Blockchain and Supply Chain Management

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Abstract

Many authors have explored the potential impact of blockchain on supply chain management, and indeed, many articles in the popular press extol the potential of blockchain to impact the supply chain. In this white paper, we argue that while blockchain does have some potential to impact supply chains in the short term, many of the potential blockchain-enabled supply chain impacts will require significant research advances. We identify four categories of issues that researchers must address in order for many of the interesting proposed blockchain-enabled supply chain use cases to be feasible. If these issues are addressed, we have little doubt that the potential of blockchain-enabled supply chain is enormous.

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1. Introduction

Blockchain is a decentralized, distributed database that maintains a continuously growing list of secure data records. It first emerged in the context of Bitcoin, where it serves as a decentralized, distributed digital ledger recording all Bitcoin transactions.[1] Bitcoin is a currency that is controlled by the network of users instead of by centralized banks. Through the use of Bitcoin, money can be transferred directly.

In the traditional banking system, when money is transferred through banks, they are notified to transfer the money; the bank(s) will send notification and update accounts appropriately. The relevant data is stored in a database owned by the bank (or in multiple databases owned by banks), and users only have partial access to that data. Users must trust third parties. This has two implications. First, the bank has to make a profit, so in the aggregate, this means less for the other participants. In addition, if some third party or the bank itself manipulates the data or commits fraud, it might be challenging for all participants to quickly and efficiently detect this.

On the other hand, the Bitcoin database is decentralized and distributed, so that everyone has the entire database on his or her own device. These are not copies of some original database – they are the database itself, and each device syncs with all others. Thus, if a specific device is hacked, or imports incorrect data, the network will not accept this, and will correct the data using other databases. Unless a single entity controls more than half of the devices on the network, it is almost impossible to delete or edit data. In blockchain, data is stored in blocks of data that are linked to the previous blocks. On average, every ten minutes Bitcoin creates a block of data and all user devices will permanently store that data. Each block references the previous blocks, so

if someone wants to change data in a block, he must change all previous blocks as well, which is almost impossible.

Consider the following quote from [2], which nicely captures the power of blockchain:

> Imagine a piece of paper with a name written on it, and that name entitles a person to a pot of gold. You put it in a room with 50 doors, and all those doors have a lock. But someone could get through one lock and replace the name on the piece of paper. That is equivalent to centralized database. Blockchain, on the other hand, will duplicate that paper 50 times and put it in 50 different room. In this setting, if someone wants to break the system and change the name on the papers needs to break [at least 25] rooms at the same time.[2]

One important difference between blockchain and a traditional centralized network is that blockchain-stored data is un-deletable and un-editable. In a centralized database, there is always risk of fraud or external hacker attacks, while in a blockchain, the network will work consistently unless an attacker manages to take control of the majority of the network; therefore, a large number of users almost significantly reduces the possibility of fraud.

Although the Internet makes it inherently challenging to confirm identities and hence to trust other parties, blockchain facilitates trade on the Internet because, in effect, "the system" ensures trust. In other words, fully secure trade with untrusted parties is possible. This property enables the removal of third-parties in many systems. "The blockchain is an enabling technology," explains Dan Burrus. "This means that you don't need a third-party any more. The network itself replaces the third-party institution. Therein lies the disruption. Whenever there is a third-party involved to produce a transaction, the blockchain could replace it." [3] "[S]ince the whole system is running transparently, the system is absolutely open source and there is no need for trust among every single node and any node can never cheat other nodes." [4]

Blockchain is also sometimes known as the "Internet of value" [5] – its advocates believe that it can revolutionize almost every industry. While blockchain is finding its way into a variety of different industries, including fine art, luxury goods, pharmaceuticals, medical devices, and jewelry, for anti- counterfeiting and tracking, and import/export, as well as real estate, etc., for record-keeping, many suggest that blockchain can make a groundbreaking impact on supply chain management (see, for example, [6, 7, 8]). Imagine using the concepts behind Bitcoin to remove the need for banks in the supply chain – in principle, this could allow everyone to trade directly through Internet. Using blockchain, one could trade directly with unknown parties, and remain anonymous. Or at least, that's why in some supply chain circles blockchain is touted as the next big thing. Clearly, the $40 trillion supply chain market is at the very least an interesting potential use case for blockchain in the future. [9]

Our focus in this white paper is on the challenges of using blockchain in supply chain (which we call blockchain-enabled supply chain). From out point of view, blockchain currently is a more effective component of financial systems than of many physical systems, although we should point our that some authors even question the value of blockchain in a financial context. For instance, Grym [10] points out while Bitcoin solved double-spending problem, it has not even attempted to solve the price stability problem and it is not clear whether or not central banks are the only solution to this problem. Furthermore, blockchain does not necessarily scale well. The volume of transactions that the Bitcoin network can handle every second is roughly ten thousand times less than payment networks like VisaNet.

