Food and Agriculture Organization
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Digital technology and agricultural markets

Background paper for
The State of Agricultural Commodity
Markets (SOCO) 2020

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Ivan Đurić
Senior Researche
Leibniz Institute of Agricultural Development in Transition Economies (IAMO)

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Abstract

Digital technologies have a high potential to enable further development of the agricultural sector, significantly reshape food value chains (FVCs), and greatly contribute towards more productive, resilient and transparent food systems. This paper provides a non-technical overview of digital technologies that have a high potential to revolutionize the agriculture and food industry, and contribute towards inclusion of small farmers into FVCs. The particular focus is on digital platforms providing e-commerce services and distributed ledger technologies (DLTs), such as blockchain, as they mutually enable more efficient and more inclusive local and global agricultural markets by tackling their contribution to reducing information asymmetries, transaction costs, and providing financial inclusion of actors along FVCs. Various examples indicate that digital technologies represent great potential benefits for small farmers including increased efficiency of production, direct access to market, inclusion in global value chains (GVCs), and access to finance and insurance services. The further potential of digital technologies, especially blockchain, could change existing linear food value chain models by providing more transparency and trust between the supply chain actors. Finally, by using digital technologies, governments can provide more efficient public services. Overall, the real impact of digital technologies on the agriculture and food industry will be more evident in the years to come when they become widely accepted by all involved actors, and their usage reaches a critical scale. The role of governments will be significant in enabling adequate environments for innovations and further technological development.

Contents

Abbreviations and acronyms

AI	Artificial intelligence
DLT	Distributed ledger technology
DVC	Domestic value chain
EU	European Union
FVC	Food value chain
GVC	Global value chain
ICT	Information and communications technology
IoT	Internet of things
ML	Machine learning
R&D	Research and development
SDG	Sustainable Development Goals
SME	Small- and medium-sized enterprises
USD	United States Dollar

CHAPTER 1

Introduction

1 Introduction

The emergence of industry 4.0[1] has set the basis for a broad spectrum of digital technologies[2]. The tremendous development of wireless communication and networking has enabled the emergence of "low"-tech mobile applications and digital platforms that provide users with access to valuable information. On the other side, the "high"-tech integrated management systems supported by the Internet of things (IoT), "big data" analytics, distributed ledger technology (DLT), and artificial intelligence (AI) provide overall connectivity between "smart" devices and humans, transforming how products are designed, produced and consumed. Whether low- or high-tech, implemented by users or by external service providers, the main incentive for adopting digital technologies lies in the expectations of users to find solutions to existing or emerging challenges (Jouanjean, 2019).

There are many constraints for small farmers[3] to get engaged in the formal economy. Most of them lack market information and do not produce enough (in volume) to incentivize actors along the food value chain (FVC)[4] to get into a formal trade relationship with them. High market entry costs, followed by high transaction costs and exclusion from financial services – such as the ability to open a bank account or obtain credit – creates additional constraints. Furthermore, traditional FVCs consist of several intermediaries that are engaged in business activities between farmers and consumers. In this business environment, farmers receive only a small proportion of the final product price, while at the same time consumers do not have any connection with farmers as final products are mainly labelled by processing companies or retail chains. Thus, transparency along FVCs is becoming one of the most essential factors for gaining the trust of consumers (Tripoli and Schmidhuber, 2018).

Agricultural and food trade faces significant challenges as well. Changes to domestic and international trade policies, characterized by significant decreases in tariffs, has supported a tremendous increase in trade flows and a number of new actors involved in global agricultural trade. These changes have brought about two significant trends: 1) increased trade for emerging and developing countries; and 2) a rapid development of Global Value Chains (GVCs)[5] (Greenville *et al.*, 2019). Nevertheless, the process of global market integration, enabled by reduced tariffs and transport costs, has also resulted in higher transaction costs, as many actors of the GVCs have to deal with more distant partners that operate under different legislations and rules (World Bank, 2019a; Goldfarb and Tucker, 2019). Thus, finding a reliable trading partner has become a significant cost burden. With better information flows, that avoid information asymmetries, actors involved in agricultural trade would be able to reduce transaction costs and thus engage in more efficient contractual agreements with other GVC actors – contractual relationships that are opposite to horizontal or vertical integration (North, 1990).

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1 The term industry 4.0 refers to the fourth industrial revolution characterized by rapid transformation of business operations and products enabled by digital technologies and the Internet (European Parliament, 2015).

2 In this paper, digital technologies refer to the devices, systems, electronic tools and software that are able to generate, store or process data.

3 There are many definitions of small farmers in the literature. The definition of small farmers in this paper refers to those with less than 2 hectares of cropland (for different definitions, see FAO, 2017).

4 Food Value Chain (FVC) consists of all the stakeholders who participate in the coordinated production and value adding activities that are needed to make food products (Source FAO: http://www.fao.org/sustainable-food-value-chains/what-is-it/en/). In this paper, term FVC refers to both domestic and global food value chains, DVCs and GVCs, respectively.

5 If any stage of the FVC takes place out of the national border – in other country or many countries – the term Global Value Chain (GVC) is used.

Digital technologies are a promising tool for FVC actors to overcome some of the previously mentioned challenges. According to Trendov *et al*. (2019), in the next decade, the agricultural system, and especially FVCs, will face dramatic changes due to the emergence of digital technologies. It is already well recognized that digital technologies represent an important tool for achieving the United Nations Sustainable Development Goals (SDGs)[6] related to more productive, resilient, sustainable, and transparent FVCs and food systems in general. Furthermore, the emergence of specific digital tools and technologies, such as digital platforms – a digital tool based on different digital technologies – offering e-commerce services, and DLTs such as blockchain, has been recognized as a possible solution to some of the critical problems facing small farmers today: 1) How can small farmers be included in the formal economy and overcome high transaction costs and information asymmetries? 2) How can they become directly linked with consumers and reduce or eliminate middleman? 3) How can small farmers be included in FVCs and even become a part of the GVCs? and 4) How can they access capital and how could their incomes be improved?

Implementation of digital technologies along FVCs, supported by integration processes of small farmers into GVCs, creates a data-intensive transformation of the agricultural sector. This transformation enables increasing demand for information along FVCs through the creation of digital data for both agricultural assets and production processes. Data generated through primary agriculture, mainly collected within the IoT system, are streamed through FVCs *vis-à-vis* both horizontal and vertical integration processes. Using "high-tech" technologies, such as AI, big data analytics, cloud computing and blockchain, data is stored, processed and transformed into decision-making tools. Thus, data plays a key role in the digital transformation of the agriculture and food industry. On the other side, the need for data results in concentration of power in the agricultural and food industry/sector, as data is recognized as the "fuel" for further profit increases of large companies.

The main aim of this paper is to provide a critical discussion on how existing digital tools, namely digital platforms, and digital frontier technologies, such as DLT (for example, blockchain), AI, and Additive Manufacturing Technology (3D printing) affect agricultural and food markets. A special focus is on identifying if selected technologies are accessible and enable inclusion of small farmers into FVCs. Furthermore, with a focus on digital technologies, policy recommendations are provided to strengthen the contribution of agricultural and food markets to sustainable development.

At present, it is challenging to evaluate the impact of the digital transformation on the agri-food sector and trade, as many digital technologies have only recently emerged (for example, blockchain, AI and 3D printing) and are still in an infancy phase of adoption. Thus, the real impact of these digital frontier technologies on agricultural development and trade will be made more evident in coming years when their usage reaches a critical scale. To enable wide technology adoption and to realize the benefits of digital technologies, cooperation between all stakeholders involved in agriculture and the food industry (for example, farmers, the private sector, researchers, government and non-profit organisations) is required. Certainly, governments will play a crucial role in enabling the digital environment, where policymakers have to reshape existing policies or create new regulations related to data privacy, interoperability of technologies, and possible liability issues.

[6] Digital tools and technologies implemented in agriculture and FVCs have the potential to advance the following SDGs: SDG 2 – Zero hunger; SDG 6 – Availability and sustainable management of water; SDG 8 – Decent work and economic growth; SDG 9 – Industry, innovation and infrastructure; SDG 11 – sustainable cities and communities; SDG 12 – Responsible consumption and production; SDG 14 and 15 – Life on land and below water; and SDG 17 – Partnership for the goals.

This paper is structured as follows: Section 2 provides a critical review of selected digital tools and digital frontier technologies that contribute to more efficient and inclusive local and global markets. Section 3 provides an overview of necessary preconditions for digital technology adoption, accessibility, and inclusion of small farmers into GVCs. How digital technologies enable creation of new market structures and enhance public services is discussed in section 4. Finally, section 5 provides conclusions and policy implications.

