Blockchain and Smart Contracts as a Supplement to Solve Food Supply Chain Inefficiencies

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Contents:

Introduction

The integration of blockchain technology and smart contracts into the agricultural supply chain has garnered significant attention in recent years. As the sector continues growing and changing, ensuring food security, transparency, and efficiency becomes paramount. An estimated 62.5 million tons of food is wasted every year in the US, with most of that waste happening before food arrives at the customer's table.[1] Some common causes of food waste across the supply chain are due to inefficiencies like asymmetric information, significant lag time between processes, and inadequate inventory management. This paper explores how blockchain and smart contracts can address critical challenges to decrease friction and ultimately reduce waste along the food supply chain.

History and Background:

The idea of blockchain and smart contract technology has been around for almost thirty years, yet the implementation of it is very surface level and still has not been popularized in the workplace. While the first mention of these digital protocols were proposed by Nick Szabo in 1998, the idea never came to fruition until the pseudonymous entity, Satoshi Nakamoto created the first blockchain in 2008 to serve as a digital currency–Bitcoin.[2] It was created to fight against malicious attacks from third-party bad actors that were able to insert themselves between a two-party transaction. For example, if person *A* gets their credit card stolen by person *C*, the credit card company (person *B*) is able to flag sketchy transactions, but is never truly able to verify if the transaction was made by the credit card owner (person *A*), or the credit card thief (person *C*). In this case, the transaction is meant to be between person *A* and person *B,* but a malicious third-party, person *C,* intervenes. This leads to credit card fraud and disputes which usually result in the credit card company refunding the charges to the card owner and taking the loss. The use of blockchain technology aims to get rid of that friction by creating a single transaction history log that connects everyone in the world, visible by everyone in the world.

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[1] MissionPoint Partners. "A Roadmap to Reduce U.S. Food Waste by 20 Percent." ReFED, 2016.
[2] "History of blockchain | Technology." n.d. ICAEW.com. Accessed April 26, 2024. https://www.icaew.com/technical/technology/blockchain-and-cryptoassets/blockchain-articles/what-is-blockchain/history.

Product Characteristics:

Blockchain has a few main characteristics that differentiates it from traditional forms of accounting and data confirmation. The first main characteristic is that it is decentralized. While blockchains are required to be initially coded and launched to the world, a true blockchain is not controlled by a centralized entity to verify what information is uploaded. This is due to the nature of them being built off of smart contracts. Smart contracts are programmable self-executing code that is contingent on certain parameters being fulfilled to execute. Using smart contracts allows for automated transactions to be initiated, regardless of the identity of either party in the transaction. An analogy commonly used is an "if-then" statement in computer science. This contributes to its notion of being decentralized, as no personal identification is needed to host a transaction.

Another characteristic of blockchain is its immutability. Each transaction is date and time stamped. Once a transaction is confirmed, it is added to a running chain of transactions that cannot be changed. If someone were to try to alter a past transaction, proof of that transaction being changed would be added to the running chain, and the discrepancy between the altered and original version would be evident.

Decentralization and immutability is important because it gets rid of biases often prevalent in peer to peer transactions. Social status, race, or past interactions are just some biases that can often influence how smoothly a transaction occurs. By having decentralized, automated processes through a blockchain, human error can be mitigated and can help improve efficiency.

The combination of these two characteristics allow for transparency between everyone who has access to the blockchain. Transparency is important not just in blockchain, but in the supply chain also. When addressing inefficiencies between supply chain processes, it can affect things like hedonic pricing when working between sellers and buyers, and build consumer trust between vendors and consumers. In addition, it can have an effect on performance risk and reliability risk, which will be touched upon later.

