NC STATE UNIVERSITY

Spring 2019

NC STATE ECONOMIST

COLLEGE OF AGRICULTURE AND LIFE SCIENCES

# Blockchain in the Food Supply Chain

By Heidi Schweizer, Assistant Professor and Extension Specialist
Kathryn Boys, Assistant Professor
Andrew Branan, Assistant Professor and Extension Specialist
Department of Agricultural and Resource Economics, NC State University

**Blockchain has potentially huge impacts on how agricultural supply chains operate. Blockchain applications are expected to minimize transaction costs and improve transparency in the food supply chain.**

**In this article, three NC State professors introduce blockchain and discuss applications of the technology in the context of agriculture.**

While blockchain technology has existed for almost three decades, commercial use is relatively recent. To date, many agricultural producers, shippers and food retailers have partially adopted blockchain technologies.

## Introduction to Blockchain

The concept of a blockchain originated in a 1991 paper that proposed methods to time-stamp digital content such that a change in a single bit of data is obvious and the time-stamp is difficult to forge (Haber and Stornetta, 1991). The first large-scale use of these methods was in the cryptocurrency Bitcoin. Historically, intermediaries such as banks verified the legitimacy of transactions between two or more parties and recorded them in centralized ledgers. In the case of Bitcoin, the blockchain verifies and records token transactions on a distributed digital ledger. Presently, "blockchain" refers to a specific family of distributed ledger technologies where a peer-to-peer network of nodes host these data rather than an intermediary.

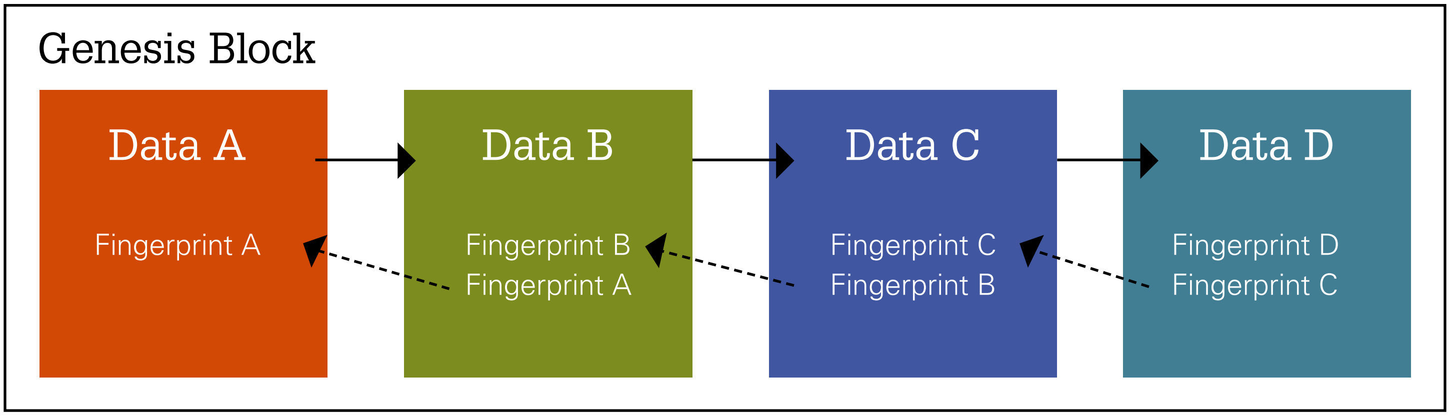
### Key Definitions

**Peer-to-peer (P2P):** Network where nodes share information without going through a centralized server

**Node:** Copy of the blockchain stored on computers or servers that are a part of the peer-to-peer network

In a simple blockchain, a single block is comprised of timestamped data, a digital fingerprint, and the fingerprint of the previous block (which is what links blocks together). The data can be anything from details of financial transactions to animal vaccination records. Fingerprints are based on the data and require time and computational energy to generate. The fingerprinting process is a critical component of a blockchain system and must meet a set of cryptographic criteria.

## *Figure 1: Illustration of data blocks forming a blockchain*




All nodes have a copy of the ledger, so adding a block to the blockchain requires updating all the ledgers. The majority of nodes, or the majority of authorized nodes in a permissioned blockchain, must agree that the new block is valid before it can be added.

Figure 1 presents a diagram of four sequential blocks. If a bad actor alters the data in block B, the fingerprint of block B changes since the fingerprint is unique to the data. Updating block B also requires updating blocks C and D, and the other network participants would have to agree to these changes. Blockchain proponents claim this system minimizes the risk of falsified data.