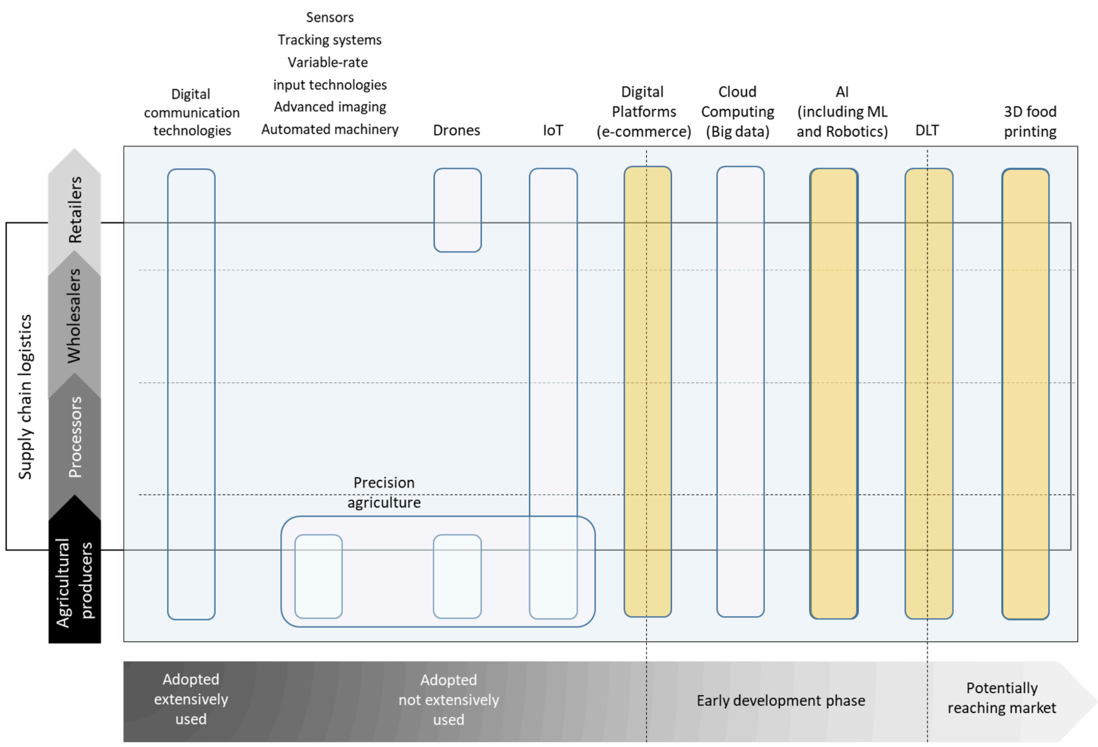
CHAPTER 2

Digital technologies and Food Value Chains

2 Digital technologies and Food Value Chains

.This section provides a non-technical overview of selected digital tools and digital frontier technologies that have a high potential to revolutionize the agriculture and food industry. Hence, the main focus is on digital platforms that provide e-commerce services, that is, a digital tool that could facilitate mix of different digital technologies; distributed ledger technologies (DLTs) (for example, blockchain) that have the potential of providing high-level transparency, data security, and trust among FVC members; artificial intelligence (AI) used for improving FVC efficiency by reducing market uncertainties through predictive analytics; and additive manufacturing technology (3D printing) to indicate a possible direction of FVC transformation in the future (see Figure 1). Most of these selected technologies are currently in their infancy phase of both development and adoption. It will probably take several years or decades until they show their full potential and become widely adopted by agri-food industry stakeholders and FVC actors. Furthermore, to unlock their full potential, most of these technologies are usually combined into one digital product or service that is usually provided to end-users via digital platforms.

Figure 1 **Selected digital technologies in the agri-food industry**



Note: Digital technologies marked with yellow are considered in this paper.
Source: Author's illustration.

2.1 Digital platforms

Supported by significant technological development and the spread of national mobile Internet networks, digital platforms[7] offer easy to use e-commerce services. Having access to a platform provides farmers, regardless of size, the opportunity to have a direct link with buyers of their products. Thus, access to markets is one of the first obstacles, especially for small farmers, that could potentially be eliminated with the emergence of e-commerce digital platforms (hereafter digital platforms). Nevertheless, there are additional core problems common to all markets: 1) How to deal with varying quality levels of the same products delivered by numerous farmers (quality standards); 2) How to overcome the issue of extremely high costs for small shipments; and 3) How to physically deliver fresh products on time. These are also core obstacles for farmers when it comes to becoming engaged in both domestic and global value chains. Together with intensive technological developments, some types of digital platforms are able to tackle the complex issue of logistics by manually controlling the quality of delivered products and providing a guarantee for buyers that products satisfy specific quality standards (Joiner and Okeleke, 2019). Nevertheless, in many developing countries, digital platforms are not taking on this responsibility – and thus farmers have more incentives to continue trading with intermediaries that are more flexible on quality issues (Kumar, 2014). Furthermore, the issue of small and costly individual shipments has been resolved by aggregating them into large batches, taking advantage of economies of scale. Some of the digital platforms provide physical logistics hubs and warehousing services that are usually located near consumers, thus reducing shipment costs and delivery times (see Box 1). These digital platforms usually have a business model that is: 1) capital intensive, and 2) considered the highest level of FVC integration and control (Joiner and Okeleke, 2019). This business model has a high level of financial risk, as the platform provider has to be sure that their storage capacities will be efficiently utilized and that farmers will fulfil their obligations to provide sufficient products that are ordered by buyers. In order to reduce the supply risk, some platforms create legal obligations through contracts with farmers detailing minimum quantities to be purchased by the platform during one season.

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7 The definition of a digital platform in this paper refers to the definition provided by the OECD: "… an online platform is a digital service that facilitates interactions between two or more distinct but independent sets of users (whether firms or individuals) who interact through the service via the Internet" OECD (2019a, p. 21).

Box 1 E-commerce platforms for agricultural trade

Company: RegoPantes belongs to the PT 8villages Indonesia Business Group (provider of mobile business solutions for farmers, https://8villages.com/). It was established in 2018 with the goal for enabling Indonesian farmers to sell fresh fruits and vegetables. Integration of farmers: Farmers' access to the RegoPantes platform is free of charge. Buyers can directly contact them.

Services: Payments by bank transfer or mobile money; logistics for farmers to deliver their products to collection hubs or warehouses; quality control of products; storage facilities; selection of products to be packed; packaging and delivery to buyers (organization of a third-party delivery service).

Similar platforms: MUCHO (Colombia and the United Kingdom of Great Britain and Northern Ireland, www.getmucho.com), Twiga Foods (Kenya, https://twiga.ke/), and TaniHub (Indonesia, https://tanihub.com/).

Technology[1]:	DVC or GVC enabling solution[2]:	Country's level of development[3]:	Farmers' cost (access fee)[4]:
Digital platform	DVC	Developing country (Lower-middle income economy)	Free

[1]Description of the technology is provided in the text; 2National level – DVC, international level – GVC; 3Classification according to the World Bank; 4Fee of using the end product based on a specific technology.
Source: Jonier and Okelek (2019)

To support farmers, and thus secure sufficient and on-time supply, some platforms even provide pre-financing to their members. Furthermore, being a member of a platform can provide access to the crowdfunding networks that usually originate in big cities where consumers are concerned about the working conditions of farmers and are ready to support sustainable production and fair financial payments. Depending on the underlying technology, some digital platforms provide payment possibilities such as mobile, tokens and cryptocurrency payments. Digital payments are peer-to-peer and done instantaneously – without time delay and intermediaries – enabling farmers to immediately reinvest in production, purchase additional machinery or inputs, or exchange their digital money for the national currency (see Box 4). There is little evidence on acceptance of mobile money systems within FVCs. Nevertheless, some evidence indicates that once digital payments are implemented and widely accepted, the development of other financial services can be expected – such as savings, credits and insurance (Babcock, 2015).

Although e-commerce digital platforms provide many potential benefits for farmers, the there are several critical issues related to: 1) How economically sustainable are digital platforms' business models? 2) Is there a risk of these platforms gaining a monopoly within markets? and 3) How is farmers' data used?

Following the idea of Moore (1993), Teece (2017) states that the business ecosystem (for example, the digital platform) consists of four phases: 1) the creation of a system enabled by innovation; 2) the expansion of the system through a scalable business model that pushes out the competition; 3) the leadership phase, during which the system maintains engaged clients; and 4) the self-renewal phase where new ideas are introduced and implemented. Thus, the business model of digital platforms has to be economically sustainable and self-renewed through innovations in order to survive on the market. Gaining a critical mass of farmers to join the platform and stay active requires tremendous effort and financial means. Moreover, building trust is a long-term process that requires an adequate business strategy. If many digital platforms appear and then quickly vanish from the market, it creates distrust among farmers, making entry into the market for new platforms very difficult.

On the other hand, if a well-established platform suddenly disappears from the market, it will cause high transition costs for farmers in finding another platform and buyers, especially if a particular digital platform was dominant in the market and most of the local farmers became dependent on that platform. By having market power, providers of the digital platform might cause a new "information asymmetry", which could lead to reduced transparency and a lowering of farmers' incomes.

Another critical issue is data handling: Data collected from farmers indeed represents critical enabler of digital platforms. To improve their service, or to create new ones, digital platforms have to rely on data received from their users. Transparency in data handling by platforms becomes an important trust-building mechanism between platforms (service providers) and users (producers and consumers). Strict regulations of data-handling procedures and privacy concerns are becoming an obstacle for scaling-up digital platforms in some developed countries, while, on the other hand, it might not be a problem in some developing countries with loose data-handling regulations (Rossotto *et al*., 2018). Beyond data directly provided by farmers, many digital platforms are collecting a large amount of data from users' activities (for example, location, demographics, prior purchases or sold items, to name a few) without transparently indicating how they use and disclose this data. Most of this data is used for targeted advertising purposes and is shared with third parties (ACCC, 2019).

Despite many open questions, digital platforms offering e-commerce services have been used for many years, confirming that the concept brings about many benefits. Thus, with further emergence of new technologies, e-commerce digital platforms will be able to offer different services to end users and contribute to further development of FVCs.

2.2 Distributed ledger technology (DLT)

Distributed ledger technology (DLT), in its core sense, is a database that is spread between many computers, or nodes, to avoid intermediaries and allow for peer-to-peer interactions. Thus, there is no central authority that governs the whole process. There are different types of DLTs such as blockchain, Tangle, Hashgraph or sidechain. Different DLT types mainly differ in the type of data structure used and consensus mechanisms, that is, how different nodes agree on the data that should be stored on the ledger (El Ioini and Pahl, 2018).

Indeed – as it represents the underlying technology for Bitcoin cryptocurrency – the most known DLT is a blockchain introduced in 2008 by Satoshi Nakamoto[8]. The main characteristic of the blockchain, compared to all other DLTs, is that data (for example, transactions) are recorded on blocks that are linked with hash codes, thus forming a chain of blocks. A consensus mechanism is used for making a mutual decision of the nodes to allow a particular block to be added to the chain. As each block in the chain references the previous block, if anyone tries to change the data in a particular block, a change in a hash of that particular block will result, leading instantly to a loss in the link with previous blocks. To make changing the data of the block possible, an agreement of the network majority is required. Considering the number of nodes that are actively involved on the network and the costs of such action, that is, the energy usage required to perform the computational efforts of such action, altering blockchain data is nearly impossible, rendering blockchain an effectively immutable ledger with tamper-proof data. Thus, supported with the latest technology in cryptography, blockchain represents a highly secured ledger that is

[8] It is not clear whether Satoshi Nakamoto is a person or group of people that are using this pseudonym.

managed by the peer-to-peer network collectively, with no central authority present to confirm all transactions.

