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Blockchain Technology in International Commodity Trading

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Abstract
A blockchain is a distributed, public or private digital ledger that uses cryptography to record transactions across computer networks to prevent records from being altered retrospectively. This paper illustrates the impact of blockchain technology on total cost, time, and risk in international commodity trading using a hypothetical case of soybean trade from Jamestown, North Dakota, to China. The results suggest that the savings include 2.3 cents per bushel of soybeans and a 41 percent reduction in the total time, including documentation and transit time. Further, the 5 percent value-at-risk model shows a reduction of 2.6 cents per bushel of soybeans traded using blockchain technology. These results are significant for agribusinesses and other agricultural stakeholders who are evaluating the benefit of adopting blockchain technology in international commodity trading.

JEL Codes: Q13
Keywords: soybeans, international trading, blockchain technology, agriculture

I. Introduction

Agriculture is a unique industry in that most food products are perishable, requiring close attention to enable their efficient flow through the supply chain in what is generally referred as farm-to-market. International trade in agriculture makes the farm-to-market

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flow even more difficult. In addition to the significant costs and losses incurred along the agricultural supply chain, the scale of transactions is large, documentation requirements are extensive, transactions are sometimes fungible (interchangeable), and banking approvals are critical to the expeditious and efficient execution of transactions.

Transparency, traceability, and efficiency are three important aspects of the agricultural supply chain. First, transparency is important because some consumers are interested in knowing the source or origin of their food. Lack of transparency decelerates the farm-to-market flow because it takes time (days to weeks) to track a food product's origin and information about the relevant parties across its supply chain (Hackett 2017). There is an added element of phytosanitary and other forms of certification in the international trading of commodities that requires the declaration of country of origin. In the case of international trading, Maersk was one of the first shipping companies to use blockchain technology to electronically track its cargo shipments through the customs process (Hackett 2017). Within bulk commodities, blockchain has largely been adopted in energy and oil trading (Payne 2018) and is being developed for grains (as discussed below).

Second, in some markets, traceability plays a significant role in the event of any food contamination originating from a certain location. For example, in April 2018, the *E.coli O157:H7* contamination of romaine lettuce led to approximately two hundred illnesses and five deaths in the United States (Phillips 2018). It was several weeks before the Centers for Disease Control and Prevention (CDC) found the source of contamination, a farm in the Yuma region of Arizona (CDC 2018).

Third, supply-chain efficiency is key in minimizing food losses due to spoilage and minimizing the time for the food to reach the final consumer. In the case of international trading, inappropriate documentation or any action that detracts from efficient shipping and execution results in additional costs, including demurrage and penalties.[1]

One method of facilitating the transparency, traceability, and efficiency of the agricultural supply chain is blockchain technology. A blockchain is a distributed, public or private digital ledger that uses

[1] Demurrage is a fee paid to the owner of a chartered ship in case of a failure to load or discharge the ship within the mutually agreed time frame.

cryptography to record transactions across computer networks to prevent records from being altered retrospectively (Carson and Higginson 2018). Blockchain technology has the potential to be widely used in the agricultural trade to make characteristics of the commodity transaction easily accessible to buyers, traders, and other entities across the supply chain. A blockchain solution involves relevant participants, including growers, first buyers (country elevators and agribusiness firms), intermediaries, exporters, bankers, and end users (food processors who crush soybeans into soybean oil and meal). In the food industry, which is part of the broader agriculture industry, the blockchain solution could include farmers and growers, food processors, wholesale and retail outlets, and final consumers.

Many groups have explored development of blockchain technology in different markets, including agriculture and food in particular. For example, in December 2017, IBM, Walmart, Jingdong (JD), and Tsinghua University collaborated to form the Blockchain Food Safety Alliance to revolutionize transparency in the agricultural supply chain (IBM News 2017). More recently, Archer Daniels Midland, Bunge, Cargill, and Louis Dreyfus Co. (ABCD) have come together to establish a blockchain platform that will automate posttrade processes in grain and oilseeds (Plume 2018; Donley 2018). Later, COFCO International, the largest food and agricultural company in China, joined ABCD to participate in the blockchain platform (AP News 2018).

Similarly, Marco Dunand from Mercuria Energy Group, as discussed in Terazono (2018), indicated that his company experimented with an oil shipment from Africa to China. Using conventional procedures, the transfer of documents took forty days, while it took four days to transfer the documents using blockchain. This efficiency resulted in substantial cost savings.

This paper evaluates and illustrates the benefits of using a blockchain platform for grain or oilseeds contracts in international trading. Specifically, we focus on addressing inefficiencies in the traditional grain supply chain where the seller is a trading firm that operates in the United States and the buyer is an importing firm that operates in a foreign country.

We discuss the traditional supply chain and the documentation involved in the commodity grain trade. Then, we discuss the blockchain solution and how it reduces inefficiencies in the current supply chain system of grain trade. Later, we illustrate the comparative analysis of base-case and blockchain-case scenarios applied to a hypothetical soybean shipment from Jamestown, North Dakota, to a port of destination in China using Monte Carlo simulation. Finally, we provide other applications of blockchain technology in the food industry.