The next innovation after Bitcoin was to represent more complex transactions. Ethereum, another blockchain platform, introduced the concept of smart contracts that code financial instruments (loans, bonds, etc.) directly into the blockchain. These contracts automatically execute when pre-specified conditions are met. For example, two businesses may automatically exchange assets once the blockchain verifies a delivery or service completion. This feature has potential to increase efficiency by reducing administrative burden, settlement time, and counterparty risk.

## Agricultural Applications

Blockchain technology is constantly evolving as hackers and businesses test its security and functionality limits. The food supply chain is an area of blockchain growth because blockchain seems to be well suited to address common hurdles in marketing food products. Table 1 lists a variety of blockchain applications related to agriculture.

The benefits of rapidly verifying and sharing data are especially relevant to perishable products and products that cross international borders. The food supply chain involves many stakeholders: farmers, shippers, processors, distributors, retailers, and customs agents. Blockchain technology could possibly reduce the cost of paperwork processing and reduce the frequency of delays due to misplaced documentation.

**Table 1: Examples of Blockchain Test Cases**

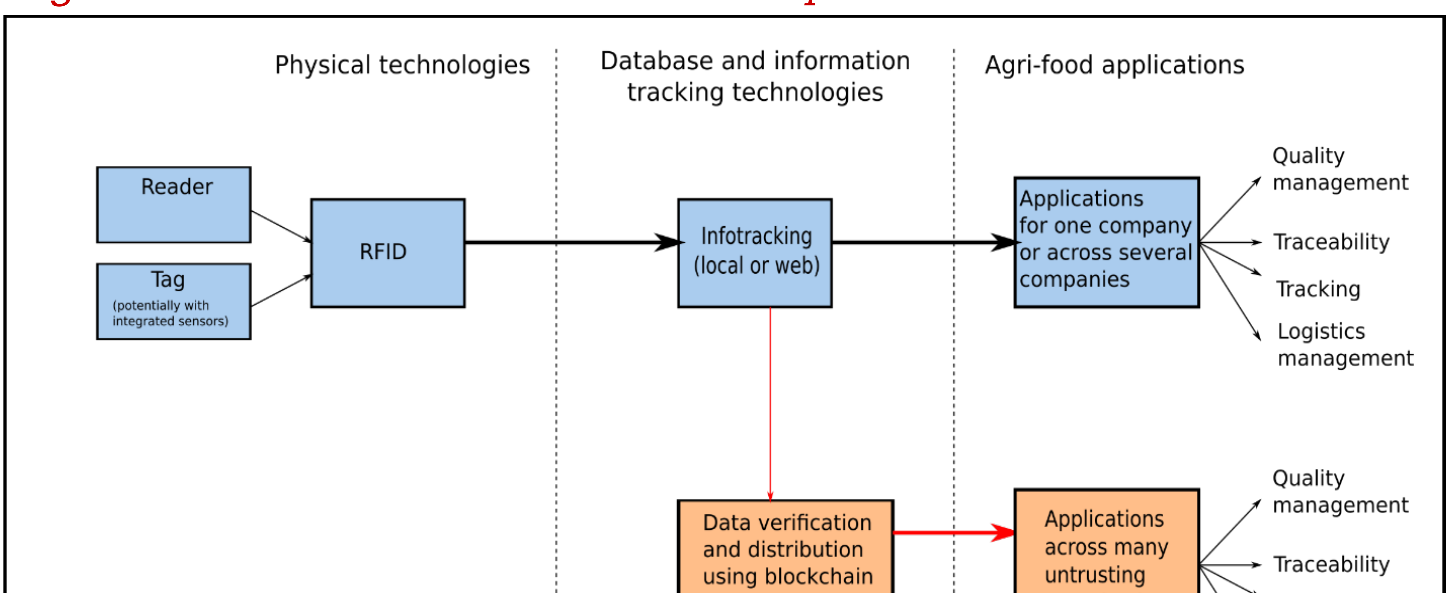
| Company | Application | Main Purpose |
|---|---|---|
| Cargill | Track turkeys to origin farms | Food safety, farm-to-fork transparency |
| Louis Dreyfus<br>ING<br>Societe General | Track a cargo of U.S. soybeans shipped to China | Minimize transaction costs |
| Walmart | Require leafy greens suppliers to use blockchain starting in 2019 | Food safety |
| Coca-Cola | Enforce employee labor agreements among sugar cane suppliers | Prevent labor abuses |

## Lessons from Previous Technologies

Blockchain has potentially huge impacts on how agricultural supply chains operate. Previous technologies such as barcodes and radio frequency identification (RFID) had similarly transformative impacts on the management of agricultural supply chains. As early as the 1990s, retailers started requiring that suppliers affix RFID tags to pallets, including those for food products. The history of RFID implementation in the agri-food sector offers insight into how this type of technology mandate can impact upstream businesses, as well as the challenges of implementing a new technology system-wide.

