Emerging Opportunities for the Application of Blockchain in the Agri-food Industry

Mischa Tripoli
Josef Schmidhuber

Food and Agriculture Organization of the United Nations

ICTSD
International Centre for Trade and Sustainable Development

Issue Paper

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Mischa Tripoli
Economist, Trade and Markets Division, FAO

Josef Schmidhuber
Deputy Director, Trade and Markets Division, FAO

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7 Chemin de Balexert, 1219 Geneva, Switzerland

Tel: +41 22 917 8492
ictsd@ictsd.ch

Fax: +41 22 917 8093
www.ictsd.org

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CONTENTS

ABBREVIATIONS

B2B	business-to-business
CCA	central competent authority
DLT	distributed ledger technology
FAO	Food and Agriculture Organization
IoT	Internet of Things
MSME	micro-, small- and medium-sized enterprise
OTC	over-the-counter
RFID	radio frequency identification
SDG	Sustainable Development Goal
SPS	sanitary and phytosanitary
TRIPS	Trade-Related Aspects of Intellectual Property Rights
UN	United Nations
WFP	World Food Programme
WSIS	World Summit for the Information Society
WTO	World Trade Organization

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FOREWORD

Distributed ledger technologies (DLTs) have the potential to transform the global food system by introducing important efficiency gains along value chains, and improving trust, transparency and traceability. While large actors are likely to make fast and significant inroads in exploiting DLTs, small farmers and processors also stand to reap significant benefits, provided the technology is made accessible to them. This raises the question of how an enabling environment can be created for smallholders to harness these new technologies, and, at a broader scale, for DLTs, so that these contribute to improving the functioning of global food and agricultural markets.

This paper, by Mischa Tripoli and Josef Schmidhuber, seeks to make an initial contribution to the emerging public debate on this issue by providing an overview of DLTs and their application in food and agriculture, examining public policy implications for food security and rural development and identifying some potential challenges, risks and the way forward.

Ricardo Meléndez-Ortiz
Chief Executive, ICTSD

Boubaker Ben-Belhassen
Director, Trade and Markets Division, FAO

EXECUTIVE SUMMARY

Distributed ledger technologies (DLTs) and smart contracts provide a unique opportunity to bring greater efficiency, transparency and traceability to the exchange of value and information in the agriculture sector. This paper aims to facilitate a better understanding of the opportunities, benefits and applications of DLTs in agri-foods. It also identifies technical limits and possible institutional barriers to their adoption.

By utilising digital records, cryptography and the disintermediation of transaction processing and data storage, DLTs can improve both agricultural supply chains and rural development interventions in a number of ways. First, the ability of the technology to trace a product's provenance, carry detailed attributes for the product in each transaction and ensure its authenticity brings vast improvements in traceability with positive impact on food safety, quality and sustainability. Second, the disintermediation of transactions in agricultural supply chains and the use of smart contracts enable frictionless and real-time payments for agricultural financial services, which can reduce transaction costs, decrease risk for buyers and sellers and increase cash flow and working capital for farmers and sellers which is usually tied up in complex and paper-heavy settlement processes. More efficient supply chains and agricultural financial services lead to greater financial inclusion and stronger business development. Third, DLTs allow users to build digital identities with their recorded digital and physical assets. The vast amount of data generated from transactions in agricultural supply chains provides more accurate market information and data for supply chain actors and the public sector, which can be used to inform production and marketing decisions, prove a farmer's track record to access credit and strengthen the enabling environment with better informed policies. Physical assets registered on the distributed ledger, such as land titles, can be used as collateral to access financing. DLTs are a secure, fast and immutable method to register land titles, providing greater legal clarity to land tenure systems.

In addition, DLTs also have the potential to improve the implementation and monitoring of international agreements related to agriculture, such as World Trade Organization agreements and provisions relevant for agriculture, as well as the Paris Agreement on Climate Change. DLTs can bring greater transparency and accountability to compliance with such agreements.

There are a number of technical, regulatory, institutional, infrastructure and capacity development-related challenges to be addressed before reaching maturity in order to ensure the scalability and accessibility of the technology. Scalability, interoperability and product authenticity through product-process links are important factors for widespread adoption of DLTs in agricultural supply chains. DLTs are not a panacea for the agriculture sector, but the technology provides great potential if the challenges for adoption can be overcome.

As DLTs continue to develop, the international community has an important role to play in contributing to the creation of an enabling environment that ensures that the productivity gains generated from DLTs can be shared by all market participants, including smallholder farmers, processors as well as micro-, small- and medium-sized enterprises. Governments together with intergovernmental organisations can lead this effort by contributing to technical dialogue on DLTs; providing policy guidance on the use of DLTs in agriculture through intergovernmental working groups and multi-stakeholder platforms; developing regulations and standards; enhancing public and private partnerships; and providing outreach to improve infrastructure and digital skills in rural areas. The technology has huge potential to address many of the challenges that disadvantaged market players face by allowing them to participate in integrated supply chains, in addition to improving rural development interventions and being an impetus to achieve the Sustainable Development Goals.

1. INTRODUCTION

All around the globe, regardless of the level of economic development, humans are constantly transferring value. The transfer of value is a fundamental human activity enabling people to trade goods and services, and accumulate productive capital and savings for their well-being. In order to lower uncertainty during the exchange of value, institutions are used to ensure trust and mitigate risk between buyers and sellers. The institutions that intermediate the exchange of value use centralised electronic ledgers to track assets and store data. Since those intermediaries often rely on manual inputs and may be vulnerable to fraud, value transfers tend to impose a high cost on buyers and sellers, which drastically increases the burdens of doing business. High transaction costs are a major deterrent to economic development. In addition, cash transactions (in both the formal and informal economy) lack traceability, which ultimately hinders the ability of micro-, small- and medium-sized enterprises (MSMEs), particularly in developing countries, to access credit and new markets and to grow.

Distributed ledger technologies (DLTs)[1] introduce a new method to accounting for value transfers that minimises uncertainty and disintermediates the exchange of value with a decentralised and shared ledger, functioning as a digital institution of trust. DLTs offer a secure system of recording transactions in a digital database that removes third-party intermediaries, reduces transaction costs, enables faster and even real-time transactions, assures immutable data entries and provides access to the database for all participants in the network. After being first introduced as the electronic cash system for Bitcoin[2] in 2008, blockchain and other DLTs have demonstrated enormous potential to enhance efficiency, transparency and traceability across the global economy. DLTs can be programmed to record not just economic transactions, but also other types of information that is of value and importance to humankind, such as: birth and death certificates, marriage licenses, deeds and titles of ownership, educational degrees or anything else that can be represented in code (Tapscott and Tapscott 2016).

Throughout the global economy, governments, private institutions and technology start-ups are exploring the possible applications for DLTs. Over the last four years, more than US$5 billion have been invested in these technologies (CoinDesk 2018). The financial services sector is one major area where the technology is being tested and implemented for payments and trading securities. Blockchain-based payments have considerable potential not only for retail banking, but also for agricultural value chains and the development sector in cash-based assistance schemes, remittances and procurement. For example, the World Food Programme (WFP) piloted cash transfers programmes using a blockchain-based technology to record supermarket transactions in a Syrian refugee camp. The pilot programmes were believed to provide substantial financial savings for WFP, by eliminating financial intermediaries, their associated transaction fees and the time spent by WFP accountants on compiling data and reports from banks and stores, which is no longer needed with automated record-keeping from the blockchain (Bacchi 2017). The potential applications of DLTs to simplify workflows and improve efficiency in the development industry are enormous. The private sector is already partnering with the United Nations (UN) to explore applications

1 For the purpose of this paper, the terms distributed ledger technologies (DLTs) and blockchain are interchangeable. It is important to note that blockchain has become a colloquial name for all types of DLTs. However, blockchain is actually one type of DLT. See section 2 for a further explanation.

2 Bitcoin is a digital currency that uses the DLT called blockchain to transfer funds between parties without a central authority.

to improve the effectiveness of its work and strengthen efficiency in the UN system (Bacchi 2017).