Relevance

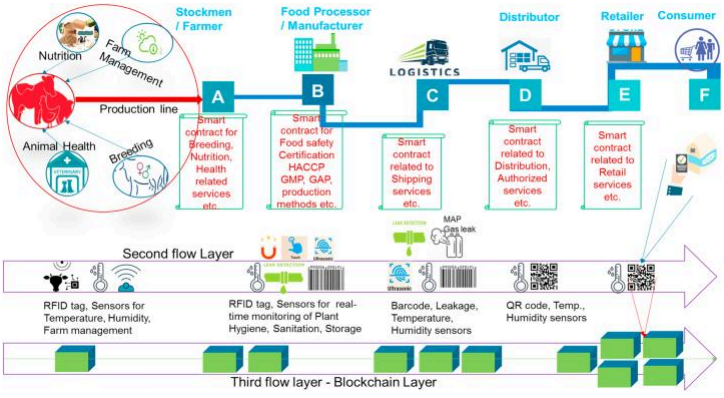
Blockchain and smart contracts are relevant to the viability of the agricultural supply chain as the qualities of the technology are highly applicable to reduce friction in existing operations. Information asymmetry between farmers and their retail partners often lead to costs

that are ultimately borne by the consumer, without their knowing. Using data from blockchain technology, hedonic pricing can more accurately price products, leading to greater consumer trust. The use of self-executing contracts based on prerequisites can increase transparency and lead to less lag time between processes. In regards to food safety, a single standardized log of accounting can lessen the chance of foodborne illness outbreaks. Lastly, a more efficient way of tracking food safety can lead to less food waste and put less stress on the environment.

Information Asymmetry:

The integration of smart contracts into the agricultural supply chain can mitigate information asymmetry. From production to distribution to consumption, information asymmetry creates friction that can often be harmful to each member of the supply chain.

Suppose a restaurant wants to source high-quality beef. Traditionally, they rely on suppliers' claims. In fact, a 2019 joint survey from the Center for Food Safety, Consumer Reports, and Natural Resources Defense Council among others showed that "out of the 21 top [US fast-food] chains that serve beef, 15 (71 percent) received failing grades for failing to take action beyond legal compliance with FDA Guidance[…] to address" a meaningful responsible antibiotic use policy for their beef supplies.[3] With the introduction of blockchain, restaurants would be able to verify the entire history of the beef—from the cattle's diet and health to the processing methods.[4] Existing methods of real-time tracking, like RFID tags, combined with temperature sensors, humidity sensors, and farm characteristics would allow for every member of the supply chain to have an immutable record of every process that happens when producing beef–from



[3] "CVM GFI #213 New Animal Drugs and New Animal Drug Combination Products Administered in or on Medicated Feed or Drinking Water of Food-Producing Animals: Recommendations for Drug Sponsors for Voluntarily Aligning Product Use Conditions with ..." 2018. FDA. https://www.fda.gov/regulatory-information/search-fda-guidance-documents/cvm-gfi-213-new-animal-drugs-and-new-animal-drug-combination-products-administered-or-medicated-feed.

[4] Patel A.S. 2023. ""Blockchain technology in food safety and traceability concern to livestock products."" NCBI. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10230213/.

health of the cow to constant temperature of refrigeration, to distribution times–all in one place.

The ability to record public information accessible to each member of the supply chain would mitigate adverse selection as each player in a negotiation would not have an upper hand over the other, as the contracts require a certain set of fulfillments in order to execute. With perfect information sharing, previously hidden characteristics would be known by each party. Moral hazard would also be reduced as the sellers can no longer participate in riskier decisions based on the imperfect information and will bear the full cost of the risk. Currently, the Food Safety and Inspection Service (FSIS) is the governmental body that regulates the claiming of labels related to animal raising standards. This includes terms like "pasture-raised" or "no hormones added." These labels have required documentation but are still misleading to purchasers of the product. For example, "pasture-raised" is a term commonly found on egg carton packaging. However, real "pasture-raised" status requires a third party certification and gets the certification of any of the following: Certified Animal Welfare Approved by AGW (A Greener World), Certified Grassfed by AGW, Certified Non-GMO by AGW and Certified Regenerative by AGW.[5] None of these labels include the term "pasture-raised;" while legal, this form of greenwashing can lead to lapses in information between parties.

