How Blockchain Technology Can Impact Agriculture

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Abstract:

Blockchain is a special type of distributed ledger technology (DLT) that enables verifying and recording peer-to-peer transactions in a distributed, append-only and immutable fashion. In this chapter, we describe applications of blockchain technology which focus on the current challenges or issues in some key sectors of agriculture as well as how blockchain technology could be beneficial in addressing those challenges. Finally, we discuss some limitations of blockchain technology.

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1. Introduction

From digitization of futures markets and cash trading to the development of precision-agriculture, the blockchain revolution in agriculture stands at the continuum of digitalization and technological transformation within the industry. This chapter's purpose is to highlight the uses of blockchain technology in various sectors of agriculture, including supply chains for food and agricultural commodity trading, agricultural finance and food safety. Specifically, we identify existing or potential problems in each sector and shine a light on how blockchain technology can benefit the respective sectors. Additionally, we discuss the evolution of blockchains, the blockchain as a general-purpose technology and some limitations of a blockchain.

We discuss several pilot projects in blockchain technology; these employ blockchain technology in diverse sectors, including energy, grain and oilseed marketing, agricultural commodities, food safety and supply chain management. Recently, the five largest global agribusinesses Archer Daniels Midland (ADM) Co.; Bunge Ltd.; Cargill, Inc.; Louis Dreyfus Co. (ABCD) and COFCO International Ltd., created a consortium to develop a blockchain alliance that can be adapted and used for international trading in the grain and oilseed sector (Reuters, 2018). We also discuss several examples of efforts to employ blockchains in the other sectors.

2.1 Blockchain Taxonomy

Blockchain technology is a distributed ledger that verifies transactions in a sequence of blocks which are tied to each other cryptographically in an immutable, secure and append-only scheme (Burniske and Tatar, 2017). As opposed to a central authority, a blockchain's distributed database enables each full participant of the network to possess a copy of the transaction details. Essentially, the blockchain ensures the existence of a shared truth among all the participants.

Blockchain technology is comprised of five key features: a distributed database, a peer-to-peer transaction mechanism, transparency, irreversibility of records and computing logic, that is, in the form of scripting language (Catalani, 2017). A distributed database facilitates each full participating node or the network user to directly access the transaction details along with the history without an intermediary. Essentially, a distributed database allows the same copy of the information or data to be available for all network participants, avoiding the control resting on any single entity. A peer-to-peer transaction mechanism is another feature associated with blockchains; the transaction takes place directly between peers rather than with an intermediary who is often costly.

In a blockchain, identity is pseudonymous, meaning that the transaction between peers happens through a 30-plus-character alphanumeric address called 'public key' that is unique to each user or a node. Anyone who has access to a blockchain network can view the transaction details which identify the users with their public key hence called pseudonymous.

Immutability is an important feature of the blockchain where each block of information, once verified and updated in all of the user accounts, is hard to tamper with because each block is connected to the prior block using Merkle tree hash functions.[1] It is almost impossible to tamper with the information which is already recorded in the blocks because it may need to change all the sequential blocks with the newly added information and that, too, in all of the user accounts. The immutability feature of blockchain maybe compromised when there is a 51% attack in which someone can take control of the network with majority of the nodes (Vyas et al. 2020).

Computational logic allows blockchain users to set prior conditions that execute transactions automatically once the set conditions are met. For example, smart contracts can be designed on a blockchain to execute a transaction using cryptocurrency between trustless parties if certain predefined conditions are met.[2] This setup will allow a peer-to-peer transaction between parties without a costly intermediary.

A distributed ledger and blockchain technology are sometimes thought to be interchangeable. However, there are few subtle differences. Walport (2016) indicated that a distributed ledger [technology] (DLT) 'is essentially an asset database that can be shared across a network of multiple sites, geographies or institutions' (p. #5). In other words, DLT is a much broader term which is used to designate any structure or a system that distributes data across multiple locations as opposed to a single (central) location. There are two key differences between blockchain technology and a DLT. First, a blockchain contains a

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[1] A Merkle tree, or a hash tree, represents the mathematical structure of branching nodes used to verify the integrity of large data which are stored, handled, and transferred in and between nodes (Werbach, 2018).
[2] A smart contract is a computer protocol that has predefined conditions programmed into it in order to digitally facilitate a contract in terms of its verification, negotiation or performance.

sequence of blocks which are linked to each other while a DLT may not contain such a chain. Second, a blockchain undergoes a verification process using a consensus protocol, such as the proof of work which involves solving a mathematical puzzle, while a DLT may not involve such a consensus protocol (Belin, 2017). RadixDLT and IOTA are examples of DLTs while Bitcoin and Ethereum are examples of DLTs that include blockchain. In summary, a DLT is an umbrella term where all blockchains are DLTs, but all DLTs may not be blockchains.

2.1.1 Different Types of Blockchains

Depending on the access to read and write, blockchains are categorized into public versus private and permissionless versus permissioned, respectively. Public and private blockchain refer access to read the blockchain's information. The public blockchain can be openly accessed by anyone while the private blockchain can only be accessed by a few specific and selected participants who are pre-approved by the blockchain's network manager who is typically under an organization's control (Parrondo, 2018).