Depending on whether the usage of a blockchain-based end user product is permissioned or permissionless, it provides transparency and traceability of transactions and data either for members of the "chain" (for example, a group of members that control application, that is based on blockchain technology) or for the public, respectively (FAO, 2019). The two most known public or permissionless DLTs are Bitcoin blockchain and Ethereum, these are decentralized digital platforms that host the blockchain database. The Ethereum platform brought along one of the key advantages of DLTs: smart contracts. Smart contracts represent a piece of code that contains pre-determined conditions set by parties involved in a transaction, with the capability of self-executing once pre-defined conditions are met. Smart contracts should not be understood as a digital version of the traditional legally accepted paper version of contracts, but rather a simple set of actions that would be triggered depending on whether a particular condition is met or not (Deshpande *et al*., 2017).

Although blockchain was first used for managing Bitcoin cryptocurrency, the advantages offered by this technology made it attractive for many different sectors – from agriculture to the aerospace industry. Regarding the agriculture and food industry specifically, most of DLT-based applications (mainly blockchain based)[9] are currently used as a "proof-of-concept", with the aim of trying to provide a solution to core challenges.

There are several examples where the blockchain features are considered as a potential solution to certain FVC challenges. As an example, blockchain might be a particularly useful tool for governments and, especially, the retail sector, when it comes to food safety regulations. In situations like food scandals or foodborne disease outbreaks, traceability of products from farm to fork, provenance (tracking the place of origin, ingredients and quality), transparency and trust are immediately placed on the forefront of political agendas[10]. Furthermore, several companies have implemented blockchain technology as a tool for consumers to gain trust in their products (see Box 2).

Providing transparency along the supply chain could potentially lead to a shift of power on the side of farmers. Consumers might be willing to support those FVCs that provide transparency on how added value is distributed among the actors. The particular focus of consumers might be on the farmers' position within the chain, and whether they receive a "fair" share of the final product's price.

Nevertheless, besides providing solutions from the consumers' side, blockchain technology has been found to have applications in solving more practical problems within FVCs. These problems include contract relations, trust between stakeholders, tracking ownership information, facilitating trade, providing access to capital, and many more. One of the characteristics of agriculture is that labour-intensive work is necessary during certain months of the year. Usually, the harvest of many products requires a large number of workers for a set length of time. Thus, a farmer or agricultural company has to deal with many temporary work contracts. Often, these contracts lack transparency in social security provided by the employer and are usually linked to low wages and insecurity for workers (sometimes leading to forced work), which could be a

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[9] When discussing the application of the DLT (e.g. blockchain) in FVCs, the discussion is related to end-user ("frontend") applications that are based on DLT technology and not about the core technology (e.g. the "backend" database that stays on the decentralized network, e.g. Ethereum network, and connects with "frontend" applications).

[10] The European Parliament introduced the General Food Law in 2002, making it obligatory for food and feed operators to introduce traceability systems (EU, 2007). This law was supported by the creation of a Trade Control and Expert System (TRACES) to track animals within the European Union and from so-called third countries.

reason for the increased number of illegal workers in specific industries.

Box 2 Blockchain for gaining food value chain (FVC) trust

Company: Provenance (the United States of America) was established in 2013 to empower companies, their products and the entire supply chains to be more transparent and traceable.

Core challenge: Consumers know little about the products they use every day. Some products have a long journey from the place of creation to consumers. On this journey, products pass through different supply chain stages wherein each stage, some modification is completed, bringing about increased costs for companies and higher prices for the consumer. The whole process is a black box where the consumer is not aware of certain negative things associated with the product they buy, such as environmental damage, unsafe work conditions, forgery, and many more.

Solution: A blockchain-based digital platform that uses digital tools to assemble images, self-evidence claims and locations to create a transparency foundation. Furthermore, Provenance uses different labels and smart tags (labels that contain transponder – chip and antenna) to link physical products with digital tools. The partnership with certifiers, auditors and data providers is established to ensure verification of information to the point of sale all along the supply chain.

Similar companies:
Everledger (United Kingdom of Great Britain and Northern Ireland, www.everledger.io),
Evrythng (United Kingdom of Great Britain and Northern Ireland, www.evrythng.com),
and ARC-NET (United Kingdom of Great Britain and Northern Ireland, www.arc-net.io).

Technology[1]:	DVC or GVC enabling solution[2]:	Country's level of development[3]:	Farmers' cost (access fee)[4]:
Digital platform Blockchain	DVC and GVC	All countries	Free

[1]Description of the technology is provided in the text; 2National level – DVC, international level – GVC; 3Classification according to the World Bank; 4Fee of using the end product based on a specific technology.
Source: www.prevenance.org

Relying on smart contracts, blockchain technology might be a potential solution for providing transparency of working contracts to the legal authorities (Pinna and Ibba, 2017). Each temporary work contract, fully complying with national legislation, could be registered on the public (permissionless) blockchain. Thus, contracts become immutable, and every relevant legal authority would have full access to the contract at any time. Also, once the agreed-upon work is done, smart contracts activate immediate payments to employees, indicating wage levels and whether the employer paid for all necessary social contributions. A few pilot projects are trying to place contractual relations along the FVC on the blockchain. As an example, the Coca-Cola Company joined forces with the Blockchain Trust Accelerator to pilot a project focused on creating transparent and verification-efficient labour policy controls within their GVC. The aims of these efforts are to prevent any possibilities of child labour, forced labour, and any land rights issues connected to their sugar supply chain around the world (Reuters, 2018).

Another common problem that is important for the inclusion of farmers into FVC is how to trust other members of the FVC. The costs of conducting due diligence for a new partner might be extremely high, especially if the partner is in another country. This might be the leading cause of why many farmers are not involved in GVCs and stay connected to the same local buyers for years – even if a new partner appears offering higher prices. The risk of not being paid or receiving financial benefits too late is high. A further problem is how to match ownership transfer with a traded asset to achieve final payments. This is especially the case with grains, as it can be difficult and costly to follow the whole batch of grains from producer to the final product. There are some indications that blockchain technology might offer a solution, as a digital title can be provided for physical commodities and digital payments can be executed between parties involved instantaneously, for example, once the commodity is delivered or quality has been proven (see Box 3).

Blockchain technology might also have a significant impact on the financial inclusion of small farmers, especially those that do not have access to banks or do not have collateral to obtain credit. The blockchain solution could be built around the fact that all information regarding a particular farmer can be recorded on the blockchain and used as a track record for financial institutions to allow them to assess a farmer's eligibility for obtaining credit (see Box 4). A similar concept could be used to provide small farmers with the opportunity to obtain insurance for their production by using smart contracts and automated payments. By using sensors for monitoring weather status, combined with data from local weather stations, and storing data on a blockchain, any potential adverse weather incidents would quickly trigger a smart contract on a blockchain and thus initiate digital payments to the farmers according to the assessed damage.

Further usage of blockchain is related to facilitating agricultural trade, one of the main components of GVCs. It is well known that agricultural trade is very complex, combining a large number of parties and a plethora of documents (for example, letters of credit, bills of lading, trading slips, different certificates, customs declarations, etc.). Also, trade finance plays a crucial role in trade facilitation – about 80 percent of global trade is financed by some financing instruments (WTO, 2016). The main contribution of blockchain technology can be seen in improving trade efficiency by enabling paperless trade (Ganne, 2018). As yet few examples exist of real-use cases of blockchain in international agricultural trade – the most known example refers to the export of 60 000 tonnes of soybeans from the United States of America to China. This trade was conducted by Louis Dreyfus Co., which joined forces with the Chinese Shandong Bohi Industry Co. (agricultural processor) together with financing groups consisting of the ING Group, Société Générale and ABN Amro Bank. This consortium used a blockchain-based digital platform to trial agricultural trade. According to Louis Dreyfus Co., the main benefit of using the blockchain was matching data in real-time, avoiding duplications in the products' checking procedures, and achieving a five times faster document processing compared to traditional trade.

Box 3 Blockchain for ownership transfer within food value chains

Company: AgriDigital (Australia) was founded in 2015 to create a cost-effective, efficient and world-leading agri-commodity management and supply chain solution.

Core challenge: Complexity of supply chains where most of the information and data handling is done manually involving a large number of participants. A particular problem arises when trying to match payments with title and asset transfer, bringing about a lack of transparency and trust within the FVC.

A particular focus in agriculture: mainly grains.

Solution: Development and implementation of the AgriDigital commodity management platform and blockchain application. The pilot test of the blockchain application was conducted together with Blue Lake Milling (subsidiary of the CBH) and considered a sequence of actions: 1) a digital record of delivered oats from producer to the mill; 2) the creation of a digital title token on the blockchain that was stored on a producer's digital wallet (online service that allows an individual to make electronic transactions); 3) once the mill confirmed the quality of delivered oats, a smart contract was activated causing an instantaneous exchange of title from producer to the buyer, and at the same time the transaction of payment from buyer to consumer. The payment was made using an "Agricoin" token (that is, cryptocurrency, 1 Agricoin is equal to 1 Australian Dollar).

Similar companies: Avenews-GT (Israel, www.avenews-gt.com) and Ripe (United States of America, www.ripe.io)

Technology[1]:	DVC or GVC enabling solution[2]:	Country's level of development[3]:	Farmers' cost (access fee)[4]:
Digital platform Blockchain	DVC and GVC	Developed country (High-income economy)	Free (only for farmers)

[1]Description of the technology is provided in the text; [2]National level – DVC, international level – GVC; [3]Classification according to the World Bank; [4]Fee of using the end product based on a specific technology.
Source: www.agridigital.io

Finally, there are numerous other possibilities of using blockchain technology – and especially smart contracts – in the agriculture and food industry. There are several such projects (pilots): land-use regulation projects in India, Sweden and Georgia; subsidy distribution in India; prevention of illegal fishing in New Zealand; providing regulations for the forestry sector in Spain and China; providing digital payments to small farmers in Pakistan and Jordan, and many more (FAO, 2019).