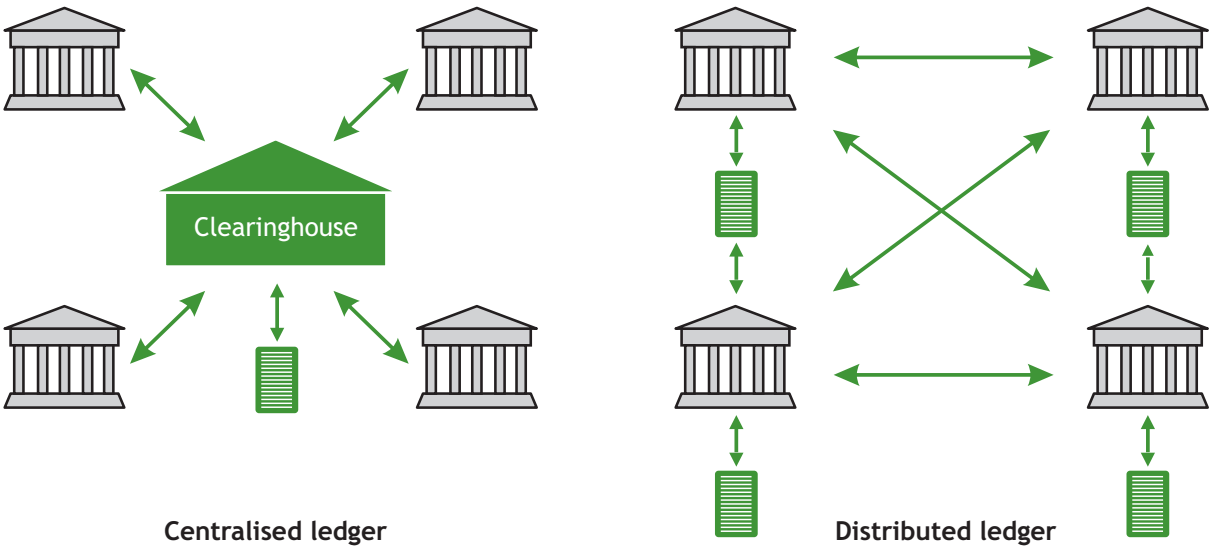
The agricultural sector is no different. There are numerous transparency and efficiency issues in agricultural supply chains, which ultimately put farmers and consumers at a disadvantage. Transactions in agricultural supply chains are inherently risky and complex, thus relying on a number of intermediaries; while more conscious consumers have poor transparency on where their food comes from and how it is produced. Ultimately, strengthening the linkages between farms, markets and consumers can generate greater income growth and job creation (FAO 2017). The potential for DLTs to increase efficiency, transparency and trust throughout agricultural supply chains and empower all market players is real. The technology has the potential to simplify and integrate agricultural supply chains, enhance food safety, reduce risk in trade finance and promote inclusive trade, increase access to agricultural financial services, generate smarter market information and provide greater legal certainty to land-tenure systems. The agri-food and technology industries are already exploring such applications. In fact, a consortium of major food companies (Dole, Driscoll, Golden State Foods, Kroger, McCormick and Company, Nestlé, Tyson Foods and Walmart) are collaborating with IBM to use distributed ledger solutions to make their food supply chains more transparent, more traceable and to streamline payments. Previously, IBM and Walmart used blockchain-based technologies to track a package of mangoes along its exact path from retail shelf to farm in a matter of seconds (Wass 2017b). This paper aims to facilitate a better understanding of the opportunities, benefits and applications of DLTs in the agriculture sector. It also identifies technical and financial constraints in adopting the DLTs in food and agriculture.

2. UNDERSTANDING DISTRIBUTED LEDGER TECHNOLOGIES

Distributed ledger technologies are an evolving technology and transaction system that has many applications. It was first introduced as the cryptocurrency system for Bitcoin in 2008.[3] DLTs can be used to make all types of transactions and store any type of data and information of value. A DLT is a digital database that uses cryptography to link and secure transactions or data entries, and disintermediates data processing and data storage with a peer-to-peer distributed network of computers that are used to validate and store the transaction history and information. DLTs function as a decentralised digital institution to ensure trust between buyers and sellers or users, thus providing an improved method to account for value transfers.

The technology has three key features that are necessary to understand (see figure 1). First, DLTs disintermediate the processing and storage of data entries. Currently, institutions ensure trust through intermediation, where they contract, clear, settle and record transactions in a centralised ledger. These intermediaries often rely on manual inputs and are susceptible to error and fraud, making the execution of transactions timely and costly. In addition, the centralised model limits access to data and control of it for buyers and sellers. DLTs do not use any centralised certifying authorities. Instead, when information is verified on the distributed ledger, it is instantly recorded on all of the participating computers on the network, which ensures every user has access to up-to-date information; there is no single point of failure and no single institution or actor can control the information. DLTs verify transactions by using a consensus mechanism to reach agreement between the participants on the status of a data in the network. The consensus mechanism uses validators (who are also participants), economic incentives and consensus algorithms to validate transactions or data entries in the shared ledger. All users of the DLT can participate in the validation process for transactions. This removes the need for intermediaries by maintaining the element of trust, while replacing the current centralised data model which drastically changes the payment-cost structure (Cant et al. 2015). This method of validating data entries offers greater cost efficiency, with lower fees and faster transactions.

Figure 1: Traditional centralised ledger and a distributed ledger



Source: Author

3 There is a spectrum of DLTs, each with a different degree of decentralisation. It ranges from permissionless ledgers (like the Bitcoin blockchain) that are censorship resistant, do not have any legal accountability and where users have equal rights to permissioned ledgers that are censored, have legal liability and where users may not have equal rights.

Second, DLTs use cryptography to ensure immutability and security for data entries. Each data entry is recorded with a timestamp and a cryptographic fingerprint of that record, called a hash, that links each record to one another, and is then stored securely across the distributed network of computers. Hashes are the basis of security and immutability for distributed ledgers, which make it impossible to modify an entry without noticeably affecting all of the entries in the ledger. This makes fraudulent activity in the distributed ledger immediately visible to all of the other users.

Third, the immutability of records and the disintermediation of data storage, through a shared ledger, make every transaction or record in a distributed ledger traceable and transparent. In theory, all participants of the distributed ledger have access to the full transaction history registered on the database. Depending on the purpose and the rules of the DLT, users have the ability to control which types of transaction details are shared, and with whom. The information stored on the ledger is protected by encryption and managed with private and public keys.[4] Together, these keys allow users to protect and control who can access their information on DLTs and when. For example, if a farmer wants to share their credit history that is registered on the distributed ledger with a lender such as a bank, then they could use the bank's public key to encrypt and send the data to the bank; the bank would use its corresponding private key to decrypt and read the information. In addition, the bank could verify that the data actually belongs to the farmer by using the farmer's public key. Ultimately, access to data in the DLT can be shared or private, depending on the rules of the DLT (which are based on the purpose of the platform) and the users' choices.

Currently, there are two main types of DLTs: public and private (Jayachandran 2017). A public DLT is an open ledger with permissionless access, where actors in the network are anonymous and do not need to have any previous relationship with the ledger. Public or permissionless DLTs are censor-proof and fully decentralised systems. Participation in the network is open to anyone in the world, which means anyone can make transactions, view the ledger's entire transaction history and participate in the consensus mechanism. The advantage of public DLTs is that no individual or entity is able to control the information on the ledger and, therefore, the system is neutral. The two most well-known public DLTs are the Bitcoin blockchain and Ethereum; the latter is a generalised transaction ledger that allows anyone to programme decentralised software applications using smart contracts and executes them on its DLT. The disadvantage of public DLTs is that there may be some malicious actors in the network, since the participants are unknown. Therefore, there may be applications where some types of information are too sensitive to be shared in a fully open ledger, such as for financial institutions.

A private DLT is a closed ledger with permissioned access, where users are identified and transactions are validated and processed by actors that are already known by the ledger. By requiring the identity of actors to be known in the private or permissioned distributed ledger, there is an additional layer of security that limits malicious actors, as they can be penalised and ejected from the network.[5] Instead of anonymous participants, permissioned distributed ledgers use already authenticated legal entities to validate transactions (Swanson 2015). Using authenticated validators to provide consensus in the network does not mean they can control the approval of transactions. In fact, there is a trade-off for permissioned distributed ledgers where censorship-resistance is sacrificed for legal accountability, while still operating without intermediaries. It is precisely the legal accountability that makes permissioned

4 In asymmetric encryption, each user has a private and public key that correspond to one another. The private key is confidential and similar to a password. The public key is like an email address and is available to users in the network.

5 For more details on the benefits of permissioned distributed ledgers, see Swanson (2015).

distributed ledgers more attractive for global capital markets, tangible assets, supply chains and smart contracts (Swanson 2015).

The anonymity of participants in public DLTs and the identity of users in private DLTs make the process for verifying the transactions quite different in open and closed systems. There are many different types of consensus algorithms that are used for public and private DLTs. Each algorithm has advantages and disadvantages, which should be understood and used according to the specific application. For example, one of the best-known public DLTs is the Bitcoin blockchain, which uses a consensus algorithm called proof-of-work. The proof-of-work algorithm is costly in terms of resources and time, and therefore is not an optimal consensus mechanism for business blockchain networks (Hyperledger 2017). The Ethereum public DLT is transitioning to the proof-of-stake algorithm, which is more efficient as it eliminates mining and the expensive computational resources used in the proof-of-work algorithm. Private DLTs employ two main groups of consensus algorithms: lottery-based and voting-based. Lottery-based algorithms are advantageous in terms of scalability but result in a longer time to finality, while voting-based algorithms are advantageous in terms of speed and finality but lack scalability (Hyperledger 2017).

Another potential efficiency gain for the global economy is the ability of DLTs to implement smart contracts. Commerce operates through contractual agreements, which are usually in the form of physical contracts. Physical contracts depend on centralised authorities to clear and settle transactions, which are costly, time consuming and plagued by error and fraud. Since DLTs have a high degree of security and immutability, they provide a sound technological platform for smart contracts. Smart contracts are computer programs that automatically execute when predefined conditions are met. Smart contracts are designed to automate much of the contractual process. The performance, monitoring and enforcement of contractual agreements are done autonomously, without any central authority or human involvement. Contract automation could provide huge savings for businesses in transaction fees and legal costs, while meeting contractual obligations in real-time (Shadab 2014; Cant et al. 2016). These efficiency gains have the potential to uproot the traditional contractual infrastructure and eliminate the need for centralised intermediaries.

The areas for potential applications of distributed ledgers are immense. The efficiency gains from executing transactions and contracts through distributed ledgers have huge implications for the financial industry, but also for other sectors throughout the economy. Seemingly every sector of the economy is trying to understand how this technology is applicable and could be beneficial, and what the challenges for implementing it are.

