Blockchain Enabled Credibility Applications: Extant Issues, Frameworks and Cases

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ABSTRACT The credibility of information is known as a major cause of a wide range of issues, such as: altered product information in food supply chains; fake transactions on E-commerce platforms; lengthy claim settlement time in agricultural insurance; and costly borrowings in agricultural financing. For a more specific example in food supply chains, end customers want to check the product information, but either doubt the authenticity of information, or simply do not have access to the information. The reason is that upstream suppliers and downstream retailers are often reluctant to share data, fearing privacy loss or business secret leakage. The consequence is that regulatory departments may face enormous challenges to identify accurate contamination sources, if there is scarce information or falsely recorded information at any stage of the food supply chain. In this paper, we focus on four common scenarios demanding information credibility in the agricultural supply chain: product traceability, E-commerce platforms, agricultural insurance, and agricultural financing. We review some high-profile smart credibility applications with emphasis on how blockchain related technologies can provide the information credibility by examining extant issues and relevant frameworks.

INDEX TERMS Blockchain, Information credibility, Supply chain

I. INTRODUCTION Credibility issues arise along the agricultural supply chain, such as the authenticity of product information or the risk assessment of agricultural stakeholders’ financing applications. The reason is that the supply chain of agricultural products from farm to fork is lengthy and contains many parties, including primary producers, processors, wholesalers, retailers, logistics, and end consumers [1]. Four popular applications of information credibility along the agricultural supply chain are investigated in this paper.

- Traceability is very important for food safety, but it is one of the most challenging aspects to be achieved throughout the lengthy and complex supply chain. In practice, regulatory departments will demand authentic food information from the whole supply chain and require all stakeholders of the chain to provide information with high credibility [2].

- Purchasing agricultural products via E-commerce platforms is totally different from the traditional way that involves on-site inspection of items. Customers decide whether to buy a product based on descriptions provided by the merchants and/or the reviews from past customers. This means it is essential that any information provided by merchants or third-party E-commerce platforms is authentic and credible [3].
The emergence of blockchain technologies has been promising in providing greater data credibility, transparency, privacy and immutability as shown in Fig. 1. If we decompose blockchain’s core technologies, it can be found that blockchain is not a new thing, but is actually a combination of existing technologies. These technologies together can provide trust among entities, who otherwise are hard to trust each other. The core features of blockchain are examined as follows.

1. Most current data collection and circulation take place through centralized systems. This implies that the infrastructure owner can potentially manipulate the data record. Blockchain adopts a distributed chained model to ensure data credibility. More specifically, before a block that contains a set of transactions can be added onto blockchain, the transactions will have to be verified first by participating nodes of the whole blockchain network. These nodes compete to solve a cryptography challenge, and the winner is entitled to wrap up those awaiting transactions into a block and then broadcast the block to the whole network. All the nodes will verify the broadcasted block. If the broadcasted block is approved, it will be added on ledgers of all the nodes in the blockchain network. It is the so-called ‘consensus’ mechanism. The common consensus algorithms are: proof of work (up to the participant’s computing power, e.g., Bitcoin), proof of stake (up to the participant’s investment, e.g., Tezos), Practical Byzantine Fault Tolerance (designed for permissioned blockchain, e.g., Hyperledger) and federated voting (simply voting, e.g., BigChainDB) [5]. The process was conducted among all participating nodes without a central authority holding or updating the record, which is why blockchain is featured as a ‘distributed’ storage technology. Table 1 summarizes fundamental differences between traditional distributed databases and blockchain. In a block, as depicted in Fig. 1, besides a set of transaction data from the same time period, the block also contains a hash of the current block and a hash of the preceding block. Thus, blocks are chained together, which is where the term ‘blockchain’ comes from. The ‘distributed’ and ‘chained’ features make the data recorded on blockchain immutable. This is because: 1) the data are stored among distributed nodes, and 2) any change of data in a block produces a totally different hash value of the block, which leads to inconsistency of chains between the tampered node and the rest nodes.