A permissionless versus permissioned blockchain is related to having access to write on the blockchain which is often referred to in the context of verifying the so-called miners' transactions. Mining is a process that involves verifying as well as adding a set of transactions into the blockchain digital ledger via solving a mathematical puzzle. In a permissionless blockchain, anyone can participate in the mining process to verify the transactions and then add them to the ledger. The permissioned blockchain only allows pre-approved participants to be involved within the transaction's verification. Therefore, a key differentiating feature between public permissionless and private permissioned blockchains is the pseudonymity. More recently, a third type of blockchain called the consortium blockchain, has emerged where a sizable group of participants or organizations are involved with the verification of transactions associated with that blockchain (Parrondo, 2018). The main difference between a permissioned blockchain and consortium blockchain is the verification process resting on the users belonging to a single organization in a permissioned blockchain versus the users belonging to a group of organizations in a consortium blockchain. In a way consortium blockchain is the middle ground between the permissionless and permissioned blockchains.

2.2 Evolution of Blockchain Technology

Blockchain technology was first described in Nakamoto's (2008) seminal white paper, 'Bitcoin: A Peer-to-Peer Electronic Cash System' in the public domain, followed by the release of the Bitcoin software in January 2009. A blockchain is the technology underlying the first cryptocurrency, bitcoin.[3] Although bitcoin become popular thereafter, most people only realized the potential applications of blockchain technology in other sectors after several years. Over time, the blockchain has gone through several phases of innovation. In this subsection, we discuss some of the major innovations for the blockchain technology's tenure thus far.

Figure 1 shows the timeline for major innovations in blockchain technology (ConsenSys, 2019). The Bitcoin software was released on 3 January 2009. Until 2013 blockchain applications were only found in financial services and focused on

[3] Often terms such as cryptocurrency, virtual currency, and digital currency are used interchangeably by some and others disagree with regards to what each term represents. For the purpose of our study, we use cryptocurrency as monetary unit in blockchain technology. Some argue that digital currency is often used to determine the government issued "fiat" currency in digital form. Also, the word "Bitcoin" (capitalized) is used when referred to blockchain network while the word "bitcoin" (non-capitalized) is used when referred to single unit of cryptocurrency.

cryptocurrencies. Buterin's (2013) 'Ethereum White Paper' was the first major innovation. Ethereum emerged as a platform to develop decentralized applications and to design smart contracts that execute and complete the transactions between two peers if and when the pre-defined conditions are met. However, blockchain consensus protocols of Bitcoin and Ethereum hinder scalability when compared with Visa, for example, for executing a number of transactions per second. Some exceptions exist. For example, the scalability problem may not be an issue in the case of Ripple.

In 2015, three major events took place in blockchain's evolution. First, the NASDAQ initiated a blockchain trial (Bajpai, 2017). Second, the R3 consortium blockchain started with nine financial companies, Barclays, BBVA, Commonwealth Bank of Australia, Credit Suisse, Goldman Sachs, J.P. Morgan, Royal Bank of Scotland, State Street and UBS, and later expanded to include other financial companies. Finally, the segregated witness (SegWit) was released. SegWit removes the signature data from the bitcoin transactions in order to facilitate more space so that the block size can be increased to accommodate more transactions (Nicolai, 2019). In 2016, the permissioned ledgers, such as the Hyperledger Fabric, boomed in addition to the release of the Homestead version of the Ethereum platform; there was a shift in the consensus protocol mechanism from the proof of work to the proof of stake in an attempt to address the scalability problem.