3. APPLICATIONS FOR DISTRIBUTED LEDGER TECHNOLOGIES IN THE FOOD AND AGRICULTURE SECTOR

3.1. Current Trends in the Food and Agriculture Industry

Similar to other sectors of the economy, agriculture and transactions in agricultural supply chains have never fully undergone a digital transformation. World agriculture is facing numerous challenges. The agri-food industry must:

- meet the food demands of a growing population;
- adjust to changing consumer preferences in low- and middle-income countries from cereal-based products towards higher consumption of animal, fruit and vegetable products;
- promote more environmentally sustainable agricultural practices and decrease environmental footprints;
- reduce supply chain costs;
- maintain high-quality sanitary and phyto-sanitary (SPS) standards;
- sustain profitable farming operations; and
- raise incomes of small-scale food producers.

Globally, the agriculture sector is a major source of employment, which absorbs roughly 30 percent of the global workforce (World Bank 2018b). For many low- and lower-middle-income countries, the sector is an important source of income for the rural populations and a major driver of economic growth.

Food systems and agricultural practices around the world are diverse and range from modern, large-scale distribution systems channels to traditional food chains. Agriculture in low- and lower-middle income countries is characterised by a majority of small farms, with three quarters and two thirds, respectively, of all farmland managed in farms of less than five hectares (FAO 2014). In these regions, agriculture is marked by low labour productivity and low capital intensity. This is in stark contrast with the predominantly large-scale farming in high- and upper-middle income countries, typically characterised by high labour productivity and high capital intensity.

Globally, both food production and retail channels are changing. There is a growing reliance on global supply chains and large-scale distribution systems, such as supermarkets. Food systems are becoming more capital-intensive, vertically integrated and concentrated in fewer hands. In some instances, there is the integration of primary production, processing and distribution; the automation of large-scale processing; and higher capital and knowledge intensities (FAO 2017). For low- and middle income countries, the changing agri-food value chains increase barriers for small-scale producers and agro-processors to participate in local, national and global markets. Many small-scale operators struggle to participate in integrated value chains, due to the lack of access to financing, issues of market accessibility and transport, and of complying with the range of standards on quality, traceability and certification (FAO 2017). By strengthening the linkages between farmers, markets and consumers, agricultural value chains can generate greater income growth and job creation.

Agricultural supply chains are risky and complex, as agricultural production depends on difficult-to-control factors (weather, pests and diseases), agricultural supply chains lack traceability and the settlement of transactions is slow and often labour-intensive. Transactions in agricultural supply chains are overrun with intermediaries and dogged by inefficiencies, while the actors that are able to consistently access global supply channels are often large-scale producers and agro-processors with a strong reputation. Agricultural supply chains need more inclusivity for disadvantaged market

players, in order to boost their economic development and contribute to the demand for greater food supplies by a growing population. DLTs have the ability to reduce risk and increase efficiency in the agri-food industry by providing transparency and traceability and by eliminating intermediaries in agricultural value chains. In addition, by reducing uncertainty and enabling trust among market players, DLTs and smart contracts also provide a real opportunity for more inclusive market participation for smallholders and MSMEs.

3.2. Agricultural Supply Chains

3.2.1 Agricultural supply chains management

Agricultural supply chains have substantial inefficiencies, which impact all actors in the chain from producers to consumers. It is estimated that the cost of operating supply chains makes up two thirds of the final cost of goods (Niforos 2017b), while seven percent of the global value of trade is absorbed by the costs of documents alone.[6] The challenges for supply chains include: the lack of transparency due to inconsistent or unavailable data; high proportion of manual labour and paper work; lack of interoperability; and limited information on the traceability of the product (Lierow et al. 2017). Both private and public sectors want to reduce the high cost of moving goods along supply chains, and the World Trade Organization (WTO) Trade Facilitation Agreement introduces measures to cut costs, avoid delays and reduce uncertainty (OECD et al. 2014).

At the same time, the private sector is always looking for technological advances to make their supply chains more cost effective and to increase competitiveness. Already supply chains are being digitised with technologies such as cloud computing, artificial intelligence and the Internet of Things (IoT). However, DLTs have the greatest potential to increase efficiency and transparency in agricultural supply chains.

The application of DLTs in agricultural supply chains would provide a digital database that records, tracks, monitors and transacts physical and digital assets. DLTs enable higher-quality transactions and enhanced traceability. The technology can integrate and manage each process and transaction throughout the agricultural supply chain in real time. Each transaction that is processed on the distributed ledger can carry transaction details and specific attributes for the product which can be added by supply chain actors. Supply chain actors can identify and examine the product's movement along every step in the supply chain from the agricultural and livestock inputs and practices (fertilisers, fodder, water practices, veterinary services, etc.) used on the farm to the transportation and storage conditions and details as the product moves to the retailer and consumer. The DLT stores immutable records that are transparent and, in theory, accessible to any user with the software. This technology has the potential to create vast efficiency gains for each actor in the supply chain.

Ensuring immutable product-process links

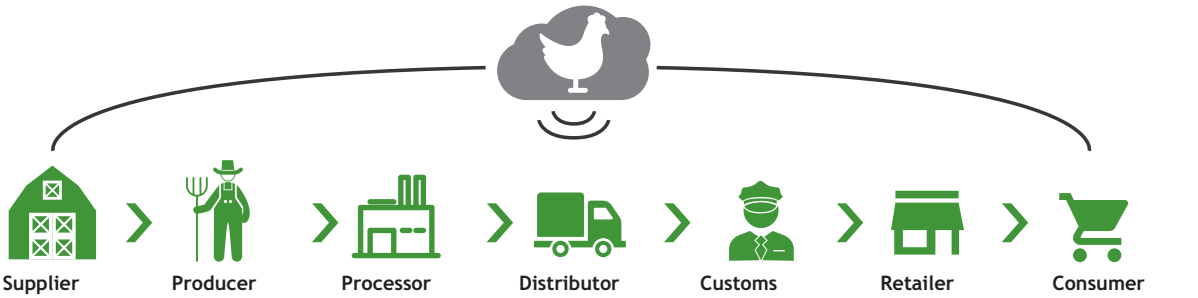
DLTs provide a platform for traceability in agriculture supply chains to track provenance and ensure authenticity of agricultural products. Regulatory control will be easier with DLTs as the product can be traced along every registered movement in the supply chain, and this allows for legal accountability for fraudulent behaviour regarding a product's authenticity. However, for transactions to be fully tamper-proof, an immutable link between the DLT (process) and the real-world product needs to be established. The basic challenge is that while the transaction data can be traced by the cryptographic fingerprint attached to each transaction, the movement of the physical product along a supply chain from farm to consumer needs to be ensured through such an immutable product-process link. Several options exist to establish these. They include the well-known QR code on the product's packaging, the more advanced radio frequency identification (RFID) chips and, more recently and most promisingly, so-called

6 See www.tradefacilitation.org.

crypto-anchors. QR codes are already used in markets and require regulators to monitor product authenticity. IBM recently developed crypto-anchors as a means to ensure product authenticity for DLTs. Crypto-anchors are tamper-proof digital fingerprints that are embedded into products in the form of edible ink using optical code or tiny computers, and linked to the DLT to prove a product's authenticity. Crypto-anchors are highly secure, unclonable, smaller than a grain of salt and cost less than US$0.10 cents to manufacture (IBM 2018a). In the case where a crypto-anchor cannot be embedded directly into a product, IBM also recently developed a technology using mobile sensors (or a cell phone) outfitted with a special optical device and artificial intelligence algorithms to learn and identify the optical structure, the DNA sequencing and other features of certain objects in minutes (IBM 2018a). For example, in the near future, a retailer or customs agent could use a sensor on a mobile phone to verify the authenticity of a tomato's provenance. The low cost and seemingly simple usability make crypto-anchors a potential scalable and useful tool to ensure authenticity.

For example, when looking at the supply chain for poultry (figure 2), we can see the real potential of an integrated supply chain on a DLT. With growing demand for more transparency and information on the origin of products, supply chain actors would use a mobile application and a QR code on the product to trace its origin and movements along each step of the supply chain. The consumer would scan the QR code on the packaging of the chicken to reveal the product information. In order to have product traceability, the chain would start with the producer, who would keep records of all information on inputs (such as feed and medicines), animal health, location, breed, age, sex, cost of production and any other technical information needed for domestic or export markets. Each time the chicken would be moved between supply chain actors, the transaction would be recorded and verified by the DLT. Other information that would be recorded is time (slaughter date, time in transit, expiration dates) as well as export-related certifications (such as health and country of origin certifications). These details and their traceability would bring large efficiency gains to supply chain management, food safety and product sustainability.