Overall, DLT development is in an infancy phase, national standards related to DLT have not been developed in many countries and, often, governments' fear of DLT is very high. Thus, different countries react differently when it comes to policy regulations. As an example, in Bangladesh, it is not possible to hold a cryptocurrency, while in China and Saudi Arabia trading cryptocurrencies or conducting Indicial Coin Offerings (ICOs) is not allowed. According to Deloitte (2016), regulatory bodies have to develop the necessary skills to be able to understand the activities taken on the ledger to assure compliance with existing national regulations or to identify which legislation segment should be adjusted to correspond towards real market needs.

Box 4 **Blockchain for the financial inclusion of small farmers**

Company: AGRI-WALLET (Kenya) was founded in 2015 to ensure that all actors in the FVC are well financed (source: www.agri-wallet.com).

Core challenge: Many small farmers worldwide have a severe challenge in getting access to financial services. One of the main reasons is that they lack credit scores or collaterals, creating uncertainties and high risks for financial institutions to provide any services.

Particular focus: Finances in agriculture.

Solution: Agri-wallet is a free digital wallet accessed by farmers in Kenya via a mobile phone application. When farmers earn revenue, they have two options. First, they can decide to be paid in fiat currency (through M-Pesa) or partially in digital tokens. Tokens are saved in their Agri-wallet. By saving tokens, farmers are allowed to get a short-term loan from Rabobank.

Similar companies: Apollo Agriculture (Kenya, www.apolloagriculture.com) and VanderSat (The Netherlands, www.vandersat.com)

Technology[1]:	DVC or GVC enabling solution[2]:	Country's level of development[3]:	Farmers' cost (access fee)[4]:
Digital platform Blockchain	DVC	Developing country (Lower-middle income economy)	Free (for using the platform); 1 percent interest per month + USD 1 processing fee (pre-payment service and overdraft credit fee).

[1]Description of the technology is provided in the text; [2]National level – DVC, international level – GVC; [3]Classification according to the World Bank; [4]Fee of using the end product based on a specific technology.

Apart from the tremendous potential of the DLTs, and especially blockchain, there are many critical issues when it comes to accessibility and adoption by end users. The core problem with DLT adoption starts with the question of whether it is needed at all. This decision is usually made at the top managerial level of the specific FVC, as it requires consensus of all FVC actors. According to a study by Wüst and Gervais (2018), blockchain technology sometimes doesn't outperform existing data-handling systems within companies or value chains. Wider adoption depends on whether stakeholders will recognize the advantage of using blockchain and change their existing business model. As an example, in the United States of America, the attempts to digitalize trade finance through the introduction of bank payment obligations ended up with high investments by both government and technology providers, but had a very slow acceptance by traders (Ehmke, 2019). For this reason, many traders in the United States of America have raised doubts about broader adoption of blockchain technology as well.

Selection of a suitable DLT is of a great importance as different DLTs and their hosting platforms are not compatible, and thus a decision to later switch from one DLT to another might cause significant costs. As an example, it is expected that DLTs are able to store large volume of real-time data recorded from all sorts of sensors and IoT devices. Nevertheless, at the current stage of technological development blockchain is mainly storing references to different databases (Ge *et al*., 2017). On the other side, emerging technology Tangle, a DLT based on directed acyclic graph, is developed with an aim of allowing communication between IoT devices. Furthermore, DLT selection greatly depends on the governance system of the hosting platforms. One of the critical issues for both permissioned and permissionless ledgers is how to set clear governance rules, given their distributed nature (Mills *et a*l., 2016). Different DLT platforms rely on different developer communities that can make a consensus on changing specific rules, directly affecting users of the platform. The size of the developer community might be a sign as to whether certain technology will be further developed and maintained. If number of developers significantly reduces, this might be an indicator that the community using a particular technology does not have incentives to further use it or do not see importance of this technology in the future (possibly as a result of the emergence of another technology). Thus, previous explanations indicate that FVCs have to consider different business strategies in order to achieve resilient business model.

Once the need for a certain DLT is recognized, the question of who will govern the initial inclusion of the FVC actors arises. Given previously described complexity in understanding DLT and selecting the proper technology (for example, blockchain), it is reasonable to expect that the initiative will follow a top-down approach, where the downstream sector of the FVC (namely, retailers), take over a lead. This process could be similar to the certification rules imposed from retailers towards the upstream levels of the FVCs (that is, processors and producers). In order to obtain traceability of products and transparency for consumers, retailers might impose the request that their suppliers join a particular DLT-based platform. The main question is who will cover the cost of implementing and using the technology. In the case of a blockchain, each transaction recorded on the ledger brings about certain costs. Either suppliers need to cover the costs of using the technology in order to maintain contractual relationships with retailers, which might affect their already low-level margins, or it's likely that retailers might cover this cost burden by transferring costs towards end consumers. Thus, it is expected that retailers start investigating DLT possibilities first with high-value products where consumers are already willing to pay a premium price to obtain quality or to support specific social initiatives (for example, fair trade and fair working conditions along the FVCs).

Further concerns arise once DLT has been implemented into a specific FVC. The complexity of interactions between different members of the FVC brings about significant complexities regarding the creation of smart contracts, which have to be regularly modified. There is the question on data security, ownership and on who has access to the smart contract data. Furthermore, smart contracts require precise semantics and, rigorous testing and validation in order to avoid possible repeated mistakes that could damage the whole system. As one of the main DLT characteristics is immutability, it is not clear what would happen in a juridical case when one party in the contract is legally obliged to change contract condition. How could the smart contract be rewritten and who would be in charge of doing it, and for which costs? Further, a critical issue is how to control that the data collected from the FVC is correct, especially when it comes to certification information, as every member of the blockchain can enter the data. Due to the immutable nature of storing data on the blockchain, the question of how to deal with false data emerges – or even how to deal with national regulations such as ones included in the European General Data Protection Regulation that consider the "right to forget", while DLT aims at the right to "never to forget" (Vota, 2019). This brings increased responsibility to users because there are no third-party regulators who would define rules, regulations and check whether the inserted data is correct or not. Thus, most of the cases related to DLT application in FVCs refer to permissioned distributed ledgers, where strict rules are set before a new member gets access to the system. Other members of the DLT-based platform could quickly sanction those violating the rules.

All of the previous concerns about implementation and DLT adoption refer to already integrated actors of the FVC. Thus, when focusing on production level of the FVC, farmers' accessibility of DLT would be higher compared to farmers that are not integrated in the FVC, as the technology is introduced by the downstream members of the FVC (for example, introduction to technology, instructions on how to use the application based on DLT technology, technical support, etc.). It is important to stress again that none of the FVC actors is dealing with the core DLT technology, that is, the digital database that stays on the decentralized network and connects with DLT-based applications. They are using a DLT-based platform where they can enter required data or get the overview of already recorded data. From this perspective, FVC actors do not need to have in-depth knowledge on how DLT technology works in order to use the application. Usually, DLT-based applications are very similar to the common digital accounting systems already in use by many FVC actors.

Overall, as technological development is rapidly progressing, along with increasing number of farmers having the access to mobile and Internet connections, DLT as an underling technology for many useful applications in FVC has a great disruptive potential to change existing agri-food system.

2.3 Artificial intelligence (AI)

Following the definition provided by the OECD (2016), AI is defined as an ability of machines and systems to acquire and apply knowledge to carry out "intelligent behaviour". Only certain aspects of AI find their application in agriculture, such as machine learning (ML) algorithms (including deep learning, supervised and unsupervised learning), image and machine vision, and robotics.

The main application of AI is to provide predictions based on data from machine or human-based inputs. From the economic perspective, AI-based models help the decision-making processes, and thus either contribute to cost reduction of the prediction or improve prediction accuracy for the same cost (OECD, 2019b). With the rapid development of ML models, mainly supported by the emergence of big data, AI-based predictions became easily accessible and more affordable. Highly accurate predictions contribute to better decision-making processes by reducing uncertainty. In the agriculture and food industry, uncertainty is one of the main factors that have an impact on the economic performance of the producers and companies. Higher uncertainty leads to higher risk, and thus to higher costs.

Predictive analytics based on image recognition, big data and ML models, together with different kinds of robots, are the most typical use cases of AI in agriculture. High-resolution photos from satellites are collected and processed, and real-time results are presented to decision-makers in the form of predictive analytics (Box 5). Furthermore, modern agricultural machinery is equipped with high-tech equipment able to "harvest" tremendous amounts of data that's transferred in real-time to farmers' computers for further processing. Application of robots in agriculture already has a long history – milking robots, for example, are already widely accepted in the dairy sector around the world. Together with the advancement of technology (for example, sensors, digital cameras and ML algorithms), the new generation of robots is being created to substitute highly demanded skilled labour, especially during the harvest periods.

Box 5 AI in crop monitoring (predictive analytics)

Company: RESSON (Canada) was established in 2013 to empower growers with digital tools enabling the use of their field data to make better-informed decisions and improve efficiency.

Core challenge: Farmers are not efficient in using data provided by their farms to make timely decisions and secure long-term profitability. Commonly, farmers spend significant amounts of time driving around their property in order to identify possible problem areas. Once detected, problematic crops are usually sprayed with an amount that could cause severe environmental damages and that has high costs (the same is true for the usage of fertilisers).
A particular focus in agriculture: All crops.

Solution: A predictive-analytics solution that combines data collected from multiple sources (for example, satellite, drones, close-proximity cameras and in-field sensors) with AI and cloud computing. This technology enables farmers to continuously monitor, analyse and predict crop health issues before humans are capable of identifying them visually.

Similar companies: Agrivi (Croatia, www.agrivi.com), PEAT (Germany, www.bluerivertechnology.com), Trace Genomics (United States of America, https://tracegenomics.com), SkySquirrel Technologies Inc. (United States of America, www.vineview.com), aWhere (United States of America, www.awhere.com), and FarmShots (United States of America, http://farmshots.com).

Technology[1]:	DVC or GVC enabling solution[2]:	Country's level of development[3]:	Farmers' cost (access fee)[4]:
Management Information System Drones IoT AI	DVC	All countries	Fee based

[1]Description of the technology is provided in the text; [2]National level – DVC, international level – GVC; [3]Classification according to the World Bank; [4]Fee of using the end product based on a specific technology.
Source: www.resson.com

Nevertheless, these "modern" robots are still in an infancy phase and it will probably take several years until they become widely adopted as standard in the agricultural sector. Most of the existing prototypes are currently used for high-value fresh products such as fruits and vegetables, whose harvest is highly labour-intensive (Box 6).