2. Data owners are not always willing to share the data due to privacy or business concerns, which will
result in data islands that lessen the value of data. Encryption algorithms, taking advantage of the hash irreversibility, isolate sensitive information from transaction data to protect users’ privacy. In addition, some protection methods, e.g., zero-knowledge proof and multi-party secure calculation, can be used to extract useful data without the need to reveal the sensitive information [6]. Privacy and transparency on blockchain are often confused. Actually, blockchain allows users’ identities to be anonymous, but all transactions and accounts linked to those transactions are visible. Therefore, the privacy protection technologies can effectively avoid the dilemma caused by the need for both data transparency and privacy.

3) There are automation processes being employed in different business, industrial or life scenarios to help people to complete repetitive tasks based on certain pre-defined rules. The major difference between the traditional automation processes and smart contracts is the latter relies on a blockchain infrastructure, which allows smart contracts to operate in a fully decentralized way, while the traditional one is defined and controlled by a central authority. Therefore, for more complex situations, especially where credibility is the major concern, blockchain based smart contracts are needed to automatically and faithfully execute commands once the agreed conditions are met. The smart contract actions not only save large amounts of time and labor costs, but more importantly, they can also be easily traced [7].

The rest of the paper is organized as follows. We first study related work and compare to our key contributions in Section II. We lay our emphasis on the permissioned blockchain system due to the nature of the four application scenarios, which are: agricultural products traceability in Section III; E-commerce platforms in Section IV; agricultural insurance in Section V and agricultural financing in Section VI. After that, Section VII discusses research challenges, and finally, Section VIII concludes the paper.

II. RELATED WORK AND OUR CONTRIBUTIONS

Wüst et al. in the seminal paper [8] presented a structural analysis on whether blockchain is indeed needed, and if yes, what kind of blockchain is suitable. The structural analysis can be summarized as follows. If there is only one writer, then it is a regular database. If there is a trusted third party (TTP), and if the TTP is online of all time, then it can be the writer and verifier; however, if the TTP is not always online, then it can serve as a certificating authority in the permissioned blockchain scenario, in which all writers of the blockchain network are known. If all writers trust each other, a database is the best choice; if they do not, a permissioned blockchain should be adopted. If the writers are not fixed or known to each other, e.g., Bitcoin, then a permissionless blockchain is the best solution.

Treiblmaier in [9] studied the impacts of incorporating blockchain into supply chains by building a theoretical framework based on four economic models: principal agent theory, transaction cost analysis, resource-based view, and network theory. The combination of these four theories enables us to get insights of the structural and managerial aspects of blockchain-based supply chains. For example, research questions like “how to structure a supply chain that employs blockchain” can be addressed by the principal agent theory, while questions like “what is needed to manage such structure” can be dealt with the network theory.

Bocek et al. applied blockchain to the pharmaceutical supply chain, which places stringent requirements on temperature and humidity of medicinal products in the logistics process [10]. For example, any temperature deviation must be faithfully recorded. The authors combined various sensors with blockchain to monitor and record all the required data during the transporting process. Once received, a smart contract will be automatically executed to check whether the environmental requirements are met, the results

| TABLE 1 Differences between blockchain and distributed databases |
|---------------------------------------------------------------|
| **Data Management**  | **Data Structure**  | **Data Operations**  | **Remarks**          |
|----------------------|---------------------|---------------------|---------------------|
| Blockchain           | Distributed and decentralized | Transactions stored in a block that points to its previous block | Read, verify, write | Immutability, and transparency |
| Distributed Database | Distributed but centralized: a central authority coordinates the whole system | Data usually stored in an entity-relationship table that consists of different attribute fields | Create, read, update, delete | Fast, and easy to be implemented |
of which can be accessed by interested parties, e.g., customers or regulators.

Feng investigated a blockchain traceability system for food supply chains [11]. The presented solution employed RFID tags and sensors to monitor and record food status at critical control points, e.g., pesticide and fertilizer residues check at the growing stage, or temperature and humidity check at the processing stage. The author adopted the Bigchain framework to address the scalability issue, which is attributed to the highly efficient voting consensus mechanism. The author also introduced a registrar that gave chain members credentials to add records, meaning the proposed food traceability platform is actually a permissioned blockchain system.