A real world application of blockchain technology for the meat industry would be to require farmers to log all data and upload certified pasture-raised certifications to the blockchain. These certifications and information on health statistics would be passed through each step in the supply chain process, from shipping to retail stores to the final consumer. By implementing a more transparent way to price products, the fair market price will be reflected onto the consumer, and hedonic pricing will be more accurately reflected. Below is an example of a hedonic regression on the factors: meat quality, pasture-raised status, input costs.

$$\text{price} = \square_0 + \square_1 \text{meat\_quality} + \square_2 \text{pasture\_raised} + \square_3 \text{input\_costs} + \ldots + \varepsilon$$

If $\square_2 = 5$, for example, a consumer would on average, pay $5 more for a certified pasture-raised product. When consumers are allowed to lack transparency in the true characteristics of their products, consumers will end up paying more. In contrast, those who have confidence in the products they are buying might end up paying more anyways, on their own

[5] "What is "Pasture-Raised"? -." 2021. A Greener World. https://agreenerworld.org/a-greener-world/what-is-pasture-raised/.

volition. Label Insight's Transparency ROI survey revealed that 78% of consumers trust transparent brands more… transparency is so important to consumers that it actually increases a product's worth in their minds. Almost three in four consumers (73%) say they would be willing to pay more for a product that offers complete transparency.[6]

Walmarts in China and Hyperledger Fabric, a blockchain based company, in collaboration with IBM have been implementing these considerations in real time. For pork in China, "it allowed uploading certificates of authenticity to the blockchain, bringing more trust to a system where that used to be a serious issue." While increasing consumer confidence in China, it has also been instrumental in tracing for possible food borne illnesses.[7]

Real-time tracking and transparency would decrease performance risk as mentioned above, and reliability risk would be decreased as immutable records would allow for proper verification before making decisions and would ensure validity over any amount of time. In addition, automated processes can decrease reliability risk as smart contracts could handle logistics, decreasing the need for human intervention, which is often time consuming and costly.

Food Traceability and Inventory Management:

Food safety and inventory management is a key point of emphasis when talking about food supply chain inefficiencies. The World Health Organization estimates that an estimated $110 billion is lost each year in productivity due to illnesses resulting from unsafe food.[8] In the US, the most recent amendment to the FDA's Food Safety Modernization Act (FSMA) was the "Requirement for Additional Traceability Records for Certain Foods." On this "certain foods" list included: raw meats, cheese, shell eggs, fish and shellfish, ready-to-eat deli salads, among others.[9]

This new amendment aims to find a solution to the existing FDA regulations on food traceability. Currently, it functions through a "one-up and one-back" traceability system. This

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[6] Forbes and Jeff Fromm. 2017. "Why Label Transparency Matters When It Comes To Millennial Brand Loyalty." https://www.forbes.com/sites/jefffromm/2017/12/13/why-label-transparency-matters-when-it-comes-to-millennial-brand-loyalty/?sh=6b8b40f63dac.

[7] "How Walmart brought unprecedented transparency to the food supply chain with Hyperledger Fabric." n.d. Hyperledger. Accessed April 26, 2024. https://www.hyperledger.org/case-studies/walmart-case-study.

[8] "Food safety." 2022. World Health Organization (WHO). https://www.who.int/news-room/fact-sheets/detail/food-safety.

[9] "Information Paper: FSMA Final Rule on Requirements for Additional Traceability Records for Certain Foods | BRCGS." 2023. brcgs. https://www.brcgs.com/about-brcgs/news/2023/information-paper-fsma-final-rule-on-requirements-for-additional-traceability-records-for-certain-foods/.

means that each member of the supply chain is only required to establish and maintain records to identify immediate recipients and previous suppliers of food. In essence, each member only needs data between two different parties, rather than the whole supply chain. This existing protocol means that "during an outbreak investigation, [the] ability to rapidly track and trace specific food products through the supply chain is often impeded by a lack of data. The result can be millions of dollars in avoidable product loss by necessitating overly broad recalls and consumer advisories, a loss of consumer trust, and prolonged outbreaks of consumer illnesses and deaths."