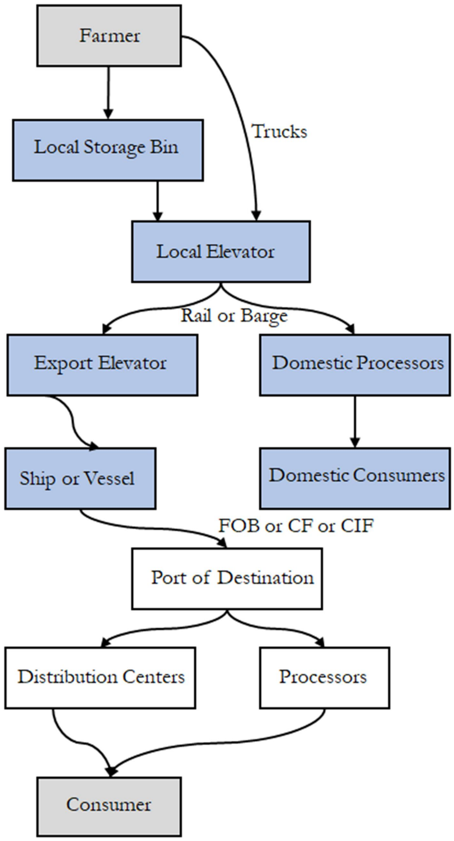
II. The Supply Chain and Documentation in the Commodity Grain Trade

Terazono (2018) describes several efforts toward digitization in commodity trading. One is the automation of commodity transactions, and it indicates a 26 percent increase in the digitization of automated trades in grains and oilseeds. While meaningful, this increase is much less than that seen in other commodities and equities. Another is the use of blockchain technology, which is particularly attractive in the food industries, and in commodities to the oil and energy sector. Adoption in the grains and oilseed trade is evolving slower.

This study focuses on the supply chain of grains in international trade. The international commodity trade from point A to point B is an extensive process with multiple parties, documentation and certificates, transaction costs, time, and inefficiencies at each point across the supply chain, all intertwined with the bureaucracy of banks and certification agencies. Across the supply chain, documentation is required among the different participants, including buyers, sellers, transportation and logistics companies, financial institutions (banks), and government institutions (United States Department of Agriculture/Federal Grain Inspection Service) for the smooth flow of the commodity from the seller to the buyer.

Figure 1 illustrates the typical flow of grain from a farmer in the United States to a consumer in another country. Though this study focuses on the international grain market channel, the figure includes the domestic channel as well because the latter provides competitive pressure to the farmer.

Figure 1. Typical flow of grain to domestic and international markets



Source: Created by the authors.

As the figure shows, depending on the expectations for the price of grain, farmers either store their harvest in their own storage bins or sell their harvest to local grain elevator firms. Next, depending on grain demand in the foreign market, the agribusiness firm, which typically owns an export elevator, contacts the local elevator firms with a price quote. If it finds agreeable contract terms, the agribusiness firm (with an export elevator) agrees to buy grain from the local elevator firm. Then, the grain is shipped from the local elevator to the export elevator via rail or barge. Depending on the contract between the agribusiness firms (between the seller at the port of exit and the buyer at the port of destination), the grain is loaded into a ship or a vessel for delivery.

The contract between the seller and the buyer could be freight on board (FOB); cost and freight (CF); or cost, insurance, and freight

(CIF) (table 1). Once the grain reaches the port of destination, the grain is either sent to the local distribution centers in the foreign country and finally to the end consumer, or it is sent to processors before it reaches the final consumer in the foreign country (US Soybean Export Council 2011).

Table 1. Payment responsibility based on sales contract

		Contract terms		
	Attributes	**Freight on board**	**Cost and freight**	**Cost, insurance, and freight**
1	Arrange a vessel at port of exit	Buyer	Seller	Seller
2	Marine insurance	Buyer	Buyer	Seller
3	Import license	Buyer	Buyer	Buyer
4	Cost of moving grain at loading and discharge points	Buyer	Seller	Seller

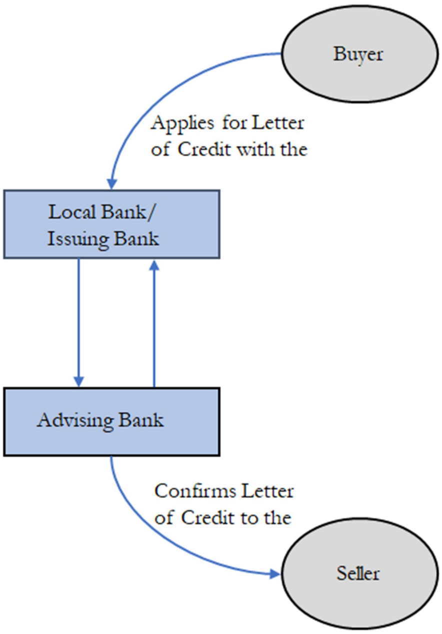
Source: Compiled by the authors using information from Slabotzky (1984).

The type of contract (FOB/CF/CIF) between the buyer at the port of destination and the seller at the port of exit determines who pays for and arranges the shipping cost. Table 1 provides examples of these types of contracts. If the contract between the seller and the buyer is FOB, then the seller's delivery of the goods to the buyer is completed when the grain is available to load at an agreed time at the port of exit, where the buyer is responsible for the transportation and marine insurance costs of the grain (Slabotzky 1984). If the contract between a seller and a buyer is either CF or CIF, then the seller is responsible for the transportation and marine insurance costs of the grain.

Also, as illustrated, the costs of loading and discharging the grain at the port of exit and the port of destination depend on the type of contract. In the case of FOB sales, the buyer is responsible, while in the case of CF and CIF sales, the seller is responsible.

In international trade between buyers in foreign countries and sellers in the United States or other exporting countries, the buyer contacts the seller with a proposal to buy grain that meets specifications such as quantity, price, time and place of delivery, and payment terms. Once both the seller and buyer agree on the specification requirements, the seller sends a price quote with similar specification requirements to the local elevator firms. Concurrently, the foreign buyer applies for a letter of credit (as per the payment terms in the contract) with a local bank in its own country (the opening bank), which in turn contacts the seller's bank (the advising bank) in the United States about approving the buyer's letter of credit (Slabotzky 1984). The advising bank confirms the status of the buyer's letter of credit to the seller. Sometimes, both the opening bank and the advising bank might be the same bank with an international presence.

