USING DISTRIBUTED LEDGER TECHNOLOGY TO AUTHENTICATE FOOD SUPPLY CHAINS

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Abstract

This paper explores the use of blockchains, or distributed ledger technology (DLT), which underpins cryptocurrencies such as Bitcoin, to address some of the issues in proving the integrity, provenance and content of global and local food supply chains.

The presence of antimicrobials (AM), such as antibiotics in milk, poses a number of problems for human health, animal husbandry and production.

The presence of AM in food products is part of a much wider concern regarding the overuse, misuse and abuse of AM in humans and animals. The key concern is the increasing antimicrobial resistance (AMR) impacting the prevention of infection and treatment of disease.

The blockchain, or distributed ledger, is the technology that underlies cryptocurrencies, but its design features of transparency, immutability, integrity and resilience make it useful for recording transactions in supply chains and proving provenance.

The focus of our research is the deployment of DLT in supply chains, and their particular use in ensuring the absence of AM in milk products. The economic and productivity challenges faced by the UK dairy industry are being addressed by the significant use of AM to maintain herd health. However, there are increasingly strict requirements to prevent AM appearing in the food chain.

Our research will build an efficient supply chain information system to collect and share information using DLT. A key research objective is to find ways of proving traceability, once milk has been mixed, so that the match to the original supplier is maintained. Cows and milk will be monitored for AM use and records will be maintained on an industry-focused distributed ledger to improve the sharing of information, to reduce risk, to reduce the cost of prevention and repair, and to improve efficiency.

Introduction

The global food industry faces significant challenges. Among these are food safety concerns such as BSE, cross contamination, counterfeiting, and adulteration. In the UK, the Elliot Review[1] into food supply network safety called for a holistic approach to create a "transparent and managed system" for food safety. A system of transparency does not currently exist. Of urgent concern is the overuse and misuse of antibiotics (AM) in food production that may lead to antimicrobial resistance (AMR) developing.

Transparency of a supply chain is '…the extent to which all its stakeholders have a shared understanding of, and access to, the product-related information that they request, without loss, noise, delay and distortion' (Hofstede, Spaans, Schepers, Trienekens and Beulens, 2004). This transparency benefits the customer by providing quality assurance, while at the same time providing benefit for the food company in product differentiation, production optimisation, quality provision, and better management of logistics. In complex supply chains, such as those found in food systems, managing transparency for the mutual benefit of both provider and customer has been shown to be difficult; requiring information technology to manage both data and process (Trienekens, Wognum, Beulens and van der Vorst, 2012). Analog methods of control, thorough legislation and standards, are difficult to enforce completely.

Digital technology offers significant opportunities for increased transparency and security. For example, using sensors to provide real time information (at each stage of the supply chain) to improve flexibility and to reduce cost and waste. The increasing deployment of sensors is providing information to allow more intelligent practices to reduce costs and to improve flexibility. However, a relatively new innovation, the blockchain, or distributed ledger, is seen by many as offering significant opportunities within agricultural supply chains.

Distributed ledger technology underpins cryptocurrencies like Bitcoin. Their main advantage is in their security, immutability, and resilience that can be achieved. Designed appropriately, they can supply a visible assurance of activities and provenance along the supply chain. Researchers, established companies, and start-ups, are exploring their use in food supply. Additional benefits of DLT technology may also be realised through reduced working capital, faster payments and cheaper cross border payments.

The purpose of this paper is to problematize the issue of antibiotics in food products and propose a DLT solution to be designed and tested.

[1] Elliot Review into the integrity and assurance of food supply networks, 2014. https://www.gov.uk/government/publications/elliott-review-into-the-integrity-and-assurance-of-food-supply-networks-final-report

Antimicrobial resistance

The final O' Neill Report (2016)[2] commissioned by the UK Government and Welcome Trust provides a comprehensive overview of the issues presented by AMR (i.e. drug resistant infections) and its effects and potential mitigating actions.

In addition to an "economic and security threat", the report clearly identifies AMR as a health risk with the potential to cause 10m deaths world wide per annum by 2050, nearly equalling combined deaths attributable to cancer, diabetes and road traffic accidents, severely impacting lifestyles and economic production.