A RFID system consists of a tag with data, a reader (some method to gather and interpret data from the tag), and a database to store these data. The tag may have integrated sensors that can alert operators if, for example, temperature conditions change. RFID technology is used for a variety of purposes including monitoring the quality of perishables, tracking inventory, meeting traceability requirements, and managing the supply chain. The potential use of blockchain enters at the database and information tracking stage (illustrated in Figure 2). This is because blockchain provides independent entities a common platform to share these data in a way that is difficult to corrupt. Such data also validate whether or not the terms and conditions specified in smart contracts along the blockchain have been met.

## *Figure 2: The context of blockchain compared to RFID*




Adopted from a summary of RFID technology in the food supply chain. See figure 3 in "A Review on Agri-food Supply Chain Traceability by Means of RFID Technology" by Costa, Antonucci, Pallottino, Aguzzi, Sarria, and Menesatti (2013).

The benefits of RFID adoption have been examined in retail supply chains. In general, investors looked favorably on supplier compliance with RFID mandates and this resulted in positive effects on supplier stock performance (Dietz, Hansen, and Richey 2009). Within retail firms using RFID, it was found that products spent less time in inventory and per-worker efficiencies were higher. RFID adoption did not, however, necessarily result in better financial performance, especially for smaller businesses (Shin and Eksioglu 2015).

There is no scholarly research documenting financial impacts specific to agri-food sector supply chains. Nonetheless, improvements in inventory management and the efficiency of labor deployment are certainly of interest to those in agriculture where products are perishable and labor availability can be a problem.

The challenge for small- to medium- sized agricultural businesses is that, in absolute terms, they have fewer resources to put towards the initial cost of adopting a new technology. In the case of blockchain, these initial costs include the cost of accessing the platform and training employees; ongoing costs depend on the approach used to enter farm- or firm-level data into the blockchain.

Given the costs of implementing blockchain, participants in the food supply chain will have to choose between two main strategies: early adoption or a "wait-and-see" approach. Early adoption gives suppliers an opportunity to establish deeper relationships with food retailers. While many view technology mandates as only benefiting retailers, they can also benefit "upstream" suppliers of those retailers by making it costly for the retailer to switch suppliers.

Drawbacks to early adoption are that new technologies often suffer from a lack of industry standards and uncertain reliability. Initial challenges to implementing RFID technologies included managing large volumes of data and varying levels of granularity (product, box, pallet, etc.) among firms collecting data. It is likely that similar issues will also confront early adopters of blockchain. Although there may be immediate benefits to blockchain implementation in terms of downstream client satisfaction and intra-firm efficiency, firms will have to weigh those benefits against the costs of early adoption noted above.

Further, while it may be feasible for larger firms to eventually get their suppliers on board, it will be more difficult for smaller firms to incentivize their supplier networks to do so. This is pertinent for farms and agri-businesses which operate in geographic areas which do not have access to the technology necessary to collect and digitize information, or do not have sufficient internet infrastructure to get it posted online. Developing country suppliers and suppliers located in rural areas underserved by internet infrastructure (including communities who opt out of adopting certain technologies—e.g. Mennonite communities) may be precluded from supply chains which adopt blockchain as a requirement.

## Some Agri-Food Sector Considerations

Some applications and features of blockchain are particularly relevant to the agri-food sector. Key among these is the potential of blockchain improve food safety and reduce its costs. There is, however, significant uncertainty when it comes to key functions of second-generation innovations to blockchain technologies that are currently in experimental stages — in particular, the legal status of smart contracts.

1. *Blockchain and Food Safety: Significant Promise, Limited (Current) Potential*

   With its ability to seamlessly and fully transfer information across market participants, blockchain offers firms potentially enhanced methods to monitor food safety.

**"Blockchain has been touted as a tool to reduce waste and improve efficiency during food recalls."**

When combined with RFID technology, for example, holding times and temperatures throughout a food's manufacturing, warehousing, and transportation steps would be quickly observable and verifiable. This would provide assurance that required handling conditions have been met, or, alternatively, would permit lots requiring additional quality testing/or disposal to be quickly identified.