Figure 2: Agricultural supply chain on distributed ledger technology



Supplier	Producer	Processor	Distributor	Customs	Retailer	Consumer
• Agriculture and livestock inputs are sold to producer and registered on DLT • Breeder enters data on egg and pullet quality and conditions, sanitation and transportation details	• Chicken is tagged with RFID chip, proving free range • Uploads data on feed, veterinary reports, facility conditions, sanitation and food safety measures, other certifications and farm location	• Gov. inspected facility gets data on chicken, prepares poultry products and adds QR code to packaging • Uploads data on storage and slaughter conditions, food safety compliance, lot number, certifications and QR codes	• Stores and transports poultry products from suppliers to retailers, restaurants and importers • Uploads data on shipment and delivery details, storage and transport conditions, and warehouse and vehicle food safety and sanitation measures	• In case of int'l trade, receives digital certifications • Uploads data on holding times, testing resultis and customs-clearing details • Allows entry for products and custom duties are automatically dispersed by smart contract	• Runs machine learning-based fore casting • Adapts orders and promos accordingly • Uploads data on delivery details, inventory metrics and sanitation measures. • Provides app for end-consumers	• Scan QR code via app • Gets full information on the poultry product such as where and where and how it was produced, processed and transported

Source: Author

Currently, there is an influx of start-ups in the food and beverage sector that aim to transition agricultural supply chains onto DLTs. INS is an e-commerce platform that aims to disrupt the concentration of power in the grocery market by using DLTs to connect manufacturers directly to consumers through the integration of data. Globally, approximately 60 percent of the grocery market is dominated by the top five retailers, which can lead to unfair trading practices for farmers and manufacturers, and high prices for consumers (Michail 2017). By bypassing grocery retailers, manufacturers could save money on the business-to-business (B2B) marketing directed at retailers, which will save consumers 20–30 percent for products bought on the INS platform (Michail 2017). INS is envisaged to give small food enterprises increased market opportunities. Ambrosus is a Swiss tech firm that aims to use a DLT, smart contracts and high-tech sensors to trace food and pharmaceutical supply chains. Ripe is another company that is using DLTs, scanners and specialised sensors to provide agricultural supply chain actors with better data on crop production to yield higher-quality produce (Massa 2017). Provenance, a UK start-up, successfully launched a pilot project to track tuna fishing on DLTs. The company aims to curb illegal fishing and fake certifications, by registering each catch on the blockchain and selling the fish with a blockchain ID in order to ensure traceability.

3.2.2 The future of food safety

By enabling transparency and recording every detail of the production and processing of agricultural goods, the ability to ensure compliance with food and sustainability standards will be improved. Data will be available on the quality (freshness, safety, geographic indications), safety (health, risk management) and sustainability (organic, fair-trade) of products. DLTs will help businesses and governments' central competent authorities (CCA) to track and monitor non-compliance with international standards and improve their ability to control plant and animal diseases in order to maintain disease-free status. In addition, the CCA should be able to easily, quickly and confidently issue export certifications. Virtually all of the required information associated with the product will be in the DLT and certifications could even be automated. CCAs will still play an important role in monitoring and inspecting farms and processing facilities' compliance with international SPS standards.

In the case of an outbreak of an animal or plant disease, contaminated agri-food products or food fraud, DLTs will also enable businesses and regulators to trace and pinpoint contaminated or fraudulent products more quickly and less wastefully. Both food fraud and foodborne diseases are extremely costly in economic terms, and environmentally in terms of wasted resources. Food fraud is estimated to cost the global food industry US$40 billion each year (PWC 2016), and the estimates of foodborne diseases in the US alone are roughly US$55 billion annually (Scharff 2015). Currently, neither firms, governments nor consumers are able to capture a product's movement along the entire supply chain, since often governments only require firms to record data on a product's movement one step forward and one step backward. This can make it more difficult to track contaminated or fraudulent products to the exact farm or plant that might have caused the outbreak. DLTs can quickly trace contaminated products to their source, allowing faulty items to be removed from stores to minimise both illness and financial losses.

The food and beverage industry is currently experimenting with deploying the DLTs into global food supply chains. A consortium of large food suppliers, including Dole, Driscoll's, Golden State Foods, Kroger, McCormick and Company, Nestlé, Tyson Foods and Walmart, is collaborating with IBM to test their DLT and identify new areas where the technology can benefit food ecosystems (Wass 2017b). The collaboration is based on a successful pilot project that IBM carried out with Walmart on how DLTs can solve food safety problems and trace contaminated products to their source.

The results from the pilot project showed that, when tracking a package of mangoes from the supermarket to the farm where they were grown, it took six days, 18 hours and 26 minutes with traditional methods, whereas with the DLT it took just a couple of seconds to identify the exact origin and the path the fruit followed to the retail shelves (Wass 2017b).

Similar projects are underway in Asia with two of China's largest e-commerce companies, with the objective to combat food fraud. Alibaba is launching an initiative with PricewaterhouseCoopers, Blackmores and Australia Post to develop and implement blockchain-based technologies into their supply chains to eliminate food fraud. Similarly, JD.com, China's second largest e-commerce company, is working with Kerchin, a Mongolia-based beef manufacturer, to track the production and delivery of frozen beef (Huang 2017).

3.2.3 Greater efficiency for trade finance

Trade finance plays a vital role in global trade. Roughly US$18 trillion of annual trade transactions involve some form of trade finance, while the total size of the trade finance market is more than US$10 trillion annually (Auboin 2015). Financial institutions bridge the gap in the exchange between buyers and sellers with some form of finance, such as credit, insurance and guarantees. There is substantial risk when two companies send high-value and large shipments domestically or internationally, such as a load of rice. The potential risks are related to the transaction between the two parties (i.e. the time difference between when sellers or exporters want to be paid and when buyers or importers will release the payment), possible alteration or loss of goods during transportation and fluctuations in exchange rates. Trade finance mitigates these risks for sellers and buyers (or exporters and importers), which is a fundamental aspect of being able to trade goods.

The current methods of trade finance are cumbersome, time-consuming and rely heavily on paper to conduct transactions. Transactions include multiple copies of agreements between the shipper's banks and receiver's banks, as well as agreements on the value of the shipment and how it is loaded. Through these complex and inefficient transaction systems, financial intermediaries lock up billions of dollars as they process the transactions. For example, the payment terms in Australia's grain sector range from two to five weeks, and these terms pose counterparty credit risk to growers (Fintech Australia 2016). Naturally, such long periods have negative impacts on sellers' cash flow, working capital and ability to manage their business.

Trade finance digital platforms using DLTs can reduce costs, reduce risks for sellers and banks and bring greater efficiency gains to supply chains. DLTs use smart contracts to auto-execute the settlement of payments in real time, by first valuing the delivery, then verifying the buyer has sufficient funds and lastly securing the funds in the buyer's name pending delivery. Once the physical delivery is made, the title for the grain is transferred to the buyer as the payment is simultaneously settled from the reserved funds (Fintech Australia 2016). Real-time approvals and payments in trade finance would eliminate the counterparty risk that sellers face and free up working capital. In addition there are huge efficiency gains through the workflow automation and digitisation of documents. All information (related to agreements and certifications) that is traditionally stored on paper would be stored on a single digital ledger, which is quickly accessible to all parties. Banks would no longer need intermediaries to assume risk. Lastly, DLTs could also improve the ability of regulators and authorities to collect taxes and customs duties. The technology brings a high level of accountability, traceability and verifiability to the transaction.

DLTs can also increase access to trade finance. Trade finance has been unable to meet demand, particularly from MSMEs and emerging economies, resulting in a loss in economic growth. In 2017, the global trade finance gap is estimated to be approximately US$1.5 trillion (DiCaprio et al. 2017). Access to

trade finance often depends on reputation and being an established player in supply chains, which ultimately is a disadvantage to MSMEs. Since DLTs reduce the risk for banks, they have a greater incentive to be more inclusive and also extend their services to MSMEs.

Currently, a number of trade finance applications using blockchain-based technologies target MSMEs and locations where trade financing is unavailable. Seven major European banks are collaborating on the development and commercialisation of a permissioned DLT trade finance platform for SMEs, hosted by IBM and powered by Hyperledger Fabric 1.0 (Wass 2017a).[7] The platform, called Digital Trade Chain, is designed to manage open account trade transactions for domestic and international trade for European SMEs. Its goals are to provide a single platform for trade deals, provide easy access to financing and reduce transaction costs for businesses. In addition, a US-based company, Skuchain, has developed a DLT to reduce friction in trade finance and global supply chains. The venture aims to make financing available to SMEs and to emerging markets where it was not previously accessible. Skuchain's blockchain technology provides a "collaborative commerce platform" that combines payments (letter of credit or wire transfer), finance (operating loans or short-term trade loans) and visibility (integration with back-office systems such as "Systems Applications and Products in Data Processing" or an "Enterprise Resource Planning" system) (Allison 2016). One potential application of Skuchain's blockchain is with WFP, as they are currently exploring options to finance the procurement of food in East Africa (Besnainou 2017).

There are many other applications in trade finance and supply chain management that are in the process of testing their proof of concept, with the intention to pilot and scale thereafter. One example is a group of Dutch and French banks (ING, ABN Ambro and Société Générale), partnered with Louis Dreyfus Co. (one of the biggest agri-food traders), to ship a cargo of soybeans from the US to China using a DLT. It is said to be one of the first fully fledged agricultural commodity transactions using the technology, which reduced the time spent on document and data processing to a fifth through digitising documents for the deal (including sales contracts, letter of credit, government inspections and certifications) (Bloomberg 2018). Another initiative, including a group of international banks (Barclays, Standard Chartered and BNP Paribas), large corporations (Unilever, Sainsbury's and Sappi) and fintech start-ups, has launched a project to use DLTs to track physical supply chains and unlock access to financing for sustainable sourcing (Wass 2017c). The first pilot plans to test the technology to track tea and tea packaging materials from farmers in Malawi to the corporations. This pilot is one of the first initiatives to combine supply chain tracking with trade financing.