In fact, it can take companies between several days to weeks to trace foodborne illness outbreaks to the original source. A 2016 experiment between Walmart and IBM aimed to compare blockchain-enabled methods of tracking inventory as opposed to traditional methods in a proof-of-concept study. A Walmart executive went to one of their stores and picked out a bag of sliced mangoes. They then went to the internal team and asked them to trace the origin of the product as fast as possible. Through the "one-up and one-back" system, the team at Walmart managed to respond back with the mangoes' origin in seven days, which was considered good for industry standard. Walmart then ran the experiment again after partnering with Hyperledger Fabric, a blockchain-tracing company. Together, they created a barcode tracking system integrated with blockchain technology. The new tracking method decreased the time it took to trace the mangoes' origin from seven days to 2.2 seconds.[10]

With a shared ledger through the blockchain, end-to-end visibility and a standardized record can be made available to every member along the supply chain. A clearer picture of contaminated food can also decrease the amount of loss as only affected products will be discarded, as opposed to current systems where whole batches are tossed due to unclear, imperfect information. In terms of performance risk and reliability risk, this study showed how using blockchain tracking allows for quicker tracing time, increasing performance in that area. It can also increase reliability as tracing is less reliant on a peer to peer interaction and the time it takes to facilitate those interactions can be lessened due to automation. In Walmart's case, the barcode system that Hyperledger Fabric implemented created a ledger that would be able to be scanned and viewed at any point, decreasing the need to talk to a previous supplier in the "one-up, one-back" system.

[10] "How Walmart brought unprecedented transparency to the food supply chain with Hyperledger Fabric." n.d. Hyperledger. Accessed April 26, 2024. https://www.hyperledger.org/case-studies/walmart-case-study.

Food Waste:

Food waste is a byproduct of supply chain inefficiencies. Much of this waste is due to poor inventory management, which can be mitigated by blockchain, as explained in the previous section. Some examples of poor inventory management include: overstocking, inadequate refrigeration and freezing systems, and inaccurate demand forecasting. One of the biggest causes of waste in the food supply chain, however, is due to the failure of a standardized date labeling system across all members of the supply chain. The following economic analysis illustrates the problem in its scope and compares it to other waste reduction methods.

Economic Analysis

The economic analysis I did was on data from ReFED, a national nonprofit dedicated to ending food loss and waste by advancing data-driven solutions. They carry data on food waste and economic value of that waste on various solutions within action areas, like food waste prevention, food waste rescue, and food waste recycling. This information is compiled for all 50 states, and was last updated in November of 2023. In their database, they cataloged the cost, benefit, and net financial impact for each of their 30+ proposed solutions for each US state.[11] One of these solutions included standardized date labeling; the implementation of blockchain would allow a singular ledger (a standardized date labeling system) which tracks product data throughout the supply chain, reducing waste from consumers being careless or clueless when it comes to "best by" and "eat by" dates. After accessing this public data, I used RStudio, an integrated development environment for the data language R, to clean, parse, calculate and rank the 30+ proposed solutions by annual economic net benefit (in dollars).

In RStudio, I used the "tidyverse" package, which includes the data manipulation package "dplyr" to clean and parse the data. First, I read the .csv data file from ReFED, titled "State Solutions Financial Summary by Stakeholder." I then selected relevant data columns to make the data easier to use, and grouped the data by solution. After grouping the data, I was able to see that there were 42 proposed solutions ReFED tracked data on. From there, I aggregated the data for all the presented solutions, and took the mean on the columns: annual_us_dollars_cost,

[11] "ReFED - Solution database: Standardized Date Labels." n.d. ReFED Insights Engine. Accessed April 26, 2024. https://insights-engine.refed.org/solution-database/standardized-date-labels.

annual_us_dollars_gross_financial_benefit, and annual_us_dollars_net_financial_benefit. Subtracting the annual cost from the gross financial benefit would allow me to find the net financial benefit for each solution. Lastly, I organized the data in descending order for net_financial_benefit.

