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Article

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Blockchain Impact On Food Supply Chains: A Critical Taxonomy

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Abstract
The aim of modern food supply chain (FSC) management is to provide products from farm to fork in the right condition, in a timely manner and at the optimal costs considering all the aspects of sustainability. Particularly in case of food products, provenance and authenticity, safety issues, food quality and cost indicators are of great importance since they can affect both human health and well-being. Notwithstanding, the growing number of stakeholders and the complexity of the modern supply chain ecosystems hinder the uninterrupted and reliable monitoring of these products. Moreover, food fraud and contamination scandals underline the need to implement emerging technologies in the decision-making process. In this paper we unveil the potential of implementing state of the art blockchain technology in the FSC ecosystem and try to answer the core question: "What is the impact of blockchain on FSC?" Through literature review and case studies we present a critical taxonomy that examines open challenges and gives prominence to blockchain solutions within FSC management.

Keywords: supply chain management, blockchain, food, taxonomy

JEL classifications: O13, M11, L14

Introduction

The definition of globalization is closely connected to the state of "being globalized", that in terms of economic relations means the modification of the nature of international trade by increasing connectivity and exchange of information. More than $4 trillion in goods are shipped annually to satisfy global market demand, and more than 80 percent of the consumer goods are carried by the ocean through multimodal and multi-partner networks [IBM, 2018]. As a result, modern supply chains (SCs) become complex and more vulnerable to disruption, counterfeit, fraud, damages, theft and pilferages. The logistics industry suffers from poor visibility, weak communication among partners, fragmented and inefficient information that heavily dependent on paper-based systems [World Economic Forum, 2016]. In this context, a more transparent SC is becoming a matter of urgency.

This need is becoming increasingly essential when:

- One-in-ten people fall ill - and 420,000 die annually due to contaminated food [WHO, 2015].

- Up to 5% of goods imported into the EU are counterfeited. They amount to approximately € 85 billion reduced revenues for the affected businesses, decreased sales volumes, lost jobs and risk to consumer welfare [EUIPO, 2017], when the global amount is the equivalent of drug trafficking [OECD/EUIPO 2016]. Counterfeit food and beverage cause loss of €1.3 billion of revenue and taxes annually along with €3 billion of lost sales to the EU economy.
- Growing demand for organics and local food is not supported by the transparent data of brands that brings a high potential for fraud (IFOAM EU Group, 2016).
- Food waste across the entire SC in the EU has been estimated at approximately 88 million ton, or 173 kg per capita per year, or 748 kcal per person per day (European Parliament, 2016).
- Poor quality customer data costs US businesses around US $611 billion a year.

Living in the industry 4.0 era where Internet of Things (IoT) technology enables real-time data retrieval and storage, SC digitalization could proceed to the next level and engage blockchain solutions. The recent research of World Economic Forum [World Economic Forum, 2016] indicates that digitization in logistics could provide $1.5 trillion in value through the year 2025. This process needs reliable software and hardware solutions in order to transform a typical SC to its digital counterpart. A 2015 report [DHL&Cisco, 2015] estimated that by the next decade, IoTs in logistics and SCs will generate $1.9 trillion in value. In this sense, blockchain technology can pioneer the future of SC management ensuring more efficient and secure data flows. Global blockchain in the SC market is expected to reach $424.24 million by 2023 with a Compound Annual Growth Rate of 48.37 % [Industry Arc, 2018]. Blockchain can form digital information chains of trust for tracking physical movement from a business source through the SC. By itself the blockchain is a new digital ledger of transparency and accountability and act as a bridge between physical products and their digital twins.

In this paper, we shed light on blockchain’s potential to be incorporated into Food Supply Chain (FSC) management. The rest of the paper is organized as follows: in Section 2 we present some technical aspects of the blockchain technology, in Section 3 we discuss the implementation options of blockchain in the FSC management, and finally in the last Section 4 we provide findings and conclusions.

Technical Information And Relation Of Blockchain Technologies To The FCS

Blockchain technology from its early steps focused on security issues as it was oriented for an electronic equivalent of paper money and introduced the first digital currency that could reliably face real world challenges, like the double spending problem where a single digital token could be spent more than once. The first integrated attempt for a crypto-currency that was based on the blockchain technology was widely known as the Bitcoin (Nakamoto, S., 2008) and it was regarded as an unexpected success until its recent backtrack (Forbes, 2018; CNN, 2018). A great number of efforts were initially motivated from the Bitcoin architecture and they created the backbone of the modern blockchain solutions like the Ethereum platform with Ether crypto-currency (Ethereum, 2018). The wide and fast adoption of the blockchain architecture created a set of innovative applications, besides e-currency, based on the blockchain solution e.g. smart contract, smart property – provenance, licensing-permission, sharing-commoning of goods and even authentication mechanisms.