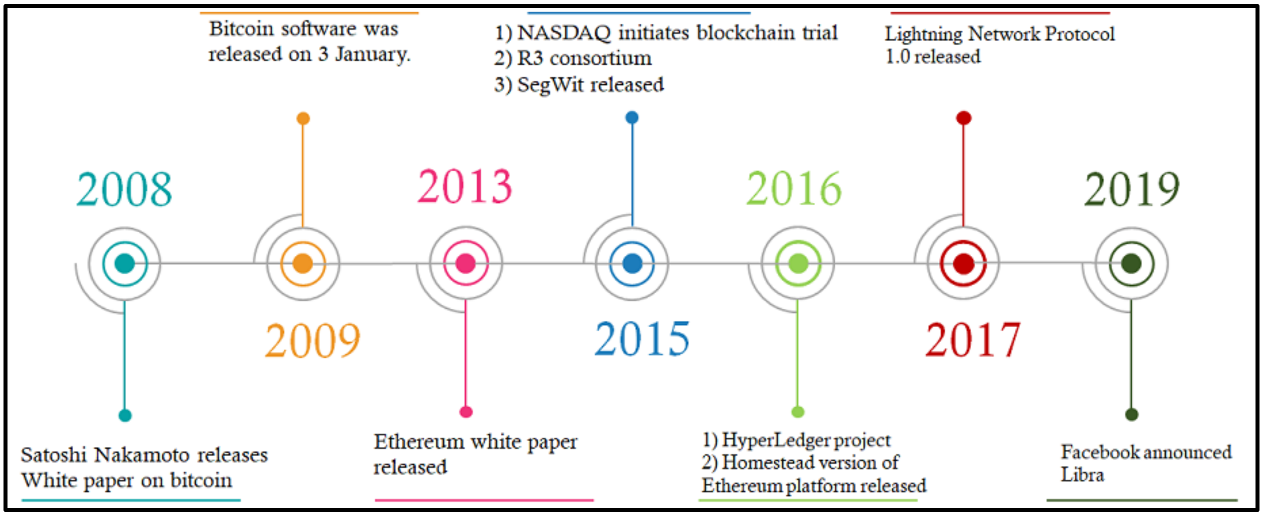

Figure 1. Timeline of important blockchain innovations

In the context of blockchains, scalability is the ability to process and add transactions to the distributed ledger in a specified time period. Addressing the blockchains' scalability issue was one of the priorities for the next time period. In 2017, some scalability solutions were proposed with the release of the Lighting Network protocol and other Layer2 solutions.[4] Layer2 solutions increase transaction throughput by performing few operations off the chain. Finally, in 2019, Facebook, Inc. announced the release of its own cryptocurrency, Diem (formerly, Libra). The Diem blockchain (formerly, Libra blockchain) is a permissionless consortium blockchain which was started with a group of 21 members based in Geneva, Switzerland. In its white paper, the Diem association (formerly, Libra association) claims that its mission 'is to enable a simple global payment system and financial infrastructure that empowers billions of people' (p.1, Diem, 2020; Paul and Irrera, 2019). Due to regulatory pushback, Diem has updated its white paper stating that it offers

[4] These solutions are discussed in detail in the limitations section

both with a single-currency stablecoins and multi-currency coin (Diem, 2020). Additionally, the white paper stated that it no longer intends to transition into the permissioned system.

2.3. Is the Blockchain a General-Purpose Technology?

Using the above-mentioned features, we analyze whether the blockchain technology is a qualified candidate to be considered as a general-purpose technology (GPT). As an overview, Catalini and Gans (2016) state that the decentralization aspect of the blockchain technology makes it a good candidate for GPT because the technology is applicable to almost every aspect of the economy.

Disagreement and confusion exist regarding the definition of GPT. This confusion stems from whether one should consider single-use or multiple-use technologies when defining the GPT (Bekar et al. 2018). Some examples of GPTs include steam engines, electric motors, semiconductors and computers (Bresnahan and Trajtenberg, 1992). Bresnahan and Trajtenberg (1992) define GPTs having three fundamental features: 1) GPTs are pervasive and are adopted by most sectors; 2) GPTs inherently develop and improve over time; and 3) GPTs catalyze innovation in complementary technologies, resulting for the invention and production of new products or processes.

In terms of pervasiveness, the blockchain technology is only an 11-year old technology, and during this period, the blockchain has already spread to several other fields, including health, agriculture and international commodity trade, among others beyond the financial sector. Catalini (2017) indicated that the blockchain technology can be used in any industry where there is some form of digital asset which can be tracked and traded between peers.

In the past decade, the blockchain technology has improved and continually evolved with new innovation and experimentation. One of those innovations include Turing completeness, which is defined as the execution of any task including simple arithmetic functions, if-else conditions or an application (that runs on a conventional computer) on a distributed ledger using its consensus protocol (Werbach, 2018).[5] For example, Ethereum is a Turing Complete blockchain that performs or executes tasks with a smart contract code given accurate instructions and sufficient processing power. Regarding experimentation, several pilot projects have been conducted in a variety of fields and are being evaluated in terms of a benefit-cost analysis; new challenges that may arise are also be analyzed. It is also important that the blockchain technology's growth depends on the respective field's inclination to change and to evolve into the new system.

Finally, when evaluated as a complementary technology, the blockchain is a stimulating innovation for other recent technologies, including the internet of things (IoT) and artificial intelligence (AI). The innovation could be related to how efficiently participants or users of different technologies can create, share and store data as well as to obtain insights, thereby creating value for the users or the system as a whole. Overall, we consider blockchain technology to be a GPT.

3. Limitations of the Blockchain Technology

Although the blockchain technology has many benefits with respect to improving the efficiency of different aspects of the business or a particular area especially when there is

[5] Turing complete is more general concept that has been in existence prior to blockchain. Some of the examples of turning complete languages include most modern programming languages such as Java, JavaScript, and Perl etc.

information to share in a trustful, secure manner, it does not come without limitations. The blockchain limitations depend on the blockchain protocol or the consensus mechanism. We discuss limitations in the context of public, permissionless blockchains although many of the agribusiness applications of blockchain technology fall under the private, permissioned blockchains. The main limitations include the scalability issues with respect to the number of transactions per second, the amount of energy needed to verify the transaction during the mining process, the issue of 51 percent attack, ability of fork and pseudonymity (Vyas et al. 2019). Businesses and the areas discussed in this chapter mostly employ private, permissionless or consortium blockchains which may not face the limitations discussed in the next section.

3.1. Scalability Problem

One major limitation of public blockchains is the scalability. For example, a Bitcoin blockchain can perform approximately seven transactions per second while the Ethereum blockchain performs 15 transactions per second. Comparatively, the speed of VisaNet is about 47,000 transactions per second (Vyas et al., 2019). Scalability is a bigger problem for public, permissionless blockchains when compared with the private, permissioned blockchains because of two main reasons. First, a shortage of the availability of the computational power of the network and second, the network itself, that is, the slow process of creating a block with about 2,000 transactions will inhibit scalability (Vyas et al. 2019).