Besides improving the efficiency of farmers, AI is also a useful tool to improve access to capital and financial services, especially in low-income countries. According to estimations of Dalberg Global Development Advisors, City Group and Skoll Foundations (2012), the estimated demand of small farmers for financing is about USD 450 billion, while the total amount of available financing is only about USD 9 billion, that is less than 3 percent of the demand. This enormous gap is mainly related to the risk that banks and other financial institutions are faced with when lending money to small farmers in low-income countries (for example, a lack of reliable data for the financial evaluation of the applicants and a high dependency of farmers' income on climate conditions).

Box 6 Robotics in agriculture

Company: Harvest CROO Robotics (the United States of America) was established in 2013 to revolutionize the agriculture industry with automation.
Core challenge: The core problem is a shift of global societal demographics accompanied by immigration, which causes significant shortages of labour, especially during the harvest seasons. In addition, the population is growing as people demand more food. Thus, CROO Robotics aims at closing the gap between shortages of labour and increasing food demand by developing "high-tack" solutions for automatization in agriculture.
A particular focus in agriculture: Strawberry harvesting (highly labour-intensive and physically difficult).
Solution: "Conservation of Motion" robotics that optimize tasks performed by a strawberry harvester. The fully automated harvester can substitute work of 30 strawberry pickers, with the potential to harvest up to 3.2 hectares per day. The main advantage of the automated harvester is that it uses many robotic hands to perform tasks, such as leaf gathering needed for visual inspection of strawberries; picking only ripe, good-quality strawberries; and directly packing strawberries for further transportation and storage.
Similar companies: Blue River Technology (United States of America, www.bluerivertechnology.com/), Abundant Robotics (United States of America, www.abundantrobotics.com/) and Ibex Automation (United Kingdom of Great Britain and Northern Ireland, www.ibexautomation.co.uk/).

Technology[1]:	DVC or GVC enabling solution[2]:	Country's level of development[3]:	Farmers' cost (access fee)[4]:
AI Robotics	DVC	Developed country (High income economy)	Fee based service

1Description of the technology is provided in the text; 2National level – DVC, international level – GVC; 3Classification according to the World Bank; 4Fee of using the end product based on a specific technology.
Source: www.harvestcroo.com

One AI-based solution is when traditional data on agricultural production and yields are combined with satellite data, and then, based on the ML models, predictions of the default risk are made. This new credit-scoring method results in lower labour costs compared to the traditional method, as there is no need for financial institution representatives to physically inspect the farms before the credit evaluation. Furthermore, the new microfinance-AI-based model reduces the investment risk for financial institutions due to the spread of individual risk to a large number of farmers.

The new AI-based scoring method is already used by some of the typical financing institutions (van der Straten, 2018). It has allowed "non-typical" financing institutions to enter the market by providing credit to farmers alongside with additional services (for example, input supply or extension services, see Box 7).

Box 7 Artificial intelligence (AI) based financial inclusion of small farmers

Company: Harvesting Inc. (the United States of America) was initiated in 2015 to bring speed, accuracy and transparency in agriculture in order to enable financial inclusion for farmers around the world.

Core challenge: Lack of traditional data – that is usually out of the reach of financial institutions – to help to create a robust risk scoring system in agriculture. Digital transformation of the agricultural sector sparks the need for combining agricultural practices with technology and regulatory requirements in the financial sector. This requires a combination of skills that is nowadays mainly available through agri-tech companies and not so much through traditional financing institutions.

Particular focus: Small farmers.

Solution: Agriculture Intelligence Engine, a digital platform that combines remote sensing satellites, agriculture, AI and financial tools to drive the financial inclusion of small farmers. Combination of remote sensing data and traditional data collected from agriculture (for example, production quantities and yields) are used for developing an innovative credit scoring system for farmer financing that: 1) increases approval rates, and thus access to credit; and 2) decreases default rates. Furthermore, continuous monitoring of farmlands provides an early warning system for repayment risk.

Similar companies: Ricult (United States of America, www.ricult.com) and Tulaa (Kenya, www.tulaa.io).

Technology[1]:	DVC or GVC enabling solution[2]:	Country's level of development[3]:	Farmers' cost (access fee)[4]:
Digital platform Management Information System IoT AI	DVC	Developing country (Lower-middle income economy)	Fee based service

[1]Description of the technology is provided in the text; [2]National level – DVC, international level – GVC; [3]Classification according to the World Bank; [4]Fee of using the end product based on a specific technology.
Source: www.harvesting.co

2.4 Additive Manufacturing Technology (3D printing)

Additive manufacturing technology – hereafter 3D printing – is believed to bring a new revolution to many industries. 3D printing is not a new technology; it dates back to the 1980s when 3D printing technology emerged and was used for rapid prototyping. Nevertheless, at that time, the technology was too expensive and not widely used. As the technology has significantly improved and its prices[11] have dropped considerably, 3D printing has found broader application in many industries since the year 2009, when an increased number of non-plastic printing materials sprung up.

Nowadays, 3D printing has many applications in different industries: aerospace, consumer electronics, medical, entertainment, industrial, consumer products, the automobile industry, and many more. Materials used for printing range from plastics (the largest market segment in 3D printing (Beyer, 2014)), biomaterials, metals, and ceramics.

The primary application of 3D printing in agriculture, at this stage of technological development, is creating spare parts for agricultural machinery (Box 8). Usage of the 3D printing concept for food production is still far from reality. Nevertheless, several companies are running pilot projects involving printing food components into different shapes (see Box 9). Most of the printed food items are end-consumer products at this stage of the technological developments.

[11] The emergence of the RepRap replication method allows for free development and replication of 3D printers.

Technology is still lacking the possibility to print ready-to-eat products, especially those that have to be cooked.

From an economic perspective, printing costs per unit and the number of units printed per minute/hour are two key components that are crucial for the broader adoption of 3D technology. At the early stage of 3D printing, it was essential to produce prototypes of products where the time component was not that important. It would take several hours or days for some industrial components to be printed, and still, the costs per unit were much lower compared to the traditional way, that would be to invest in the whole production line before testing the final product. Nowadays, as the technology is radically improving and 3D printing is being used beyond just prototyping, both costs and speed are gaining importance. 3D printing devices are becoming cheaper, and some of the 3D printer producing companies claim that their devices could achieve a printing speed that is 25 to 100 percent faster than traditional printers.

3D printing is estimated to have a significant impact on international trade (Arvis *et al*., 2017), as technology allows for automated production on site, eliminating the need for unskilled labour from other countries. On the other hand, there is the essential question of the environmental sustainability implications of 3D printing. According to an OECD (2017) study, it would be necessary to aim towards sustainability of both the materials used for printing and of 3D printers.

It is expected that 3D printing will have more of an impact on food supply chains' logistics than agricultural production. Although not necessarily in a conventional way, agricultural products still have to be produced, and then transformed into "food cartridges" that are delivered to retail shops or directly to consumers. The advantage of using "food cartridges" would be to eliminate the perishability of certain products and food waste, as cartridges would be able to preserve the quality of ingredients for many years (De Clercq *et al*., 2018). Thus, one of the FVC sectors that will sustain significant transformation is likely to be the processing industry.

Box 8 Additive manufacturing technology (3D printing) and agricultural machinery

Company: AGCO (United States of America) was established in 1990 to help farmers become more productive and profitable. The company is a global leader in design, manufacture and distribution of agricultural solutions.

Core challenge: To develop prototypes of new tools and spare parts. The traditional prototyping procedure took up to five weeks for a third party to design the component, followed with an additional two weeks of research by the company.
A particular focus in the food industry: Agricultural tools and machinery.
Solution: Usage of 3D printers to develop prototypes of new agricultural tools and machinery. The 3D printing solution allows for creating a prototype of the product and up to five tests within a five-year period that was previously needed for product design alone. New technology enables faster implementation of ideas into real use-cases.

Similar company: GVL Poly (United States of America) https://gvlpoly.com/.

Technology[1]:	DVC or GVC enabling solution[2]:	Country's level of development[3]:	Farmers' cost (access fee)[4]:
3D printers	DVC	Developed country (High income economy)	Fee based service

[1]Description of the technology is provided in the text; [2]National level – DVC, international level – GVC; [3]Classification according to the World Bank; [4]Fee of using the end product based on a specific technology.
Source: www.agcocorp.com

CHAPTER 3

Accessibility of digital technologies and inclusion of small farmers into global value chains (GVCs)

Box 9 Additive manufacturing technology (3D printing) in the food industry

Company: 3D Systems (United States of America) was established in 1983 to connect customers with digital manufacturing workflow required to solve real business problems. It was the first 3D company in the world, thanks to the founder Chuck Hull who patented the Stereolithography Apparatus (SLA). The SLA technology converts liquid plastics into solid objects and was first commercialised through 3D printing technology.

Core Challenge: How to use 3D printing technology in combination with traditional craft to create the future of food.
A particular focus in the food industry: confectionary sector, specifically, cakes and candies.

Solution: Culinary Lab and Chefjet 3D food printer. Culinary Lab is a learning, collaboration and exploration space where innovators work closely together with chefs to create a new culinary ecosystem based on usage of 3D printing technology. The Chefjet is a 3D printer created for restaurants that want to experiment with innovative food items.
Similar cases/companies: www.wiiboox.com (confectionary sector), www.tno.nl/en (pasta), www.naturalmachines.com (wide range of food products).

Technology[1]:	DVC or GVC enabling solution[2]:	Country's level of development[3]:	Farmers' cost (access fee)[4]:
3D printers	DVC	Developed country (High income economy)	-

[1]Description of the technology is provided in the text; [2]National level – DVC, international level – GVC; [3]Classification according to the World Bank; [4]Fee of using the end product based on a specific technology.
Source: www.3dsystems.com/culinary/culinary-lab

This section provides an overview of the necessary preconditions for digital technology adoption and the current state of technological accessibility. Furthermore, assuming that small farmers have already adopted some of the available digital tools and technologies, the inclusion of small farmers into GVC is also discussed.