The extended use of the blockchain technology in non-currency solutions is examinded by Yli-Huumo et al. (2016). In their paper the authors identify that over 80% of the existing papers are based on Bitcoin and cryptocurrencies and less than 20% deal with other blockchain applications including smart contracts. Yli-Huumo et al. (2016) believe that future research will not only focus on Bitcoin or other cryptocurrencies, but on other possible applications using blockchain as a solution in order to revolutionize the way companies can promote their products. Khan and Salah (2018) discussed how blockchain could transform the IoT characteristics in order to create security mechanisms. They examine smart contracts in Ethereum, Hyperledger, Eris, Stellar, Ripple and Tendermint blockchain platforms in order to embed them to the lifecycle of the connected devices. Christidis and Devetsikiotis (2016) are also motivated by the explosion of blockchains and explore their use in the IoTs domain. The authors argue that the combination of blockchains and IoTs facilitates the sharing of services and resources and allows secure execution of workflows in several industries.

Typically, the FSC involves all the farming practices as a farmer uses natural resources and even fertilizers and antibiotics for crops and livestock protection. These processes entail to the final agricultural product that travels through the FSC with different actors (farmers, industries, wholesalers, markets, consumers) to the final consumer. From the FSC perspective, it is evident that food supplies are prone to security issues like provenance of goods, food storage and transport conditions, as well as food management strategies. Technically speaking, blockchain could become an answer to solving security issues on the route from farm to fork and provide visibility throughout the FSC. Tian (2016) states the potential of using RFID and Blockchain technology in the agrifood sector for minimizing agrifood loss ratio in China. He analyzes the RFID and Blockchain advantages and disadvantages and explains their incorporation to the FSC in a farm-to-fork perspective. Foth (2017) discusses blockchain technology under the human-computer interaction (HCI) viewpoint and creates a nascent agenda for the early adoption of HCI in blockchain applications. He argues that HCI can be connected to technological innovations in an early stage of adoption and introduces the blockchain environment by examing the case study of the Australian meat industry and the BeefLeadger project architecture that provides credentialed food provenance and smart contracts in the beef SC. Kim and Laskowski (2018) developed an Ontology based blockchain application for determining provenance in FSCs using Ethereum smart contracts and IoTs. They used the TOVE Traceability Ontology and to the best of their knowledge this is one of the first attempts on Ontology based blockchain applications. Their modelling approach was based on informal, semiformal and formal ontologies. Lu and Xu (2017) truck agrifood products and use smart contracts with OriginChain, an adaptable blockchain software. The system is integrated with several big Chinese e-commerce retailers, provides transparent traceability data and automates regulatory-compliance checking. Also this system discriminates between on-chain and off-chain data in order to increase performance and enforce privacy constraints.

Taking into consideration the aforementioned case studies, we conclude to the proposed integrated solution. Blockchain architecture could be private or public according to the number of stakeholders, the amount of information stored in the platform and the overall needs of the SC. Each step in the farming practices should automatically generate (with the use of IoTs) blocks of relative information that are securely stored in the blockchain. Miners are special tools that ensure the information process and the storage of blocks. Therefore, food origin and quality is ensured and could lead to the automatic smart contract activation, as all the stakeholders have reliable and accurate information. Finally, at every step within the FSC, smart devices provide information about the agricultural product’s status and generate additional blocks that are embedded in the blockchain using miners. This ensures that at all steps of the procedure, from farm to fork, all entities are aware of the food quality and can optimize the decision making process.

Incorporating Blockchain Into FSC

Using blockchain in the SC has the potential to improve SC transparency and traceability, to provide greater scalability and improved security as well as to reduce cost and enhance the organization’s position on the market [Leng, et al., 2018]. Information sharing between growers, logistics providers and retailers is critical to the timely movement of perishable inventory.

