and the growth of mobile money platforms.

Taking advantage of digital disruptions introduced by blockchain and the IoT requires that government departments and relevant stakeholders shift from paper-based systems to electronic processes of capturing data in the industry. This requires building widely accessible systems or platforms to enable the linking and sharing of electronic data between producers, relevant government departments, ports, logistics, and other industry stakeholders. Currently, there are no systems for linking producers' in-house systems to ports, logistics companies, and shipping lines—causing congestion at the ports (Chisoro-Dube et al. 2019).

There is a critical lack of skills in many markets, and this is exacerbated by the demand for the new skills required to operate new technologies. Skills development is urgently needed in partnership with the private sector to meet the demand for different and more advanced skills and to ameliorate losses of low-skill jobs in some processes (Chisoro-Dube et al. 2019).

Government should also play a key role in supporting the development of testing and research facilities, along with the broad-based adoption of new technologies for the overall growth of agricultural and agro-processing markets. This includes investment in laboratory equipment and skills to promote the local breeding of varieties for greater control over production. This can be extended to the Southern Africa region, investing in regional testing facilities and labs, or regional centres of excellence in agriculture and agro-processing.

Development finance for investment in capabilities and learning is also necessary in the adoption of new technologies. There is a need for 'patient capital', given that time and scale may be required to benefit from some of the technological disruptions (Bell et al. 2018).

Scale and network economies are resulting in the growing dominance of large platforms. Platforms are also increasingly vertically integrating into supply and logistics networks, creating concerns about foreclosure and leverage abuses. There is a need for competition authorities in the Southern Africa region to be alert to possible abuses of market power and to act on these abuses to curb anti-competitive outcomes. The collection and use of big data by these and other platforms further requires a national data regulatory policy to be formulated and adopted to govern and protect the ownership and use of this data.

Lastly, there is an urgent need for better co-ordination between government departments and institutions such as the Department of Agriculture, Land Reform and Rural Development; the Department of Trade and Industry; the Department of Science and Technology; the Agriculture Research Council; and the Council for Scientific and Industrial Research, to create an enabling environment for the development and adoption of technology. Partnerships with the private sector are essential to building dynamic capabilities, and policy decisions in this space need close public–private collaboration. The role of technology and innovation in making agricultural value chains more inclusive needs to be taken into account in key policy interventions in the sector, such as in the current development of the South African Agriculture and Agro-processing Masterplan.

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