2. Preliminaries

Various authors have explored the potential impact of blockchain on supply chain management, and indeed, many articles in the popular press extol the potential of blockchain to impact the supply chain in the short term. For example:

- Jeremy Wilson, vice-chairman of Barclays Corporate Banking, points out that blockchain can reduce supply chain paper work. He mentions the first blockchain-based trade-finance deal. The process, from issuing to approval of the letter of credit, usually takes between seven and 10 days, but could be reduced to less than four hours.[11] The potential lead time reductions exist more broadly in global supply chains—import, export, and port documentation could all be expedited.
- Hofmann et al. [12] claim using blockchain in supply chain finance could expedite processes and lower the overall costs of financing programs. For instance, blockchain could simplify payment insurance methods, decreasing the need for letters of credit and therefore reducing transaction fees, increasing speed and transparency, and so on.
- Some individual products are challenging to duplicate, and individual items are relatively easy to identify. In these cases, the key to supply chain management involves establishing provenance of items being traded, and blockchain can ensure a transparent, secure, un-editable and un-deletable provenance which could help all parties in the supply chain.

While the potential of these impacts and applications to reduce costs and expedite supply chain tasks should not be minimized, these are hardly path-breaking changes to current supply chain operations. However, much of the discussion of the impact of blockchain on supply chain management is more forward-looking; not so much exploring how blockchain could impact supply chain today, as focusing on potential future supply chains.

Tapscott and Tapscott consider the possibilities of using blockchain technology for the end-to- end supply chain in their book, Blockchain Revolution [5]. They explain that Smart Contracts (which we explain below) will enable companies to contract for price, quality, and delivery dates with just a few clicks of mouse, and suggest many other ways that blockchain can impact supply chain management. Indeed, many similar ideas can be found in articles written in the past two years. However, all of these are presented at a relatively conceptual level, so it's difficult to assess how practical these scenarios actually are. Later, we discuss limitations of current Smart Contracts, and the innovations that we believe are necessary for them to significantly impact supply chains.

Alsmiller [13] suggests that blockchain can be used to track items from suppliers to ensure that products are genuine and accurately described and safely and correctly transported. Williams and Gerber [14] also discuss the benefits that transparency will bring to the supply chain, focusing on how blockchain will allow us to see where our food was grown. In principle, we could track each ingredient in our food from its origin, so that we could, for example, understand whether the bottle of olive oil we just bought is 100% olive oil, or if it is blended with other types of oil. According to Project Provenance Ltd [15], since every transaction along the blockchain-enabled supply chain is auditable, smart phone applications will be able to display all relevant information to the consumer in real time, and crucially, this information can be completely trusted. However, many hurdles currently exist that make using blockchains this way challenging if not impossible—we discuss these below.

Several researchers have also considered the application of RFID to agri-food traceability. Tian [4] specifically explores the potential of an agri-food supply chain enabled with RFID tags and blockchain technology. He highlights an important question that has not been considered previously: "whether the information shared by supply chain members in the traceability systems can be trusted." He also claims that RFID and blockchain can together improve the efficiency and reliability of the agri-food supply chain, because he believes the biggest problem in traditional centralized supervision of the agri-food supply chain is "[M] onopolistic, asymmetric and opaque information system which could result in the trust problem, such as fraud, corruption, tampering and falsifying information." While Tian highlights an important concern, as we discuss later in this white paper, it is unclear how his solution can fully address this concern.

Each of these visions of future blockchain-enabled supply chains raise important questions. Indeed, these and similar views suggest that markets will no longer need third parties to preserve trust and ensure quality, and as a consequence, prices will decrease. Blockchain will provide the opportunity to track every single part of each good to its origin. At a fundamental level, this is the benefit that many pundits claim for blockchain-enabled supply chains. In our view, blockchain and related technologies will need significant enhancement for these visions to become reality. We discuss the key challenges that need to be overcome later in this white paper.

