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BUSINESS VALUE OF SMART CONTRACT: CASE OF INVENTORY INFORMATION DISCREPANCIES

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Completed Research

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Abstract

Firms are increasingly interested in Blockchain Smart Contracts as a solution for the visibility of the digital supply chain. Blockchain can help realize the cost reductions by providing a "single version of the truth" for a firm and its trading partners. By sharing important information such as inventory levels, manufacturing performance and operations indicators, and order and shipment information, firms can eliminate the delays and uncertainties in the information that contributes to "the bullwhip effect" and inflates required buffer stock. This paper focuses on the impact of blockchain in an inventory operation to cope up with information discrepancies. We present and compare the cost differences between an existing technology (like EDI) and blockchain. Using technologies like blockchain and smart contracts will enable a more transparent, sustainable, and resilient supply chain.

Keywords

Blockchain Smart Contracts, Inventory Management, Information Discrepancies, BVIT.

Introduction

Inventory inaccuracies are part and parcel of the modern supply chain operations (Fleisch and Tellkamp 2005). Previous studies investigated the Inventory Record Inaccuracies (IRI) that are related to the differences in the counting of the inventory levels (Iglehart and Morey 1972). According to a recent study, nearly 47 Billion dollars were lost due to inventory information discrepancies, shrinkage, and theft in the retail sector alone (McCue 2019; NRF 2019).

Inventory information discrepancies are results of poor information synchronization between the firm and its partners and an extension of IRI where the records of a product relating to its origin, manufacturing, transportation, and storage conditions are also recorded within an information system and transferred over the communication channel to the next step in the supply chain operations. Information discrepancies wreak havoc on the supply chain operations as well as on the firm's public perception. An example of devastating effects of information discrepancy can be seen from a decade-old food safety scandals where massive quantities of milk and infant formula (across China) were adulterated with melamine, a white solid that is derived from cyanamide (Scholl et al. 2017). This scandal resulted in the consumption of contaminated milk by over 300,000 people, affecting them, both physically and mentally, with six infant mortalities and around 54,000 infants being hospitalized with serve symptoms (Branigan 2008).

An incident like this usually takes weeks to be resolved. However, as blockchain can record and store the information regarding the source and the flow of the material through the supply chain, it can assist in swiftly pinpointing the problem origin (Corkery and Popper 2018; Nestlé 2019). Inventory operations are inherently a complex dynamic interaction of people, warehouse management systems (software), inter-organizational communication systems, physical product, operating policies and procedures, and the product information. The problem of inventory discrepancies originates because of a technology's inherent limitations, for example, Electronic Document Interchange (EDI) follows specifications for designed by the

EDIFACT standard and can only transfer specific information in a specific format (XML) (Cannella et al. 2017; DeHoratius and Raman 2008; Georg 1993; Rekik 2011). Similarly, Radio Frequency Identification (RFID) in presence of inventory errors decreases efficiency, negatively impacts profits and costs, contributes to lost sales, missed service level contracts, and enables suboptimal operational performance (Kök and Shang 2014). Electronic Data Interchange (EDI) implementation under the presence of inventory errors resulted in similar negative effects on the production and inventory costs and requires human intervention when the correction in the records is required (Mukhopadhyay et al. 2006; Premkumar et al. 1994). These issues, when coupled with the complexity of the technologies, increase the overall cost of the inventory operations. We utilize the definition of Inventory Information Discrepancies from Cheong et al. (2015, pp. 195–196) as "*Information discrepancy is the difference between the actual information of a product and the information recorded in the firm's and its partner's information system regarding that product.*" We extend the definition of information discrepancies to include not only the product's core attributes but also the supplementary information regarding the supply, manufacturing/production, and distribution operations, including but not limited to location, storage conditions, the origin of raw materials.

The smart contract, a feature of the blockchain technology, is specifically of interest. Smart Contracts can record, programmatically evaluate, and parallelly correct the information available on the chain by comparing it with the past available information. We believe this feature of blockchain will be very useful in mitigating the ill effects of the information discrepancies. Although technologies like EDI and ERP are being leveraged and have been instrumental in improving SC operational efficiency, discrepancies in information capture processes are prevalent in facilities utilizing them.