3.1 Accessibility of digital technologies

Apart from the tremendous potential of the previously presented digital tools and technologies, there are many critical issues when it comes to their accessibility and adoption. The use of digital technologies has the potential to reduce both fixed and transaction costs and eliminate information asymmetries - the three important conditions for enabling the inclusion of small farmers into FVCs. However, certain preconditions have to be met in order to utilize the full potential of available digital technologies.

First, access to information communication technology (ICT) services has to be spread across different regions. According to GSMA (2018a), mobile phone network coverage significantly increased in recent years, with about 66 percent of the world's population reported as mobile phone users and about 43 percent as mobile Internet users. Nevertheless, most of the people that do not have access to mobile phone networks live in rural areas (approximately 1.2 billion people) (GSMA, 2018b). Furthermore, the quality of the mobile network and Internet connection has to be sufficient to allow for stable and constant connections between farmers and technology providers. For example, if we consider that a small farmer has access to a digital platform offering e-commerce services, there are several critical issues connected to unreliable mobile or Internet connection. Any delay in receiving information due to loss of Internet or mobile connection could result in additional costs. Farmers might lose buyers that could quickly reach their competitors, and they might even be considered unreliable and excluded from the platform. The same is true for a technology provider. If a platform's accessibility is constantly questionable, buyers might be afraid of spending their money on that platform, which would ultimately affect the platform's financial state.

Second, even if the first precondition is fulfilled, and ICT infrastructure is available in rural areas, it doesn't necessarily mean that it's accessible. Small farmers have to have sufficient financial means to pay for mobile or Internet access. Furthermore, certain technology providers might request an access fee from farmers in order to use certain technologies (such as an access fee for digital platforms offering AI-based crop monitoring service, see box 5). Nevertheless, if the potential benefits of participating in the platform outweigh the cost of using the platform, the incentives of farmers to participate and use available technology will significantly increase. However, emerging business models aim at reducing, or completely eliminating, entry costs for farmers, enabling them to use high technology-based services (for example, AI and blockchain). Overall, inequality in access to technologies leads to inequality in opportunities to be included in FVCs.

Third, farmers have to have a minimum level of both general literacy (to know how to read and write) and digital literacy (to open a SMS message or a certain application) in order use the provided digital solutions. Nevertheless, digital tools are becoming user friendly to the extent that even if someone does not know how to read and write, they still can use certain digital tools by using icons, or audio-video messages, instead of letters.

Fourth, land tenure security is an important precondition for small farmers to capitalize on adopting certain innovation (World Bank, 2019b). Many small farmers around the world do not have formal title to their land or, due to unstable political conditions, could easily lose their rights.

Fifth, the lack of information on available technologies together with a lack of the skills necessary to use these new technologies are also among the crucial obstacles to farmer technology adoption - and thus the opportunity to be included in FVCs. Farmers need to be informed that certain technologies exist and see themselves as an example of someone who can use particular technologies to resolve some of their problems. Formal education of farmers is one of the key components in technology adoption. As recognized in many studies, more educated farmers tend to adopt new technologies earlier (World Bank, 2019b; Foster and Rosenzweig, 2010). Once certain digital solutions are recognized as feasible options for farmers, gaining the necessary skills to use the technology is necessary and important. New digital technologies are becoming more skill intensive and require more managing activities by the side of farmers (Gollin *et al*., 2005). Uninformed and unskilled farmers will not be able to utilize digital technologies, and thus they'll have a higher chance of being excluded from the FVCs.

Finally, technology providers themselves also need to understand the local issues faced by farmers and create easy-to-use solutions. Digital products based on "one solution fits all" principle usually fail when it comes to adoption by farmers. Furthermore, according to Aker *et al*. (2016), digital products and services should be adjusted to local ICT conditions, paying attention to the gender digital divide, and most importantly, they should be provided by a trusted source. In many developing countries, these conditions are very difficult to achieve as many technology providers try to scale up their business model and thus tend to provide general products.

In most of the cases where these preconditions are fulfilled, small farmers using certain digital tools, such as digital platforms, are not even aware of the underling digital technology (for example, DLT or AI). The most important accessibility criteria, from the end-users point of view, is that a certain digital tool (based on certain digital technology) is: a) Perceivable – the user can visually identify the content; b) Operable – the user can easily use the provided controls to navigate through provided interface; c) Understandable – the provided interface is consistent in presentation and format; and d) Robust – the provided tool should be compatible with different digital technologies. Thus, technology providers are responsible to maintain the technology and provide easy to use applications to their clients. In most of the cases, technology providers approach small farmers with specific digital solutions to their problems, providing the instructions to farmers on how to use their digital tools and how to benefit from them. As technology providers need a critical mass of users to maintain their business model, most of them provide services with no fee to farmers. In this way, a complex technology such as DLT and AI are almost freely available to small farmers, however, they still need to pay for mobile and/or Internet access.

When looking from the broader perspective, not strictly focused on small farmers, early adopters of new technologies are usually farmers that could be classified as large. These farmers usually have secured land tenure, access to finance, are already receiving support from extension service providers, and are willing to take risk (Feder *et al*., 1985). As an example, implementation of digital technologies in the Russian Federation and Ukraine is almost exclusively done by large agro-industrial holdings (sometimes called agroholdings) (Baryshnikova *et al*., 2019). Some of the top Ukrainian agro-industrial holdings are investing up to USD 7 per hectare (for example, Karnel agro-industrial holding invested about USD 2.7 million in digitalization, covering 540 thousand hectares of land) (LaScalA, 2019). These large agricultural producers are able to access capital needed for further infrastructural investments compared to other farm types – such as family farms – that dominate agricultural markets in the Russian Federation and Ukraine.

3.2 Inclusion of small farmers into global value chains (GVCs)

Once all preconditions for technological accessibility and adoption are fulfilled, small farmers have an opportunity to get involved into FVCs. As already mentioned in the previous section, available digital tools and technologies provide a wide range of possibilities to FVC actors, and especially small farmers, to enhance productivity, profitability and performance. Furthermore, certain tools and technologies could help promote the participation of small farmers in international trade through GVCs.

It is estimated that about 80 percent of global trade is conducted through GVCs (UNCTAD, 2013). Most of the parties directly involved in GVC trade are large companies, although they represent a small percent of total companies in the global economy; small and medium-sized enterprises (SMEs) continue to dominate. SMEs are mostly indirectly involved in GVCs, as they are often suppliers for those enterprises that are export oriented (WTO, 2019). Nevertheless, WTO (2016) findings indicate that digital technologies greatly enable SMEs in both export and import activities, whereby export costs could be reduced by up to 82 percent together with reductions of up to 59 percent in the operating costs associated with dealing with foreign markets (AMTC, 2018). Within the agriculture and food industry, the situation is similar: large companies are mainly involved in international trade. Most of the small farmers - including SMEs in the food industry - are mainly focused on local markets and DVCs.

Important preconditions for supporting small farmers inclusion into GVCs are access to information related to regulation and standards in different countries, and access to finance. Digital platforms are used in many countries to provide valuable information on a range of regulations and standards (such as sanitary and phytosanitary measures) that exporters should consider when engaging in international trade. In combining digital platforms with blockchain technology, there is a potential in achieving almost paperless trade. E-certificates could easily be shared between the authorities even before the shipment physically reaches the border, significantly reducing the time for clearance at the border (Jouanjean, 2019). Knowing the strict rules of other actors within the GVC is of great importance, especially as inclusion in a certain GVC might be conditioned by the use of a certain technology. In an example provided by the World Bank (2019a), certain retailers might request that suppliers introduce traceability systems, such as blockchain technology, in order to increase response times in case of a foodborne disease. Such preconditions for being included in the GVC might be a crucial obstacle for farmers who do not have sufficient financial means to implement this technology. Thus, access to finance should be adjusted to small-farmers' needs to enable inclusion in international trade and GVCs. Digital technologies provide practical solutions, especially for small farmers and SMEs in developing countries that do not have access to traditional financial tools (for example, credit). Blockchain technology might serve as a convenient tool for using the recorded data as proof of being credit worthy without a need for possessing the collateral (see section 2.2). Furthermore, blockchain also enables peer-to-peer payments that exclude the banking system from transactions, thus eliminating the need for traditional financial instruments.

Digital technologies offer many opportunities for small farmers to get engaged in GVCs and improve their financial condition. For example, blockchain has a great potential in transforming GVCs by providing transparency of supply chain actors and their practices, improve cost efficiency, radically reduce fraudulent actions, provide near real-time data traceability, overcome trade financing problems, and provide new types of contractual relations between GVC actors. Being a member of a GVC that uses blockchain technology allows for a business model that does not require strong vertical integration of the value chain. As all of the actions within the chain are recorded without a possibility of changes being made, incentives for fraudulent action from the members are almost eliminated, allowing for more flexible contractual relations within the chain (that is, there is no need for strict vertical integration of the GVC). This contractual flexibility, further supported through the usage of digital platforms, allows farmers to be members of many GVCs at the same time (as long as they can fulfil their obligations).

Blockchain technology also has great potential to empower fairer distribution of added value along the GVCs, especially in the first mile of the supply chain (namely, small farmers). There are many pilot projects that use blockchain technology to provide transparent systems of added value distribution along the GVC (see Box 10). Equitable prices for farmers could be achieved by blockchain's traceability feature. Consumers could trace the origin of a certain product, get quickly informed about the working conditions of the farmers, and be sure that farmers received an ethical price for their products.

Besides many benefits of using digital technologies to promote GVC participation, the same technologies might actually hinder the need for GVCs, and thus enable conditions for further development of short (local) DVCs. With the same traceability feature of the blockchain, consumers could be ensured that certain products originate from their region, and be informed of different environmental and social aspects of food production. Thus, consumer behaviour, empowered by digital technologies, might cause reshoring initiatives (Ferrantino and Koten, 2019). Overall, it remains unclear as to how digital technologies may affect the very development of GVCs in the future.