As we can see from the data manipulation, standardized date labeling was the ninth best solution in terms of net financial benefit as a waste reducing method. While this does not necessarily mean that it would reduce the most waste, we can see that it is one of the most cost-effective methods to contribute to less waste along the supply chain. This is because the costs are relatively low to implement.

Code:

```
library(tidyverse)

data <- read.csv(file = "~/Downloads/foodwaste_data.csv", header = FALSE)
data

ordered_data <- data %>%
  select(V3, V4, V5, V6, V7, V8) %>%
  group_by(V3) %>%
  summarize(mean_cost = mean(as.numeric(V6)),
            mean_gross = mean(as.numeric(V7)),
            mean_net = mean(as.numeric(V8))) %>%
            print(n = 42)

ordered_data %>%
  arrange(desc(mean_net)) %>%
  print(n = 42)
```

Table:

```
# A tibble: 44 × 4
   V3                                          mean_cost mean_gross  mean_net
   <chr>                                           <dbl>      <dbl>     <dbl>
 1 Consumer Education Campaigns                   986927.   86904539. 85917612.
 2 Portion Sizes                                  297052.   60171827. 59874775.
 3 Meal Kits                                     6164303.   61655116. 55490813.
 4 Waste Tracking (Foodservice)                 11824929.   50933757. 39108828.
 5 Manufacturing Byproduct Utilization (Upcycling) 19636229. 47469551. 27833321.
 6 Markdown Alert Applications                   6235947.   31391074. 25155127.
 7 Manufacturing Line Optimization              11742237.   35879356. 24137119.
 8 Active & Intelligent Packaging                3643448.   24166478. 20523031.
 9 Standardized Date Labels                        53800.   19407813. 19354013.
10 Buyer Specification Expansion                   39259.   18433940. 18394681.
11 Donation Education                            1499272.   16673002. 15173730.
12 Imperfect & Surplus Produce Channels         10203244.   23728413. 13525169.
13 Dynamic Pricing                               5480205.   18891517. 13411311.
14 Package Design                                 389497.   12514812. 12125315.
15 Decreased Transit Time                        1797742.   11069584.  9271842.
16 Intelligent Routing                           2203170.   10842792.  8639622.
17 Donation Transportation                       1339146.    9543682.  8204535.
18 Enhanced Demand Planning                      1087437.    9189200.  8101763.
19 Decreased Minimum Order Quantity              1254761.    9268331.  8013570.
20 Donation Value-Added Processing                143774.    7415686.  7271911.
21 Trayless                                       411000.    7392556.  6981555.
22 First Expired First Out                       2102697.    9005286.  6902589.
23 Temperature Monitoring (Pallet Transport)      604574.    5122248.  4517673.
24 Minimized On Hand Inventory                    338226.    4765633.  4427407.
25 Donation Storage Handling & Capacity           957621.    3951410.  2993789.
26 Donation Coordination & Matching               269670.    2865314.  2595644.
27 Assisted Distressed Sales                       34748.    2067143.  2032395.
28 Buffet Signage                                    647.    1764152.  1763505.
29 Increased Delivery Frequency                   416100.    1897482.  1481382.
30 Livestock Feed                                1878270.    3337022.  1458752.
31 Partial Order Acceptance                       475632.    1107800.   632169.
32 K-12 Lunch Improvements                         85840.     701110.   615271.
33 K-12 Education Campaigns                        25066.     302406.   277340.
34 Reduced Warehouse Handling                      54303.     299788.   245485.
35 Small Plates                                    21462.     234727.   213265.
36 Gleaning                                        39278.      83107.    43829.
37 Temperature Monitoring (Foodservice)              365.      28017.    27653.
38 Co-Digestion At Wastewater Treatment Plants    3734886.    3643517.   -91369.
39 Centralized Anaerobic Digestion                4410238.    4067951.  -342287.
40 Community Composting                           2804837.    2227600.  -577237.
41 Centralized Composting                        11078395.   10158692.  -919703.
42 Home Composting                                2966827.    1771754. -1195074.
```