The report identifies mitigating actions. These include: reducing demand (and hence use and make current useful antimicrobials (AM) last longer; and increasing supply (there are few new AM's under development). Recommendations to increase supply include the establishment of a global innovation fund and better incentives for firms to research and produce new AM's, and improve existing ones.

In terms of demand reduction the report suggests seven linked recommendations. These are: improve awareness of the issue of AMR; improve global surveillance and measurement; address the pay and recognition workers dealing with infectious disease; reduce the need for their use through improving sanitation and disease prevention; and using vaccination alternatives. Two recommendations are directly related to the food sector: reducing unnecessary use in agriculture and avoiding leakage into the environment; promoting new rapid diagnostics. Our research impacts in part both of these agricultural industry recommendations, with respect to AM in food products.

Transparency and traceability in food supply chains

Extant research provides depth of knowledge in several areas from the perspective of both the consumer and the producer. The consumer perspective provides a focus on the assurance of quality and the transparency of the operational systems which manage the flow from producer to consumer. On the producer side, production and distribution are intrinsically dynamic (Grunow and van der Vorst, 2010). To illustrate this, we draw on research on complexity in food supply chains, sustainability practices, and the standards governing the industry.

Consumer demand for transparency in the food supply chain received significant attention after the appearance of horsemeat in European beef supply chains in 2013. The resultant outcry

[2] O'Neill, J. 2016. Tackling drug-resistant Infections globally: Final report and recommendations. The review on antimicrobial resistance. Wellcome Trust. HM Government. http://amr-review.org/sites/default/files/160525_Final%20paper_with%20cover.pdf

from consumers prompted major UK grocery retailers to closely examine their upstream chains. The investigations surfaced issues concerning poor supplier management, prompting the desire for increased levels of transparency across the entire span of the chain. An increase in transparency was shown to provide substantial benefits to a breadth of supply chain stakeholders through increasing timely access to accurate and up-to-date chain information (Hofstede, Spaans, Schepers, Trienekens and Beulens, 2004).

While transparency may emerge from a producer's response to regulation, it may also be the product of proactive strategic action. Wognum et al, (2011), use transnational corporations as examples of using conformance to regulation as the catalyst for implementing more ambitious approaches to impact production management for competitive advantage.

Further, the investment in information management infrastructure to enhance transparency can be justified with a second known benefit. Increased levels of transparency were shown to have a positive correlation on the customer's willingness to spend more on a product (Napolitano, Braghieri, Piasentier, Favotto, Naspetti and Zanoli, 2010).

Delivering transparency to the customer is the responsibility of producers within a complex network of suppliers. This is often difficult due to disparate data sets and IT systems that are unable to easily share information. Trienekens et al (2012) (drawing on Taylor & Fearne, (2006)) emphasise the need for improved information management systems to cope with varying information requirements from different food-producing markets. Their research showed increased capability in information management is needed for data capture, storage, and exchange across the food supply chain.

Increases in demand due to population increases, suggests that global food production may have to increase by 70 - 100% by 2050 (World Bank, 2008[3]; Royal Society, 2009[4]). Given the nature of current demand and the expressed need for increased production, any and all losses of food productivity would impact the effectiveness of the system. Thus, swiftly identifying and rectifying any production errors carries greater importance. Chains for products, such as dairy and meat, where different production processes frequently converge and diverge again (e.g. cheese and pork products), create a significant challenge to traceability (Trienekens, Wognum, Beulens and van der Vorst, 2012). In these cases, a wide array of products can contain mixed ingredients from multiple suppliers, and can be then distributed to multiple markets. Furthermore, an impact on efficiency is likely from those information systems which can quickly and accurately identify provenance, and identify, for recall, the location of already-distributed products linked to that provenance.

[3] World Bank. 2008. *Global Food Crisis Response Program (English)*. Washington, DC: World Bank. http://documents.worldbank.org/curated/en/717381468137698947/Global-Food-Crisis-Response-Program

[4] https://royalsociety.org/topics-policy/publications/2009/reaping-benefits/

DLT applications to provenance

DLT was developed to create the Bitcoin cryptocurrency, “A purely peer-to-peer version of electronic cash [which] would allow online payments to be sent directly from one party to another without going through a financial institution” (Nakamoto, 2008)

Transactions are recorded in a “block” which is then cryptographically linked to the previous block in the chain. This makes the alteration of records close to impossible. The whole blockchain is shared amongst its operating nodes, making it extremely resilient with no single point of failure. Blockchains are secure, resilient and immutable, and can be designed with varying degrees of transparency to users. The need for trust in 3rd parties to validate transactions and actors is removed by a consensus mechanism which validates and secures the chain (mining).