Figure 2. Banks and firms: Process of obtaining a letter of credit



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Once the letter of credit is confirmed, the seller is given a pre-advice period of at least ten days to plan for loading the grain into the vessel at the port of exit (Slabotzky 1984). Ideally, it is advised that the seller should not start the delivery arrangement before receiving confirmation of the letter from the buyer.

The seller is responsible for obtaining various documents, depending on the grain or commodity, the port of destination, and the type of sale (FOB/CF/CIF). In general, shipping documents include weight and inspection certificates issued by a reliable third party agreed upon by both the seller and the buyer, and certificates for protein content, phytosanitary requirements, and country of origin, as specified in the standard contract language (Slabotzky 1984). Sometimes, the seller is also required to obtain a stowage certificate certifying that the ship or vessel was cleaned before loading the grain into the vessel (Slabotzky 1984).

For traditional bulk shipments on nondifferentiated commodities, the marketing system has evolved and is fairly efficient. Traditionally, the predominant purchase method was cash against documents (CAD), which occurred at the shipment's origin. CAD still applies to some shipments. Typically, in the case of CAD, documents must be presented to the bank for the seller to request payment prior to loading the grain. If documents do not arrive on time, shippers have to pay demurrage (Ehmke 2019).

More recently, CAMR (cash against mate's receipt) has become common. In the case of CAMR, the shipper gets paid upon the receipt of documents by the bank in the importing country. The normal transit time for the load to reach the destination is approximately fourteen days. Typically, it takes one to two weeks to prepare documents, although in some countries, document preparation can take months. There is often a degree of uncertainty about whether documents will be ready at the time the vessel or ship arrives at the port of destination. In such a case, the seller can purchase a letter of indemnity that acts as an insurance policy to protect both the seller and buyer from penalties and demurrage.

While this system is already fairly efficient, blockchain technology has the potential to accelerate the execution of transactions, reduce risks to participants across the supply chain, assure delivery times, and facilitate traceability; altogether, it reduces transaction costs. A challenge for blockchain technology in nondifferentiated grains and oilseeds is that it will be hard to lower costs when payment occurs within twenty-four hours (say, in the case of CAMR).

III. Blockchain Technology

A blockchain is a public or private digital ledger technology that is distributed, cryptographic, and immutable. Distributed means that many computers with fully participating nodes in various locations share a copy of the transactions, as opposed to using a traditional, centralized database. Cryptographic means that the transactions are verified cryptographically: that is, using hashes. Immutable means that the information is added to the chain in append-only fashion (Burniske and Tatar 2017).

Beginning in 2008 with the digital currency experiment bitcoin, the application of blockchain technology has evolved over time. Given bitcoin's success, it is no surprise that applications of blockchain technology have quickly spread to many industries, including agriculture, to improve business operations.

Additionally, major innovations surrounding blockchain technology include addressing scalability issues and improving consensus protocols for verifying transactions in the blockchain. Our paper primarily relies on the use of blockchain-based "smart contracts" in the context of international trading and how they can reduce efficiencies and benefit businesses in conducting settlements and transactions.

A. Smart Contracts

International grain marketing often deals with proprietary details, including orders, margins, quantity, and prices of goods traded (Alicke et al. 2017). Therefore, a private and permissioned blockchain is best suited to the grain-marketing use case. A *private* blockchain allows only a few selected participants to be part of the blockchain in order to access or read its content. A *permissioned* blockchain allows the selected participants to be involved in processing transactions or validating that blockchain.

Several stakeholders, including the buyer, the seller, banks (both local and advising), shipping agencies, customs, and the Federal Grain Inspection Service, are involved in the international grain trade. Currently, the process of acquiring and transferring the documents between the parties is tedious. To streamline the process, stakeholders can come together to be part of a smart contract. The term "smart contract" has been used since 1994 (Szabo 1994), and the technology has become popular because it is useful for creating digitized contracts and streamlining the contract process by either eliminating or changing the role of intermediaries. A smart contract is a predefined trigger event written in the form of a programmatic code in a blockchain to automate an action or an event between untrusted or partially trusted parties.

Ethereum is an open blockchain platform where decentralized applications (DApps) are built for arbitrarily complex computations in the Ethereum Virtual Machine (EVM) (Ethereum 2017).[2] In simple terms, a DApp is a blockchain-enabled website in which a smart contract is a back end that connects the DApp to the blockchain. The Ethereum blockchain essentially tracks the states and

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[2] Although Ethereum is a public ledger, this paper refers to Ethereum in the context of its private implementation designed to create a network, deploy nodes, and select the participants to make a permissioned network.

their transitions, including the transfer of value or information between the accounts (Ethereum 2017).

In Ethereum, there are two types of accounts: externally owned accounts (EOAs) and contract accounts (CAs). EOAs are owned and accessed by network participants using their private keys. CAs are governed by the contract code (smart contract) and are prompted by a user with an EOA using the contract address (Ethereum 2017). Using their accounts, the network participants interact with the Ethereum blockchain via *transactions* while a smart contract interacts with other smart contracts via *messages* (Ethereum 2017).