Box 10 Blockchain for fairer global value chains (GVCs)

Company: Moyee Coffee (Ireland), bext360 (United States of America) and FairChain Foundation (The Netherlands). A pilot coffee project Moyee Coffee started in 2017 to prove that the coffee food value chain (FVC) could be honest and fair.

Core challenge: Coffee production and processing is a complex process that involves a large number of intermediate actors within the GVC. It is estimated that coffee producers account for only 2 percent of the added value of every cup of coffee sold to the customers in the coffee shops. Furthermore, many of the coffee certification schemes do not provide sufficient transparency demanded by consumers. Moyee Coffee is grown in Ethiopia (the Limu and Jimma regions) by farmers owning about one hectare of plot. The average production of 200 coffee shrubs would secure an annual income of about USD 400.
A particular focus in agriculture: Coffee

Solution: Moyee Coffee blockchain-based social business model supplying Ethiopian roasted specialty coffee to consumers in Ireland. The key innovation refers to usage of cryptotokens to achieve transparency along the chain. At the point of coffee collection a special token is created on a blockchain platform directly presenting the value of the commodity. As commodity goes along the chain, additional tokens are created at each stage. Thus, the whole process of added value is transparent. Usage of tokens indicates possibilities for significant transaction cost reduction along the entire GVC. Furthermore, the Moyee Coffee project pays a 20 percent FairChain premium to farmers who commit to stay organic and attend specialized trainings.

Similar companies: infinca (Colombia, www.ifinca.co).

Technology[1]:	DVC or GVC enabling solution[2]:	Country's level of development[3]:	Farmers' cost (access fee)[4]:
Digital platform Blockchain IoT AI	GVC	Developing country (Low-income economy)	Free

[1]Description of the technology is provided in the text; [2]National level – DVC, international level – GVC; [3]Classification according to the World Bank; [4]Fee for using the end product based on a specific technology.
Source: https://moyeecoffee.ie; www.bext^{360}.com; www.fairchain.org

CHAPTER 4

New market structures and enhancement of public services

4 New market structures and enhancement of public services

This section provides a discussion on how previously described digital tools and technologies enable significant changes in agricultural and food markets from two different perspectives. The discussion starts from the digital technology providers and the downstream sector of FVCs to identify emerging new market structures. Also, some thoughts are provided on how digital technologies contribute to a better provision of public goods and services related to agriculture.

4.1 Incentivizing new market structures

The classic economic concept indicates that digital technologies reduce the transaction costs of accessing information. If there are information asymmetries present, transaction costs will be so high that certain interactions will not take place. For example, a small farmer may not be able to obtain credit from a financial institution that does not have enough data to evaluate the credit status of the applicant (Deichmann *et al*., 2016).

Once an innovative digital technology is accepted and widely used in the market, transaction costs significantly drop compared to the period before the innovation. An example could be the acceptance of Internet and mobile phones to receive information. Given that farmers have access to mobile phones or Internet, it has become very easy for them to receive different information relevant to their farming decisions. Nowadays, having a mobile phone might be sufficient for obtaining access to different financial services - even without a formal bank account or providing certain collateral (see Box 4, section 2).

Finally, there are emerging business models, based on different digital technologies that essentially lead towards almost zero transaction costs. The best example would be digital platforms with e-commerce services. After the initial high costs of building a platform and the first digital product (for example, providing a digital record of farmers' activities to determine their credit score, see Box 7, section 2), the costs for replicating the product significantly drops with higher numbers of users of the service. In other words, products could be offered instantly with very low or almost zero marginal costs. This business model refers to the new emerging digital economy in which new market structures are created based on economies of scale.

The new emerging digital economy is based on two features: potential to scale and the importance of intangible capital. The potential to scale has already been explained through the example of digital platforms. The importance of intangible capital is significantly growing together with technological development. Intangible capital refers to a business idea, branding, software, licenses and much more. According to Haskel and Westlake (2017), investments in the intangible exceed investments in the tangible, as is the case in Finland, the United Kingdom of Great Britain and Northern Ireland, the United States of America and Sweden. Furthermore, Haskel and Westlake argue that there are four economic properties of intangible assets: "scalability", "sunkenness", "spillovers", and "synergies", which allow for the rise of large digital companies, in addition to leading to more mergers and acquisitions, and a higher concentration in the industry.

The main characteristics of the digital economy are present in the agriculture and food industry as well. Large agri-food companies are also the owners of large digital platforms[12] that collect enormous amount of data from farmers. The need for "data harvesting" is significantly increasing, as sophisticated ML models need big data in order to provide accurate predictions. It is becoming common for large input and machinery companies specifically to acquire or partner with different software companies that are usually developing digital technologies for farmers. As an example provided by Mooney (2018), to improve its own services, Monsanto - one of the largest agricultural companies worldwide that recently merged with Bayer - acquired two software companies (Precision Planting and The Climate Corporation); a company providing a service for planting prescriptions (FieldScripts); and two companies that developed web applications for climate and fertilizer use (Climate Basic and Climate Pro). Further on, Mooney indicates that large companies tend to gain control over big data coming from agriculture because it helps them to better understand the general food system, and thus easily eliminate competition and increase profit.

The concentration of companies is visible in almost all sectors of the agricultural production and food industry. For example Bayer–Monsanto (Germany) and Corteva Agriscience (the United States of America) control 54 percent of the seed market; Bayer–Monsanto and ChemCina–Syngenta control 46 percent of the agrochemical market, Nutrien (Canada) and Yara (Norway) have a dominant position on the fertilizer market, and John Deere (the United States of America), Kubota (Japan), and CNH Industrial (the United Kingdom of Great Britain and Northern Ireland and the Netherlands) have the highest shares in the agricultural machinery sector (Mooney, 2018). It is expected that concentration will continue in the coming years - and especially in the agricultural machinery sector as new digital technologies implemented in agricultural machinery are able to collect real on-farm data and send it to whomever is in charge. Thus, if not seriously monitored by government regulations, a continuation of centralization processes in the agriculture and food industry might lead towards duopolies or even monopolies in who is controlling food production, processing and distribution.

12 Note that these platforms are not e-commerce based, as referred to in the rest of the paper. These platforms are usually providing farm management and agronomic services for farmers.

4.2 Provide better public services in agriculture

"Pure" public goods are products or services that, when provided to one individual person or a company, still remain available to others at no additional expenses. The two most important components of a public good are non-rivalry and non-exclusion (Samuelson, 1954). Non-rivalry refers to the simultaneous consumption of the product or usage of the service, while non-exclusion refers to the fact that a person or a company can't be excluded for consuming a public good. If one of these two components is not achieved, then it refers to an imperfect or ineffective public good (that is, a "pure" private good).

According to economic theory, markets are functioning well and add to social welfare in cases where supplied products or services are rival and excludable in nature (Gans *et al.*, 2012). In other words, someone cannot use a product or service unless she or he pays for it, and using it prohibits others from gaining the same benefit. Thus, the theory states that markets fail when both non-rivalry and non-exclusion exist at the same time, when social welfare is sub-optimal. In this situation, as companies or individuals fail to provide products or services needed by society, governments need to react by providing public goods, as the benefits of governmental action exceed cost (Griffith *et al.*, 2014).

When considering agriculture, all of the products produced are actually non-public goods provided by the private sector. The non-rivalry condition is not met since consumption of a certain product depends on the level of demand; increased demand leads to a reduction in available amounts of the product. Furthermore, many consumers are excluded from consumption of certain products as farmers are "free" to set the price of their products (greatly depending on the market conditions).

Nevertheless, there are public goods directly related to agriculture, such as provision of public services through Research and Development (R&D) and extension services. Both. of these public goods relate directly to digital technology adoption. In fact, digital technology could itself be used by governments to provide more efficient public services and targeted policies that ensure no one is left behind when it comes to accessibility and adoption of new technologies in agriculture and FVCs. Such an approach could ultimately prevent a digital divide[13].

The public sector has traditionally been the engine of R&D in agriculture, mainly based on open access to intellectual property, that is, it is an impure global public good as defined by Dalrymple (2004) (Piesse and Thirtle, 2010). Nevertheless, this trend was dominant until the end of 1990s. The latest available figures from 2011 indicate that public R&D accounts for 55 percent of the global USD 69 billion spent on R&D (Pardey *et al.*, 2016). The trend from recent years indicates a significant slowdown of public spending on R&D, especially in high-income countries. On the other hand, private investments in R&D are recording rapid growth. This trend could be directly associated with constraints in fiscal policies of many countries, advancements in genetic engineering, technological innovations (digitalization and robotics) and increased marketization of supply chains (Jaruzelski *et al.*, 2017). Similar to developments related to concentration of primary data in agriculture (see subsection 4.1), private sector investments into agricultural R&D are dominated by large international seed, chemical and biotechnological companies such as BASF, Bayer (Monsanto), Syngenta and others. This trend might potentially lead towards oligopolistic competition in agricultural innovations (Piesse and Thirtle, 2010).

[13] The term digital divide is defined by the OECD (2001, p. 5) as the: "…gap between individuals, households, businesses and geographic areas at different socio-economic levels with regard both to their opportunities to access information and communication technologies (ICTs) and to their use of the Internet for a wide variety of activities".

Public-sector R&D is particularly important for low-income countries where demand for increased productivity in agriculture is high. If innovations are not easily accessible to farmers, general agricultural productivity will be reduced and, in particular, low-income countries that rely heavily on the agricultural sector will suffer. Thus, it is of great importance that R&D is further supported especially in low-income countries. As there might be many fiscal constraints from the public sector, governments could provide the incentives for public-private partnership to leverage public investments in R&D related to agricultural innovations. Public-private partnership in R&D could contribute to reducing a gap between innovation being found and the time needed for it to be implemented and widely adopted (adoption of agricultural innovations might take 15 to 25 years) (Moreddu, 2016).

One of the direct consequences of low investments in public R&D is the quality of public extension services. In theory, extension services provided could be of great help, especially for getting small farmers familiar with available digital technologies through knowledge-transfer activities (for example, visiting other farms that are already using certain technologies, conducting on-field tests, providing exert presentations, and many more), ultimately leading towards better digital literacy. Nevertheless, there are many factors that cause inefficient public extension services in practice. According to Feder *et al*. (2001), there are eight important factors: scale and complexity of services; policy environment; weak interaction between knowledge generation systems and extension providers; difficulties in tracing extension impact; accountability of service providers; weak political support; different knowledge transfer difficulties; and finally, fiscal unsustainability of many countries.