Ge et al. in [12] built a demonstrating application for organic table grapes from South Africa. The demonstrator adopted the permissioned blockchain framework based on Hyperledger, and the aim of the demonstrator was to link farmers, certifiers, auditors, and table grape traders to keep track of organic certificates involved in the supply chain. The blockchain certifying process is as follows. First, a certification authority issues the signing authority of organic certificates to a farm, which thus is empowered to certify individual boxes of grapes by a unique identification number (e.g., a barcode). After that, the certified grapes are sent to retailers, shelfed in supermarkets, and then eventually purchased by consumers. All participants in the supply chain can check the provenance and the validity of organic grapes on blockchain. However, other grape conditions, e.g., grape statuses in the transferring and distributing steps, are not added on blockchain.

Min et al. in [13] presented a novel permissioned blockchain consensus model for E-commerce platforms. The key idea is to divide nodes in the blockchain network into sub-systems. Each sub-system runs an independent consensus collection process to verify transactions and blocks. The sub-systems are created randomly to minimize the influence of dishonest nodes. Each sub-system contains a group of committees, who is responsible for validating and writing transactions to blocks. The authors claimed that the sub-committee design not only can support instant transactions and provide credibility for E-commerce platforms, but also can remove the scalability barrier of blockchain.

Chen et al. discussed the key promises that blockchain can bring for finance, and investigated innovative financial applications relying on blockchain [14]. The key blockchain promises for finance include 1) decentralization, meaning no single authority has sufficient power to monopolize the network; 2) innovativeness, as there is no controlling entity, therefore, allowing open access and permissionless innovations to thrive; 3) interoperability, meaning traditional financial applications work in isolated silos, while the decentralized financial ones are built on blockchain with open standards and interoperability; 4) borderlessness, meaning transactions on blockchain is inherently borderless, not bound to any fiat currencies, and thus, can easily flow across geographic areas. The new financial business applications include payment networks, decentralized currencies, fundraising, and smart contracting.

Salviotti et al. in [15] proposed a framework to assess blockchain based business applications. The framework has two components: 1) a study on the core features of blockchain (e.g., cryptography, decentralization and consensus), and 2) analyze and categorize blockchain applications based on the study. The authors gave three interesting observations: 1) cryptocurrency is the most common blockchain application, which is followed by financial transactions and certification; 2) according to the ownership, two kinds of blockchain platforms are identified - permissionless and permissioned, either of which has its own suitable scenarios; 3) the most widely adopted consensus mechanism is proof of work, while Ethereum is the dominating development platform.

Kim et al. in [16] presented a public-private hybrid blockchain framework for a crowdsensing-based smart parking system. In the public part, participating nodes can provide parking data via the public blockchain, and claim corresponding rewards. In the private part, a group of special nodes designated by the service providers will process the received parking data, and make them available to subscribed users. The authors concluded that the hybrid public-private blockchains possess the advantages of both kinds of blockchains: e.g., data integrity and persistence from the public one, and e.g., transaction speed and security from the private one.

Qu et al. in [17] proposed a credibility verification structure for IoT devices. The authors conducted experiments to demonstrate the validity of the proposed method in satisfying the credibility requirement, which cannot be guaranteed by IoT networks. Similarly, Yang et al. simulated a blockchain-based reputation system in vehicular networks to prove that blockchain related techniques can handle the credibility issues of received messages among vehicles [18].

Generally speaking, there are two kinds of blockchain, as observed in the reviewed literature - permissionless and permissioned. In a permissionless blockchain, the network is open to all participants, meaning any node can read, verify and write transactions. Another prominent feature of a permissionless blockchain is that there is no need to have a trusted third party, as the trust can be built among equal peers through a consensus protocol. In a permissioned blockchain, there are trusted parties responsible for giving permissions to nodes to read, verify and write transactions. The ‘read’ access can be public to all, while the ‘verify’ and ‘write’ operations are restricted to a group of trusted nodes, which are usually delegates of the key stakeholders of the blockchain platform or the consortium of certain industry. For example, a customer can check the provenance and logistic records of a product he/she bought, while only the
producer and those entities involved in the supply chain can write information to the blockchain. Thus, the permissioned blockchain system can rely on lightweight consensus mechanisms, enabling it to operate more efficiently and keep business sensitive transactions more securely compared to its permissionless peer. Note that, although there is a reduced number of controlling nodes, it is still very difficult to tamper data on the permissioned blockchain, due to its inherent chained data structure and distributed data storage. Table 2 summarizes fundamental differences between permissionless and permissioned blockchains.