3.2.4 Agricultural value chain financial services: payments, insurance, credit and derivatives

Other types of financial services, like payment services, insurance and credit, also play an important role in helping agricultural supply chain actors to reduce risk, improve crop yields, manage liquidity and maximise returns. DLTs have the potential to reduce friction costs and increase access to agricultural value chain finance particularly for smallholders and MSMEs. According to Capgemini Consulting, distributed ledger-based smart contracts are estimated to save consumers up to US$16 billion annually on banking and insurance fees (Maity 2016), and certainly savings from reduced friction costs generated by DLTs will also apply to agricultural financial services. Greater efficiency in supply chains and agricultural financial services can lead to greater financial inclusion and stronger business development.

7 The banks include: Deutshce Bank, HSBC, KBC, Natixis, Rabobank, Société Générale and UniCredit.

Payments

Financial transactions, such as payments to and from farmers, traders, processors and exporters for goods and services, or loan disbursements and repayments, are the most common type of agricultural value chain services. For many agricultural value chain actors, financial transactions are overwhelmingly cash-based. The process of handling, delivering and collecting cash is slow and expensive and is subject to risks such as theft and loss (Mattern and Ramirez 2017). Digital payment services have already proven to reduce costs and risks from cash-based transactions, while also generating data on value chain actors' cash flows which can be used to assess credit risk. For example, the digital payment venture called M-Pesa has already shown that mobile money can provide a simple way of transferring money, which leads to greater access and utilisation of financial services for more successful business development. There are now more than 30 million M-Pesa users in 10 Africa countries (Krishnakumar 2017). However, DLTs present an even greater opportunity for frictionless and real-time payment services.

A number of financial institutions are testing proof of concepts and already using DLTs for payments.[8] For many firms, their interest in DLTs stems from the opportunities to reduce friction and costs (Tapscott and Tapscott 2017). Digital payments are still relatively slow and expensive and use a centralised data model. Bypassing existing intermediaries with DLTs can provide significant savings for both consumers and financial institutions. A report by Santander InnoVentures claims that DLTs could reduce banks' infrastructure costs for payments, securities and regulatory compliance by US$15–20 billion a year by 2022 (Belinky et al. 2015). In 2013, BitPesa launched a DLT-enabled payment service that serves African and international businesses to make payments to and from Africa and facilitates approximately US$20 million of transactions a month (Aglionby 2018). In September 2016, a group of some of the largest banks in the world created the first interbank group to facilitate real-time global payments using DLTs, in this case using the Ripple blockchain (Treacher 2016).[9] Other financial institutions have begun using the Ripple blockchain to facilitate instantaneous remittance payments (Ripple 2017). Similarly Nasdaq and Citigroup recently launched a new integrated payment solution to enhance liquidity in private securities and for global payments by using a DLT powered by Chain.com (Nasdaq 2017). These examples from retail banking indicate the real potential of the technology, which can also be applied in agricultural finance. DLTs have the potential to provide even greater financial inclusion for MSMEs and low-income countries, and to enable agricultural value chain actors to save and invest more in their businesses.

Agricultural insurance

Agricultural insurance is a risk management tool to help stabilise farm income and investment in the event of losses, due to natural disasters or low market prices. These tools cushion the shock of income losses to help farmers initiate crop production after a bad agricultural year and spread the losses over time to enable continued investments in agriculture. Agricultural insurance products

8 Financial institutions have made significant investments in DLTs. Visa, Nasdaq, Citi and other industry players invested US$30 million in Chain.com, a blockchain developer platform (Shin 2015). Ripple, an enterprise blockchain solution for global payments, is backed by Santander InnoVentures and other major financial institutions (Elison 2016). Another major blockchain technology called Ethereum launched an initiative in 2017 (to improve standardisation and scalability of its blockchain technology for enterprises) with 116 members, headlined by JP Morgan Chase, Intel and Microsoft (Shin 2017). Distributed ledger solutions are being developed for a range of financial services such as moving value through payments and remittances, trading value in financial assets, and insurance. The benefits of distributed ledgers for financial services will certainly trickle down to financial institutions focusing on agriculture value chains.

9 Including Bank of America Merrill Lynch, Santander, UniCredit, Standard Chartered, Westpac Banking Corporation and Royal Bank of Canada.

are often unavailable in developing countries and in particular for smallholder farmers. For smallholders, this is due to the high costs of verifying loss claims in geographically dispersed areas, the relatively small size of individual policies and the limited understanding of insurance providers of the agricultural risks for smallholders (Mattern and Ramirez 2017). For farmers that have access to agricultural insurance, policies are paper-heavy and rely on substantial manual labour to verify claims, which ultimately increases the cost of insurance.

Digital technologies provide the possibility to address some of these challenges by enhancing actuarial estimates and reducing the cost of delivering and monitoring insurance products. In the case of weather-indexed crop insurance, for instance, mobile phones allow consumers to be geotagged, which (in combination with automated weather stations and satellite imaging) eliminates the need for insurance providers to conduct in-field loss assessments (Mattern and Ramirez 2017). In combination with smart contracts implemented by a DLT, insurance claims and pay-outs would become completely digitised and automated. For example, a smart contract could be used to issue and auto-execute the settlement of a weather-indexed crop insurance policy for a farmer. First, the insurance provider would develop a digital contract of the insurance policy for the farmer. In the event of a weather shock such as flooding that destroys the farmer's crops, an automatic payment would be released to the farmer on the blockchain, if the actual quantity of rainfall indicated by the meteorological station surpasses the predefined measurement of rainfall and time period in the smart contract, bypassing the need for administrative tasks and verification by insurance companies. This example would hold true for other weather indexes that serve as a sound proxy for crop loss, where other parameters, like temperature, wind and sunshine, among others, could be measured.

Smart contract-enabled agricultural insurance on a DLT would provide better insurance coverage for a greater number of farmers and supply chain actors. By eliminating the need for human intervention to assess insurance claims, the process becomes simple, transparent and efficient. Smart contracts would remove the risks of fraudulent claims and corruption from insurance providers, as the terms of insurance policies would be unable to be tampered with once agreed upon. Even data collected at weather stations could be registered on a DLT to ensure its integrity. The automation from smart contracts would drastically reduce the cost of insurance policies for both consumers and insurance providers. The reduced costs and risk for insurance providers would allow them to provide insurance to more farmers. For farmers, the disbursement of pay-outs would be virtually instant. The data captured by the DLT throughout the whole supply chain would allow farmers and insurance providers to better assess risk and provide more accurate insurance policies to reflect the farmers' situation.

A few companies are utilising DLTs to roll out agricultural insurance products. A Swiss-based blockchain start-up company called Etherisc is building a platform that uses DLTs to bring crop insurance to developing countries, in particularly in Africa (Krishnakumar 2017). Autonomous insurance network, Aigang, and a drone imaging business called Skyglyph have partnered to develop an autonomous crop insurance product using drone hardware, GIS software, the blockchain and smart contracts (Staras 2017).

Agricultural credit products

The main impediments for financial institutions to provide MSMEs with credit products are the cost of servicing remote areas, the lack of data to assess the creditworthiness of applicants or of collateral (Mattern and Ramirez 2017). The integration of agricultural supply chains into DLTs could provide financial institutions with rich data on the operations of farmers and other value chain actors which is needed to provide numerous financial services, such as direct credit or warehouse receipts. By moving to a DLT system, a small-scale farmer or agro-processor will be able to build a digital identity which records their physical assets, such as

immutable land titling that can be utilised as collateral (see section 3.3 below), and digital assets, such as their economic activity (credit history, quality and quantity of agricultural products, etc.) and other production factors like weather information to determine their creditworthiness. This rich data and overall transparency can enable financial institutions to increase financial services for MSMEs in agricultural supply chains.

Warehouse receipts allow farmers to access post-harvest financing by using their stored crops as collateral. When market prices are low at the end of a crop season and farmers need liquidity, they often store their crops in a warehouse for a fee. This allows farmers to secure financing, which in turn frees them to find the best market opportunity for their harvest (Varangis and Larson 1996). Warehouse receipt systems usually require verifiable data on the quality and quantity of the crops being stored, which are not often available for smallholders in developing countries (Mattern and Ramirez 2017). By using DLTs to implement the warehouse receipt system, farmers would easily be able to provide the necessary data about their crops to prove their creditworthiness to financial institutions in order to secure a loan.

DLTs would eliminate the need for some types of financing, like invoice discounting. Due to logistical challenges, liquidity constraints and heavy friction in transactions, it can take weeks for traders and processors to make payments to farmers for their produce or pay service providers like transporters. This delay can entice farmers to breach contractual agreements and sell their produce to another buyer for an immediate payment, often at a lower price due to the immediate need for liquidity (a practice known as side-selling). Invoice discounting is the practice of using accounts receivable as collateral to receive a loan, in order to ensure suppliers are paid on time and to reduce side-selling. Currently, the main challenge for MSMEs to access invoice discounting loans is the lack of formal records on their operations (Mattern and Ramirez 2017). DLTs could provide the necessary data for MSMEs and financial institutions, but ultimately the technology will eliminate the need for invoice discounting altogether, as it is a type of financing derived from inefficiencies and friction in supply chains. By utilising smart contracts to automate payment processes, DLTs eliminate the need for intermediaries and allow for the disbursement of payment upon the receipt of goods, which will provide real-time payment and increase the working capital of farmers, MSMEs and all supply chain actors.