Constraints

While there are many appeals to blockchain technology in the supply chain and in general, there are some areas to consider that can affect its efficacy in supply chain processes. Three of the most prominent areas to highlight are costs, environmental impact, and mainstream adoption and diffusion.

Costs:

One of the common hesitations about blockchain technology is its cost-effectiveness compared to traditional forms of accounting. Many blockchains are incredibly energy intensive, relying on large servers to hold data of each transaction, and many processing units to verify and execute each smart contract. The amount of electricity typically scales with the amount of information in each transaction, so it is not a completely free method of tracking.

Each transaction has a cost called *gas,* akin to that of gas for cars. It is a fee required to pay the blockchain that helps reward the nodes, or computers, who are verifying the transaction, as well as keep deflationary pressure to prevent the double-spend flaw.

Still, recent improvements in blockchain technology have found ways to make these processes more energy and cost efficient. For example, the introduction of layer two modular networks have greatly increased capabilities and access for the everyday user. Layer two networks are applications and platforms built on existing blockchains such as Ethereum. They use the expensive base layer as a security layer, while using their own native platform to bundle up transactions and then authenticate and sign.[12] An analogous current process is taking a folder of .pdf, .jpeg, .doc files and creating a .zip file to send to a friend. The data inside that .zip file is bundled up into a single file, saving storage space and decreasing the time it takes to send.

Environmental Impact:

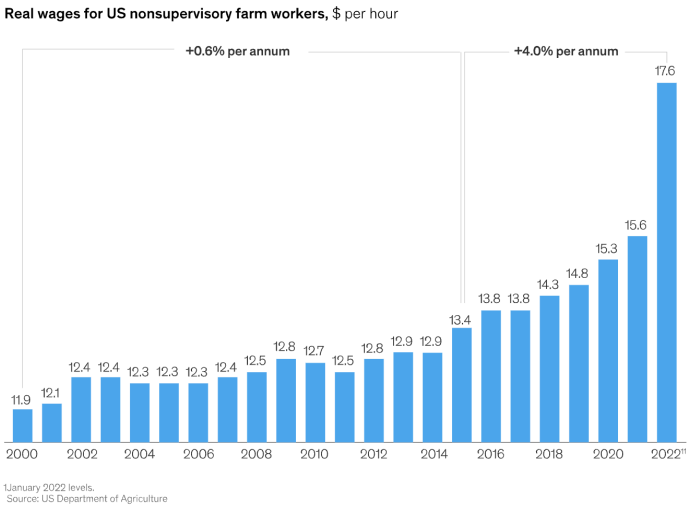
Another critique is a blockchain's heavy impact on the environment. Heavy computational intensity leads more energy use and in turn leads to a greater carbon footprint. Beyond the mention above of ways to cut down on emissions such as building eco-friendlier layer two applications, there are companies innovating to introduce climate friendly alternatives that are less carbon intensive. The biggest change in creating an environmentally friendly

[12] Das, Lipsa. 2024. "What Are Ethereum Layer 2 Blockchains and How Do They Work?" Ledger. https://www.ledger.com/academy/topics/blockchain/what-are-ethereum-layer-2-blockchains-and-how-do-they-work.

initiative is the switch from Proof-of-Work (PoW) to Proof-of-Stake (PoS). The first blockchains historically worked through PoW mechanisms. Miners would verify transactions by solving complex cryptographic puzzles to create new blocks to add to the blockchain. This often required energy intensive computers. Now, more blockchains are switching to PoS protocols, where validators stake collateral in order to have a chance at being chosen to verify transactions. PoS protocols have the ability to be as energy efficient as checking an email or sending a text message, which has led to a more accessible and mainstream adoption.