Since the emergence of DLTs, coders, entrepreneurs, governments, NGOs, scholars and others have been exploring more diverse potential application areas. One area where it is believed DLT is having an impact is in supply chains or provenance traceability, which Greenspan and Zehavi (2016) speculated may be DLT’s best use case.

Identifying provenance, an artefact’s origin and history of ownership, remains an important and ongoing consideration for business, government, consumers and wider society. The particular characteristics of DLTs, a distributed, timestamped, immutable, transparent ledger of record, allows us to conceive of systems, insomuch as design choices direct, in which the transfer of digital assets, records of ownership and value exchange can be safely stored and maintained. That is, from a supply chain perspective, DLTs can provide both a current register of ownership, a record of previous owners over time (when and for how long) and the transactions between them. The particular advantage that DLTs offer over existing approaches is, in combination with other technologies such as RFID, IoT and NFCs (e.g. (Tian, 2016), (Manski, 2017), (Lemieux, 2017)), in being able to cope at a more granular level with the increasingly complex interactions of global supply chains (Boucher, Nascimento and Kritikos, 2017).

The general use case for DLTs is to disintermediate so-called trusted third parties who mediate transactional relations in an ecosystem where actors do not trust each other. These ecosystems relationships are flawed, do not operate optimally, and are expensive. This situation may be addressed by a DLT approach; particularly addressing the issue of provenance.

Kim and Laskowski (2016) have demonstrated the feasibility of developing DLT applications for supply chain provenance. They incorporated ontologies comprised of fundamental traceability concepts into smart contracts which were thus enabled to execute a provenance trace and also enforce traceability constraints. Specifically, they wrote source code on the Ethereum blockchain incorporating concepts from the Traceability Ontology developed within the Toronto Virtual Enterprise (TOVE) initiative (Fox and Gruninger, 1998).

Amongst the more noteworthy start-ups in this space is London-based Provenance.org who, building on the Ethereum blockchain, have created a transparent ledger for global supply chain data first applied in the context of sustainable fishing. This has been designed to enable secure traceability of certifications and other salient information in the supply chain: in effect, provisioning every physical product to come with its own digital 'passport' proving authenticity (Provenance, 2015). Similarly, Everledger, another start-up, having created a method for digitally fingerprinting diamonds, uses the Bitcoin blockchain to create a permanent ledger for diamond authentication and to provide an audit trail from mine to end-user.

Both these use cases point to the usefulness of DLT in being able to track the movement through a supply chain of individual artefacts (diamonds, high value luxury goods, tuna etc…) by provisioning them with discrete identities. The cases of Provenance and Everledger attest to the usefulness of DLTs in tracking the provenance and authenticity of physical artefacts. Spanaki et al. (2017) have recently proposed the concept 'Data Supply Chain' through which data, not physical artefacts, move. Increasingly, use cases are emerging for DLT in the management and curation of data in addition to physical products through supply chains.

The provenance, ownership, use and security of data are important concerns for those who use data as well as for those about whom the data relates. Additional beneficiaries include the regulatory authorities. In light of regulations such as GDPR, mechanisms are required to support data accountability and provenance tracking (Neisse, Steri and Nai-Fovino, 2017). In the case of effectively managing and securing patients' medical records, Xia et al. (2017) design a data sharing model consisting of cloud service providers, blockchain, smart contracts and access control mechanisms "*to effectively trace the behaviour of the data as well as revoke access to violated rules and permissions on data"* (Xia, Sifah, Asamoah, Gao, Du and Guizani, 2017:9)

Relatedly, DLTs are also being used to help authenticate and manage intellectual property. Historically, ownership rights of digital art have been difficult to assert, however O'Dair and Beaven (2017) claim that the accuracy and availability of copyright data can be improved, near-instant micropayments for royalties facilitated, and transparency of the value chain significantly increased with DLT. DLT has also been used in the case of digital art where, on the ascribe platform (McConaghy, McMullen, Parry, McConaghy and Holtzman, 2017), the Bitcoin blockchain is utilised as part of an integrated solution to identify and authenticate ownership of digital art. Supplemented by web-crawling and machine learning technologies, the ascribe model is able to search the web to find similar instances, and unauthorised use of the original digital artwork, allowing the owner to prompt the unauthorised user to acknowledge, pay, or desist from using the work (McConaghy, McMullen, Parry, McConaghy and Holtzman, 2017).