This paper focuses on the permissioned blockchain, and proposes a possible approach to access blockchain business applications in agricultural supply chains. The main contributions are threefold. First, we seek to clearly identify what specific features of blockchain can provide information credibility. Second, we study four common permissioned blockchain applications demanding information credibility, and explore the basic functionalities that blockchain can bring for the four scenarios (traceability, E-commerce, agricultural insurance and financing). Third, by looking into some high-profile smart credibility applications and examining extant issues, we build respective blockchain frameworks that can address the credibility issue for each of the studied agricultural scenarios.

### III. BLOCKCHAIN + TRACEABILITY

#### A. EXTANT ISSUES

According to the statistics from Centers for Disease Control and Prevention (CDC) official website, there were 48 million people who got sick from foodborne illness, 128,000 were hospitalized, and 3,000 died each year in the US [19]. In 2017, some eggs, originating from farms in the Netherlands, were accidentally contaminated by Fipronil (a type of insecticide), and then sold worldwide. Soon after, the error was found, leading to millions of contaminated and uncontaminated eggs urgently recalled from market shelves in 26 EU states and 45 countries worldwide [20].

In the era of food globalization, the supply chain is more complicated than ever. However, consumer trusts become more fragile. With the quick propagation of social media, the news of food safety incidents can spread around the world within hours, bringing in enormous impacts and pressure on the traceability system to identify and contain the contamination sources. The extant issues in traditional traceability systems are as follows.

1) The law enforcement departments rely on product data to trace possible contamination sources. Traditionally, product data is stored separately at each link along the supply chain. Thus, if there is scant information or falsely recorded information at any stage of the chain, it will present the regulatory departments with difficulties when attempting to determine the possible sources.

2) Information asymmetry within the long supply chain causes customers to doubt the information authenticity or in other cases they simply do not have access to product information.

3) One of the one side, it is hard for suppliers or retailers to present convincing information of product quality, due to the complex structure or interactions within supply chains, even when products are truly of high quality. On the other, some suppliers or retailers are reluctant to share data due to concerns of privacy or business secret leakage.

#### B. BLOCKCHAIN ENABLED TRACEABILITY

In order to tackle the extant issues mentioned above, clearly, new traceability methods are required. Blockchain utilizes the chained data structure, cryptography, consensus mechanism, distributed storage, and timestamp to realize data immutability, traceability, and transparency. By benefiting from these blockchain features, we can disrupt information islands and establish a cross-institutional traceability system to effectively monitor the product status. For example, Walmart and IBM built a Hyperledger food traceability system, which showed that the time to locate possible contamination sources could be reduced from several days to
Another well-known traceability system is AntChain, which is developed by the Ant Group [22]. It integrates Internet of Things (IoT) and blockchain to record and track the flows of tangible goods and intangible information. It has the potential to effectively solve problems, such as data credibility, data islands, and transparency in the product supply chain.

AntChain doesn’t create a new permissionless or permissioned blockchain platform. Instead, it is compatible with other mainstream open-source frameworks, e.g., Ethereum or Hyperledger. On the other, AntChain enhances the conventional framework in areas such as large scale consensus algorithm, privacy protection, and blockchain storage.

The structure of AntChain is illustrated in Fig. 2. There are six key components for the AntChain traceability system, which are listed as follows.

1) PRODUCTION
In the primary production stage, raw materials are packaged and then labelled with identity codes, such as bar codes, QR codes, RFID or NFC tags, which will be unique for each product and may include information like the origin of raw materials, the soil status, the air quality, or other relevant factors. The regulatory departments will specify the types of information to be integrated in the production stage.

2) PROCESSING
In the processing stage, the manufacturing information on dealing with primary products, such as temperature, treatment methods and ingredients, hygiene control, and processing results, will be added by processors. The added new information can be appended to previous production codes, or attached to new tags.

3) STORAGE
In the storage stage, the real-time product information, including product categories, quantities and status, can be accessed remotely to help manage inventories. At the same time, warehousing conditions, such as location, temperature, humidity, brightness, or air pressure, can be updated in the existing tags or created in new tags.