In general, there are two critical steps to complete a transaction in the blockchain: 1) ‘block time’ and 2) adding a block to the ledger. Block time is the time needed to validate a block (Vyas et al., 2019). In a Bitcoin blockchain, the block time is approximately 10 minutes; each block consists of about 2,000 transactions with a size of 1 MB (Vyas et al., 2019). The second step of adding the block to the distributed ledger can take a few minutes to a few days; this process involves a transaction fee or a miner's fee in case of a public, permissionless blockchain such as a Bitcoin blockchain.

In order to address the scalability problem, some innovative solutions have been proposed. These solutions include SegWit, Layer2 solutions, the Lightning Network, and Metahash. The focus of these solutions is to increase the speed for verifying and adding the block of transactions to the distributed ledger.

With all the unique features of public, permissionless blockchains, including openness and decentralization, it is hard to achieve a high transaction throughput. One line of thinking to address this scalability problem is to go in the direction of changing the consensus protocol mechanism. The second line of thinking is the 'Layer2 solutions' (Narula, 2018). The Lighting Network is a promising work for the Layer2 solutions. The Layer2 solution uses a blockchain as an anchor of trust but conducts most transactions off the chain (Narula, 2018). The immediate question that arises is about the points of the blockchain if one has transactions off the chain. Interestingly, the Lightning Network and Layer2 solutions offer the same security properties as a blockchain (Narula, 2018).

3.2. Other Limitations

Other limitations include the 1) use of an excess-energy consumer during verification for 'mining', 2) the 51 percent attack, 3) confusion due to the blockchain's forking ability, and 4) pseudonymity in public blockchains. During the block-time procedure, miners have to be involved with a computationally intense activity which requires a lot of energy. Depending on the verification activity, on average, Digiconomist estimates that verifying the transaction in a Bitcoin blockchain requires about 200 kWh of energy (Vyas et al., 2019).

Public and permissionless blockchains operate under the principle of democratic governance. The 51% attack occurs when a group of miners get ahold of at least 51 percent of the network's computational power (Vyas et al. 2019). This attack has severe consequences in terms of taking control of the network and approving the double-spend transactions by modifying the blocks. The chance for a 51 percent attack increases with decreased mining-network power (Fairfield, 2014).

Forking is the ability to create a new chain of blocks that may or may not be compatible with the original blockchain. Forking is a well-known practice. There are two views to the blockchain's forking feature. One positive view is that, if there is a disagreement between blockchain developers with regard to the blockchain's direction in terms of different rules or protocols, the majority view cannot overrule the minority opinion. This situation could result in two different blockchains because of forking from the original blockchain. A negative view is that forking may create confusion and weaken trust. There are two fork types: a soft fork and a hard fork (Vyas et al., 2019). Both forks are a result of forking, but a soft fork is compatible with the original blockchain while the hard fork may not be compatible with the original blockchain.

Pseudonymity is the result of having a public key or address in the form of a hash rather than the actual names of the transacting parties. As a result of this pseudonymity feature, some people argue that it is used for illegal and criminal activities, such as money laundering. In a private blockchain, this issue should not be a problem because the participants are known prior to joining the blockchain network.

The disadvantages of private blockchains are that they, as a unit, act as a central authority, restricting any information details to only be visible within the company. Private blockchains may increase efficiency within the organization, but without integration with other organizations or when there is no interest to share information with others, a private blockchain may not be beneficial. Consortium blockchains are midway between the private blockchains and public blockchains.

4. Applications of the Blockchain Technology in Agriculture

In this section, we discuss the applications of blockchain technology in agriculture specifically focusing on various sub areas, including agricultural commodity trading, food safety, supply chain management, and agricultural finance. We described specific examples of either proposed or piloted blockchain solutions for specific issues in each of the subareas.

4.1. Commodity Trading in Agriculture

Commodity trading in agriculture has evolved over time, going from in-person transactions via cash and regional open markets to organized exchanges and then to the current digital mechanisms, including the blockchain. There has also been an increase in contract specificity because buyers have become more demanding in terms of quality specifications and end-use requirements. Additionally, commodity trading firms possess an advantage by having access to information, ownership, and control of assets and trading capabilities.

Although electronic trading via exchanges has proven to have a lower cost with fewer transaction errors there is still room to improve efficiency in cash transactions. including reduction of complexity for processes with multiple parties involved, of time taken for documentation, and of otherwise avoidable human error. In this section, we provide examples of blockchain projects (and their testimonials) which are at various development stages. Overall, the blockchain, with its unique characteristics, can help improve efficiency for agricultural commodity trading by digitization, automation and quick payments via smart contracts, real-time accessibility of transaction information without central authority and security.

In agriculture, blockchain applications have been preceded by a multitude of digital supply chain management software (Eka, and now Cargill-Eka, among others) as well as the migration of trading to digital platforms, although neither of these is prerequisite for development of blockchain applications (Belt and Boudier 2016, 2017a, 2017b). As blockchain evolves, the number of transaction mechanisms have been developed; they may be referred to as 'surrogate' blockchains. One example was Cargill's digital coordination of the cocoa supply chains in Africa, a process which provided traceability and a digital interface between the farmer and the buyer. Another example was the National Grain and Feed Association (NGFA) system to trade barge freight for grain and rail (Gordon, 2020), referred to as the Barge Digital Transformation Project and a partnership with essDocs (providing paperless trade). They suggest that digitization provides a substantial cost savings for the industry.