In particular, blockchain has been touted as a tool to reduce waste and improve efficiency during food recalls because it produces information that is actionable up- and down-stream from where a negative food-safety event is identified. Buyers of an affected lot could be precisely identified, and the product could be specifically removed from retailer inventories. Blockchain would also permit more precise traceback to the origin of an outbreak. The use of blockchain thus also has obvious implications for assigning liability in cases of foodborne illness. Compare this to current recall practices that are often slow, or unable, to identify the source of a problem. During the time it takes to identify the cause of a foodborne illness outbreak and to determine which specific product lots may be contaminated, the affected products can continue to be consumed - thereby enlarging the reach and size of damages caused by the outbreak. During this period of uncertainty, agri-food firms are usually proactive and recall any potentially affected products, frequently leading to the destruction of larger quantities of food products than is necessary.

At present, however, the potential that blockchain offers to improve food safety is rather limited. Blockchain has not been widely adopted by firms, and companies who are using blockchain are still exploring approaches to access and make use of all the information which is (or could be) transferred via blockchain.  For an agri-food firm to be able to reap the potential food safety benefits, they would need to not only adjust their own internal recordkeeping and information storage practices, but they would need all other businesses along their supply chain to participate in the blockchain network as well. Common rules and standards of data entry, reporting and access would be required.

**"At present, however, the potential that blockchain offers to improve food safety is rather limited."**

Firms also must determine whether it is to their advantage to make full use of blockchain by posting all information related to their food products. It has been proposed, for example, that results of product and facility testing be posted directly to the blockchain by third-party labs and auditors. While this certainly would offer benefits in terms of the efficiency of reporting and documenting test results, a firm could increase their exposure to liability if it is publicly documented that they are aware of a food safety problem but do not take what are deemed to be sufficient steps to address the issue.

The alternative of allowing companies to choose — or not— to post test results may address some of this concern; but it also opens the possibility of firms ordering duplicate tests and selectively putting good results onto the blockchain, thus reducing confidence in the system.

2. *Incorporating Smart Contracts into the Blockchain*

Another source of both optimism and apprehension towards blockchain is the self-executing performance and payment obligation interchanges that we call "smart contracts." Receipt of code verifying preconditions have been satisfied triggers payment without human decision during the transaction. Each smart contract code exists across the decentralized blockchain network, rendering each transaction transparent and traceable and, in the short-term, irreversible.

As mentioned previously, platforms such as Ethereum digitally code self-executing payment obligations into the blockchain. They do so in the form of an automatic escrow release upon verification that relevant preconditions have been satisfied. Currently a popular model is to transfer cryptocurrency (like Bitcoin). However, in the long term banks and clearinghouses are likely to find ways to represent traditional assets digitally with the features that make cryptocurrencies complementary with blockchain.

**"Another source of both optimism and apprehension towards blockchain is ... 'smart contracts.'"**

For raw food products, preconditions obligating payment could include automatic verification of quantity, product grade and production practices certification.

For processed food products, similar verification of manufacturing, storage conditions (e.g. proof of proper refrigeration) and mode of delivery might serve as preconditions. All manner of data on temperatures, point-to-point delivery time, weight after grading, moisture content, and the like could be accessed by smart contracts searching, and then checking off, preconditions.

Product certification requirements, such as firm inspection and audit reports related to Good Agricultural Practices (GAPs), the USDA National Organic Program, water testing, and animal welfare approved production practices could be stored and verified as well.

3. *Enforceability of Smart Contracts*

Though smart contracts are often lauded for reducing the need for human involvement in a transaction sequence, the code used to do this must itself satisfy state commercial contract law. Such smart contract transactions are in most respects a new frontier of acceptance of electronic commerce. Legal acceptance of electronic commerce was first upheld by the U.S. Supreme Court over a century ago in a case involving encrypted code, transmitted by telegraph, being used for cotton futures contracts.

Because there is no federal contract law, all contracts are subject to state law. All states (with the exception of Louisiana) codify a version of what is known as the Statute of Frauds: a general requirement that certain transactions, such as the sale of real property or the sale of personal property over a certain amount, be in writing and signed by the parties.

Statutes of fraud are embedded in each state's version of the Uniform Commercial Code (UCC). For example, North Carolina's UCC requires that written contracts for the sale of goods over $500 indicate "that a contract for sale has been made between the parties at a defined or stated price, reasonably identifies the subject matter, and is signed by the party against whom enforcement is sought or by its authorized agent" (North Carolina General Statutes §25-1-201, 1997).