In this paper, we are interested in evaluating the impact of blockchain-based smart contracts in mitigating the inventory information discrepancies. We develop a general additive model to understand such an impact. This model builds on the quantitative framework presented in Iglehart and Morey (1972) and McElroy (1987). We note the two-fold contribution of this paper, first, to the best of our knowledge this is one of the first attempts in evaluating business value of the blockchain technology and second in extending The Mathematical Theory of Inventory and Production by incorporating technology and error as intermediate components leading to an updated production function specification for a technology. To the best of our knowledge, this is the first study that explicitly incorporates both technology and error components in inventory information management related penalty directly originating from information discrepancies.

There have been attempts to solve information discrepancies in both academia and industry by implementing IoT devices like passive RFID (Kök and Shang 2014; Rekik et al. 2009), by implementing information systems like EDI (Georg 1993; Kekre and Mukhopadhyay 1992) or by making organizational alterations like labor change (Chuang and Oliva 2015). However, these attempts focus on stopping or reducing the discrepancies rather than dynamically correcting the discrepancies in real-time. We believe the blockchain-based smart contracts will reduce inventory information discrepancies endlessly and dynamically. Consequently, we address the question: *how do blockchain-based smart contracts impact the information discrepancies in inventory operations?*

Practical Background of Blockchain and Smart-Contracts

Blockchain is a distributed ledger that stores data using a cryptographic hash function (SHA256, or SHA3 family). Blockchain refers to the connected blocks that are part of a communication network utilizing secure communication protocols and distributes the copy of the record through the entire network. While doing so, the network nodes vote on the validity of the record through a consensus mechanism that is preserved on the immutable chains of the blocks on each node of the network (Nakamoto 2008; Yli-Huumo et al. 2016).

The blockchain protocol has a few characteristic similarities with TCP/IP. It can be seen as an addition on TCP/IP at the application layer to enable the economic transactions between the interested parties through the node network. Blocks of the blockchain are format & device-independent and can store multiple types of information in various formats (XML, HTML, JSON, etc.). This specific feature of the blockchain is very helpful in recording details of inventory operations, monitoring, and tracking assets (digital and physical with the help of IoT devices) (Shetty et al. 2019).

The smart contracts are defined as "a computerized transaction protocol that executes the terms of a contract" (Szabo 1994, 1997). The smart contracts are mostly a java program stored on the blockchain executed with a java virtual machine. As they are stored on the blockchain, each smart contract gets a unique address. When a smart contract needs to be executed, a trigger response is set that will notify the smart contract to execute on every node. This nature of smart contracts make them trustworthy and immutable (Christidis and Devetsikiotis 2016).

We believe the auto-execution mechanism, in addition to the blockchain's distributed-storage, will be instrumental for storing additional information regarding a product's flow, essentially making the product's flow "story" a transaction through the supply chain. In contrast, the "story" can then be checked at each stage of the operation for correctness through the smart contracts. For example, assume that a shipment (Twenty-foot equivalent unit, TEU) of antibiotics was shipped from Jakarta to Dallas, and the entire process from manufacturing to loading to shipping (roughly 15 steps) is recorded on the blockchain. A smart contract is programmed on the chain that records the storage conditions (temperature, humidity, etc.) of the container every 2 hours with the help of an IoT device on board. In addition, the blockchain also has information regarding past storage and operating conditions. When the shipment reaches Dallas, it is discovered that one of the shipment containers is contaminated. A little investigation shows that the contamination occurred at the manufacturing facility. With traditional technologies like EDI, it will take at least a week to determine the root cause as EDI is not equipped to record granular details of manufacturing or logistics operations. On the other hand, a look at blockchain's recent block and the smart contract's execution log showed that the contamination occurred at the 5^{th} step (Corkery and Popper 2018; HyperLedger 2018; Yap and Emont 2020).