4) LOGISTICS
In the logistic stage, the freighting information, such as product batches, travelling time, and distributors, are added. In addition, by setting up sensors and transmitters, a real-time monitoring system can be established to record product status, such as temperature and humidity during transit. The system can send out warnings or record instances if the logistic requirements are violated.

5) RETAILING
In the retailing stage, merchants can utilize the traceability system to monitor and record the status of products. At the same time, consumers can also access reliable product information.
information all the way back to the primary production stage, through APPs or websites.

6) REGULATORY DEPARTMENTS
Regulatory departments are responsible for the allocation and the activation of traceability codes. In addition, they are also responsible for the product quality monitoring. Blockchain traceability systems enable regulatory departments to quickly determine possible contamination sources if a food safety incident occurred, which can greatly minimize damages and costs in terms of public safety and investigating efforts [23].

IV. BLOCKCHAIN + E-COMMERCE

A. EXTANT ISSUES
In the past decade, E-commerce has been thriving with a stunning speed, greatly transforming the way of life for everyone. During the shopping festival from 1st to 11th of November in 2020, the Chinese E-commerce platforms - Alibaba and JD.com created a total Gross Merchandise Volume (GMV) of $115 billion, breaking their own records of 2019 [24]. Nevertheless, the huge volume of online transactions presents E-commerce platforms with the following issues.

1) Inconsistent pricing. In order to attract customers, some online merchants deliberately inflated prices before reverting them back to the original ones in order to create an illusion of discounts [25]. The other common trick is misleading information, where merchants put perpetual sales on some items, so the discount price is in fact the regular price.

2) Shoddy products or fake transactions. A study by the United Nations Industrial Development Organization (UNIDO) pointed out that selling low quality products is a prevailing problem in E-commerce platforms [26]. When customers shop online, they mainly decide whether to buy goods based on the merchant’s description and customer reviews. It is not an easy task to judge the product authenticity or quality of products via online descriptions, especially when it comes to agricultural products with different regional features. In addition, some third-party agents even offer to falsify customer reviews, while others may hire people to submit phony orders, send out empty parcels, and then manipulate comments to artificially inflate the transaction volume and favorable reviews [27].

3) Vague boundaries of responsibility. The responsibilities of supply chains among E-commerce platforms, merchants, and logistics are not clearly defined. For example, the spoilage of frozen goods may occur due to the improperly controlled temperatures, which could have happened before goods were transmitted to logistics, during the process of logistics, or after the goods were received by retailers. It is often difficult to ascertain the source of such problems, which leads to accountability issues.

4) Data leakage. Shopping on E-commerce platforms inevitably involves personal information (e.g., name, address, and purchased goods) or sensitive business secret (e.g., ordered materials, quantity, and suppliers), which can be potentially leaked at each part of the supply chain due to human or system vulnerabilities [28].

B. BLOCKCHAIN ENABLED E-COMMERCE
Blockchain enabled E-commerce platforms can simplify the transaction process, reduce the transaction cost, and also hold the potential to effectively solve the above-mentioned issues. The key components and workflows of blockchain enabled E-commerce framework (Fig. 3) are discussed as follows.

1) MERCHANTS AND E-COMMERCE PLATFORMS
Merchants will need to submit all product parameters to third-party E-commerce platforms for auditing. After the information is checked, merchants can release products to platforms. Customers look through the audited information and communicate with merchants about trade details. They will sign a smart contract once an agreement is reached. Then, the transactions will be automatically forwarded to logistics for delivery. Lastly, the money frozen by the smart contract will be instantly released to merchants when customers confirm that they are satisfied with the received goods.

Retail.Global is an innovative E-commerce platform, which permits merchants to customize the functionalities of their stores [29]. For example, in the module of products & orders management system, the goods will be taken out for deliveries, and the balance will be paid when the goods are received by customers based on predefined smart contracts; in the loyalty rewarding module, customers’ feedback will be analyzed, and they will be rewarded with crypto tokens.

2) CUSTOMERS
Customers can query the provenance, logistics parameters and past prices of products, which are held on the blockchain. When customers confirm the receipt of the goods, they can still make comments through smart contracts, which effectively sidesteps the issue of false comments and phony transactions. For example, BuyerDao is the first E-commerce platform using smart contracts based on Ethereum [30].

