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Blockchain: case studies in food supply chain visibility

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Abstract

Purpose: This paper investigates how blockchain has moved beyond cryptocurrencies and is being deployed to enhance visibility and trust in supply chains; its limitations, and potential impact.

Approach: Qualitative analysis undertaken via case studies drawn from food companies using semi-structured interviews.

Findings: Blockchain is demonstrated as an enabler of visibility in supply chains. Applications at scale are most likely for products where the end consumer is prepared to pay the premium currently required to fund the technology, e.g. baby food. Challenges remain in four areas: trust of the technology; human error and fraud at the boundaries; governance; consumer data access and willingness to pay.

Research implications and limitations: The paper shows that blockchain can be utilised as part of a system generating visibility and trust in supply chains. Research directs academic attention to issues that remain to be addressed. The challenges pertaining to the technology itself we believe to be generalisable; those specific to the food industry may not hold elsewhere.

Practical implications: From live case studies we provide empirical evidence that blockchain provides visibility of exchanges and reliable data in fully-digitised supply chains. This provides provenance and guards against counterfeit goods. However, firms will need to work to gain consumer buy-in for the technology following repeated past claims of trustworthiness.

Originality: This paper provides primary evidence from blockchain use cases 'in the wild'. The exploratory case studies examine application of blockchain for supply chain visibility.

Keywords: blockchain for good, research4good, blockchain, supply chains, supply chain visibility

1. Introduction

The growing understanding of blockchain as a tool to enhance supply chain visibility has led to a body of work falling into two categories: an academic literature conceptualizing blockchain for supply chain visibility (e.g. Saberi et al. 2019; Madhwal and Panfilov 2017; Tian 2018), and an industry literature providing examples of trial applications (e.g. Verhagen and Welsh 2017; IBM 2017; Ross 2017). The academic literature has few empirical studies of live cases. Three exemplar papers stand out: McConaghy et al.'s (2017) study of blockchain's implementation for rights management in digital art; and studies by Motta et al. (at press) and Kshetri (2018), which use archival material rather than primary research. This paper is thus among the earliest case studies of blockchain's use as a tool providing visibility in supply chains and the challenges that remain.

Product traceability has long been an issue in supply chain management (SCM), and uses include mitigating risks of tainted food (Pouliot and Sumner 2012), counterfeit luxury goods (Guercini and Runfola 2009), and labour abuses (Jones et al. 2019). Technology solutions including RFID tags have been applied successfully in a number of cases, including in the food industry (Attaran 2007). The increasing complexity of supply chains continues to raise issues and the search for reliable technological solutions to offer assurances on data quality and enhanced data security persists (Parry and Turner 2006).

Blockchain, widely-known as the technology underpinning Bitcoin (Kiviat 2015), a cryptocurrency renowned for data security, has recently become the subject of tests in other capacities, including in community-owned green energy networks (Mengelkamp et al. 2018), underpinning emerging economy land registries (Lemieux 2016), and smart contracts (Nugent et al. 2016; Nofer et al. 2017). Increasing uses are now being found for blockchain in supply chains (Abeyratne and Monfared 2016).

This paper investigates how blockchain may provide visibility for SCM. Valid use cases already exist that create authenticity and traceability by storing supply chain data and making it difficult to change (Galvez et al. 2018). The proposed benefits of applications suggest that blockchain can enable enhanced visibility through deepened connections with digitised supply chains (Kharlamov and Parry 2018), reduced potential for human error and fraud (Cole et al. 2019), and creating trust in product veracity (Kamath 2018). It is this public trust of products, particularly foods, which Babich and Hilary (2019) highlight as a driver of adoption by firms such as Walmart, because of the volume of adulterations and their potential harm.

The paper presents four cases studies of blockchain use for agriculture, fishing, wine, and infant formula. These cases address specific problems currently faced in food supply chains - which are particularly acute given the importance of risks and perishability of the products (Diabat et al. 2012) - the suitability of blockchain in each case, application of the technology, and residual issues are observed. We provide a rationale for blockchain adoption, a set of optimal preconditions, and highlight areas in which blockchain is unlikely to be the panacea hoped for by many.

The paper begins with a review of the current literature. The methodology used is explained before the detail of the four use cases. Finally the practical implications for supply chain visibility (SCV) are discussed and suggestions for future work.

2. Literature review

2.1 Need for visibility in supply chains

Efficient supply chains require managers to have the ability to process the enormous volume of data generated in order to make decisions (Williams et al. 2013). Traditional supply chain centralisation has not offered that possibility to all parties because centralisation has created information asymmetry (Treiblmaier 2018), typically favouring larger organisations or IT systems implementers, preventing optimisation of supply chain efficiency (Michalski et al. 2018).