For supply chain actors that already have the track record of being creditworthy to access agricultural loans, DLTs will provide them mainly with lower transaction fees and simplified loan processing and repayment options. Financial institutions should be able to expand coverage to provide more credit products to a larger quantity of agricultural value chain actors, particularly smallholders and MSMEs.

Agricultural derivatives

Agricultural markets are inherently volatile; farm incomes and prices are vulnerable to exogenous shocks. Some agricultural producers use derivatives (futures contracts or option contracts) as a risk management tool to hedge price risk and fix a future price for the harvest. DLTs have the potential to be applied to agriculture derivative markets in the near future.

Currently, securities trading is another area of financial services that is being transferred onto distributed ledgers. Most of the blockchain innovations for securities focus on the over-the-counter (OTC) markets, because they have less transparency and regulation than exchanges, and also depend on timely manual input and paperwork. Nasdaq, in collaboration with Chain.com, has been a leader in the development of DLTs for securities trading. In 2015, they launched the first DLT-based platform called Linq for private securities trading in the OTC market. Nasdaq Linq has proven to be successful and will help reduce processing time (from three days to less

than 10 minutes), settlement risk exposure, capital costs and administrative burden in OTC trading (Nasdaq 2015). Other blockchain companies are also focusing on OTC markets, like Clearmatics, who are developing a clearing and settlement platform that brings together custodians, dealers, trading venues, buy-side firms and data providers onto a single platform. Clearmatics' platform can settle securities trades and automate the valuation and margining of derivatives and other financial contracts, using DLTs (Swanson 2015). Producers that use agricultural derivatives will likely experience greater efficiency and lower trading costs from DLTs in the future.

3.2.5 Smarter and more accessible data and market information

DLTs allow users to build digital identities with their recorded digital and physical assets. DLTs generate a vast amount of data from the high-quality transactions in agricultural supply chains and agricultural financial services. DLTs store every recorded transaction, which can provide supply chain actors with detailed records of their operations, financial service activities and more accurate and better-quality market information. The improved access to data is enabled by the fact that data entries are digital and immutable, and that in theory every network participant has a copy of the ledger's transaction history. However, confidential data may be encrypted, in which case it could only be decrypted and shared with others by the user or owner of that data. Ultimately, DLTs provide an additional information source for data and statistics in the agricultural sector, as well as a platform to improve market transparency in agricultural supply chains and markets.

The enhanced market information can be used by supply chain actors to inform production and marketing decisions, and agricultural and related policies. They would likely include governments, intergovernmental organisations and possibly even data centres that would analyse the data for businesses, in addition to potentially using the data stored on the DLT for official statistics. Other supply chain actors, such as farmers, will be able to access data on prices, demand in retail markets and current supply levels in specific markets. This allows producers and other supply chain actors to incorporate better analytics into their operations, helping them better understand and react to consumer preferences. Greater access to accurate data could bring huge efficiency gains for all actors, but in particular for agricultural producers and processors in locations where market transparency is currently weak. Ultimately, this should allow supply chain actors to increase sales and reduce food loss and waste through more profitable business practices and efficient supply chains.

DLT platforms have the potential to create monetisation opportunities with the vast amount of transaction data. First, the accumulation of detailed data on every transaction in the DLT will build a reputation and a track record for all supply chain actors. Second, the DLT enables greater trust, accountability and predictability between market players. Agricultural supply chain actors can now do business without intermediaries brokering trust, knowing that each participant has a transparent track record and that the ledger and smart contract will execute payment only once contractual agreements are met. Smallholders, MSMEs and other disadvantaged market players too will now have a track record and a system that allows them to engage in new market opportunities, as the risk for both parties in a transaction will be greatly reduced. In addition, for MSMEs who struggle to access financing, the abundance of data can provide them with the financial evidence regarding their operations to obtain and access financial services. Lastly, since DLTs can communicate up supply chains, there are incentives for farmers to use more costly farming methods to produce higher-quality goods, which can be monetised through traceability and transparency. This could open more opportunities for farmers in the specialised market segment.

Lastly, governance and institutions play an important role in creating a strong enabling environment with policies and programmes that facilitate business development in agricultural supply chains. More accurate and accessible data through DLTs can strengthen the ability of governments and intergovernmental organisations (like FAO) to analyse markets, market players and agricultural and related policies, in order to develop more informed policies. Particularly in areas where data or the accuracy of that data is presently lacking, there will be the ability to create smarter policies from smarter data. These areas could include: production capacity and market participation by geographical location and segments of the population, agricultural input data, price data, trade flows, consumer preferences, agricultural finance, government subsidies, taxes and customs duties.

3.2.6 The future of agricultural supply chains

DLTs have the potential to serve as a foundational technology that integrates other emerging digital technologies into its platform to continuously improve agricultural supply chain management. These other digital technologies, like artificial intelligence, IoT, big data and 3D printing, could all contribute to form a more efficient and informed agricultural supply chain. For example, the IoT uses devices and sensors to collect data on the conditions and characteristics of production, processing, movement and storage of agricultural products throughout the supply chain. The rich data generated from the IoT could enrich transaction details that are registered on the DLT in agricultural supply chains. The large amounts of data could fuel data-driven decision making in agricultural supply chains. Big data management uses analytics to develop digestible information and to inform decision making. Artificial intelligence using machine learning and other analytics tools can facilitate predictive and data-driven decision making. Food companies will be able to use 3D printing to develop specialised packaging for food products with smart tracing sensors to track food products in the DLT. The immutability and security of data in DLTs provides these technologies with a sound platform to generate, use and store reliable and secure data.

3.3 Land Registries

Secure and formal property rights are crucial to the livelihoods and economic development of humans worldwide. However, there are still major challenges to accessing and maintaining secure and formal property rights around the world. It is estimated that 70 percent of people lack access to proper land titling or demarcation worldwide (Heider and Connelly 2016). Land registries are typically operated by the state, and therefore their performance level depends on the level of corruption, organisation and overall functioning of national institutions. In addition, land registry systems are low-tech and largely inefficient. They typically depend on paper documents, handwritten signatures and manual labour to register land titles. Errors and fraud can be common practice, which result in costly disputes.

DLTs are able to address many of the shortcomings in traditional land registries. First, DLTs provide a secure, fast and immutable method to register land titles, which will promote confidence in the reliability of the system. The immutable and traceable transaction history protects farmers and land owners against corruption and fraud and helps resolve future disputes once the land is registered. By restoring confidence in land registries, land owners will engage and gain access to formal land titles which will unlock potentially large amounts of capital. Formal land titles and new capital will allow land owners to use the land as collateral to gain access to credit markets. Second, the digitisation of land registries through DLTs can reduce financial costs and time spent on registering land titles, since it eliminates the paper and manual labour-based system.

Numerous countries have already begun implementing projects to transfer land registries onto DLTs. Bitland is working with the Land Administration Project and national

authorities in Ghana to survey land and record title deeds on its blockchain. Initiatives have tried to solve the land dispute problem in Ghana for more than 17 years (Aitken 2016), and Bitland believes blockchain-based applications are the solution. Similar projects have been implemented by BenBen in Ghana, Bitfury in Georgia, Factom in Honduras, ChromaWay in Sweden to name a few. One of the main challenges for these projects is first to clarify land ownership in order to register the land on the blockchain. The process of clarifying property rights can be subject to corruption and disputes and remains an obstacle for land registries.

3.4 International Agreements Related to Agriculture

3.4.1 WTO agreements on agriculture

DLTs also have a potential to improve the implementation and monitoring of WTO agreements and key provisions relevant for agricultural trade. First, as mentioned above, smart contracts can automatically disperse customs duties upon acceptance of goods at customs, and DLTs can store accurate data on tariff rates. This will bring greater transparency and accountability to country-specific tariff commitments, and improved tariff data. Second, the enhanced traceability and transparency will improve the ability to enforce compliance with the WTO SPS Agreement. The high-quality transaction details in agricultural supply chains and uploaded digital certifications should include the SPS measures adopted throughout the supply chain. This will provide easily verifiable proof on compliance with international standards, supporting scientific evidence for adopted measures and providing specific geographical locations where disease outbreaks or non-compliance is found for SPS monitoring. Third, the high degree of traceability from DLTs will improve the ability to enforce the rules of origin to ensure food safety and that the accurate customs duty is applied to the good in question. Fourth, the traceability and transparency of DLTs also provide a strong platform to monitor intellectual property rights and geographic indications under the WTO Trade-Related Aspects of Intellectual Property Rights (TRIPS) agreement. Overall, DLTs have the potential to bring greater accountability and transparency to compliance with international trade rules on agriculture.

3.4.2 Climate change

The negative impacts of climate change on agricultural production and the challenges to food security are well documented (FAO 2016). DLTs can contribute to climate change mitigation in two ways. First, DLTs are a sound platform for reporting and monitoring country commitments in the Paris Agreement on Climate Change, such as Nationally Determined Commitments, the global stocktake, internationally transferred mitigation outcomes, climate finance and green finance. Second, carbon credits markets could benefit from using DLTs as a marketplace to trade credits. DLTs would reduce friction and bring a more transparent and efficient approach to carbon accounting and offsetting (IBM 2018b). In conclusion, both of these DLT applications can benefit from greater transparency, efficiency and accountability in climate change mitigation.