3) LOGISTICS
Key product status and parameters are recorded along various stages in supply chain. Any status change or condition violation will be recorded, so that merchants and customers can trace the concerned information, while regulatory departments can identify the responsible sources when the goods were damaged or lost.

4) REGULATORY DEPARTMENTS
Agents of regulatory departments can monitor the whole supply chain and ensure market stability. More specifically, they will be examining product quality, auditing product certificates, detecting arbitrary pricing and investigating fake transactions, based on data faithfully recorded on the blockchain system.
V. BLOCKCHAIN + INSURANCE

A. EXTANT ISSUES
Agricultural insurance, an effective way to hedge risks, provides a safeguard against economic losses caused by accidents, natural disasters, or epidemics. In 2017, the overall premium of agricultural insurance in China was around 47 billion RMB, ranking in the second place after the United States [31]. Although the scale of China’s agricultural insurance was large, the sustainable development of agricultural insurance was prevented by adverse selection, moral hazard, high assessment cost, and low settlement efficiency, all of which are caused by the information asymmetry between insurance companies and customers [32]. Thus, we can summarize the main extant issues of agricultural insurance as follows.

1) Difficult to validate insurance objects. The insurance objects can include crops, plants, livestock, or aquatics. One the one hand, it is difficult to accurately quantify the number of insurance objects on a large scale. On the other hand, it is also difficult to tell whether the claimed insurance objects are indeed the original ones. These issues not only increase costs and risks for insurance companies, but also result in increased premiums, leading to a decreased enthusiasm for insurance among farmers, namely, the adverse selection phenomenon.

2) The high cost and low accuracy of claim assessments. Loss assessment of agricultural insurance is mainly dependent on on-site inspection or subjective experience, which leads to high costs and low accuracy. Furthermore, many agricultural insurance objects (e.g., plants) are growing at the time of assessment and afterwards. As such, the object value is often in a state of flux.

3) The lengthy claim settlement cycle. Compensation can take months to years, because the claiming process includes several stages, such as customers submitting required documents and evidence, experts visiting on-site to assess damages, and bilateral negotiations [33].

B. BLOCKCHAIN ENABLED INSURANCE
Most current insurances provide compensation based on damage assessment. But there are aforementioned problems, e.g., difficult to validate insurance objects, and long settlement time. Therefore, the index based insurance was formulated with the help of blockchain [34]. The process determines compensation based on certain pre-determined indexes. It mainly entails three steps, namely: insurance quotation and purchase, index acquisition, and claim settlement. For example, Arbol, as illustrated in Fig. 4, is a weather risk-management platform that taps into real-time databases to trigger smart contracts on Ethereum [35]. Arbol connects to the meteorological bureau’s database via a third-party link to obtain factors like excessive rains, snowfall or high temperature during the claimed period of time. The policyholders only need to clarify some basic information, such as locations, the claimed time, risk parameters, and
FIGURE 4. Arbol scheme of index-based blockchain insurance. Indexed events in the pool (e.g., rains or snowfall). Then, smart contracts can automatically pay premiums to policyholders [36]. The core components of the formulated framework for blockchain-based insurance are as follows.

1) PREMIUM QUOTATION AND PURCHASE
Insurance companies provide an event pool that contains all the insurable contingencies, such as excessive or insufficient rains, thunderstorms or extreme temperature. Insurance customers select potential contingencies from the event pool, which will be combined with personal data, farm specific information, and some other external parameters to create quotation models. The premium quotes will be issued automatically [37]. If a quotation is accepted, customers will sign smart contracts with the insurance companies and become policyholders.

2) INDEX ACQUISITION
Smart contracts are executed when insured contingencies are triggered. The index data will be acquired via a third-party platform that connects reliable sources to the blockchain. That is to say, the index data will be sent to blockchain combining with reliable environmental data, to ensure the authenticity and timeliness of data. Compared with the traditional compensation, which is based on expert visits or expert experience, this objective index data can solve problems that arise from information asymmetry, thus reducing the compensation inconsistency between policyholders and insurance companies [38].

3) CLAIM SETTLEMENT
Since smart contracts are connected to reliable databases, the claiming process and the payment are automatically implemented, eliminating the need for expert visits and the laborious efforts of dealing with tedious checks.

