Blockchain Technology—A New Traceability System in Prevention of Fraud-Ridden Food Safety Issues

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Abstract. In the past few decades, food fraud and safety issues have given rise to growing concerns from the society. With the purpose of efficiently detecting and preventing food safety problems and tracing the accountability, the establishment of a reliable traceability system is indispensable. For a traditional traceability system, the support of blockchain technology can effectively remove its defects in terms of data tampering and sensitive information disclosure. The paper looks into different respects such as facts identified as food fraud, factors suitable for detecting food fraud, deficiencies of blockchain application in solving food safety problems, etc., using research methods of questionnaire survey and semi-structured interview. The finding is that although blockchain is a promising technology for the food safety traceability system on account of its possession of features such as tamper-resistance and distributed ledger technology, the application of this technology in food safety protection at current stage is faced with many challenges on the way to universalization, which still needs the effort of the government and influential associations to set up laws and regulations and tackle issues concerning trust of the blockchain network and the authenticity of original data.

Keywords: Blockchain Technology · Food Safety · Food Fraud · Traceability System · Distributed Ledger Technology · Smart Contract

1 Introduction

1.1 Background of Fraud-Ridden Issues

The last two decades around the world have witnessed many business failures to comply with the food regulation, as a consequence of sub-standard materials and ingredients like horsemeat, gutter oil, as well as the illegal use of food additives and chemicals such as clenbuterol, Sudan dyes, etc. In China, food safety has been a growing concern especially since the outbreak of the scandalous melamine-tainted milk formula.

Amongst all that have caused hazards concerning food safety, fraudulence has been one of the most obvious sources in industrial history. At its most basic level, the concept of fraud, as it is commonly understood, is a way of making money illegally via deception

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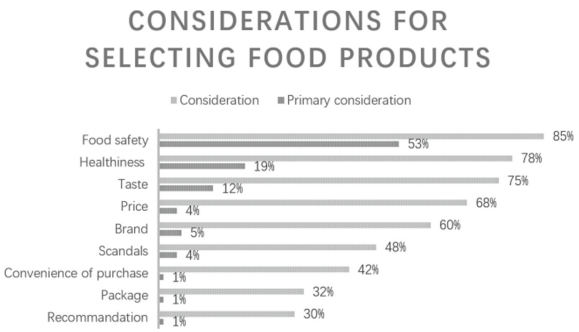

Fig. 1. Considerations for selecting food products (The figure is original)

that involves a process of some form of dishonest or deceptive practice and an outcome that is some form of advantage as a goal [9]. When lured into the pursuit for such form of advantage, companies are prone to commit fraud by means of counterfeiting in the attempt to create a false impression of high quality to the customers and the public.

However, as Motarjemi states, "Despite our continuous attempts to draw attention to the scientific evidence, food safety remained an afterthought at best [13]". All of the evidence adds up to the fact that the present food regulation system has been found wanting in dealing with the issues of food safety from the source, i.e. to take early actions by nipping the peril of accidents and frauds in the bud. A proactive countermeasure against food hazards is desperately needed.

1.2 Purpose and Substance of Research

According to the result from an investigation concerning food safety conducted by Ipsos [7], food safety is Chinese consumers' major concern when it comes to the purchase of food products. About 85% of Chinese consumers will take safety into account while buying food, furthermore, 78% of them are also interested in the healthy nature of food as shown in Fig. 1.

It's an obvious fact that consumers in the present circumstances have come to value food safety and healthiness more than any other conventional factors such as taste, price and brand. However, the intricacy and extent of modern supply chain may involve an increased risk of fraudulence in labelling and marketing, which can result in trust crisis among stakeholders. On top of that, the traditional food supervision system has inherent defects in data fragmentation and centralized control that could give way to even more worries [8].

2 Literature Review

2.1 Food Fraud Hazards

Previous studies have researched on the food safety issues from a broad overview that boils down to the presence of toxins, contaminants and pathogens in food which are

fundamentally associated with environmental pollution, the ineptitude of science (as regards biotechnologies such as genetic modification), laxity in practice of food hygiene, corporate or industrial lack of due care, or even worse—by fraudulence.

Food fraud, which is sometimes referred to as "economically motivated adulteration" [13] has long been perceived as a chronic menace that undermines human health and the society. Take the tainted milk formula for instance: melamine was once used by a company in China to increase the proportion of nitrogen—the main indicator for the testing of protein level in dairy products—in infant milk formula, which notoriously brought about a nationwide panic over infantile renal disorder, having afflicted nearly 300,000 children of whom a few dropped dead [17]. Food adulteration and food fraud are not only gaining widespread media attention from time to time, but they cause also problems for the proper functioning of a fair market and consumer trust. The horsemeat scandal detected in 2013 is the initial spark in Europe for reflecting on related legislative and regulatory aspects and actions as well as on upcoming challenges and potentially new scenarios [5].