Typically, EOAs exist for those peers or users who are involved in receiving or sending ether, a cryptocurrency in the Ethereum network, which is used to pay for the "gas" or computing power needed to process the smart contract.[3] The user (with his or her EOA) interacts with a smart contract using its address. Every contract has its own address, which is akin to a wallet address, usually starting with "0x" and followed by letters and digits. The blockchain is immutable, which means that one cannot edit the smart contract at its original address after it is deployed onto the blockchain. However, a smart contract can be edited, recompiled, and redeployed to create a new contract (address).

In general, a computer has three important functions: complex computation, file storage, and communication between the computer and its user. Similarly, at a high level, the Ethereum network consists of different components, including smart contracts, the EVM, Swarm, and Whisper, which together enable the Ethereum network to operate as a "world computer." Each component has its own function in the Ethereum blockchain. As mentioned earlier, smart contracts serve as a backend that connects both the DApps and the blockchain. The EVM is an application server that processes the programming functionalities of the smart contract. Essentially, the contracts are compiled prior to deployment in the blockchain because the EVM stores the contracts in the form of bytecode. Swarm is an application useful for hosting the files that are sent to the blockchain through DApps. Finally, each component of the Ethereum blockchain interacts with other components via a decentralized message or communication through Whisper.

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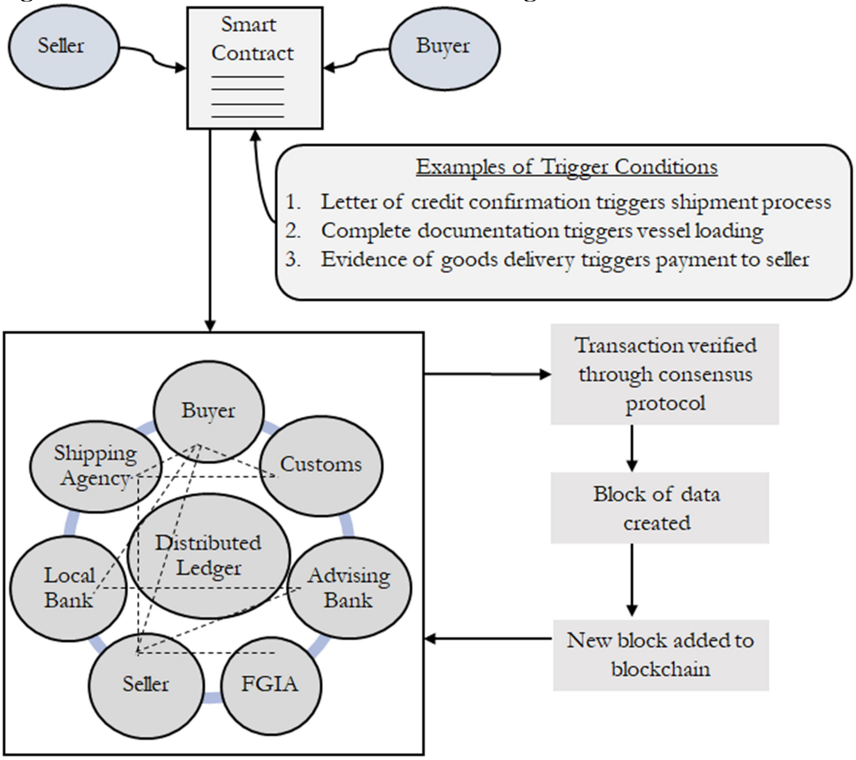
[3] A fraction of an Ethereum token is called gas. Gas refers to the fee required to successfully execute a smart contract on the Ethereum blockchain. The fee is based on the computational work required to execute a smart contract.

Depending on the agreement, several trigger conditions or events are programmed into the smart contract. In our study, the examples of possible trigger events in a smart contract include (1) a sales contract (along with a letter of credit) between buyer and seller triggers the shipment of goods with a reminder to the seller, (2) a complete documentation triggers the loading and movement of the goods into the vessel, and (3) passing the initial inspection of the goods delivered to the buyer triggers the payment settlement to the seller.

In our study, figure 3 shows the distributed ledger consisting of all the stakeholders involved in the international grain trade. Specifically, the smart contract is agreed upon and signed between the buyer and the seller with predefined conditions. Consider an example of predefined trigger conditions: delivering goods to the buyer in a mutually acceptable condition triggers the transfer of payment to the seller. The buyer, using their EOA, sends a transaction to a smart contract to emit an event that is picked up by a backend application running on a server, which in turn makes a corresponding request (on behalf of the user) to a local bank to transfer payment to the advising bank. At this point, the settlement between the buyer and seller is complete. This transaction is broadcasted to all the participating nodes of the distributed ledger (the blockchain), resulting in the creation of a new block (Sekar 2019). As part of the validation, participating nodes then run the EVM to process the smart contract and eventually check for the sync in the data across all the nodes to maintain consensus in the blockchain. In simple terms, this means that the participating nodes validate the successful execution of the smart contract.

Figure 3. Blockchain solution for international grain trade



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The financial institutions in the above case act as a costly intermediary. The potential exists to eliminate these intermediaries in the grain commodity supply chain under the condition that both parties to the smart contract agree to a payment settlement in a cryptocurrency—Ether, in our case. However, at present, most parties would not agree to a payment settlement in cryptocurrency due to high volatility in its value. Therefore, the parties typically facilitate a payment settlement in US dollars, which need a trusted third party in the form of banks between the buyer and the seller.

B. Blockchain Solution

The process of obtaining multiple documents has evolved to be fairly efficient for many shipments. However, the risks, costs, and significant time lags in documentation offer potential for improving efficiency. In addition, as noted above, costs and time lags are greater for more differentiated agricultural commodities. In the case of grains and oilseeds, costs and time lags are particularly important for organic, nongenetically engineered, and other specifications that require additional documentation, including documentation of testing and certification. Additionally, it may take several weeks to obtain the required documents, with issuing and confirming the letter of credit taking the longest.