The emergence of sophisticated technologies such as AI, big data analytics, and cloud computing have resulted in new ways of delivering extension services. As it becomes possible to tailor services to a specific field and farmer, the incentives of farmers to pay for such services also increase – thus leading towards a transition from publicly offered, low-efficient and out-dated services towards highly efficient private for-profit services.These newly emerging services offered by the private for-profit sector are a type of quasi-public good as they are non-rival in nature (they can be used simultaneously) but are excludable, (they can only be used by those who pay for the service). It is important to note that the emergence of disruptive digital technologies brought about a concept of data-driven business models in services related to agriculture. As mentioned in Section 2, the business model of some digital platforms does not require users to pay for using their services. Nevertheless, the platform might use sophisticated technology to collect users' data, based on their behaviour while using the platform (for example, users may provide personal data on production, quantity of inputs used and their costs, interest in particular services, and so on), which is then sold to third parties. In this business model, and assuming a lack of strict data-privacy regulations, services offered to platform users are both non-rival and non-exclusive (if assuming that technology is accessible and other preconditions are fulfilled, see section 3).

Besides supporting development of digital technologies, governments could also use some of the digital solutions to provide more efficient public services, especially in agriculture. There are many examples where digital technologies help reduce the time needed to apply for the agricultural services (for example, in Estonia, Kärner (2017)), or reaching a higher number of beneficiaries for lower costs (for example, Nigeria, see Box 11). Furthermore, the usage of AI – ML models based on big data – to analyse large amounts of data from different IoT devices could help governments create automated early warning systems. Providing critical information on time significantly reduces the risk of farmers not taking certain measures, and thus reducing possible negative consequences. Overall, there is great potential for governments to use digital technologies and improve the way the public sector operates. As there is a rapid development of digital technologies, it might not be cost-effective for governments to constantly adjust to new technological developments. Therefore, governments should focus on better collaboration with the private sector to embrace the latest technology and know-how.

Box 11 Digital technologies and public services in agriculture

Focus country: Nigeria

Public service: Growth enhancement support scheme aiming to lift 20 million poor farmers out of subsistence and into self-sufficiency.

Core challenge: The federal Government of Nigeria created a subsidy programme that showed a low effect since only 11 percent of the USD 200 million reached farmers. For example, most of the inputs provided to farmers through the subsidy programme, were subsequently sold by them on the black market. This situation greatly affected local businesses (input suppliers) as the prices offered by farmers were below the market prices.

Solution: e-Wallet, and electronic distribution channel that provides efficient and transparent systems for the purchase and distribution of agricultural inputs. Registered users of the subsidy programme would receive eWallet vouchers that they could redeem for agricultural inputs directly from agro-dealers for half of the costs. The second half of the costs was covered by the federal government.

Effects: According to Cellulant, the e-Wallet technology provider, 90 percent of farm inputs provided by the scheme were used by the selected farmers. As a result, the average annual income of these farmers transitioned from USD 700 to USD 1 800. Furthermore, it is recorded that the government managed to reach 4.3 million farmers with about USD 96 million in 2013, compared to reaching about 700 000 with USD 180 million prior to the e-Wallet implementation.

Technology[1]:	DVC or GVC enabling solution[2]:	Country's level of development[3]:	Farmers' cost (access fee)[4]:
Digital platform	DVC	Developing country (Lower-middle income economy)	Free

[1]Description of the technology is provided in the text; [2]National level – DVC, international level – GVC; [3]Classification according to the World Bank; [4]Fee of using the end product based on a specific technology.
Source: www.cellulant.com

CHAPTER 5

Conclusions and policy implications

5 Conclusions and policy implications

5.1 Summary discussion and conclusions

Disruptive digital technologies have a great potential to enable further development of the agricultural sector, significantly reshape GVCs, and greatly contribute towards more productive, resilient and transparent food systems. As most of the technologies with the highest potential to revolutionize the agriculture and food industry are in their infancy phase of development (such as, blockchain, AI and 3D printing), it is still too early to access their true impact. Wide technology acceptance greatly depends on all involved actors, as governments have to enable adequate environments for innovations and further technological development. Providers of the technologies have to understand and match market needs, while technology users have to understand and adopt different technologies.

Digital technologies are not the panacea for all challenges facing the agriculture and food industry. Nevertheless, the discussion provided in this paper indicates that digital technologies could significantly reduce transaction costs – and especially resolve the information asymmetry problem. Furthermore, this discussion has revealed that there are great benefits of digital technologies, particularly for small farmers, FVCs (their business models), technology providers (agricultural companies providing digital tools for farmers), and governments.

Mobile phones, the Internet and especially digital platforms offering e-commerce services are among the most important enablers of small farmers getting involved with formal economies. With very low costs for using the technologies, small farmers are able to get direct access to market information and become involved with trading activities. Digital platforms – supported with AI and blockchain technologies – play a key role when it comes to small farmers' abilities to increase the efficiency of production (see Box 5) and get involved with FVCs (see Box 1). Furthermore, the combination of different digital technologies helps farmers to overcome additional key problems, such as access to finance and insurance services (see Box 4).

Concerning FVCs in general, digital technologies have a great potential to change the existing linear business model. Blockchain technology brought with it the possibility of a decentralized tamper-proof data storing system, leading to high levels of security and trust. For FVCs, this system has many potential benefits. For example, internal contractual relations within a particular FVC do not need to be strict and heavily regulated, since fraudulent actions would be easily recognized and sanctioned by other members of the FVC. Thus, there would not be a strong need for strict vertical integrations of the FVCs (see Box 3). Also, the possibility of safely storing data on a blockchain has great potential in international agricultural trade since all of the documents related to trade could be digitalized and simply follow the physical movement of goods within a GVC. Ultimately, FVCs might gain more trust from consumers because they would be able to provide traceability and provenance of their products (see Box 2).

Finally, governments can benefit greatly from using digital technologies related to agricultural sector activities. More specifically, they could use different ML models to analyse large data sets and make better assessments regarding who should be targeted with specific measures and how much financing should be allocated. Furthermore, digital technologies help with more efficient allocation of funds, for example, subsidies (see Box 10), and better monitoring of the impact.

Besides having numerous potential benefits, the use of digital technologies also encompasses many concerns and risks. Lack of sufficient information, or understanding, of what a particular technology might provide as a benefit and the potentially high costs of technology implementation, represent some of the greatest obstacles for wider acceptance of various emerging technologies.

Another major concern is data protection. As indicated in this paper, most of the emerging technologies greatly rely on large amounts of data collected from technology users. Even if users sometimes receive access to a certain technology for "free", the question is whether it is really for free, as users' data is collected and processed. It's then either used by technology providers to improve the technology or create well-targeted marketing campaigns, and/or is sold to third parties. As it's not always clear who actually owns the data, this problem can be quite complex.

Once a farmer or an SME is using a digital platform, or is operating on a blockchain, there is always a concern of who is governing the technology and which decisions are being made. If a particular digital platform suddenly stops operating, users could face high transaction costs as they would need to look for a new platform and customers. The same applies to the governance of different platforms hosting blockchain technology that rely on communities of programmers. The question of what could happen to the data of the blockchain users if the community decides to make a major change or stop working on further platform development needs to be considered. Governance of the technology is crucial when it comes to scalability issues as well.

Digital technologies also contribute to the creation of new business models based on economies of scale. Besides providing enormous possibilities for businesses to grow – as they produce digital products with almost zero product replicability costs – it also leads to a potential danger in the market. This is especially the case for large agri-food companies, mainly input and machinery providers, who develop their own digital platforms and try to "harvest" as much data as possible in order to control bigger market shares and increase profits. This "hunger" for data is displayed through massive mergers between companies in the agri-food sector leading towards clear concentration in certain segments (for example, seed production and agricultural machinery sectors).

5.2 Policy implications

Based on the discussion provided in this paper, the following recommendations refer to both policy makers and technology developers.

Ensure that regulatory bodies obtain the necessary skills to understand the technical characteristics of the digital technologies in order to identify which national legislations have to be adjusted to respond to market needs.

Promote and support investment in ICT networks in remote areas. As ICT enables digital technologies, it is important to provide access to as many individuals as possible to avoid digital divides.

Provide support for education activities in rural areas, especially taking into consideration gender aspects. It is important to support education of rural population in order to enable faster adoption of innovations in agriculture.

Provide clear national data protection regulations to ensure digital privacy. There is a need for clear guidance from national governments on data protection rules. Furthermore, to ensure compatibility, regulations on data protection should be in line with existing international standards. Many developed countries already have strict regulations on data-handling procedures compared to the still loose regulations in place in many developing countries (Rossotto *et al*., 2018). Thus, as digital products might easily reach customers out of national borders, it is important to have a common understanding of rules and regulations. Furthermore, it is important to revise certain existing rules in order to account for newly emerging technologies (for example, blockchain and DLT standards).

Implement measures to ensure market transparency and access to information. Governments might consider implementing obligatory traceability requirements, such as the European Union General Food Law (European Union, 2007), because of phytosanitary issues. As consumers request more transparency and information about the food they eat, a similar initiative could also come from the side of FVCs. Implementing measures in support of market transparency and access to market information could significantly improve the participation of domestic producers in GVCs.

Strengthen market competition regulations. New regulations should particularly refer to the emerging business models based on economies of scale, such as digital platforms. It has already been shown that digital platforms can easily scale to the level of having market power. Furthermore, governments should prevent strong centralization of digital technology providers, as this might lead to higher costs of using the technology, and thus potential digital divides.

Support public–private partnerships to foster R&D and enable wider technology acceptance. Both the public and private sectors could benefit from a joint effort to develop new digital solutions through R&D in agriculture. Public–private partnerships using digital technologies have already had some positive results in many countries, specifically regarding more efficient allocations of government funds (for example, the agricultural subsidy programme in Nigeria), improved efficiency of general services provided to society (for example, e-government services in Estonia), or numerous examples of private companies providing improved extension services for farmers.

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