A number of papers provided the motivation to develop a blockchain for commodities and energy. Melavi et al. (2019) state that blockchain 'promises to fundamentally transform the commodities sector—a sector that is still analogue and relies on processes that were not evolved from what Venetian or Dutch traders followed during the Renaissance' (p.8). They suggested that a blockchain could provide transparent records, track goods and reduce fraud (Melavi et al. 2019). IBM played an important role in blockchain development. In a white paper describing the supply chain's revolution, they stated 'More than 85% of Chief Supply Chain Officers say it is already exceedingly difficult to predict and proactively manage these disruptions and risks' (p. 3, Frost and Sullivan, 2019); the authors go on to indicate that ocean freight, which is dominant in commodity industries, has never been digitized and is highly dependent on paperwork. Ultimately, Frost and Sullivan (2019) conclude that blockchains can do all of these functions more efficiently and faster than manual methods. Finally, Amic (2020) observed that in light of the numerous new entrants and the large trade volume, fraud has been more common. He suggested that a way to mitigate this problem is through a digital platform that 'tracks the entire logistics lifecycle of a transaction which validates invoices against the physical products.'

Energy is one of the major commodities that has benefitted from the digitization of trading: firstly, in futures, then in cash markets and now quickly adopting blockchain technology (Payne 2018; Sekar, 2019; Terazono 2018a, 2018b). The Mercuria Energy Group described how it had experimented with an oil shipment from Africa to China (Terazono, 2018b). Using conventional procedures, the document transfer took 40 days while it took 4 days using a blockchain. This efficiency resulted in substantial cost savings and provided motivation for a more accelerated approach to develop and to adopt blockchain for energy.

Within agriculture, supply chains for food commodities adopted blockchain more quickly than agricultural commodities (Kamath, 2018). The digitization of trading as well as employing blockchain technology was slower for grain, and other related sectors. International commodity trading for soybeans utilized a blockchain as early as 2018

(Reuters, 2018). One of the most appropriate sectors for a blockchain was cross-border commodity trading. A blockchain allowed real-time monitoring by multiple geographically separated parties, expedited, and simplified document exchange in a digital, secure, and decentralized manner (Lakkakula et al. 2020).

A major development for grain commodities is Covantis, which is a blockchain system which was developed by a joint venture for ADM, Cargill, Bunge and Dreyfus (Ledger Insights, 2019; Plume, 2018); others, including COFCO (COFCO International, 2018) and Glencore Agriculture, joined the project.[6] While this system had been under development for some time, it was accelerated with the COVID-19 pandemic, a common theme suggested by Blackburn et al. (2020). The goal for Covantis was to replace the legacy post-trade processes with a blockchain, artificial intelligence (AI) and other solutions. A major focus for Covantis was to digitalize documents and trade executions.

Technically, Covantis is a legal entity in Geneva, Switzerland. The initiative's goal is to modernize global grain and oilseed trade operations. The partners are working with ConsenSys, an Ethereum blockchain technology company, to develop a transformative platform. The blockchain network leverages ConsenSys's enterprise-ready blockchain products and services, including ConsenSys Codefi, PegaSys, Orchestrate, Kaleido, and MythX. A secured platform based on Quorum, a permissioned Ethereum-based blockchain will be developed to allow both small and large players across the supply chain. In summary, Ethereum (2017) indicated 'This platform is evidence that blockchain technology

[6] A video describing their blockchain network (Covantis) is available at https://player.vimeo.com/video/341746033?playsinline=0 (accessed 25 June 2021)

has started to deliver on its promise of unlocking value through collaboration and removal of information silos within and across industries.'

Covantis provides an illustration for a recent soybean trade to Singapore using a blockchain. 'The trade took a total of just five days to settle, whereas traditional trading processes can take up to a month. The platform created a shared, unchangeable record of the transaction—a single source of information for all parties.' (Saddler, 2020). The blockchain platform affords a repeatable framework for end-to-end digital trade executions by digitalizing the documents and trade-execution process. Rabobank was involved with this transaction and stated that 'It's our mission to digitize trade finance operations. Consensus-driven smart contracts in this deal minimized our time spent on processing documents by more than half' (Saddler, 2020). For this transaction, the buyer was Agrocorp International, a Singapore-based trading firm, which said:

> 'We have been engaging in digital trade execution using blockchain for over 18 months now and have been able to increase efficiency internally and externally considering the logistical challenges to move physical documents around the globe, this is just a start and we hope to execute more trades via the platform in the near future.' (Saddler, 2020)

Taken together, there is an increase in efficiency with this organization/firm (internal efficiency) and outside his organization, such as the process of interacting with other actors (external efficiency).

Another example is using a blockchain for a wheat transaction between Soufflet and Mondelez (AgriCensus, 2020). The blockchain platform allows two of France's biggest agribusinesses to enable the traceability of wheat and its products along the supply chain. The Soufflet Group is one of France's largest wheat traders. The counterparty is Mondelez one of the France's largest end-users. The platform is being developed by Connecting Food, a startup that said, 'From upstream to downstream sectors, this platform transparently promotes the stages of the journey from raw material to finished product. Using the QR code located on the product packaging, the consumer will be able to access information relating to the route of raw material via the mobile application' (AgriCensus, 2020). Finally, Soufflet indicated its intentions to connect all its silos to the platform and to issue auditable blockchain certificates in order to certify the finished product's origin.