The upstream/downstream inventory information shared with the firm's partners helps the firm to better predict the stock levels to keep the backorders to a minimum. A smart contract, thus, can note, pinpoint, and correct the information at the granular level, improving efficiency by eliminating the manual search, monitoring, and updating efforts and time. Smart contracts reduce the number of intermediaries and require less manual interventions, which result in reduced operational costs (Bocek et al. 2017). Readers are referred to as Christidis and Devetsikiotis (2016) for a detailed explanation of blockchain's and smart contracts' working mechanisms.

Theoretical Background

A scant amount of literature in the information system (IS) has dealt with inventory discrepancies by applying economic theories of the firm. In the literature, IS has been counted as one of the inputs to an organization's production function. Although the approaches are mostly similar and evaluate comparable attributes, they differ in (1) the functional form of production function, (2) estimation methods used, and (3) measures of the appropriate use of an IS. This results in a limited evaluation of IS impact on the individual components within a specific domain (Barua et al. 1995; Barua and Lee 1997; Mukhopadhyay and Cooper 1993).

We utilize Production Theory to show that the inventory discrepancies have a significant impact on the firm's production and operation costs and create a suboptimal performance for the firm's processes (Barua and Lee 1997; Mukhopadhyay et al. 2006; Ragowsky et al. 2005; Serpa and Krishnan 2017). We address the cost function approach using the Mathematical Theory of Inventory and Production (MTIP) as Arrow et al. (1958) explicitly develop and address the inventory costs model with the assumptions consistent with the production theory. The MTIP provides an ideal framework for the analysis of information discrepancy at the micro-level because it characterizes the firm's optimal use of inputs to achieve goals (cost minimization, production targets). We also utilize the additive general error models of production costs that includes production error specifications (McElroy 1987). It is used to connect the impact of information discrepancy on the firm's costs when the firm is unable to eliminate them with the currently available technologies.

Information Discrepancy in Supply Chain

Existing literature has used multiple methodologies to investigate the managerial approach in evaluating, monitoring, and controlling the information discrepancies in inventory operations. Table 1 shows the compilation of the studies and the classification based on the methodologies they use. The majority of the studies follow the analytical modeling and simulation methodology to investigate the negative consequences of the inventory discrepancies on the inventory performance (DeHoratius and Raman 2008; Kok and Shang 2007; Lee and Özer 2007). The analytical research in this area tries to understand and model the stochasticity of the information discrepancy mechanism while ignoring an "error-correcting" information system like smart contracts.

Of the few empirical studies, DeHoratius and Raman (2008) examined the scope and scale of IRI by analyzing the one-day operation of a retailer. A commonality between some studies within the approach is the use of cycle counting-based SKU sample that assesses the overall inventory record accuracy (Heese 2007; Kull et al. 2013; Sheppard and Brown 1993). A subset of the empirical studies has studied the impact of an IoT device like RFID on the mitigation of the information discrepancies within the retail operations. These studies focused on the daily inventory counts concentrating on product movement, mean transactional times, and the cumulative impact of RFID on the reduction of IRI, respectively (Delen et al. 2009; Hardgrave et al. 2013). We, on the other hand, recognize that the current supply chain's complex nature requires the information sharing at a granular level and blockchain's capability to handle information sharing nearly real-time that could impact the inventory information discrepancies (Corkery and Popper 2018; HyperLedger 2018).

Our analysis of the literature underscores two research gaps. First, by relying on just the operating principles, the studies have shown the partial impact of the technology but have missed the theoretical connection of the inventory discrepancies, and the production and cost functions, resulting in partially understood impact information discrepancies. By adopting the MTIP perspective in an inventory operation setting, we aim to develop a better understanding of how the blockchain technology impacts informational discrepancies. Second, despite the critical role that the blockchain technology could play, the information system and information discrepancy literature have overlooked it in the context of both analytical and empirical research. To address these gaps, we provide an analytical model in the context of inventory operations. Further, following McElroy (1987) and Arrow et al. (1958), we extend the mathematical theory of inventory and production to explore the impact of the blockchain-based smart contracts on the inventory information discrepancies.