4. PUBLIC POLICY IMPLICATIONS FOR FOOD SECURITY AND RURAL DEVELOPMENT

Public policies aim to create an effective enabling environment that facilitates inclusive economic growth in the agriculture sector, promotes rural development and ensures food security. In addition, sound public policies are central to achieve the Sustainable Development Goals (SDGs), which are of particular importance for developing countries. The application of DLTs in agricultural supply chains, land registries and financial services can help the public sector achieve their public policy goals for food security and rural development, and be an impetus to meet the SDGs.

4.1 Enhancing Trade Facilitation and Food Security through Efficient Institutions, Traceability and Market Transparency

The WTO Trade Facilitation Agreement highlights the common goal for national policies to cut costs, avoid delays and reduce uncertainty in agricultural trade. Enhanced trade facilitation can play a key role in achieving SDG 2 to end hunger and improve food security. By facilitating domestic and international trade through efficient and transparent agricultural supply chains, DLTs and smart contracts make substantial contributions to improve trade facilitation: they provide a more efficient and effective institutional infrastructure for transactions in agricultural supply chains, enhance traceability and transparency for food safety and quality and improve market transparency.

Institutional infrastructure plays an important role in facilitating the free flow of goods, services, investments and labour in the agricultural sector. The lack of effective institutional infrastructure is a key factor that causes trade barriers and low productivity in many developing countries. DLTs serve as a digital institution of trust that provides a more transparent and efficient system for transactions and record-keeping than traditional private and public institutions. Through the disintermediation of transactions, DLTs replace inefficient verification, contractual and settlement processes provided by institutions to execute transactions. This eliminates the need for some forms of institutions to intermediate transactions in agricultural supply chains, which are costly in general and typically even more so in developing countries. In addition, smart contracts strengthen the institutional infrastructure by reducing the number of parties involved and by removing the need for some types of institutions that currently safeguard the contractual process. Smart contracts and DLTs automate the contractual process in real-time and provide savings for supply chain actors in transaction fees and legal costs.

Ultimately, lower transaction costs enabled by DLTs and smart contracts can support policy goals to increase productivity and efficiency in agricultural supply chains, resulting in lower operational costs and higher incomes for smallholders, MSMEs and other actors, and lower food prices for consumers. The efficiencies that are generated by these technologies can strengthen rural incomes and thus improve food security. In addition, the technologies can enhance accountability and transparency in government transactions, such as subsidy programmes, taxes (VAT, customs tariffs, etc.), environmental programmes, social protection, government-led development programmes and international agreements, among others.

A common public policy goal in the agriculture sector is to ensure the safety and quality of agricultural products both in trade and domestic production. DLTs provide a platform for enhanced traceability and transparency for food safety and compliance with SPS standards. The ability of DLTs to trace a product's provenance, carry detailed attributes in each transaction and ensure its traceability offers huge improvements for food

safety; the ability to respond more quickly to disease outbreaks and contaminated agri-food products; environmental and sustainability certifications; combating food fraud; and potentially reducing friction at the border.

Market transparency and enhanced market information are recognised as key factors to strengthen food security around the world. DLTs provide a platform for this utilising the vast amount of data generated from transactions in agricultural supply chains. Apart from the huge efficiency gains for agricultural supply chain actors, greater access to more accurate market information can strengthen the global food system and reduce the incidence and impact of price surges that are a major threat to food security. The combination of lower transaction and legal fees, automated contractual processes with real-time settlement and enhanced traceability and transparency for food safety and markets can improve trade facilitation.

4.2 Strengthening Rural Development Outcomes for Inclusive Economic Growth

The promotion of inclusive economic growth and increased incomes for micro-, small- and medium-sized agricultural supply chain actors are key for rural development policy agendas. DLTs offer greater economic and financial inclusion for disadvantaged market players, like smallholders and MSMEs. Transparency, digital records and enhanced trust through DLTs and smart contracts enable disadvantaged market players to build a digital identity and track record, which can prove their creditworthiness to access financial services and lead to new market opportunities since the risk of doing business with MSMEs will be considerably less by eliminating uncertainty with smart contracts. These new market opportunities and access to financial services can lead to greater economic growth for smallholders and MSMEs.

Remittances are a form of social protection that positively contributes to economic growth as well as to achieving the SDGs in a number of areas (Ponsot et al. 2017). Remittances generally help poor and vulnerable populations reduce poverty, access better health, nutrition, education opportunities, improved housing and sanitation, entrepreneurship, financial inclusion and reduce inequality, particularly in rural areas. Remittance payments are typically affected by high transfer fees, volatile currency exchange rates and inconvenient physical locations of collection access points for some rural populations. By providing a real-time cross-border payment outlet with low transaction fees, DLTs can enhance access to social safety net payments like remittances and directly contribute to achieving SDG 10.C by providing substantial savings in transaction costs for recipients.[10] DLT-enabled remittance payments provide cost efficiency in the process of establishing a digital identity that is used as part of "Know Your Consumer" verifiability, and by providing a digital fiat for currency conversion (Niforos 2017a). In addition, smart contracts can automatically deliver the funds to the beneficiary's financial institution and notify the appropriate regulator. Ultimately, the efficiency gains from DLTs for remittance payments can contribute greatly to social protection programmes for rural development.

Secure and formal land rights—at the core of rural development policy and covered throughout the SDGs—are a critical component of achieving economic development and food security, particularly in rural areas. The lack of reliable land registries can drive conflict, corruption and poverty. The secure, fast and immutable method to register land titles using DLTs provides greater legal clarity to land tenure systems. The immutable and traceable transaction history protects farmers and landowners against corruption and fraud, helps resolve disputes once the land is registered, unlocks large amounts of capital

10 SDG 10.C states: "By 2030, reduce to less than 3 per cent the transaction costs of migrant remittances and eliminate remittance corridors with costs higher than 5 per cent." See https://sustainabledevelopment.un.org/.

and allows farmers and other businesses in rural areas to utilise this precious asset to its fullest.

Lastly, DLTs can also provide positive outcomes for women's inclusion in agricultural supply chains, in access to financial services and land ownership. Similar to other disadvantaged market players like MSMEs, women, both individually and as business owners, lack sufficient access to financial services for credit, savings and insurance, which ultimately limits growth. DLTs can help women overcome their comparatively low access to formal identification for financial inclusion (World Bank 2018a) with a cost-efficient digital identity, and provide entry points to formal roles and remuneration in agricultural supply chains (Niforos 2017b). In addition, DLTs can provide women with secure land titles and protect their ownership in the case of disputed land.

5. THE WAY FORWARD FOR DISTRIBUTED LEDGER TECHNOLOGIES

5.1 Challenges and Risks for Distributed Ledger Technologies

As DLTs continue to evolve, there are a number of technical, regulatory, institutional, infrastructure and capacity development related challenges to be addressed before reaching maturity in order to ensure the scalability and accessibility of the technology. DLTs are not a panacea for the agri-food sector, but the technology provides great potential if the challenges to its widespread adoption can be overcome.

5.1.1 Technical challenges

On the technical side, the evolution of DLTs has led to the development of both public and private DLTs, which both use different consensus algorithms to validate data entries. Current development efforts are implementing a wide range of different consensus mechanisms and types of DLTs. As discussed in section 2 above, each algorithm has advantages and disadvantages, which should be understood and the most suitable one adopted according to the specific application. For example, for public DLTs using the proof-of-work consensus algorithm, its high energy consumption, poor cost efficiency and transaction speed pose challenges to its scalability. While for permissioned DLTs, lottery- or voting-based consensus algorithms have better scalability and transaction finality, but there is a trade-off in terms of anonymity and identity. Ultimately, understanding the technicalities of each DLT will determine the technology's success and impact on the ground. This highlights the importance of open-source platforms and of transparency in technology communities to share code and technical approaches to DLT development. In addition, current ventures are using both public and private ledgers, which will require interoperability between ledger types. Data portability between different ledgers requires clear standards on data protection to determine how data should be stored and shared between public and private DLTs.

In addition, data accessibility for DLTs is a key challenge that requires special attention as the technology continues to be developed. Access to data in DLTs can be private or shared, depending on the rules of the DLT that are based on, the purpose of the platform, as well as the preferences of the users. There are many different types of permissioned DLTs, which have varying approaches to data accessibility. These approaches are evolving and the best methods for data protection and transparency in DLTs are still being developed and tested. Certainly, transactions include some types of confidential information, such as personal data, that are not suitable for public knowledge. However, for example, in a transaction between a farmer and a trader, should the price paid for a tonne of wheat be hidden and protected or disclosed and shared? The decentralisation of transactions in DLTs gives users ownership and control over their data and the choice of whom to share it with, but the DLTs for agricultural supply chains should be developed with core principles built in to ensure market transparency and inclusivity. As transparency is a key feature of DLTs for agricultural markets and supply chains, there should be careful consideration of the types of data that should be protected and disclosed, and lastly of how DLTs can be developed to incentivise data sharing by supply chain actors. Since DLTs offer huge potential for enhanced market transparency, it is important that key data is actually accessible.