Adoption and Diffusion:

The last constraint of blockchain and smart contract technology is the adoption and diffusion in a workplace setting. Challenges like the initial cost of implementation and education to new technology can hinder adoption throughout the world. Automation is currently being used in processes like planting and seeding, harvesting, and soil sampling. Still, a 2022 McKinsey Farmers Global Insights Survey saw that "less than 5 percent of farmers across Asia, Europe, North America, and South America are using [automation], compared with 21 percent using farm management software."[13] Still automation through smart contracts can have an effect on the labor challenges that farmers currently face. "Real wages have increased at a faster rate in previous years, increasing economic pressure on farmers." The US Department of Agriculture has seen an average four percent increase in real wages for US nonsupervisory farm workers per hour since 2015, as opposed to 0.6 percent average in the twelve years prior.



[13]Bland, Rob, Vasanth Ganesan, Evania Hong, and Julia Kalanik. 2023. "Trends driving farm automation | McKinsey." McKinsey & Company. https://www.mckinsey.com/industries/agriculture/our-insights/trends-driving-automation-on-the-farm.

public support for its adoption. By nature of it being decentralized, many countries have been staunch proponents or hesitant to create legislation to support it. Countries like China, the Netherlands, and Saudi Arabia have all written legislation to ban cryptocurrency. Still, many remain hopeful as blockchain technology is not synonymous with cryptocurrency and have other value propositions beyond just financial payment systems.

In terms of fit, the companies that will drive the support for adoption are most likely larger companies, like Walmart. Walmart is a large company that is both horizontally and vertically integrated. Walmart owns and operates stores, warehouse clubs, distribution centers, and a trucking fleet to meet the needs of their customers.[14] Having control over many processes can already decrease lag time between processes, so instead of creating a whole new correspondence system between different companies, Walmart would have an easier time supplementing and replacing some of their internal processes to accommodate blockchain technology. Another benefit to larger companies adopting first would be the fact that smaller companies can learn from Walmart in what works and what doesn't. While a concern would be that the smaller companies might lose value by adopting later, an argument could be made that there is less risk in adopting a new technology that has proof of concept, and the value lost by adopting later could be less than the value lost if the smaller company were the first to take on the fixed costs, experimentation and implementation costs that come with a new technology.

Conclusion/Recommendations

In conclusion, smart contracts and blockchain technology can further revolutionize the already changing agricultural supply chain. The ability to have an immutable tab of every transaction can not only make processes smoother and more transparent within each step in the supply chain, but also increase transparency between the companies and their consumers.

A recommended application for smart contracts in the current supply chain is the use of immutable and transparent tracking coupled with existing RFID technology as a supplement for tracking processed red meats. Each cow is tagged with an RFID barcode, with information on feedstock, medication, and breeding habits. In addition, any certifications from AGW or another third party can be uploaded and logged. Once animals are processed and sent to meatpacking facilities, temperature, humidity, and process time can be logged. During shipping, method of

[14] Kenyon, Matt. 2023. "The game-changer for eCommerce: vertical supply chain." Linnworks. https://www.linnworks.com/blog/supply-chain-verticals/.

transport, date and time, and payment can be sourced on the blockchain. An estimate from Kaitlin Wowak, associate professor of IT, analytics and operations at the University of Notre Dame estimated that “80% of food products involved take around 10 months for the issue to be resolved, and the product to be removed from the market.” In the event of an illness outbreak, the Walmart study showed that blockchain technology can decrease this time for food to be traced back to its source.

The integration of blockchain technology and smart contracts into the agricultural supply chain has garnered significant attention in recent years and continues to grow and optimize. Its applications can help decrease supply chain inefficiencies like asymmetric information, inventory management failures, and communication lag times. This technology can supplement current processes to decrease friction and reduce waste along the supply chain.

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