VI. BLOCKCHAIN + FINANCING

A. EXTANT ISSUES
According to a report by the People’s Bank of China, the loans to farmers only accounted for about 3 percent of its total in the first quarter of 2020 [39]. The main reasons that financial institutions were reluctant to provide agricultural loans are as follows.

1) Lack of valid collaterals. In general, the ideal mortgageable property is the one that is free of ambiguity in terms of value or property ownership. However, most current collaterals for agricultural loans are either warrants of immovable property or pledges of products (e.g., livestock, plants or crops), which can not be easily traded, traced or priced. In addition, the ownership, operation rights or procurement contracts...
(collateralizable) sometimes belong to different parties, which complicates the relationship of collaterals [40].

2) Costly risk assessment. In order to ensure the information accuracy of rural mortgaged property, mortgage institutions of different regions need to establish collaborative assessment systems. In addition, it is tough for agricultural rights to be digitized to form digital assets for online assessment, which thus increases the labor cost [41]. Especially, these issues made it hard for small and medium farms to get agricultural loans, even though they usually only need small and short-term loans to maintain seasonal operations and avoid the liquidity squeeze.

3) High risk of loaning. Information asymmetry and lack of credits not only increase the cost of risk assessment, but also increase the default risk. For one reason, financial institutions cannot monitor collaterals in real time. For another, it is difficult to continuously track farming operations to ascertain that the provided funds are being used for what the credits are given for [42].

B. BLOCKCHAIN ENABLED FINANCING

Blockchain’s transparency and immutability can help to build resilience and reduce financing costs. Thus, blockchain based financing can address the above-mentioned issues and provide greater financial inclusion in the agricultural field. According to a report by Santander, blockchain could reduce the cost of financing infrastructure by up to $20 billion [43].

The blockchain enabled financing framework are discussed as follows.

1) BLOCKCHAIN-ENABLED CREDIT MODEL

The borderlessness feature of blockchain enables trusted entities to share loan information across a large geographic area. In addition, the farming operation and transaction data are recorded and shared among lenders on blockchain. Meanwhile, the upstream or downstream data flows are also added to enhance the risk control. Different stakeholders can upload or access to the concerned information through the blockchain network, which greatly helps to reduce information asymmetry between financial institutions and agricultural borrowers [44].

2) AUTOMATIC PROCESS

Smart contracts are utilized to automate processes, such as credit approval, loan granting and loan payment. The employment of smart contracts also enable the quick circulation of credits and reduce the cost of third-party commissions. More importantly, the granted funds will be automatically transferred to the targeted entities, which reduces the risk of inappropriate fund uses.

3) FINANCING ALTERNATIVE

The blockchain ledgers eliminate the need to rely on centralized financial institutions for credit checks. Compared to the traditional financing model, in which only the centralized financial institutions have the access to check the credit of borrowers, the blockchain financing alternative enables small entities or even individuals to get access to the credit information [45]. For example, HARA is a blockchain-based data exchange platform for agriculture in Indonesia [46]. HARA helps solve the information asymmetry between farmers and financial institutions, which provides a connection to credit data that is usually difficult to be obtained. The platform contains four stakeholders: data provider, data qualifier, data buyer and value-added service, as shown in Fig. 5. Data providers, such as farmers and field agents, are the spearhead of this system. Data qualifiers are those who verify the data. They work as guardians of data quality. They will receive rewards in the form of tokens related to their verifying work. If the submitted data are deemed with good potentials to be accessed by agricultural insurance or financial institutions (data buyers), the data providers will get tokens, which can be monetized. Data buyers get benefits from the verified data. They can use the data to check credits and mitigate loaning risks. The access to

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**FIGURE 5. The ecosystem of HARA**

(Data Provider: is rewarded for data submission. Data Buyer: who accesses the data. Value-added Service: raw data are processed to ‘enriched data’. Data Qualifier: who verifies the data.)
data enables more financing alternatives, such as peer to peer financial applications and Initial Coin Offering (ICO). The submitted data can be further analyzed to provide enriched information, which will be value-added services.

VII. CHALLENGES

Blockchain based systems possess unique features that differentiate them from the traditional ones, e.g., data immutability, transparency and data security. However, there are several issues that still need to be further studied before we can take full advantages of blockchain.