2.2 Traceability System in Food Supply

Food safety traceability system represents an information supervision system which covers all processes across the supply chain to let the consumers be aware of whether the production of food is sanitary and secured, in a way consumers' trust on the safety of food products they bought can be improved [11]. The traceability system for food ensures traceable data from farm to table by dint of tracing some certain indicators that worry the consumers across the supply chain [6].

Food safety traceability system has been one of the key factors to study and make the food safety policy. Many effective management measures such as ISO 9000 and HACCP have been introduced to control the food safety and achieved a certain effect in the practice [10]. But the above-mentioned measures are mainly for processing chain and lack the means to connect the whole supply chain. The traceability system emphasizes the unique mark of product and the whole process tracking for foodstuff, capable of tracing the product information in each process through the entire supply chain by quality control methods like HACCP, GMP and ISO9001. It can effectively situate the source of the food and call back the unqualified product range on time to minimize the loss once there is food safety problem [16].

2.3 Blockchain

According to M. Niranjanamurthy, Nithya & Jagannatha [14], a Blockchain can be considered as a digitalized public ledger that would record all the digital transactions in a chronological order, or a data structure of "Completed Transaction Blocks" that can save the data in a distributed manner across a network. This ledger would be available for anyone to download who can connect with this network. The Blockchains are implemented using three major technologies: (1) Private Key Cryptography, (2) Peer to Peer Network, (3) Program (the Blockchains protocol). The major advantage of a Blockchain is its usage of distributed computing technology that helps it overcome problems of load sharing. Distributed computing technology also supports graceful degradation that

makes Blockchain technology very reliable to store sensitive information like medical records, management activities, transaction processing, documenting derivation, food traceability or voting.

Trust is the most important issue of the Blockchain. The interactions between the nodes within the network ensure that trust is achieved. The participants of Blockchain network rely on the Blockchain network itself rather than relying on trusted third-party organizations to facilitate transactions [3]. A blockchain network can offer more than just traceable facts, but also act as a custodian to whom the traders entrust the recording of their transactions in the absence of a third-party facilitator, differentiating itself with five key properties—immutability, non-repudiation, integrity, transparency and equal rights—so that a multifaceted management of food supply chain is achieved by providing information as a basis for supervision, food recall and prior warning, which also meets with the government's demand for food supply chain system [14].

3 Data Collection and Analysis

3.1 Questionnaire Survey

3.1.1 Facts Identified as Food Fraud

Figure 2 shows that most of the participants considered the concealment of inferior quality (89%) and imitation of foodstuff (87%) as food fraud. Some of the participants pointed out in the open-ended question that misdeclaration (70%) and mislabelling (69%) not only can be done with fraudulent intent, but also by accident. Of all the participants, 15% indicated in the open-ended question that there were other facts that should be included within the scope of food fraud. For example, the sale of rotten goods or the addition of rotten substances, the use of unauthorized genetically modified organisms (GMOs) in food and the use of contaminated additives as well as the falsification of the best-before date should be counted as food fraud.

Fig. 2. Facts that are identified as food fraud. The participants (n = 167) of the online survey stated which facts are counted as food fraud in their opinion. For this purpose, the facts presented were individually assessed as "Yes", "No" or "Not sure". The results are displayed as stacked bars. (The figure is original)

3.1.2 Factors Suitable for Detecting Food Fraud

With regard to the suitability for predicting food fraud, the following three factors were ranked in descending order on the left side of Table 1:

- Origin of the foodstuff or raw materials (mean value 10.81),
- Price fluctuations of the food or its raw materials (mean value 9.88),
- Previous food fraud cases within the company (mean value 8.93).

The participants with education level of bachelor's degree or higher ranked all factors from place 1 (most suitable) to place 7 (least suitable). Three of all factors were ranked by other participants in descending order from place 1 (most suitable) to place 3 (suitable). The factor ranked first received 14 points, the factor ranked second received 12 points, and so on (two points for each rank in descending order, starting with 14 points).