Table 1 Inventory Record Inaccuracy research by methodology and context

Research Focus	Analytical	Conceptual	Empirical
General	(Kok and Shang 2007; Kwak and Gavirneni 2015; Lee and Özer 2007)	No Studies	No Studies
Type of Supply Chain	(Cannella et al. 2015; Fleisch and Tellkamp 2005; Heese 2007; Kök and Shang 2014)	No Studies	No Studies
Retail Store	No Studies	No Studies	(Alpar and Kim 1990; DeHoratius and Raman 2007, 2008; Mersereau 2013; Raman et al. 2001)
RFID	(Dai and Tseng 2012; Fleisch and Tellkamp 2005; Heese 2007; Ishfaq and Raja 2019; Kang and Gershwin 2005; Kök and Shang 2014; Rekik 2011; Rekik et al. 2009; Zhang et al. 2018)	(Lee and Özer 2007)	(Delen et al. 2009; Hardgrave et al. 2013; Rekik 2011)
Human Resource	(Chuang and Oliva 2015; Zhang et al. 2018)	No Studies	No Studies
Blockchain	Our Study	No Studies	No Studies

Analytical Model

To investigate the information discrepancies in the real world inventory operations, we focus on a cost system of an inventory operation based on McElroy's (1987) additive general error production model (AGEM). Although the AGEM includes the error structure for production and cost functions and establishes the different representations of technology's specifications, it stops short of precisely specifying its impact on the inventory cost functions (McElroy 1987, p. 739). We utilize Iglehart and Morey (1972) specifications of error manifestation on the buffer stock values, specifically referred to as "error buffer stock," then extend the model of AGEM. Table 2 defines the notations used within the remainder of the paper.

Table 2 Summary of Mathematical Notations

Notation	Description	Notation	Description
TC(**X**,**W**,**ϵ**)	Total inventory cost	c(**X**,**W**)	Inventory ordering cost
h(**X**, **W**)	Inventory holding cost	p(**X**,**W**,**ϵ**)	Inventory backorder cost due to inventory error
α (alpha)	Operability threshold (1%,5%)	$\Phi^{-1}(\cdot)$	Standard normal CDF
B(·)	Buffer stock for errors	μ, σ	The mean and standard deviation of the inventory position
X	Inputs (incoming/withheld products)	**W**	Price of product
ϵ	Information discrepancy (percent) (inventory error)	δ	Product demand (to illustrate flow in the numerical example, not part of the analytical model).
k	Technology operability parameter $(0 \leq k \leq (2-\alpha)^{-0.5})$	n	The number of periods between the inventory counts.

Model and Analysis

In general, the firm is responsible for managing its inventory and usually suffers from information discrepancies. In the presence of information discrepancies, 'error buffer stock' will be affected the most, in turn, influencing the inventory backorder cost. To avoid the backorder penalty cost, the firm needs to set this buffer stock sufficiently high and in relation to the upstream demand. The probability that the next order will trigger the backorder needs to be set to 1 – α. This section will primarily focus on the backorder penalty cost as the information discrepancies affect it the most and remaining model parameters remain the same.

Consider two identical firms A and B. Firm A chooses Electronic Document Interchange (EDI) as a mechanism for information sharing, while Blockchain is the preferred choice of the technology for information sharing for firm B. Reflecting on the discrepancy in the inventory process, we now develop the model for both the firms.

Information Discrepancies under Electronic Document Interchange

The firm A anticipating the information discrepancies, for any price, will determine the optimal price and the optimal buffer stock quantity (B(x)). The minimum expected cost is given by:

$$TC(\boldsymbol{X},\boldsymbol{W},\boldsymbol{\epsilon}) = \mathbb{E}[h(\boldsymbol{X},\boldsymbol{W}) + c(\boldsymbol{X},\boldsymbol{W}) + p(\boldsymbol{X},\boldsymbol{W},\boldsymbol{\epsilon})] \tag{1}$$