A. DATA AUTHENTICITY

Data traceability and immutability of blockchain can provide credibility for those data that are recorded on the chain, but the data authenticity before being added to the chain is still a major problem. Therefore, some mechanisms to guarantee the information authenticity at the data source are needed, especially when the data are about to write into the chain. Obviously, the guarantee mechanisms are outside the blockchain itself. One possible solution to this challenge is to introduce more data checks. For example, Wang et al. in [47] proposed a certificate based multi-dimensional information cross verification scheme to detect possible incredible data.

B. CRYPTOGRAPHIC ALGORITHMS

At present, privacy protection technologies, such as zero-knowledge proof and multi-party secure computing, can solve the dilemma between data transparency and privacy. In the short term, the current computational capability does not pose an imminent threat to the cryptographic algorithms [48]. Nevertheless, the cryptographic algorithms may face serious challenges in the context of the rise of quantum computing. Therefore, one of the key research questions of blockchain is to study new cryptographic systems that can resist quantum attacks [49].

C. SMART CONTRACTS

Smart contracts execute the predefined rules automatically when triggering conditions are met, which can greatly reduce wastes of time and labor. In practice, smart contracts may be triggered by some force majeure or illegal reasons. However, the smart contracts cannot be withdrawn once triggered, which is inflexible. In addition, a study showed that around 45% of smart contracts are vulnerable, due to risks such as transaction ordering dependence, mishandled exceptions, and reentrancy vulnerability [50]. Thus, the security of smart contracts needs to be enhanced. To address this challenge, Huang et al. in [51] suggested to examine the security risks of smart contract from a software lifecycle perspective.

D. SPEED AND SCALABILITY

The transaction speed of blockchain based systems is much slower than that of the traditional ones. Although this issue can be alleviated in the permissioned blockchain systems, the convergence speed is still a problem, as long as the number of nodes reaches a certain level. It is because the design of chained data structure and distributed consensus mechanisms to validate new transactions and blocks. Therefore, efficient distributed consensus protocols to accelerate the validation of transactions need to be studied.

In the context of the four reviewed agricultural scenarios (as summarized in Table 3), permissioned blockchain systems can be an alternative solution, which allows the
system to appoint a group of participants who are given authority to validate transactions. This is due to the fact that the four types of blockchain applications discussed in the paper are applied within private organizations or sectors [52].

E. LEGAL CHALLENGES

Blockchain is a newly introduced technology, so governmental supports are crucial for it to succeed, e.g., setting up blockchain-based pilot initiatives. Regulatory authorities are concerned about the potential misuses of the blockchain - tax evasion, money laundering, or uncontrolled fund flows. According to an interview with Steven Mnuchin, the former US Secretary of the Treasury, mentioned that the US would regulate money flows under the Bank Secrecy Act to avoid the financial innovation to jeopardize its financial stability [53].

However, the regulatory supervision usually fails to keep up with the innovation pace [54]. In the case of blockchain, a lack of suitable regulations is one of the key challenges hindering its large-scale deployment. In order to take full benefits of blockchain, some regulatory administrations started to test pilot projects in a supervision sandbox, which is a kind of closed testing grounds for developing new business models that cannot be supervised by current regulations [55].

VIII. CONCLUSIONS

We examined four blockchain credibility scenarios in this paper: traceability, E-commerce, insurance, and finance, which all deal with problems proceeding from questions around data credibility. We have reviewed the literature and examples of high-profile projects to identify the extant problems and summarize the frameworks of blockchain-enabled solutions for the four types of agricultural applications.

Pioneering applications have already demonstrated that blockchain holds transformative potentials for addressing many challenges faced by traditional systems. For the next step, we will need to take a notice of the following two things. First, because blockchain is relatively new and blockchain-enabled agricultural applications are still evolving, this paper specifically investigates the permissioned blockchain, which is the best fit for the reviewed scenarios in our perspectives. However, we did observe that some permissionless or hybrid blockchain frameworks were adopted for agricultural supply chains in the literature. We will need to study the purpose and the performance of permissionless blockchain systems in the next stage. Second, this paper presents a first step in studying blockchain’s benefits for agricultural supply chains. However, the unclear effects the blockchain may bring, the potential exposure of privacy or sensitive business secrets, and the costs of introducing blockchain to supply chains, will need more rigorous studies.

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