While DLTs' provide interesting opportunities for application in supply chain management, there remains much work still to be done to realise viable DLT-based supply chain management infrastructures. Notably the social and economic challenges must be addressed as well as the often cited technical issues.

Previous scholars, industrialists and regulators have speculated about motivations and incentives for existing supply chain actors to engage in this apparently liberating technology. After all, some actors currently may accrue advantage from supply chain opacity. Vested interests among existing actors may prove a constraint to adoption through a whole supply chain. One solution to this may rest with market forces. For example, increasingly, consumers in developed economies are requiring that their food, clothing and other purchases are sourced and produced in an ethical and environmentally friendly way.

Thus, products that are able to robustly and rigorously establish and demonstrate provenance and which have certificates of authenticity and compliance, may attract a premium amongst consumers. Products unable to demonstrate such provenance may be looked upon with suspicion. Of course, actors prepared to be transparent may accrue certain economic benefits from doing so, either in terms of efficiency gains or by being able to demonstrate social and environmental responsibility (Manski, 2017).

This means that claims to authenticity, validated in the supply chain, shifts the value system towards origin and provenance (Kewell, Adams and Parry, 2017). Such considerations raise questions about the business models to support a DLT infrastructure and whether or not they are maintained by, for example, subscription of actors, an independent NGO or trade association. These new business models may accrue a percentage of the transacted value as their monetisation strategy or some novel business model approach (O'Dwyer, 2017).

For supply chain actors and consumers who do not care whether or not their products or consumption behaviour complies with such standards, for example, ethical production or conforming to the requirements of the UK's Modern Slavery Act[5] or the principles of the Sustainable Development Goals (UN, 2015)[6], then these stakeholders will not adopt such a supply chain infrastructure. The consequence of these decisions may, however, be reputational damage.

While the technology promises to deliver its widely trumpeted immutability, transparency and traceability, high profile cases of breach, fraud and loss have given some observers pause for thought (e.g. (Shermin, 2017). There remains something idealistic, but practically difficult, about the vision of DLT and O'Dwyer (2017) has provided a reflective critique. Rightly, she points out that, despite claims of disintermediation or of being the new 'Trust Machine' (Economist, 2015) [7], in many use cases, DLT ecosystems replace one set of intermediaries with others and still require authenticators to establish 'truth' *ab initio*.

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[5] See http://www.legislation.gov.uk/ukpga/2015/30/contents/enacted accessed 16 November, 2017

[6] http://www.un.org/sustainabledevelopment/blog/2015/12/sustainable-development-goals-kick-off-with-start-of-new-year/

[7] https://www.economist.com/news/leaders/21677198-technology-behind-bitcoin-could-transform-how-economy-works-trust-machine

The new intermediaries are the technological elite who control 'the keys to the kingdom' and trusted third parties are still required to authenticate or attest to claims at the start of the supply chain.

DLTs, like other technologies, are vulnerable to the 'Garbage In Garbage Out' problem. This implies that there remains a need for trusted third parties as authenticators at the beginning of the supply chain. For example, the requirement of having to rely on actors logging key information, such as a product's current status/location, as a it moves through the supply chain, in itself, requires a network of trusted authenticators, standards authorities, registrars to assert the honesty of the input (Taghiyeva, 2017). Its success requires things to remain 'in the system', and for the analog artefact and the digital record to remain matched.

Of course, DLTs remain a young technology and its application areas are still being explored. As demonstrated above, their application in the area of intellectual property promises fair, appropriate and timely remuneration through micro-monetisation structures for cultural goods (e.g. (O'Dair and Beaven, 2017), (O'Dair, Beaven, Neilson, Osborne and Pacifico, 2016), (McConaghy, McMullen, Parry, McConaghy and Holtzman, 2017).

However, O'Dwyer (2017) questions whether or not such arrangements might not be antithetical, through the imposition of a quantified economic standard, to the irreverent, organic and collaborative character of cultural creation. That is, can the necessary formality of the record and remuneration adequately reflect the distributed, social, aesthetic and difficult to measure contributions in the production of a cultural artefact?