The opportunity to rank all seven factors was applied by 118 of the participants who are college students and who have already received bachelor's degree or above. Despite that the rest of participants whose education was below that level was only allowed to rank three factors amongst the seven, the first three ranks were taken by the same

Table 1. Ranking of factors considered suitable for detecting possible occurrence of food fraud

Factor	Rank	Ranked with all factors		Ranked with three factors	
		Mean value	Standard deviation	Mean value	Standard deviation
Origin of the foodstuff or raw materials	1	10.81	2.89	9.97	2.57
Price fluctuations of the flood or its raw materials	2	9.88	3.44	8.66	3.33
Previous food fraud cases within the company	3	8.93	3.60	5.17	4.38
Product category of the foodstuff	4	8.08	3.99	2.41	4.25
Production pattern	5	7.03	4.02	2.21	4.17
Supply chain length	6	6.17	3.55	1.62	3.81
Market supply of goods or its raw materials	7	5.08	3.01	0.38	1.98

Ranking according to the online survey. Left: ranked with all seven factors (n = 118), right: ranked with three factors (n = 49). (The table is original)

three factors. In the ranking of all seven factors, the standard deviation of Origin of the foodstuff or raw materials is lower than all other ranked factors, which means that its variance is the lowest.

As is shown in the result, the origin of food products is the absolutely essential factor for detecting fraud-ridden food safety problems.

3.2 Semi-structured Interview

3.2.1 Knowledge About Blockchain

All four participants who are PwC employees confirmed during the interview their knowledge about blockchain technology, although through different ways like corporate project, Bitcoin, news website and communication with colleagues. One of the participants said it would be an essential technology that could lead a future revolution in all industries, whilst the other three's first impression about blockchain technology was that "it's too complex and opaque to understand its mechanism", especially for a layperson. None of the participants have partook in any project related to blockchain, but they all admitted having heard about such projects being taken care of properly within the firm. Participant D said that the most well-known characteristic of blockchain would be security traceability, believing that this feature alone could resolve many problems in lots of industries, on account of the fact that such technology can act as a third-party which is completely objective and trustworthy compared with human intermediaries.

3.2.2 Opinion on Blockchain Being Applied to Solve Food Safety Problems

When asked about opinion on blockchain technology solving food safety problems and food fraud, participant A said, "Even though a lot of people think highly of blockchain, one should not forget this technology is still under development". In other words, it's only arising but not mature. For a problem affecting people's well-being like food safety, the main force still depends on the government's decision about whether or not to widely promote this technology and implement relevant policies. Participant B found it very constructive, but she also added, "it's never easy to popularize a new technology, and not every food company is capable of affording the operation of a blockchain system." Participant C thought it might be promising but full of obstacles on the way to maturity, he believed that the government should stipulate the involvement in blockchain-driven food safety system as mandatory for every food company, otherwise it would be too difficult to execute. Participant D suggested that blockchain developers could cooperate with retailers like T-Mall, who already have tens of thousands of sellers and customers on their platform in order to promote this technology faster and more easily.

3.2.3 Description of Ideal Blockchain-Driven Food Safety System

In participant A's view, an ideal blockchain system protecting food safety should be spread among the masses in the form of an app, which is controlled by official body such as the government or large enterprises, so that an ordinary individual can get to know the details about the origin and other information of a certain product, in a way that is perfectly objective and free from the interference of food businesses themselves.

Participant B pointed out the system should be able to detect every indicator that might involve fraudulence or safety problems, and that no food business could be given control to this system in case of data fabrication, which might disrupt the credence of this whole system. Participant C added, the system should give the public access to all information, i.e. to describe in the system the meaning of some unfamiliar statistical indicator so as to let all ordinary people know what the data demonstrates. Participant D imagined the system holding a uniform standard of logic for the convenience of general understanding.

3.2.4 Deficiencies of Blockchain Application in Solving Food Safety Problems

Participant A believed that, apart from the development of blockchain technology itself, the support of the government would be most indispensable. Participant B mentioned her concern about the reliability of the original data, worrying even if blockchain was tamper-resistant, how this technology could guarantee that the data was genuine from the beginning. She was convinced that this was particularly significant since it would make the solution meaningless if the authenticity of original data can't be safeguarded. Participant C said, "Apparently there is a lack of laws and regulations regarding blockchain technology." He thought it was problematic and too demanding for a group of consulting agencies to lead an industrial revolution, because the government must pull its own weight to protect this system by legislating against potential hazards. Participant D deemed it necessary as well for the government to help, not only with the system, but also with the SMEs by funding them in blockchain establishment.