Furthermore, the buffer stock under the information discrepancy and cost of the buffer stock is given by (Iglehart and Morey 1972, p. B-390 Proposition 1; McElroy 1987, p. 742 equation 2):

$$\boldsymbol{B}(x) = \sigma\sqrt{n}\Phi^{-1}\left(1-\frac{\alpha}{2}\right) \tag{2}$$

$$TC(\boldsymbol{X},\boldsymbol{W},\boldsymbol{\epsilon}) = \mathbb{E}[h(\boldsymbol{X},\boldsymbol{W}) + c(\boldsymbol{X},\boldsymbol{W}) + p(\boldsymbol{X},\boldsymbol{W})] + \min(p,h)\,\boldsymbol{B}(x) \tag{3}$$

The ordering cost (c(·)) and holding cost (h(·)) in equation 3 do not include the discrepancy term as the information discrepancies do not affect them. The reason being ordering cost is mostly dependent on the past demands, and holding cost is generally dependent on the average inventory on hand (Kwak and Gavirneni 2015). The discrepancy affects the backorder cost the most as each discrepancy recorded within EDI will show that the firm needs to order one item more than that was originally scheduled. Such dynamic results in increased buffer stock and consequently increased ordering cost. Additionally, we can consider that the backorder penalty cost is higher than the holding cost ($h<p$) (Iyer 1999; Özsen 2014), resulting in buffer stock cost of min(h, p). Hence, the cost of the buffer stock can be calculated as:

$$min(\mathrm{p},\mathrm{h}) * \sigma\sqrt{n}\Phi^{-1}\left(1-\frac{\alpha}{2}\right) \tag{4}$$

And the total cost (TC) then will be:

$$TC(\boldsymbol{X},\boldsymbol{W},\boldsymbol{\epsilon}) = \mathbb{E}[h(\boldsymbol{X},\boldsymbol{W}) + c(\boldsymbol{X},\boldsymbol{W}) + p(\boldsymbol{X},\boldsymbol{W})] + min(\mathrm{p},\mathrm{h}) * \sigma\sqrt{n}\Phi^{-1}\left(1-\frac{\alpha}{2}\right) \tag{5}$$

Equation 5 illustrates that when the information discrepancy increases, the available sales inventory will decrease, which in turn will require the firm to order more. The discrepancy specification in the equation represents a simple setup where the EDI stores the information, and each inspection cycle reduces the discrepancies, but as there is no automatic mechanism for inspection within EDI the information records will need manual intervention to correct the discrepancy. Equation 5 also shows the limitation of the technology as it can only work at technical efficiency achievable by EDI (Georg 1993).

Information discrepancies under Blockchain Technology

Firm B shares information over the blockchain. The auto-execution timer on the smart contract programming that records and checks the information with the periodic interval. Assuming that the inventory position at each period is M with a mean μ and standard deviation σ. For the fixed number of periods (n) when the count is triggered and known α (alpha) we can develop the probability of asset depleting the stock as:

$$\mathbb{P}\{\epsilon + M \leq B(n)\} \geq (1-\alpha). \tag{7}$$

Iglehart and Morey (1972) prove and discuss that the coefficient k as an indicator for a more advanced inventory count technology, e.g., smart contract, controls the standard deviation of inventory position and subsequently the average buffer stock for n period. Using the Chebyshev's inequality (see Iglehart and Morey (1972, p. B-392)) and the approximation from the theory of weak convergence of probability measures (Billingsley 2013, pp. 2–5) the minimum expected buffer stock level under the information discrepancy will be reduced to:

$$\mathbf{B}(n) = \sigma\sqrt{n}\Phi^{-1}\left(\frac{1}{2}-\frac{1-\alpha}{2(1-k^{-2})}\right) \tag{8}$$

The factor k is the technology operability parameter that is tied to the operability threshold by $0 < k \leq (2-\alpha)^{-0.5}$, representing the 'efforts' needed from the technology to maintain the said operability threshold. The change in the term of standard normal function from $\left(1-\frac{\alpha}{2}\right)$ to $\left(\frac{1}{2}-\frac{1-\alpha}{2(1-k^{-2})}\right)$ causes a reduction in the needed buffer stock and primarily, it explains the saving associated with the automatic counting applying a blockchain-based smart contract. The new cost function under the smart-contracting inventory counting system is revised as follows.