3. "Pure" Blockchain and Supply Chain

Recall the time when supply chain management was first entering the popular consciousness—it seemed that everyone had a different definition and understanding of this concept. Two authors could discuss two entirely different things and call them supply chain management. Something similar to this currently exists in the blockchain space.

To emphasize the difference between blockchain and similar concepts, we list characteristics that are inherent in what will call "pure blockchain" to highlight this difference: pure blockchain is a distributed, decentralized database that maintain a continuously growing list of secure data records without the need for trusted third-parties oversight or admission control to the system.

Blockchain can make the most impact when it ensures trust via system design, rather than through verification of players/nodes. Hence, it is unlikely to lead to pathbreaking changes in supply chain management if it doesn't eliminate the need for trusted parties in the network.

To see this, consider a setting where a single party owns all nodes in the blockchain network; would that party benefit from using blockchain? Does blockchain add any value in this setting over what can be accomplished using distributed databases or centralized databases? We believe the answer in general is NO. (Here, blockchain would simply be a database technology.)

Although one of the key defining characteristics of blockchain is its distributed database, a distributed decentralized database is not equivalent (even conceptually) to pure blockchain.

Many authors discuss the concept of private blockchain, which is a closed system that features a decentralized, distributed database. A private blockchain requires permission to join issued by a third party. The third party who gives permissions to different users needs to be trusted by the entire system; otherwise, it can add so many untrusted nodes to the system that the system can break down, and changes can be made to stored data.

Recall the original point of pure blockchain—to ensure trust in the system while removing the need for third parties who do not add value beyond ensuring trust. Private blockchain, on the other hand, needs trusted third-parties to add nodes to the system. If such a party exists, an integrated centralized database could be used for this type of system. While some argue that blockchain-based private networks might be marginally cheaper or more secure, this is a far cry from the benefits that have been claimed. Indeed, from our perspective, private blockchain might add little value over a trusted integrated database. Interestingly, many of the suggested potential use cases for blockchain-enabled supply chain focus on private blockchain, although we believe that a private blockchain is a fundamentally different concept from blockchain as it is commonly defined.

Pure blockchain is also not equivalent to public blockchain. Public blockchains are distinguished based on who can access the system, where users do not need any permission to join the network while pure blockchains are distinguished based on the absence of trusted third parties.

3.1 Using Pure Blockchain in Smart Contracts

Smart Contracts are computer codes/programs that control the transfer of digital currencies based on predefined conditions. For example, consider a Smart Contract for betting on a game. After the result are revealed, there is no need for payment since the system will transfer the digital money from the loser to the winner automatically. Many articles have been written about blockchain-based Smart Contracts, but supply chains typically involve the physical flow of products from initial suppliers to end customers, and in this regard, the most important difference between supply chains and financial institutions involves the existence of physical products. While various authors (such as Tapscott and Tapscott [5]) have claimed that blockchain-based Smart Contracts allow companies to develop payment, release date, and even quality-based contracts, all of these require verification of some kind to ensure that the proper amount of the proper quantity of materials have been delivered. Furthermore, as we discuss below, it isn't clear at all that cur- rent barcode/RFID-tag/3D-stamp/sensor technology is sufficient to provide this verification. In addition, the nature of supply chains is significantly more complex than the straightforward examples typically given for Smart Contracts. Indeed, it seems that given current technology, Smart Contracts will need trusted third-parties to be used in most supply chain applications, so they don't immediately fit into a pure blockchain framework. Research will be needed to overcome this limitation, as we discuss below.

3.2 Using Pure Blockchain for Track and Trace

The notion of being able to trace ingredients of any food or product back to its origin is very compelling. For example, if one is interested in eating organic foods, it could be valuable to be confident in food's origins. Although the use of blockchain to achieve this seems appealing, it isn't immediately clear how to ensure trust in such a system. How would the data be imported into the system? How would it prevent a party in the supply chain from committing fraud? How would this huge amount of data be stored in all devices? According to Tian [4], RFID together with blockchain renders trust unnecessary. He explains: "since the whole system is running transparently, the system is absolutely open source and there is no need for trust among every single node and any node can never cheat other nodes." This point of view is consistent with many other blockchain-enabled supply chain articles, but in our opinion misses a key point.