4 Blockchain Technology Against Food Fraud

4.1 Ongoing Blockchain Application in Food Traceability

In response to food safety failures transpiring all over the globe, governments have been pulling out all the stops to re-examine the current food regulatory framework together with the inspection system. Consumers want to be confident about—most of all able to follow—the information regarding the quality and origin of their food ever since the infamous scandals of horsemeat and doctored milk formula. Each year one of ten people fall ill globally as a result of food borne diseases and of those around 420,000 die. Clearly food companies, distributors and retailers addressing these issues globally are facing considerable challenges.

Some hope the answer lies in applying distributed ledger technology (DLT), also known as blockchain. And, if retailers and distributors could see and validate with certainty, e.g. where some certain crops were grown, handled, stored and inspected, plus each and every stop made on the way to the store, the details could be shared via the distributed ledger of blockchain. During a pilot program conducted with Walmart, testing found that by applying blockchain the time it took to trace a package of mangoes from the farm to the store is reduced from days or weeks to only 2.2 s. IBM Food Trust, using blockchain technology running on the IBM Cloud, can connect growers, processors, distributors and retailers through a permissioned, permanent and shared record of food-system data that can drastically cut the time needed to trace produce from farm to store so that the contamination control can be relatively ameliorated, the appraisal of health

risks throughout the supply chain is therefore attainable to cope with a health hazard at an early stage [4].

Blockchain technology enhances information sharing in the secured situation through the entire supply chain. The data stored on the public blockchain is accessible to everyone and cannot be tampered with. Therefore, it increases the trust, security and transparency in Wal-Mart's food supply chain. From the perspective of consumers, they are able to know more accurate tracking details of food from their smart phones, which enhances their confidence. As for organisations, Yiannas, who is Wal-Mart's food safety chief, claims that although paper records have the risk of being changed, they still dominate in food industry. However, through digitization of documents and recording the data of parties who input it on the blockchain, the demand for manual data management declines. In light of this, human errors can be limited, and the chance of corruption can be reduced because no one can change the data history [12] so that food fraud is expected to be prevented. Furthermore, blockchain technology is also a powerful tool for regulators to help Wal-Mart examine its food supply chain and the responsibilities of all the parties clearer according to the immutable records [15].

4.2 Comparison with Other Measures Against Food Fraud and Safety Problems

In light of national policies, China's FDA is actively addressing food safety and supply chain integrity in these new retail channels, and recently published measures targeting e-commerce. Take the "Measure to Handle Online Food Safety Violations" (Order 27) as an example, which became effective starting on 1 October 2016 [2].

Both blockchain-driven traceability system and the Order 27 are targeted at the insurance of the genuine information of food safety, but to some degree they differ a lot in some respects.

Order 27 aims to protect consumers from fraudulent marketing and unfounded health claims, but some clauses are focused only on the surface, since the origin of information is in fact unprotected. In the Order 27, e-commerce platforms must ensure that online information is factual by monitoring and conducting spot checks on food service providers' operations. The third-party platforms and food producers or traders who sell products online are responsible for the truthfulness of online food safety information. However, it is stipulated in the order that product information published online must match that of the product's actual label, which means the order basically ensures nothing, or simply a very low level of safety, because the unethical businesses might jolly well commit mislabelling.

It is also forbidden in Order 27 to state or imply that non-health food has health functions, or that infant formula can improve intelligence, immunity, etc. Health food information must prominently display the following: "This product cannot be a substitute for medicine". Food producers or traders who conduct business online must prominently display all relevant business, production and trading permits and licenses. Food safety inspection grades must be prominently displayed on food service providers' main activity page. Online sellers of health food, infant formula or food with special medical formulations must display the products' registration or filing certificate, the advertising approval number and a link to the relevant information on the China FDA's website [1].

Nonetheless, it is obvious to see that Order 27, as a microcosm of many other governmental policies, pays its most attention to titles, certificates and qualification, but in spite of everything it overlooks what really matters. To be specific, the Order 27 fails to take notice of the origin of information, which could still bring about hazards when left to its own devices. At the same time, a blockchain-driven traceability system, irrespective of all that qualification, regards all businesses as equal ones however powerful or renowned they are from the look. It protects the authenticity of data from the origin so that nobody has the chance to tamper with even one single figure.

As one would expect, clarifying food safety responsibilities of course will help protect brands by improving practices throughout the supply chain and reducing the risk of food safety incidents, but there is every chance for fraud to happen in a system as such. The Order 27 involves challenging compliance requirements for record keeping, information verification, and monitoring of online food service providers and online food producers and traders. The new requirements will favour companies with sophisticated food safety and supplier management, efficient operations, and robust information technology. By contrast, the blockchain-driven traceability system is controlled by a neutral third party, so no compliance from food producers or traders is required, because they're the ones under supervision in this mode. All they have to do is to be honest to their customers and receive inspection from the blockchain.