How long it takes to obtain various documents is significant in the context of agriculture for various reasons. For example, many agricultural products are perishable; agricultural commodity prices are volatile because of constant exposure to contingencies in the weather and shipping; and transportation costs related to shipment delays are expensive. Most trading firms do not account for delay costs in their operating budgets. Therefore, any disruption in the supply chain diminishes trading profits.

In the case of international grain sales, the settlement between the buyer and seller is completed when the seller's bank (the advising bank) is credited with money from the buyer's bank (the opening bank), and when the buyer has possession of the commodity grain from the seller. The reconciliation process comes into play in verifying whether (1) the letter of credit is in line with the sales contract, (2) the commodity obtained by the buyer meets the specification requirements, and (3) the commodity reaches the buyer at the requested delivery date.

To reduce inefficiencies in settlement, reconciliation, and documentation involved in the above transaction, as well as to allow the buyer and seller to access the information in (almost) real time, a "smart contract" using the Ethereum blockchain and involving all relevant participants could be beneficial. The relevant parties in the proposed blockchain include agribusiness firms (both buyer and seller), the Federal Grain Inspection Service, shipping and logistics companies, financial institutions such as the buyer's and seller's banks, oracles (more on this later),[4] local elevator firms, and so on.

In international grain sales, a blockchain solution involving all relevant participants could minimize the inefficiencies in the system. The blockchain solution particularly reduces transaction costs, risks, and time for the settlement of transactions between the buyer and seller. Blockchain technology has the ability to reduce transaction costs and risks in international trading. An example is the courier fees for sending the documents to the issuing bank so that the buyer can

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[4] A blockchain oracle is a trusted third party that provides off-chain data to the blockchain.

access the documents before taking possession of the cargo at the port of destination. The blockchain solution with smart contracts could reduce transaction costs by providing simultaneous accessibility of documents to the blockchain participants in almost real time. Although blockchain technology accelerates obtaining the required documents, the banks still could charge the same fees that they traditionally charge.

Smart contracts can reduce transaction settlement times between buyer and seller. For example, in early January 2018, the first international soybean trade was conducted using a blockchain platform among different participants that included Louis Dreyfus Company (LDC) (the seller), the Shandong Bohi Industry Company (the buyer), and banks. The participants realized that the time taken to process the documents was reduced fivefold (Reuters 2018). LDC indicated that it reduced its costs by 25–30 percent by using the blockchain platform for conducting soybean trades. Presumably, these are costs related to documentation and the facilitation of payments, although the source of these cost savings was not indicated. Major benefits of using the blockchain platform versus the traditional platform in international trading include digitization, automation, real-time accessibility, security, and quick payments.

In blockchain technology, the last-mile problem refers to the disconnect between online and offline events (i.e., the point at which the blockchain ends). While using blockchain technology to improve business efficiency does not necessarily involve the elimination of intermediaries, the roles of the intermediaries could change based on how well they adapt to the blockchain technology. Some intermediaries survive, while others are eliminated or replaced.

Smart contracts would be helpful in obtaining required documentation only after addressing the last-mile problem, which is the key for improved efficiency in the supply-chain system. In the case of the international grain supply chain, the last-mile problem is the timely delivery of grain that meets the buyer's specifications. Timely delivery to the buyer could be solved by effectively monitoring the offline events through Internet of Things devices to collect and exchange electronic data about the grain along the shipping route. Meeting the buyer's specification requirements could be solved by a blockchain oracle to test whether the grain at both the port of entry and the port of destination meets the specification requirements agreed upon in the sales contract or purchase order.

IV. Illustrating the Blockchain Solution Using a Monte Carlo Simulation

In international trading, blockchain technology brings about lower costs, lower risks, and added value. The technology provides more cost efficiency, lower transaction costs, and improved access to information without a centralized authority. Added value comes from the quick movement of documentation and commodities without customs delays at the port of destination due to improved access to information about the commodity.

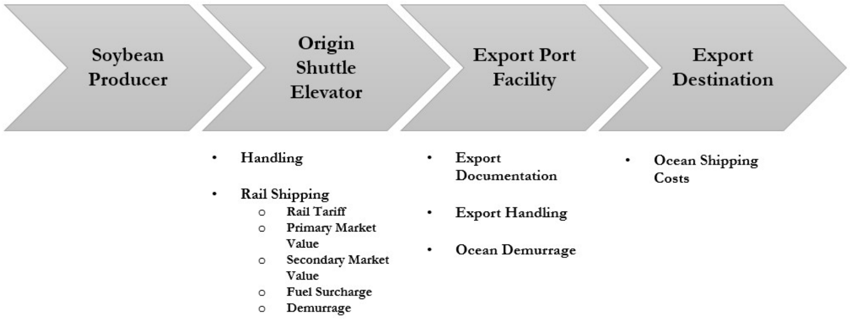
To provide perspective on the prospective cost savings due to blockchain technology, a Monte Carlo simulation model was constructed using @Risk in Microsoft Excel (Palisade 2019). The model was run and the results compared under two scenarios: (1) a hypothetical soybean shipment from Jamestown, North Dakota, to a port of entry in China without the implementation of blockchain technology, and (2) the same scenario with blockchain implemented. The model assumes that both the cost (in US dollars per bushel) and time (in days) at each stage are stochastic random variables. The cost of time is calculated by multiplying the annual interest rate by the total time (total days divided by 365 days per year). This product is then multiplied by the farm-level soybean price (in US dollars per bushel) to get the total time cost.