It is reasonable to argue that smart contracts satisfy these requirements if the code concerning each side of the transaction (the combination of which forms the smart contract itself) is inserted into the blockchain by each party that is to be bound by its automatic operation. Indeed, the holder of the escrow likely writes the code that automatically releases payment.

Signatures, the other requirement of a contract, can be inserted into the database as markers to the code. These are likely to be upheld, thanks to state electronic commerce legislation like North Carolina's Uniform Electronic Transactions Act and the federal E-Sign Act. Of course, a "smart contract" likely satisfies the Statute of Frauds and UCC requirements if it is supported by a separate agreement outlining the products, payments and perhaps the code itself.

It would additionally seem critical that all parties participating in the blockchain signify acquiescence to the actual code that executes the series of transactions; that is, there must be some acknowledgement of legal sufficiency to signify agreement. This agreement could be stored on the blockchain for all to see. As with some food safety applications, though, this approach may also raise concerns of sharing proprietary business information.

## Concluding Remarks

The prospective benefits of blockchain in the agri-food sector stem from linking the entire farm-to-fork system on a global scale. At the forefront of the supply chain, farmers will play an important role in data gathering, whether blockchain or some other technology is used to modernize supply chain records. After widespread adoption, consumers are likely to benefit through increased safety and transparency. However, there are a number of economic, social, regulatory and logistic hurdles remaining for this emerging technology.

**"Farmers will play an important role in data gathering ... to modernize supply chain records."**

The tangible benefits offered by blockchain vary depending upon the size of a company and the extent to which a firm is willing to integrate its information systems with those of its suppliers and buyers. To be clear, firms can benefit from blockchain even if they do so solely to improve their own internal processes.

In the short-run, estimates have found an over 50% reduction in human involvement in processes using smart contracts (IBM, 2017). However, the more substantial benefits offered by blockchain, such as improving food safety, will only be fully realized once all market players in a particular supply chain are using blockchain. It can reasonably be expected that, with time, blockchain will become more widely adopted; but at present, firms seeking to use blockchain to improve their food safety performance should expect that a very long time will be needed to realize a return on this investment.

Smart contracts offer one of the more important potential benefits of blockchain for agribusiness firms. Use of a smart contract offers the potential to remove human subjectivity, eliminate human error and reduce the time required to physically complete and document transactions. There is much uniformity of state law concerning e-commerce, via the Uniform Commercial Code. However, parties must agree on questions of venue to resolve disputes and applicability of state law, all before the computer code for using blockchain is written. This is particularly true for goods in interstate commerce.

Finally, an issue that needs to be further explored is the feasibility of automated bank releases of escrow payment funds without human verification—a challenging prospect in the era of cybersecurity concerns. (Adoption of cryptocurrency by blockchain participants would be another alternative). It appears that best practices would dictate that parties to smart contracts develop written agreement concerning state law governance, the forum for resolving disputes, and any quality or grading matters unique to state law.

**Resources**


Deitz, G., Hansen, J., and R. Richey. 2009. "Coerced integration: The effects of retailer supply chain technology mandates on supplier stock returns. International Journal of Physical Distribution & Logistics Management 39(10): 814-825. www.emeraldinsight.com/doi/full/10.1108/09600030911011423

Haber, S., and S. Stornetta. 1991. "How to time-stamp a digital document." Journal of Cryptology 3: 99-111. https://doi.org/10.1007/BF00196791

IBM. 2017. "Using Blockchain to disrupt trade promotions." IBM Cognative Process Transformation. White Paper. August 2017. https://www.ibm.com/downloads/cas/MJ3R0A4K

Landt, J. 2005. "The history of RFID." IEEE Potentials 24(4): 8-11. https://ieeexplore.ieee.org/abstract/document/1549751

Shin, S. and B. Eksioglu. 2015. "An empirical study of RFID productivity in the U.S. retail supply chain." International Journal of Production Economics 163: 89-96. https://doi.org/10.1016/j.ijpe.2015.02.016



**Heidi Schweizer**

Extension Specialist and Assistant Professor of Agricultural and Resource Economics at NC State. Her commodities markets research focuses on production, supply chain management, and transportation.



**Kathryn A. Boys**

Assistant Professor of Agricultural and Resource Economics at NC State. She conducts research on international trade, food supply chains, local food systems, and food safety issues.



**Andrew Brannan**

Assistant Extension Professor of Agricultural and Resource Economics at NC State. He is a lawyer who concentrates in agriculture, real property, and natural resource law, with a focus on farm and land succession.