A final example for blockchain development in agricultural trading is that by Olam (Ellis, 2020). They had been looking to digitalize for 5 years, but the advent of COVID-19 motivated an acceleration of the initiative. The platform was being expanded from twenty thousand farmers (at launch) to fifty thousand farmers (in 2020), with the potential to include many more. The motivation was to utilize technological solutions to bring efficiency to the supply chain. Further, they explained 'A chunk of time is wasted in physically shifting things, [on] bills of lading, and so on' (Ellis, 2020). The blockchain platform was being developed as a global supply chain.

4.1.1. Strategic Implications for Blockchain Adoption in Commodity Trading

There are several strategic issues and implications with the development and adoption of blockchains in agricultural commodities. One implication is that transaction costs can be reduced in terms of time, cost, and risk. There are numerous reasons that errors or fraud can be reduced, thereby minimizing the risk. For example, Lakkakula et al. (2020b) developed a simulation model using a hypothetical example of soybean exports from North Dakota to

China, illustrating that the transaction costs were reduced by 2.3 cents per bushel; the time required for documentation can be reduced by 41 percent and risk is reduced substantially.

Another strategic implication is related to the first-mover advantage and control of the blockchain system. Other studies suggest that it is important for leaders to adopt technology which may provide them with the first-mover advantage within the industry. However, there could be more benefits with a consortium blockchain that has more organizations or firms in that industry compared with a private blockchain for each organization. It is not clear how the new organizations would be permitted to join the incumbent blockchains.

Inherent in commodity trading is asymmetric information which generally gives sellers an inherent advantage over buyers (Akerlof, 1970). It is largely for this reasons that a significant volume of international buyers use bidding (or tendering) as a mechanism to identify suppliers. This asymmetry of information might be related to quality, shipping and logistics (that is, timing of the ship or rail-car arrival) and credit terms (creditworthiness of the buyer) (Herstsgaard et al. 2019; Wilson et al. 2019). In the case of quality, the seller knows, or has the ability to know, the quality attributes. A blockchain has the effect of reducing the information asymmetry. Indeed, Lakkakula et al. (2021) use decision trees and a simulation model to illustrate how a blockchain reduces the asymmetric information by hypothetically utilizing transaction data for a local country elevator in North Dakota and an agribusiness located at the Pacific Northwest (PNW) export port. Further, the seller can expend effort, including testing, blending prior to shipping or blending at different origins, all of which involve costs and are not necessarily observed by the buyer.

Finally, it is not clear if and how price transparency will be affected by the wide-scale adoption of blockchains. Price transparency refers simply to the observability of transaction prices. In futures market trading, transactions are perfectly transparent. However, transactions between buyers and sellers are typically not observed, and hence the trade terms and prices are not transparent. In general, open and transparent markets are desired characteristics of commodity markets. Over time, some terms of trade, notably the shipping prices and costs, have become more transparent. There has always been limited transparency for other terms of trade (for example, quality specificity, origin versus destination quality evaluation and other quality terms, the timing of export sales/shipments, and other logistics). It is important that the blockchain is not a 'trading' platform but, rather, a mechanism to facilitate transactions; for this reason, the blockchain would not likely influence price transparency. However, it remains to be seen whether and how transparency for other terms of trade would be affected.

4.2 Supply Chain Management

The Council of Supply Chain Management Professionals (CSCMP, 2020) defines supply chain management as follows:

> 'Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies.' (CSCMP, 2020)

Across the supply chain, companies aim to add value to the consumer's experience by forming the appropriate partnerships to efficiently share the product's information and physical flow. Currently, information about the supply chain exists within each company, and corporations do not share information with each other without relying on middlemen. Although the middlemen seem to have a very important role, they are often costly for both parties.

Organizations regularly track the product/good across the supply chain using several technologies which have evolved over time. A few of these tracking abilities include barcode, 2D codes, radio-frequency identification (RFID), telematics and sensor-enabled technologies. These tracking systems collect data, and then, the data are managed by each entity associated with the supply chain without integration among them due to trust issues.

RFID technology cannot, on their own, track the good or any shipment between locations. An internet-of-things (IoT) technology combined with a blockchain and RFID can help track the ship or vessel to determine its location and to appropriately communicate between buyers and sellers (or both, and other blockchain participants), depending on the contract terms. A combination of IoT sensors, including location-tracking as well as accelerometer sensors, can be utilized to trace the vessel's location. Typically, the collected data are stored in a local microcontroller device. These data are then transferred to end-user devices, such as phones or laptops through wireless technologies. Some examples of wireless technologies include a range of options from Wi-Fi, cellular data, long-range radio to narrow band IoT (Vyas et al. 2019).