Note that transparency in blockchains refers to data and digital ledgers; it is not about products. If we have a data in the database that says our factory bought a hundred ton of olives of grade A quality, no one can delete or edit this data; however, the olives themselves can be switched with olives of inferior quality. In addition, there are likely to be non-blockchain-based markets and outlets for olives, and reliably integrating trades in these markets with blockchain data is likely to be complex. At a very high level, the key goal of blockchain-enabled supply chains is to obtain 100% certainty of provenance without the need for a trusted third-party; In this case, however, the lack of a trusted third-party and inspections in the network only encourages (or at least, doesn't discourage) fraud.

4. Blockchain CAN revolutionize Supply Chain Management IF the following problems are addressed

Despite the concerns we have raised, we are optimistic about the future of pure blockchain-enabled supply chains—we believe that the solution to the following open questions will revolutionize blockchain-enabled supply chains. Indeed, our goal in preparing this white paper is to encourage researchers to explore the following questions:

- How can physical products be linked to the digital ledger?
- How can blockchain-enabled networks be linked to other external markets?
- How can blockchain be enhanced to account for complicated supply chain structures?
- How can enough space be reserved to store the amount of information required by supply chains?

4.1 Problem 1: How can physical products be linked to the digital ledger?

Bitcoin is a digital currency and each digital coin is attached to its digital ledger by definition. In other words, Bitcoin is not separable from its digital ledger. However, supply chains consist of physical products, equipment and materials which are separate or separable from their ledgers. If we want to use blockchain for handling and tracing products to their origins, we need to find a way to attach digital ledgers to the physical products.

According to Kim and Laskowski [16], “Internet-aware sensors capture finely granular real-time data about products and environment characteristics as well as location and timestamps throughout the supply chain. So, lack of a digital footprint may no longer be an issue. Furthermore, distributed, shared databases using blockchain technologies promise to offer highly secure and immutable access to supply chain data.”

Unfortunately, currently available technologies such as barcodes, RFID-tags, 3D-stamps, and sensors, have two significant limitations. Much of this technology is duplicable. Consider, for example, an RFID on an original product or a barcode on a pharmaceutical product. A criminal can duplicate the RFID or copy the barcode and put it on thousands of fake products. In addition, much of this technology can be removed and replaced. Consider a sensor in a truck that is keeping track of the temperature of the foods. These kinds of sensors are used to ensure foods are not exposed to temperatures outside of the allowable range (so that for example, fruits do not glaciate in low temperatures, or meat or wine don’t spoil in high temperatures, etc.). A criminal could potentially relocate the sensors to a small constant-temperature container, and this fraud could never be found.
Effectively linking physical products with digital ledgers could solve most of the aforementioned issues and bring many opportunities to a variety of industries. The appropriate technology could truly smooth the way for expansion of blockchain-enabled supply chain.

4.2 Problem 2: How can blockchain-enabled networks be linked to other external markets?

Bitcoin cannot be used in any platform other than the blockchain network. In Bitcoin, all transactions are traceable; however, this is in general not true in the supply chain.

Figure 1: Some of the fraud opportunities when current barcode/RFID/3D-stamps/sensor technology is used in blockchain-enabled supply chain.

Consider, for example, an olive oil manufacturer. If there were no market other than the blockchain network, it would be possible to analyze inputs and outputs to verify claims regarding purity, so the manufacturer would be prevented from mixing olive oil with other kinds of oil and claiming the olive oil is pure. Unfortunately, even if we solve ”Problem 1” above, the system cannot ensure customer that the company is selling pure olive oil, because other markets and sales opportunities exist, and the firm can sell some of their olive oil (and buy other kinds of oil to blend with the remaining oil) without being tracked; in other words, the entire market is not integrated. Figure 2 depicts this fraud opportunity.