In an interesting study involving both digital supply chain and DLT practitioners, Korpela et al. (2017) found that DLT is able to address some of the long term issues and missing capabilities in how digital supply chains operate. The most attractive functionality addressing these issues is the secure ledger and smart contracts / contracting.

DLToffers additional, "data security and cost-effective transmission of transactions in peer-to-peer networks with no central system" and timestamping, enabling both b2b and IoT information integration. Financial systems currently operating lacked features such as timestamping, information flow end to end, and secure tracking: all of which are provided by DLT technology. A significant downside noted was the current lack of DLT interoperability.

Our project proposal

The provenance of food can be broken into issues of food safety, fraud and wider public health risks which lead to problems of consumer concerns. Issues around fraud led to the commissioning of the 2014 Elliot Review into food supply networks safety which reported that counterfeit food is eroding consumer confidence in high profile brands. The Elliot Review recommended that the "food industry must demonstrate that having a safe, high integrity food system for the UK is their main responsibility and priority", and that this would require "a willingness by the industry to share sensitive information". More recently the O'Neill Reports in 2014[8] and 2016, have highlighted the use of pharmaceutical products in the livestock industries as a problem alongside the rise in AMR in the environment, in animals and in humans.

Dairy cow health is one of the biggest animal care issues in the UK today. AM are routinely used in the dairy industry to treat or reduce the incidence of mastitis, lameness, pneumonia and other diseases. Illness and treatment leads to lost yield and lower productivity, with mastitis and udder disease estimated to cost nearly £200m in 2001. (Bennett, 2003),(Bennett and IJpelaar, 2005). The issue that integrates animal welfare, food provenance and safety and human health is AMR, which the UK Chief Medical Officer described as at a "*critical point*, *(we) must act now on a global scale to slow down antimicrobial resistance*".

The link between AMR in humans and anti-biotic use in animals is accepted but the extent of this link is yet to be established (Landers, Cohen, Wittum and Larson, 2012), (Marshall and Levy, 2011). The current situation in the EU is that antibiotics are not allowed to enter the human food chain above a certain limit, through treated cows being identified and separated, and their milk prevented from entering the milk supply chain. The UK Food Standards Agency has rigorous guidelines[9] regarding inspection. Processors carry out routine inspections and are liable to levy heavy penalties on offending farms.

There are a number of risks associated with antibiotics entering the supply chain: the financial cost (money and time) of inspection, recall and loss of a batch (mixed from a number of farms) if AM's are identified during testing; the compromise of manufacturing techniques (e.g. yoghurt) by an affected batch; the reputational risk on the entire supply chain from farmer to retailer; the health risk of AMR for humans being impacted by use on animals, and the allergy risk due to trace amounts of AMs in food. The localised nature of the recording and inspection of the dairy system means it is difficult to establish patterns of AM use at farm level and to acquire sufficient data to determine the risk of AMR in human pathogens that may be attributed to antimicrobial use in animals. AMR is a major issue in the UK, and as intensive practices extend to developing countries, dairy cow management,

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[8] O'Neill, J. 2014. Antimicrobial resistance: tackling a crisis for the health and wealth of nations. *Review on antimicrobial resistance*, 1-16.

[9] Food Standards Agency Guidelines; Testing milk for antibiotic residues: guidance. 27 August 2015. https://www.food.gov.uk/business-industry/farmingfood/dairy-guidance/guidancemilktestantibioticres

already an area of economic and biological concern in the UK will become increasingly important globally.