5.1.2 Institutional challenges

On an institutional and regulatory level, another huge challenge is merging the current complex legal frameworks—that govern rights of ownership and possession along supply chains and across borders—with DLTs and smart contracts. First, the technology industry, in collaboration with the agri-food industry, must develop best practices and standards for distributed ledger and contract structures across international borders and

jurisdictions (Casey and Wong 2017). In addition, both private and public sectors need to be prepared to ease the transition from existing legacy systems to distributed ledger systems. This will require industry plans and procedures to facilitate the coexistence of different systems during the transition period and beyond. A set of common standards that facilitate interoperability across DLTs and legacy systems will be important to help the technology reach scale. The appropriate governance structures at the international, regional and national levels will need to be developed to establish the necessary regulatory frameworks and standards for DLTs, as well as perhaps even to participate in DLTs for global supply chains and international trade. A number of international bodies could adopt such a governance role in agricultural supply chains, international trade and rural development, such as the World Summit on the Information Society,[11] the World Trade Organization and the World Economic Forum.

The success of DLTs will largely depend on its acceptance and promotion by the public sector. As a technology that promotes transparency, immutability, traceability and efficiency, actions (such as transactions and records) made by governments and institutions will be evident to the DLT network participants and potentially the public. DLTs will bring an increased level of accountability for governments that should not be resisted, as it could delay and potentially even minimise adoption of this overall beneficial technology.

5.1.3 Infrastructure and capacity development challenges

DLTs can only be applied as long as an internet connection is available, which can still be a challenge in some developing countries. Recent data from 2016 shows that roughly four billion people did not have access to the internet, most of whom are in developing countries (ITU 2016). This indicates that in order for DLTs to be accessible to people in developing countries, internet services need to become more accessible, particularly in Africa, parts of Asia and Pacific and Arab States which have the lowest percentage of internet users (ITU 2016).

The use of public and private keys for data encryption in DLTs may present a challenge for DLT adoption in some developing countries. The lack the public-key infrastructure in some developing countries poses an obstacle to the use of DLTs (Zambrano 2017). Public-key infrastructure is a set of rules, policies and procedures for the secure electronic transfer of information, which is the system that is currently used to manage asymmetric encryption and ensure ownership of key pairs. Either alternative solutions need to be developed and adopted, or the public-key infrastructure needs to be developed in those developing countries where it is lacking.

The complexity of DLTs represents a potential challenge for widespread understanding of the technology, which could hinder adoption in the short term. The process of integrating all actors in agricultural supply chains onto DLTs will be challenging and will take time. It is unrealistic to expect that all participants will adopt the technology initially, as there will likely be hesitation and resistance from some actors. In addition, some will lack the skills and knowledge required. For market players, utilising the technology should involve using an application on a mobile device. However, accessing data and developing applications require digital skills, which companies will need. The lack of such digital skills will be an obstacle for adoption, especially for MSMEs. Ultimately, this could lead to greater marginalisation for MSMEs at least initially, or until they increase their capacity in this area. Strong awareness-raising and capacity development programmes by governments,

11 The World Summit for the Information Society (WSIS) is a multi-stakeholder platform facilitating the implementation of the WSIS Action Lines for advancing ICTs for sustainable development (WSIS 2018).

intergovernmental organisations and development partners will be needed for all stakeholders.

Even if the technology is only partially adopted in agricultural supply chains, it will still provide substantial benefits. For example, a farmer and a supermarket may be connected on a DLT; however, the trucking company is not. During production, the farmer inputs details about the food (type, practices, harvest date, etc.) and the trucking company picks up the freshly harvested produce. The arrival of the food at the supermarket is the next point visible on the DLT. The supermarket registers the delivery on the DLT, and the smart contract sends an assertion to the farmer that the delivery is completed. Despite the missing transport data, the supply chain still benefits from the system. In the same example, even if the farmer was not using the DLT and the trucking company was, the food could still be traced back to the farm from the transportation data assertions. However, the points of origin in agricultural supply chains are the most important to have on the blockchain, in order to have detailed production data.

5.2 The Way Forward for the Public Sector

Despite DLTs' rise in popularity over the past decade, overall there still remains a knowledge gap on the technicalities of the technology, its potential applications, challenges and way forward for many governments, intergovernmental organisations and supply chain actors. In order to leverage DLTs to develop inclusive agricultural supply chains and achieve public policy goals for rural development and food security, governments and intergovernmental organisations need to build their capacity to support the development and implementation of the technology in a number of areas. First, the public sector needs to continue to improve its understanding of how DLTs can improve transparency, efficiency and traceability in agricultural supply chains, and help achieve their policy objectives. Building this knowledge base will help enable governments' commitment to develop, utilise and promote the technology.

Second, the public sector needs to contribute to the development and implementation of DLTs to ensure their inclusivity and accessibility for smallholders and MSMEs in agricultural supply chains. This means the public sector (both governments and intergovernmental organisations) should contribute to technical dialogue on research and development with the private sector (technology firms and agribusinesses), for example, on the data accessibility issue among others. In addition, governments—together with intergovernmental organisations focused on agriculture—should partner to establish an intergovernmental working group on DLTs in agriculture to take the lead in providing policy guidance on their use in agricultural supply chains and rural development. Other potential multi-stakeholder platforms whose scope might be expanded to address the topic could include the e-agriculture Action Line in the Geneva Plan of Action of the World Summit for the Information Society (which could also focus on the application of DLTs in agriculture), as well as the World Economic Forum's System Initiative on Shaping the Future of Food.

Governments will need to develop regulations and standards for DLTs in general and for supply chains in particular, in order to transition from legacy systems to DLTs. In order to enhance public and private sector partnership in DLT development, one strategy that could be effective would be to promote private-sector DLT development by establishing a global "regulatory sandbox"[12] for promising use cases in agricultural supply chains and

12 According to the UK's Financial Conduct Authority, a regulatory sandbox is a safe place where innovators can test their products and business models without following all legal requirements while under close government supervision for a predefined period of time (FCA 2015). For a full explanation on why a regulatory sandbox is needed in the context of DLT development see Maupin (2017b).

rural development (Maupin 2017b). This would provide a platform to test and refine different technical deployments of DLTs in an environment where innovators can cooperate with national and international regulators to address different cross-border regulatory concerns and other regulatory issues (Maupin 2017a). In the future, intergovernmental organisations focused on agriculture should consider leveraging existing knowledge products and developing guidelines for inclusive DLTs in agricultural supply chains. Lastly, government, intergovernmental organisations and development partners will play a vital role in providing outreach to improve infrastructure and digital skills in rural areas. This should include pilot projects in agricultural supply chains.

6. CONCLUSIONS

Distributed ledger technologies provide a unique opportunity for the agricultural sector. The technological platform introduces a new digital institution of trust to lower uncertainty between buyers and sellers and brings greater efficiency, transparency and traceability to the exchange of value and information, which is fundamental to the agricultural sector and the entire global economy. By removing friction and intermediaries though a simplified, peer-to-peer transaction network and using smart contracts, efficiency gains can be made in agricultural supply chains, agricultural finance and the agriculture sector as a whole. Through enhanced transparency and higher-quality transaction details, DLTs deliver improvements to food safety and quality (such as product sustainability) and consumer awareness. The vast amount of data from transactions also can strengthen market information and market transparency, which could benefit low- and middle-income countries greatly. Through the digital and physical assets registered on DLTs, agricultural supply chain actors have the ability to build a reputation and track record in the marketplace needed to increase access to financial services and new market opportunities, which is particularly beneficial for disadvantaged market players, like smallholders, MSMEs and women. Ultimately, DLTs can help governments achieve their public policy goals for inclusive economic growth in the agriculture sector, rural development and food security, as well as be a catalyst for sustainable development and for fulfilling the SDGs.

DLTs also pose a number of challenges to make the technology accessible and usable in high-, middle- and low-income countries. Currently technology companies, food and beverage industry leaders and even some governments are developing and testing concepts and applications to determine its possibilities and limitations in the food and agriculture sector. In order to realise the full potential of DLTs for food and agriculture, the technical, institutional, infrastructure and capacity development challenges need to be addressed to ensure the technology achieves the benefits it could deliver. It is necessary to keep improving digital infrastructure and skills, particularly in developing countries and in rural areas. As DLTs continue to develop and evolve, the international community should ensure their development and implementation is done in an inclusive manner that is beneficial for the agri-food industry as a whole. The technology has huge potential to address the challenges that MSMEs face through enabling their participation in integrated value chains.

At the current rate of development, multinational agri-food companies will most certainly be the first to implement the technology in the agri-food industry. In order to ensure all market players benefit from the productivity gains generated by DLTs, it is important that intergovernmental organisations focused on agriculture take the lead in raising awareness, developing the capacity of agricultural stakeholders to adopt DLTs and promoting international cooperation between the public and private sectors to develop and implement inclusive DLTs in the agriculture sector. Cooperation through public and private sector partnerships will likely be the fastest and most efficient way to develop DLTs, create the appropriate regulatory environment and transition from current legacy systems. Agriculture-focused organisations should continue to improve their knowledge base and conceptualise the types of technical assistance needed to prepare and support agricultural actors and governments in playing an active role in blockchain-enabled agricultural value chains. As industry leaders continue to innovate and develop DLT solutions, further research is needed to analyse these applications and their potential implications for the agriculture sector in greater depth. Intergovernmental organisations focused on agriculture should also explore possible applications of DLTs to improve the effectiveness of their operations.

History has shown that technological advancements that generate productivity gains prevail, regardless of public opinion. DLTs will continue to be adopted throughout the global economy, shaping the future of agriculture, as long as the productivity gains are real. Therefore, it is imperative for the international community to ensure developing countries and disadvantaged market players also benefit from these gains generated by DLTs. It is necessary for the agri-food industry to understand and prepare for these opportunities and forthcoming changes.

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