$$C(\boldsymbol{X},\boldsymbol{W},\boldsymbol{\epsilon}) = \mathbb{E}[h(\boldsymbol{X},\boldsymbol{W}) + c(\boldsymbol{X},\boldsymbol{W}) + p(\boldsymbol{X},\boldsymbol{W})] + min(p,h)\,\sigma\sqrt{n}\,\Phi^{-1}\left(\frac{1}{2}-\frac{1-\alpha}{2(1-k^{-2})}\right) \tag{9}$$

A Numerical Example

The numerical example is calculated for one item, two identical warehouses scenario, utilizing EDI and BCT at different warehouses. The demand at warehouse 2 is 15 units, it has a capacity (S) of 400 and pulls units from warehouse 1 every 40 days (S, s inventory policy), or 9 periods. The inventory recount cost is $150 every count period, and each item stocked costs $1.50. Based on the equations presented above, we can calculate the cost per item in the inventory for the information discrepancy for:

$$h = \$1.50; \sigma = 20; p = \$2; \alpha = 1\%; n = 9$$

Then the associated buffer stock and the cost (buffer stock cost, BSC) associated with under the influence of the EDI technology can be calculated as:

$$\boldsymbol{B}(n) = \sigma\sqrt{n}\Phi^{-1}\left(1-\frac{\alpha}{2}\right) = 154.4$$

$$\boldsymbol{BSC_{EDI}}(n) = \min(h,p) \times B(n) = \$231.8$$

Firm's B blockchain, on the other hand, handles the information discrepancies at the same workload and chance of error. Suppose the smart contract operability factor is set at $k = 0.5$ per inspection cycle. From equation 8 the buffer stock and its cost (BSC) are calculated as:

$$\boldsymbol{B}(n) = \sigma\sqrt{n}\Phi^{-1}\left(\frac{1}{2} - \frac{1-\alpha}{2(1-k^{-2})}\right) = 25.6$$
$$\boldsymbol{BSC_{BCT}}(n) = \min(h,p) \times B(n) = \$38.3$$
$$\Delta\boldsymbol{BSC}(n) = \$231.8 - \$38.3 = \$193.5$$

The numerical example above shows a single item calculation for EDI and Blockchain demonstrating significant cost difference, ceteris paribus, when the inventory operations being influenced by information discrepancies.

Conclusion

Electronic Document Interchange is a widely used demand information capture and sharing technology by industry. Even though EDI had been instrumental in improved information exchange in supply chain operations, discrepancies still persist in information capture and sharing processes in the facilities where EDI system is equipped. The Blockchain technology is quickly becoming a highly sought-after product identification and data capture & sharing technology and an alternative to EDI. Information discrepancies within the supply chain have been shown to have cascading effects leading to monetary loss (Cannella et al. 2015; Dai et al. 2016). To our knowledge, this is the first study in information systems that analytically links the effects of the blockchain to the information discrepancies. As stated before, the information delays and information discrepancies contribute to the bullwhip effect, one of the main threats to the sustainable and resilient supply chains. The research extends to the sustainable IS research by showing the resilient nature of blockchain and its applicability to the information discrepancies thereby shining a light on the applicability of blockchain in improving supply chain sustainability.

In this paper, we considered the impact of blockchain technology on the inventory information discrepancies. Our model examines how blockchain affects information discrepancies, by increasing additional buffer stock costs and highlights the way firms can reduce them by implementing blockchain smart contracts. One salient feature of our model is the new cost component, i.e., the discrepancy cost. The best-case model above estimated a percentage buffer stock cost saving of 83.47% for the operability threshold of 1%. Insights obtained clearly show the value of blockchain in mitigating discrepancies and effectively reducing the cost of the inventory operations. The simple cost function we developed demonstrated that there is a value in implementing a private-permissioned blockchain between the firm and its partners and could lead to reduced operating cost.

We believe that there is room for improvement as in the real world, the information technologies used by the firm are rarely separable and often built upon the same infrastructure. For example, EDI and Blockchain can use similar server and communication infrastructure without a significant change in hardware requirements (Barua and Lee 1997; Shetty et al. 2019). This warrants further investigation by utilizing a multi-technology framework where the marginal impact of the technologies and the cost structure associated with it can be optimized together.

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