Blockchain can be used within and outside an organization to facilitate information and transaction sharing across enterprises in order to improve decision-making, sourcing, inventory tracking, transparency and visibility. It can be integrated with existing enterprise resource planning (ERP) systems in order to: (i) address common procurement challenges (sourcing decisions, supplier selection, payments etc.), (ii) manage and track orders through real-time inventory visibility (e.g. via smart contracts), (iii) organize supply and demand planning based on consensus-driven causal forecasts, (iv) simplify auditing, and (v) enhance the efficiency of logistics management and distribution [Banerjee, 2018]. The impact of blockchain in SCs can be evaluated with the help of the following criteria of sustainability [Kayikci, 2018]:

- Economic: savings of logistics cost, improvements of delivery time, reduction of the transport delay times and inventory volume, reduction of lost/damaged goods, increase in resource utilizations rates, decrease of demand uncertainties and finaly increase of logistics quality.
- Environment: resource efficiency, changes in energy requirements and fuel consumption, reduction of waste and pollution.
- Social: reduction of disease caused by logistics side effect, changes in labor intensity, employment schemes, reduction of accidents in supply chain activities.

Blockchain technology can be applied at every part of the FSC (e.g. beef, pork, dairy, egg, broiler, commodity crop, fruit and vegetable SC) [Kshetri, 2018]. In primary producing level blockchain can solve the problem of unique animal identification and complete traceability of seed or plant stock used to crop planting. Furthermore it could trace the animal’s or plant’s growing conditions and even improve the problem of low efficiency of small volume agricultural commercial enterprises participating in the real-time wholesale market. Addressing harvesting and packaging issues, smart packaging improves the ability of IoT systems to be integrated into transportation units using smart interconnected devices (e.g. tags, seals, trackers, tracers, sensors) that record data and store them on the blockchain. Food is tracked by lot, batch or date code. This information can address capacity and routing, location and scheduling issues, loading/unloading procedure and can be used for minimization of transportation disruptions. The ability to share information between supply chain partners ensures appropriate timing for crop picking, processing and delivery, which in turn reduces pipeline inventory, spoilage and energy consumption. Efficient information management also eases food safety investigations when problems occur [FAO, 2007]. In these terms blockchain can provide product description information, lot numbers, the product’s harvest information, the pack dates and a comprehensive record of handling activities and handling dates [Hofmann & Rüsch, 2017; Tian, 2017]. Enhanced traceability efforts of blockchain aim to provide real time and valid information about the origin and handling history of a particular agrifood product. Traceability can be used to enhance producers’ marketing efforts and build brand image [Hackius & Petersen, 2017]. For example, such attribute differentiations like organic or sustainable growing practices and geographic demarcation (e.g. protected geographical indication, protected designation of origin, traditional speciality guaranteed) can be ensured by the use of blockchain. Traceability is also important in logistics management of niche products (e.g. kosher foods, organics, products for special dietary needs). Blockchain can greatly improve and streamline the implementation of pricing policies as it allow retailers to collect and share data with different tiers of the SC in real time. It could also avoid of changing “use-by” dates.

At the final step of FSC blockchain can provide solutions to manage last mile delivery and order transactions between retailers, logistics companies, and consumers within the city [Polim, 2017] thus creating a secure communication platform for a smart city. Collected information can be implemented for different waste management scenarios [Saberi et al., 2018]: still edible but unmarketable products or surplus from lower than foreseen sales can be redistributed to the final consumption points for vulnerable social groups or for recycling for animal feeding; inedible – for composting, energy recovery or disposal. The redistribution of perishable products from various collection points by means of reverse SC management (e.g. collection, sorting, disposal, repackaging and redistribution) includes transportation, storage and distribution issues that need uninterrupted and reliable information flows for increasing efficiency and effectiveness in SCs.

Conclusions

Providing real-life tracking and reliable recording of all transactions across FSC, the blockchain technology can improve regulatory compliance, increase quality control, provide enhanced inventory management and higher profit margins, while also focusing on a sustainable, transparent, and consumer oriented SC. Blockchain technology assists B2B, B2C and C2C interactions and can be implemented in production and material planning, operations, inventory management, warehousing, marketing, distribution, accounting and customer services. Blockchain is a tool that links information flow to the material flow and enables the delivery of reliable information to all the stakeholders for decision-making activities. It is worth to mention that blockchain technology is not a panacea, since the human factor could still affect the system, so SC professionals should focus on establishing a balance between technology and the human factor in the supply chain ecosystem.

At the moment there is a gap in the literature concerning the actual implementation of blockchain to FSCs. The majority of studies are based on Internet sourced information and on limited pilot projects implemented worldwide. Moreover, since blockchain technology has started its commercial implementation recently, there are limited real world application scenarios and related applied operations research. Future research efforts should focus more on these aspects and provide a holistic framework that enables the incorporation of blockchain technology to FSCs.

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