Benefits of Using DLT in AM recording

- Prevention

  It will provide easier recording for the farmer, and more easily physically prevent milk from treated animals entering the supply chain. Better decisions on treatment strategies and reduced drug use and cost are expected, leading to better stewardship.
- Efficiency and effectiveness
  - Better decisions on treatment strategies and reduced drug use and cost are expected
  - Better knowledge of AM use, and in particular effective treatment strategies for the herd, could lead to better animal and human health
  - By reducing prevention, inspection and recovery costs and time, new innovative business models could be explored that provide greater security and lower cost
  - Improved traceability will improve resilience of a supply chain, preventing a fault by one farm leading to multiple loss in many small farm businesses.
  - Better ability to capture value from proven provenance
  - The Industry would be enabled to take ownership of regulation and avoid a more onerous burden of imposed legislation
- Risk management
  - Operators could assess risk, potentially reduce inspection costs, and have better upstream traceability
  - Improved data to allow the development of models to predict the emergence of AMR from dairy systems influencing the presence in humans and affecting human health
- Transparency
  - DLT's rather than various disparate databases, as presently used, would enable producers and retailers to have a full visibility of the supply chain. This would be an immutable audit trail record of treatment and processing.
  - Regulators and oversight authorities would have better records and visibility of treatment strategies, enabling them to devise policy to reduce AM use.
- New business models will be facilitated in the supply chain
  - Business models will be more secure and operate at lower costs (as duplication and multiple inspection costs are reduced) as operators could assess risk through better upstream traceability enhancing food security.

Research Question and Project Objectives

The discussion presented above has allowed the following research question to be developed: How can we reduce the risks and costs associated with antibiotics entering the milk supply chain using DLT? To address this question, the following project objectives have been identified:

1. To research the feasibility of applying DLT to monitor the use of antibiotics in the milk supply chain. This objective will be achieved by developing a proof of concept which demonstrates the use of an app for inputting data into the DLT.
2. To research how DLT can reduce the cost of reporting for regulation (including food contents and welfare of animals) for organisations.
3. To develop a proof of concept to enable non-expert users to readily report farming data and deploy bespoke DLT applications and to reduce the cost of a centralised system.
4. Given the absence of a trusted central system - To identify a conceptual framework that can be used in the wider farming domain based on different criteria for data collection.
5. To develop new business models using DLT in supply chains.

A significant issue we will seek to address in the research is the matching and mixing issue – i.e. how to ensure that the digital record and the analog real world item (in this case liquid milk) can remain linked, even if they have been mixed in collection or production. At present the best solution we can foresee is that we can use DLT to track absence of AM along the supply chain. The four step process below provides an example:

1. Cows are milked at a farm, with any cows currently being treated with AB identified and their milk separated. You store the AB free milk awaiting shipment. You conduct chemical analysis of it. You find no AM traces in the milk. You state this in the blockchain ledger.
2. The dairy or transporter collects the milk, along with milk from other farms The dairy conducts yet another chemical analysis of it. No traces found. It records into the blockchain. The dairy further aggregates the “clean” milk with other batches of “clean” milk. It records into the blockchain
3. The cheese maker or food business operative, receives a batch of “clean milk” from the dairy, it may or may not check AM existence (or do it on random basis for quality control purposes). It records this in the blockchain.
4. The retailer may also choose to conduct testing and record these tests in the blockchain. The ledger is transparent to all parties (or to relevant parties) so that batches can be traced easily through the supply chain.

If a “dirty” batch or cheese is found it is relatively straightforward to trace back where issues arose the process. In other cases provenance of biological products might be established with biological markings (e.g. DNA analysis) or by inserting chemical components into it (e.g. a protein or something similar to “sign” it). We are hoping that our research programme will be able to establish such procedures cheaply and effectively.

Concluding remarks

This paper has set out a research proposal to use DLT and other technology to reduce the incidence of antimicrobials in food, in this case milk, and to reduce the costs associated with current manual practices and the amount of waste in the food supply chain if antimicrobials are detected at later stages in production or at the retailer.

Within the wider food supply chain, the challenge for current methods is twofold. Some supply chains too complex with too many moving parts for any individual to keep track of, meaning there is no clear view of the whole supply chain. It is not in a single firm’s interest to do this. Relatedly, firms are not incentivised to have a view of the whole supply chain – maybe maintain up to a tier 3 or 4 view, but not beyond that. Regulations don’t necessarily require it, but retailers are increasingly concerned about health risks to their customers and associated reputational risk. US and UK retailers are beginning to accept the reputational risk and customer satisfaction issues inherent in making claims on no AM in their foodstuffs. Animal husbandry could also be impacted favourably by the greater awareness of use.

However, DLT offers the opportunity to join up all the discrete parts of supply chains that are already being recorded by disparate parties. Using DLT could also help reduce the amount of food waste in current systems. At the moment it seems we have to wait until we get to the end of the supply chain to discover whether or not it’s contaminated. In these circumstances, the whole chain can get wasted. BC should immediately make it obvious, and so trail of waste is limited.

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