A. Estimation of Cost Distributions

The typical soybean export supply chain (FOB basis) is illustrated in figure 4 along with the associated supply-chain costs. At the origin elevator, handling costs generally include unloading, elevation, additional drying and conditioning, sorting and segregation, storage, and railcar loading. Rail tariffs are generally published at irregular intervals by the railroads. Primary and secondary railcar market values are generally at a discount or premium to the published tariff. Primary market values are derived from the primary railcar auction markets and accrued by the buyer. Secondary market values come from the resale of primary cars to handle anticipated surpluses (sellers) and/or shortages (buyers) in needed railcars. There exists an active cash brokerage in these markets (e.g., Tradewest Brokerage).

The fuel surcharge represents an add-on cost that is typically based on a step function applied to a fuel price index. These costs generally only become effective in times of high fuel prices. Demurrage is a charge that compensates rail carriers when the origin elevator detains cars beyond a certain time window based on constructive placement of the railcars at the origin facility.

Figure 4. Illustration of soybean export supply chain (FOB terms) with related costs



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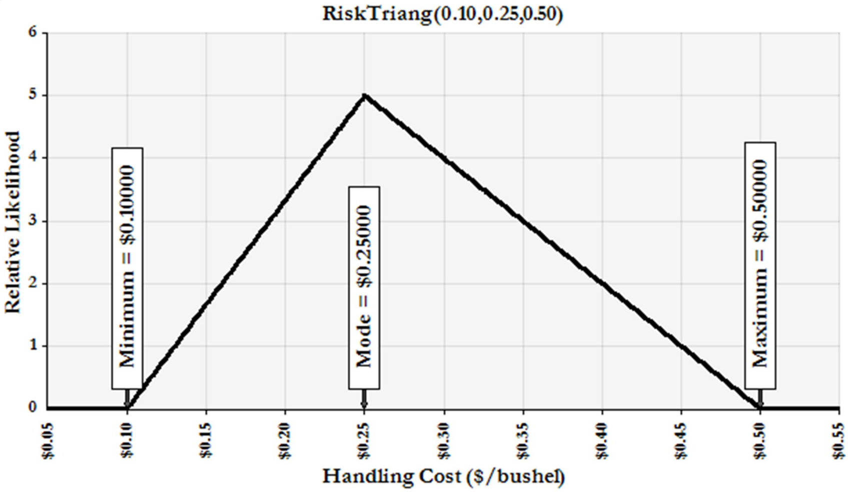
At the export facility, the handling costs are similar to those at the origin, with the exception that the activities are limited to the unloading of railcars, grain elevation, and the loading of ocean vessels. Therefore, handling costs at the export location are typically much lower than those at the origin. Demurrage costs are also similar, except they apply to delays in loading out constructively placed ocean vessels rather than railcars. Export documentation has already been discussed in detail in earlier sections of this study. Exports sales made under free-on-board (FOB) terms generally mean that the seller quotes a price that includes the cost of loading the shipment onto an ocean vessel. Ocean transportation (including insurance) is the buyer's responsibility.

In the Monte Carlo simulation model, a triangular distribution represents the range of possible cost values. This distribution is one of the many used to represent subjective estimates and is characterized by minimum, most likely (mode), and maximum values. Figure 5 shows the triangular distribution as it is applied to origin handling costs in the simulation model.

Figure 5. Triangular distribution as applied to origin handling costs using @Risk



Source: Created by the authors.

Table 2 shows the distribution assumptions used in the Monte Carlo simulation model and the sources for the parameters. It is assumed, based on discussions with industry participants, that the cost of export documentation is completely attributed to the preparation time rather than being assigned a direct cost.

Table 2. Distributional assumptions and data sources for cost distributions

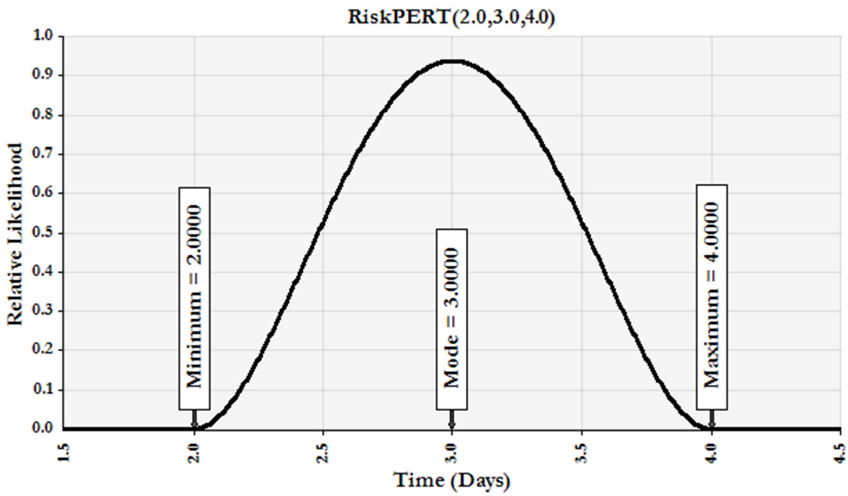
Stage No.	Cost variable ($/bushel)	Triangular distrib. parameters			Source[a]
		Minimum	Mode	Maximum	
1	Country handling	$0.1000	$0.2500	$0.5000	Wilson (2017)
2	Rail primary market	$0.0002	$0.0003	$0.0004	Wilson (2017)
3	Rail secondary market	$(0.1254)	$(0.1254)	$1.1486	USDA–AMS[b,c]
4	Rail tariff	$1.5656	$1.6872	$1.1486	USDA–AMS[b,c,d]
5	Rail demurrage	—	$0.0208	$0.0312	Wilson (2017)
6	Rail fuel surcharge	—	—	$0.2788	USDA–AMS[b,c]
7	Export documentation	—	—	—	Industry discussion[e]
8	Export handling	$0.0800	$0.1000	$0.1200	Wilson (2017)
9	Export demurrage	—	$0.0036	$0.0054	Wilson (2017)
10	Ocean shipping	$0.3487	$0.3487	$2.4087	USDA–AMS[b,c,f]