In the last few decades, the technology in the supply chain management (SCM) has evolved. Four technologies changed the face of SCM in the last four decades: material requirement planning (MRP I), manufacturing resource planning (MRP II), enterprise resource planning (ERP), and advanced supply chain planning and optimization (APS/APO) (Banerjee 2018). The advent of enterprise resource planning has significantly improved efficiency and, thereby, the performance of supply chain management, especially in the last two decades. However, the ERP only improves the efficiency of supply chains within organizations, not across organizations or companies (Banerjee, 2018). As long as there is no shared and trusted information among organizations for a supply chain, the efficiency with the entire supply chain management is very limited. In order to address the challenges with complexity in the supply chain management, traceability and transparency, one solution is to employ blockchain technology as part of the operations.

Major challenges for supply chain management are traceability, transparency and efficiency. One source of inefficiency is that repetitive product verification is often done at most points in the supply chain. Moreover, consumers may want to know the origins of their food. A private blockchain could help address these above challenges. For example, the blockchain is comprised of the network's relevant, full participants which are known prior to the deal (transparency) and records the transactions at each exchange point in the supply chain which is accessible to every full participant (traceability). Finally, the distributed database ensures that each of the network's full participants has the same copy, eliminating product verification at each point in the supply chain (efficiency).

There have been plenty of applications for the blockchain technologies in various fields of supply chain management. However, our focus is to describe the application of pilot projects which employed blockchain technology in some form or other for their operations as well as to outline the resulting benefits in the form of traceability, transparency and efficiency (Lakkakula, 2020b). In the United States, IBM operates the IBM Food Trust, a blockchain that integrates and digitizes transactions in order to improve the food supply chain's efficiency for the network participants, including growers, processors, shippers, retailers, regulators and consumers (IBM, 2020). The IBM Food Trust's initial goal was food safety across the supply chain, but later, several network participants that joined the Food Trust had other goals in addition to food safety. IBM's Food Trust blockchain contains several network participants, including some of the world's biggest retailers, such as Walmart, Albertsons and Carrefour. Walmart was one of the first companies to join the Food Trust in 2017; then, others joined. Albertsons joined the IBM Food Trust in order to track high-risk produce, such as romaine lettuce, from the farm to the store (Wolfson, 2019). Carrefour, a French retailer, has been part of the IBM Food Trust blockchain and tracks food items, such as milk, meat and fruit, from the farm to the store (Thomasson, 2019). Carrefour claims that sales for the food items in the blockchain increased (Thomasson, 2019).

AgriDigital (2020) is an Australia-based blockchain platform with the specific goal of providing improved efficiency for the agricultural supply chain. AgriDigital was launched in 2015, and it processed the sale of 23.46 tons of grain with the successful execution of payment between the two parties within hours (ICT4Ag, 2017). Bob McKay, the executive chairman of AgriDigital, commented, 'there certainly is the scope for real-time payment, which would reduce farmer's counterparty risk' (ICT4Ag, 2017, p. 9). Overall, the advantages of the AgriDigital platform include having fast and real-time payment and improving the grain's traceability.

4.3. Food Safety

Often, companies spend a significant amount of money to ensure food safety across the supply chain, starting at the source and going until the product reaches the final consumer. Losses due to food-illness outbreaks may have different forms, including the lives lost, hospitalization, and food recalls (thereby affecting sales and revenues) after determining the cause of contamination or infection from the food source. According to the US Department of Agriculture's (USDA) 2014 estimates, major food-borne pathogens, including salmonella ($3.67 billion), toxoplasma ($3.30 billion), listeria monocytogenes ($2.83 billion), norovirus ($2.26 billion), campylobacter ($1.93 billion) and others, cause illnesses which cost the US economy $15.6 billion (USDA, 2017).

In the past, it was very hard for retailers and others to track the source of a food-borne illness across the supply chain. Over time the United States ramped up the surveillance and investigation capabilities across the counties and states with collaborative efforts from the US Food and Drug Administration (FDA), the Centers for Disease Control (CDC) and the US Department of Agriculture's Food Safety Inspection Service (FSIS). As a result, identifying the source of food contamination has improved over time (CDC, 2020a). During a food-borne outbreak, the time taken to identify the exact source of contamination is very critical. The CDC takes few days to a few weeks to identify the outbreak's source, depending on the nature of the food-borne outbreak and the complexities involved. For example, it could take multiple weeks to trace the source of contamination for an E. Coli outbreak from romaine lettuce after detecting a human infection (CDC, 2020b). During this traceback period, the outbreak was spreading into 16 states with 62 reported cases and 25 hospitalizations (CDC, 2020b).

Major challenges for the food-safety sector include tracking time and transparency. This and other pilot projects we present use a blockchain as a way to address both challenges. Many pilot studies have shown that, if the entities at each point in the supply chain could come together and form a blockchain network where they record all the required information about the produce, it takes a very little time to narrow down the options to detect the potential outbreak points which are investigated. For example, Walmart, in collaboration with IBM, has conducted a pilot study to track mangoes and has included all the relevant parties across the supply chain. The end result is that it took a few seconds to track the source of origin with a blockchain as opposed to approximately a week otherwise (McQuinn and Castro, 2019).

4.4. Agricultural Finance

With commodity or product exchanges between two transacting parties, a trusted intermediary, such as the banks exists to guarantee the payment to the seller as well as the goods being delivered to the buyer in accordance with previously agreed-upon contract specifications. Although the financial institution's role is important to guarantee the payment and transaction settlement between the parties, it comes with a significant cost. For example, with international commodity trade, there is an extensive bureaucratic process that could take weeks when preparing and transferring the documents between the advising bank (a bank associated with the seller) and the issuing bank (a bank associated with the buyer). Document transfer between these two banks on behalf of their parties may include a letter of credit from the buyer to the seller and a confirmation letter from the seller to the buyer. Other documents include bills of lading, country of origin and documents which satisfy the importing country's phytosanitary requirement.