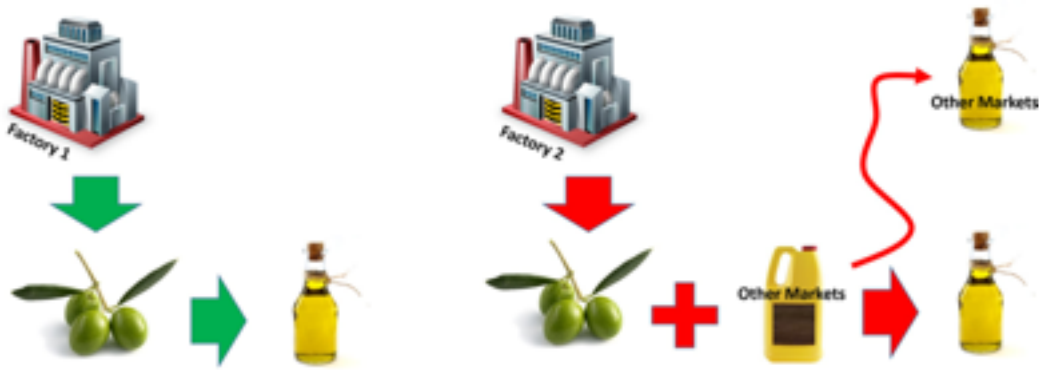

Figure 2: A fraud opportunity due to external markets not integrated into the blockchain.

It would be interesting to explore the ways that a blockchain network and other non-blockchain- based markets could interact.

4.3 Problem 3: How can blockchain be enhanced to account for complicated supply chain structures?

In Bitcoin, all transactions are one-to-one; assembly, disassembly, transformation, waste, break- down, defect and other typical supply chain activities and characteristics are not relevant to the Bitcoin network.

In contrast, relationships are often not one-to-one in supply chain. Consider a factory that assembles a set of parts. How would the blockchain network capture this assembly? If a factory ships assembled products to another node in the network, how would the data be stored? How could the system distinguish between shipping a kit of unassembled parts from shipping the assembled part?

Similar, consider waste. When a factory cuts parts from a sheet of metal, what happens to the scraps? Are they useful for cutting other parts? Will they be disposed of? How can this data be stored? Similar issues arise with tracking divergent supply chains, defects, breakdowns, transformations, and so on.

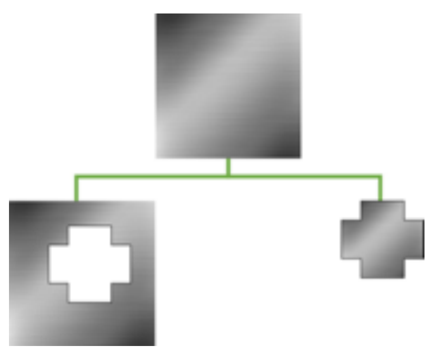

Figure 3: The challenges of tracking scrap and transformation in supply chains.

These kinds of relationships in the supply chain are more complex than the simple transactions in Bitcoin, and the blockchain that we know from Nakamoto's paper [17] is not designed to handle the sorts of complex relationships often relevant to supply chains. Research is needed to overcome these limitations.

4.4 Problem 4: How can enough space be reserved to store the amount of

information required by supply chains?

Bitcoin requires an amount of disk space that is increasing approximately every ten minutes. Based on the data presented in [18], its required disk space has increased 26 GB in 2015 and 41 GB in 2016. Consider that blocks in Bitcoin save only transactions, while in the context of supply chains, we may need to store product details, manufacturing specifications, machines and workers that have contributed to the manufacturing, and many other details (for instance, the volume of documentation for just a shipment of roses from Kenya to Rotterdam can generate a pile of paper 25cm high [11]). There is a tremendous amount of data for each product and distributing all data among all parties may not be possible. On the other hand, saving this data on central servers cannot ensure trust (and if it can, why use blockchain?). Similarly, sharing data with only a few parties in the network will require a third-party to manage data sharing.

It is an interesting research problem to find a reasonable way to manage sharing this data.

5 Conclusion

Thus, for blockchain to have a significant impact on supply chain management, it has to eliminate the need for trusted third parties, and to be adapted to the specific needs to supply chains, both in terms of data requirements, and in terms of the potentially complex structures of supply chains. We believe that in order for blockchain-enabled supply chain technology to reach its potential, and indeed, for many of the interesting proposed blockchain-enabled supply chain use cases to be feasible, technology must be developed to adapt and extend pure blockchain. If it is, we have little doubt that the potential here is enormous.

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