[a] Assumes 3,667 bushels of soybeans per railcar and 36.7433 bushels of soybeans per metric ton in making conversions.
[b] USDA–AMS Transportation Datasets from ams.usda.gov.
[c] Estimated using @Risk Bestfit application on monthly data, Jan. 2004–Dec. 2016.
[d] Bestfit applied to residual of linear trend projection and added to trendline projection.
[e] Based on discussions with industry participants, this cost is completely tied to time.
[f] Based on ocean freight rate from Pacific Northwest to Japan.

B. Estimation of the Time Distributions

For simulating the elapsed time at each stage of the supply-chain process, a PERT distribution was used. Like the triangular distribution, the PERT uses the minimum, most likely (mode), and maximum values as the input parameters. Figure 6 shows the PERT distribution as applied to the elapsed time for the origin handling stage.

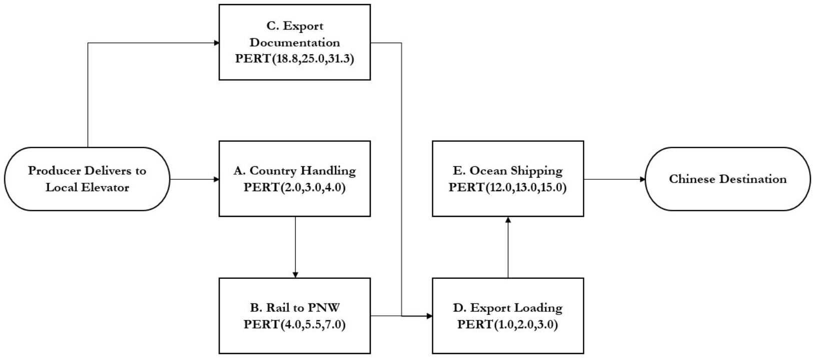
Figure 6. PERT distribution as applied to origin handling stage in @Risk



Source: Created by the authors.

A flowchart of the entire soybean supply-chain process along with the PERT distribution parameters is shown in figure 7. With exception of the export documentation stage, the parameter data are derived from Wilson (2017). The export documentation stage parameters are based on interviews with industry participants. The total cost attributed to time is calculated by simulating the total elapsed time using the flowchart schematic in figure 7. This elapsed time is divided by 365 days to convert into years and then multiplied by an annual interest rate of 6 percent, which is multiplied by a soybean price of \$8.50 per bushel. So, for example, if the simulated time were forty days, the total interest cost would be \$0.056 per bushel [$\left(\frac{40}{365}\right) \times .06 \times \$8.50$].

Figure 7. Soybean export supply-chain processes with PERT parameters (min, mode, max)



Source: Created by the authors.

Interviews with industry participants and other sources indicated that the introduction of blockchain technology has the potential to decrease the elapsed time for documentation by approximately a factor of five. Therefore, the simulation model that assumes the use of blockchain reduces the PERT parameters of the export documentation phase to 20 percent of their base simulation values (minimum of 3.8, mode of 5.0, and maximum of 6.3 days). The simulation analysis compares the cost (direct and time) distributions for the base (without blockchain) and blockchain scenarios to estimate the potential cost savings from using blockchain.

C. Monte Carlo Simulation Results

The @Risk Monte Carlo simulation model was iterated for 5,000 times under each scenario (base and blockchain) using the same random seed value. Table 2 shows the summary statistics for each scenario for both the total cost and elapsed time. The results indicate that the introduction of blockchain reduced the mean elapsed time by 16.5 days and the mean cost by 2.31 cents per bushel. The 5 percent value-at-risk (VaR) cost is measured by the 95th percentile and shows a reduction of 2.63 cents per bushel with the introduction of blockchain.

A two-sample, one-tailed *t*-test (N = 5,000) testing that the mean cost under the blockchain scenario was lower than the mean cost under the base scenario was significant at the 95 percent confidence level. A similar test conducted on the mean elapsed time differences was significant at the 99 percent confidence level.

Table 3. Monte Carlo simulation statistics for both scenarios

Simulation statistic	Total cost ($/bushel)			Elapsed time (days)		
	Base	Blockchain	Difference	Base	Blockchain	Difference
Mean	$3.5677	$3.5447	$(0.0231)	40.2	23.7	(16.5)
Std. deviation	$0.5767	$0.5766	$(0.0001)	2.5	1.0	(1.5)
Minimum	$2.3276	$2.3035	$(0.0241)	33.2	20.6	(12.6)
Maximum	$5.6840	$5.6605	$(0.0235)	46.9	27.0	(19.9)
5th percentile	$2.7213	$2.6984	$(0.0229)	36.1	22.1	(14.0)
10th percentile	$2.8520	$2.8294	$(0.0225)	36.9	22.4	(14.5)
90th percentile	$4.3686	$4.3434	$(0.0252)	43.4	24.9	(18.5)
95th percentile	$4.5803	$4.5540	$(0.0263)	44.2	25.2	(19.0)

Source: Created by the authors.