One challenge for agricultural finance is to reduce the cost of financial intermediation (banks). Blockchains can either eliminate the intermediary or change its role in a transaction between the seller and the buyer. The banks' role could be changed in terms of lowering their fees for its users, improve efficiency within by cutting costs and risks across the banking industry. With its consensus protocol mechanism, a blockchain replaces the intermediary to verify the transaction. Cryptocurrency plays a critical role to eliminate the intermediary's role, and that step, among others, is what the blockchain was originally intended to do. Presently, banks are part of the blockchain networks because, due to the highly volatile nature of the cryptocurrency value, it may not be feasible for the seller and the buyer to exchange goods using cryptocurrency (Lakkakula et al. 2020b).

Agricultural insurance is another opportunity where a blockchain has applications. For this sector, the challenges include automatic and timely payment to the affected party. In general, the loss assessment and the payments made to the farmer or the receiving party depend on the type of agricultural insurance. Examples include 1) an indemnity insurance payout to the farmer or the affected party based on the damage evaluated by the field expert and 2) the index-based insurance payout to the farmer based on a predefined, measurable index, such as the amount of rainfall measured by a nearby weather station (Xiong et al. 2020). Although index-based insurance can reduce the asymmetric information and moral hazard problems which are common with indemnity insurance (Just et al. 1999), a blockchain can improve the efficiency for index-based insurance, particularly with timely and automatic payments to the affected party (Xiong et al. 2020).

Depending on the situation, sometimes on-site verification has to be completed before an insurance payment is given to the affected party. In that case, a blockchain oracle, which is a trusted third party that verifies the conditions for the insurance payout at the site (off-chain data) and then enters off-chain data into the blockchain, can be used.

Arbol and Etherisc are two examples which utilize blockchain technology (smart contracts) in agricultural insurance markets to hedge against weather risk along with big data and artificial intelligence. Arbol is the smart-contract platform which is built into the Ethereum blockchain that is comprised of various stakeholders, including farmers, agribusiness groups and livestock producers (Jha et al. 2018). Arbol platform claims that there is an exchange of millions of dollars in risk among different users of platform (Jha et al. 2018). Etherisc's decentralized insurance protocol is a permissionless network built in Ethereum which is designed to create a marketplace for insurance, enabling independent insurance service providers to offer certain value for risk in terms of price, service and/or transfer of insurance (Mussenbrock, 2017). Most of the Etherisc's software products are at prototype or at design stage.

5. Summary and Concluding Remarks

Our focus in this chapter was to identify the current or potential sectors of the agriculture discipline and then to discuss how blockchain technology could alleviate those challenges. Specifically, we looked at various sectors, including agricultural commodity trading, supply chain management, food safety and agricultural insurance. We argued that blockchain technology has the potential to become a general-purpose technology.

Overall, this chapter described several pilot projects, which were at various development stages, showing that blockchain technology has penetrated into agriculture. In agricultural commodity trade, the blockchain can be used to overcome the current challenges in order to reduce complexity in the process, apart from digitization; to automate repetitive tasks; to reduce the risk of human error; and to create quick payments and transaction settlements between the buyer and seller. Taken together, adopting the blockchain for commodity trading will affect some traditional sources of a strategic advantage. One of these is risk reduction and risk-taking activities for commodity traders. Commodity trading is rife with risk. Tradable instruments can be used to mitigate risk in price levels. Many other functions of risk include risk related to basis, logistics, quality and credit terms. Commodity sellers are usually better at managing these risks, thereby earning a premium for so doing. A blockchain has the effect of reducing these risks, taking away the advantage held by large trading firms. Historically, trading firms had more information (asymmetric information favoring them) than others, hence they were in an advantageous position. The blockchain has the potential to reduce the asymmetric information and to ensure a more level playing field for both the buyers and sellers as well as the big and small firms in the blockchain network.

For food safety, the time taken to identify the contamination source during a food outbreak could be the key to minimize the loss of life and food recalls, thereby lessening financial losses. Because the blockchain network consists of various participants along with the information about the product across the supply chain, a blockchain could be beneficial for tracking the product's history in the supply chain in almost real-time instead of taking weeks via the traditional approach.

With supply chain management, tracking abilities can be enhanced by using a blockchain and complementing it with other recent technologies, including IoT and AI, to access real-time information about the condition of food produce. For example, these technologies, along with a blockchain, can be used while transporting produce, generating insights using data. The end result is a more efficient supply chain as well as minimizing losses due to early detection of a product's condition. We also provided examples for agricultural insurance where the blockchain technology can be used both to efficiently disburse payouts to farmers or affected parties and also to serve as an insurance market.

In summary, blockchain technology has come a long way with applications spread across a variety of fields beyond the financial sector and cryptocurrency world. Additionally, more substantive benefits for the blockchain can be seen by combining it with other recent technologies, such as IoT and AI, to solve complex questions about the enormous amount of data generated, data storage and dissemination, and the generation of value for the insights from those data across the fields.

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