Likewise, the governmental measures including Order 27 also bring additional costs and complexity for businesses, and so will the blockchain technology. It is believed in industry, and as was shown in the author's interview result, that the mature form of blockchain-driven traceability system will no doubt induce a large amount of money as financial support that is too onerous for SMEs to afford.

4.3 Barriers to Blockchain Adoption

A company creating a blockchain for itself will undoubtedly confront challenges related to internal buy-in, data harmonization and scale. Still, this company can set and enforce the rules of the blockchain, just as it does with its ERP today. But generally speaking, people can hardly realize the return on investment in blockchain if they're building it just for themselves. Blockchain's benefits are best realized when different industry participants come together to create a shared platform. It is way too expensive for companies to establish blockchain systems for themselves, and even if they can afford it, a set of divided blockchain network fundamentally loses its inherent meaning of existence when data are divided and therefore untraceable.

Another remarkable conflict of the blockchain technology is reflected in the interview survey, that although blockchain is capable of tracing the origin the data, but itself alone can barely guarantee that the data is truthful form the origin when a fraud was behind the scenes manipulating data and figures. The innate nature of blockchain is supposed to promote trust as one would expect. But in reality, companies confront trust issues at nearly every turn. For one, users must build confidence in the technology itself. As with any emerging technology, challenges and doubts exist around blockchain's reliability, speed, security and scalability. And there are concerns regarding a lack of standardization and the potential lack of interoperability with other blockchains.

Also contributing to the blockchain trust gap is a lack of understanding. Even now, many executives are unclear on what blockchain really is and how it is changing all facets of business. Although the public narrative has moved beyond bitcoin, even the more recent focus and hype around ICOs only hint at the potential impact. Blockchain's role as a dual-pronged change agent – as a new form of infrastructure and a new way to digitize assets through tokens, including cryptocurrency – is not easy to explain. In comparison with other new technologies: users can try on virtual reality goggles or watch a drone take flight, but when it comes to blockchain, it appears abstract, technical and happening behind the scenes.

Another challenge for blockchain is building trust in the network. It is perhaps ironic that a technology meant to bring consensus with a stumbling block on the early need to design rules and standards. Take payment systems and mechanisms in banking for instance, though everyone plays by the rules of existing systems today, they don't necessarily agree on how an alternative blockchain-based model should be designed and operated. Likewise, there's a lack of comfort regarding regulation. The majority of regulators are still coming to terms with blockchain and cryptocurrency. Many territories have begun studying and discussing the issues, particularly as they relate to financial services, but the overall regulatory environment remains unsettled.

As a distributed ledger that can settle the concerns on trust, blockchain technology has attracted more and more attention. However, as the application market of blockchain is at the early stage of development, the public and enterprises still lack enough understanding for blockchain technology.

Whenever a new technology or system is arising, the support of laws and regulations is absolutely necessary considering the popularization of the e-commerce. There is a period when everyone was suspicious of the reliability of e-shopping, and thanks to the effort of platforms and the government that has finally built up trust in the system, now people embrace it with open arms, and so will blockchain. When the blockchain technology is applied as a supervision mechanism, first and foremost, it is essential for the government and influential associations to promote this technology so as to make the ordinary people realize what kind of safety and benefits this system can bring over to their lives, when the masses start to trust and ask for this insurance, the food producers will accept it of their own will.

5 Conclusion

In conclusion, this paper investigates the adoption of blockchain technology in food supply chains in order to address fraud-ridden food safety problems, in comparison with other existing countermeasures and government policies in answer to food safety issues. Questionnaire survey, semi-structured interview and case study are used as the research methods and data analysis tools. From the analysis of findings and facts, although the industry has initiated blockchain adoption which indeed brought opportunities, the generalization of blockchain adoption still faces a lot of challenges.

Further development demands amelioration of the technology and relevant supply chain management, which will entail the effort of many different roles from the society to set up regulations and resolve problems like data authenticity, as well as popularization

of trust among the industry and the masses. The study has possible limitations. Extra cases along with other data analysis methods may be adopted to discover more practical solutions or sensible findings regarding the application of blockchain in prevention of fraud-ridden food safety hazards. With the aim of investigating more values that may refine the practice of blockchain technology, further research could enquire deeply into food industries together with the blockchain domain.

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