The simulation results show that introducing blockchain technology to the soybean supply chain has the potential to reduce total costs by approximately 2.3 cents per bushel (or approximately 0.6 percent) on average. The cost savings were entirely achieved through a reduction of 16.5 days (a decline of 41 percent) in the average elapsed time from the farmer's delivery of soybeans at the Jamestown origin facility to the unloading of the soybeans at the Chinese destination. A one-tailed *t*-test indicated that the blockchain mean cost was significantly lower than the base scenario at the 95 percent confidence level. While these results might seem like an insignificant cost savings, they do equate, at the mean, to a savings of $84.34 per loaded railcar or $9,278 per 100-car shuttle train or $48,243 per loaded Panamax vessel (5.2 shuttle trains)—so, they are materially significant when examined in the aggregate.

V. Other Applications of Blockchain Technology: The Food Industry and Commodity Trading

Amen and Ehmke (2018) list various blockchain applications in the agricultural supply chain, including food traceability, commodity tracking, and grain trading. Of all the agricultural industries in 2018, the meat industry is at the forefront in the application of blockchain technology.

For example, Cargill implemented a blockchain-based solution that allows buyers to trace the Honeysuckle White brand of family-farm-raised turkeys from farm to fork. This particular blockchain solution involved creating a personalized digital trail of activities to trace the turkeys purchased from the company. Each consumer is provided images of the actual turkey that the consumer purchased, information about the farm the turkey was purchased from, and the story of the farmer who raised the turkey (Bricher 2018). Javier (2018) discusses how blockchain technology provides the traceability of Auvergne chickens sold by Carrefour stores through different data points entered at various stages of its supply chain, including hatchery, producer, processor, and consumer. The tamper-proof nature of blockchain means accountability could be readily traced in case of any adulteration of the food product (Javier 2018).

In commodity trading, Belt and Kok (2018) take a cautious approach to integrating blockchain technology in international commodity trading, arguing that the current information technology infrastructure involved in international trading is already advanced. Other applications of blockchain technology in agriculture include precision farming, farm source management (e.g., machine maintenance records), and quality control of crops during different stages of crop growth until harvest (Schmaltz 2018).

A. Benefits of Using Blockchain in the Food Industry

In the United States, on average, the national cost of food-borne illnesses is $55.5 billion to $93.2 billion per year (Olya 2018). Fast traceability of the source of a contaminated food product (e.g., romaine lettuce) is important for food safety and recalls.

Recalling a food product is an expensive process. Food manufacturers may spend several million dollars per recall depending on the food product involved; 77 percent of food, beverage, and consumer product companies incur approximately $30 million for a recall (Scharff 2015). In general, recalls involve either an external regulator who coordinates a recall due to a lack of reliable information (FDA 2018) or a provider who can immediately identify the source of the outbreak (Corkery and Popper 2018).

Most food companies buy product recall insurance to protect themselves from the costs involved: notifying retailers and regulatory bodies, pulling food products, storage and disposal of food products, and additional labor costs (Scharff 2015). Companies must also purchase product liability insurance to cover product lawsuits related to recalls and other problems (Insureon 2018).

Blockchain technology could reduce the costs of food recalls. It minimizes the time to trace the origin of the contaminated food product (making it almost instantaneous) and consequently minimizes most costs related to notifications, pulling product, storage, and disposal. Blockchain technology additionally has the capability to reduce the cost of recall insurance for food manufacturers. Through the incentives of cost and reputational savings, blockchain technology can serve a valuable regulatory role.[5]

VI. Conclusion

This paper has discussed the blockchain solution for improving efficiencies in international grain sales. While fairly efficient mechanisms for settlement between buyers and sellers already exist in international commodity trading, blockchain technology could accelerate settlement execution. Our simulations suggest that using blockchain technology in international commodity trading (1) decreases total cost by 2.3 cents per bushel of soybeans, (2) decreases the total time required for documentation and transportation by 41 percent, and (3) reduces risk by decreasing VaR by 2.63 cents per bushel of soybeans.

In general, blockchain technology may have applications and be beneficial to international grain trading. The greatest source of value in nondifferentiated commodities is the ability to expedite payment. The added value largely depends on the specification requirements of a sales contract. If the commodity is nonspecific and highly homogenous, using common or standard certification and documentation processes, the use of blockchain technology may have little value, though it still has potential to reduce the risks of inappropriate documentation. However, as commodities become part of an integrated supply chain that is less homogenous—requiring more certification, documentation, and traceability—blockchain may have greater applicability. For example, blockchain technology will have a greater benefit for traded commodities requiring traceability, including organic, nongenetically engineered, or glyphosate free commodities. Similarly, if the cost of traceability can be reduced through blockchain, more commodity specifications may find blockchain attractive.

Adoption of blockchain technology ultimately depends on effort by parties across the supply chain, including farmers, handlers, exporters, banks, inspection agencies, buyers, and distributors. Blockchain adds value by lowering transaction costs, including

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[5] In a different context, Stringham (2015) and Berg et al. (2018) discuss the impact of regulatory authorities on the successful implementation of blockchain technology.

reducing costs and risks and accelerating the execution of transactions. Successful adoption of blockchain technology could put pressure on small players in the industry (Ehmke 2019).

Finally, blockchain technology in agricultural marketing and trading has not grown as expected and is not without challenges (Ehmke 2019). The most important challenges include (1) blockchain technology has been slow to gain industry acceptance; (2) complexity is involved in the commodity-marketing supply chain, particularly in blending heterogenous lots to create a more homogenous lot; and (3) widespread adoption of blockchain would require investment in sensors to segregate high-value or value-added commodities where tracking is desired.

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