Combatting data fragmentation requires collaboration along the whole supply chain, the ultimate goal of which has become SCV (Samaranayake 2005). SCV can be described as enabling "the identity, location and status of entities transiting the supply chain, captured in timely messages about events, along with the planned and actual dates/times for these events" (Francis 2008). Access to the accurate, timely, usable information that characterise SCV offers a range of benefits (Parry et al. 2016). Supply chain professionals consider visibility an important enabler of inter-company collaboration (Francis 2008), allowing for integration between tiers up to and including the customer (Schoenherr and Swink 2012), enhancing trust (Johnson et al. 2013), and increasing efficiency (Bartlett et al. 2007). Visibility thereby facilitates action in the supply chain (Delen et al. 2009) and reduces decision risk (Christopher and Lee 2004). This improves overall supply chain performance as it provides firms "capabilities to reconfigure their supply chains and create strategic value" (Wei and Wang 2010, p.245).

Many aspects of successful SCM, including cost, inventory management, and physical logistics rely on visibility (Kwon and Kim 2018). Efficient use and, crucially, sharing information with suppliers (Kaipia and Hartiala 2006) can deliver benefits including the responsiveness of supply chain partners (Kim et al. 2006), enhanced measurement (Acquaye et al. 2014) and design of key metrics (Caridi et al. 2013), improved productivity, customer service, and overall firm performance (Frohlich and Westbrook 2001). This has led to the deployment of a succession of technologies aimed at creating greater visibility along the value chain. Early systems automated the bill of materials (Molla and Bhalla 2006), then extended to include materials resource planning (Parry et al. 2003). In the early 2000s digital visibility expanded to include order further functions such as product and delivery management via enterprise resource planning (ERP) (Parry and Graves 2008) enterprise resource management (ERM) (Chuang and Shaw 2008), and customer resource management (CRM) (Lambert and Schwieterman 2012).

The use of such systems necessitates a link between physical objects and the digital world. Barcodes have become prevalent due to their low cost and simplicity (Apiyo and Kiarie 2018). Although more costly, radio frequency identification (RFID) tagging of goods can now offer organisations real-time data at the individual product item level (Wang et al. 2017). As Spekman and Sweeney II (2006, p.736) highlight early in the technology's lifecycle, "visibility in materials flow… among all supply chain members is improved and the accuracy of the information shared is greatly enhanced." As technology has developed, the Internet of Things (IoT) has been conceived as a way of connecting devices to allow greater visibility of processes along the entire supply chain and further minimise of human error (Majeed and Rupasinghe 2017; Parry et al. 2016). More recently, some firms have begun to adopt quick response (QR)-coding of items in order to balance the benefits of tracking with reduced costs (Parreño-Marchante et al. 2014).

Demand for technologies which allow stakeholders to see the dynamics of supply processes rather than simply tracing where and when a process occurred, points to visibility being increasingly embraced in SCM. Traceability enhances product security and process controls (Musa et al. 2014), but does not address more fundamental risks. Traceability is passive, following a product's journey through the nodes of a supply chain (Jansen-Vullers et al. 2003), but not visibility of what happens at those points (Kwon and Kim 2018). Since supply chain risk is found in materials used (Mohammaddust et al. 2017), processes employed (Cicculllo et al. 2018), and people engaged (Gold et al. 2015), visibility offers what traceability cannot. Supply chain managers are unable to see what is done at each node, by whom, and what the impacts are (Abeyratne and Monfared 2016). Traceability does not provide data giving managers the capability act (Parry et al. 2016).

2.2 Barriers to adoption of technologies

Information technology innovation is influenced by ideas relating to potential transformative effects shaped by social context (Avgerou and Bonina 2019). Given the novelty of blockchain as a SCM solution it is likely to be subject to similar factors that delayed or prevented the adoption of previous technologies. With regard to uptake of the internet as a SCM tool, Tarofder, Azam and Jalal (2017) find a lack of senior management support, budget concerns, and insufficient competitive pressure account for wariness. A lack of executive support is highlighted as potentially terminal to new technology adoption (Asare et al. 2016), though management are often aware of the need for new technologies but uncertain about the impact of its adoption on workforces (Fawcett et al. 2008).

Balocco et al. (2011) investigate uptake of RFID, a precursor and complementary solution for blockchain, finding inter-firm factors, including issues of profit-sharing, more important barriers, though elsewhere complexity and cost are found to be key (Chuang and Shaw 2008). Hardt, Flett and Howell (2017) assert that issues of cost, inter-firm trust, and technical aspects are at the forefront of a lag in uptake of QR codes. Interestingly, in one of the only studies on blockchain adoption to date, Saberi et al. (2019) find a combination of these factors, and the immaturity of the technology itself, to be obstacles to adoption at the operational level. Van Hoek (2019) discovers that the costs and benefits of the technology are poorly understood at executive level, preventing firms from employing the technology.

2.3 What is a blockchain and what are its benefits?

Blockchain is an emergent technology which we can describe in its most basic form as a shared list that is difficult to change. Blockchain is the specific term for the Bitcoin variant of distributed ledger technology (DLT), but has come into common parlance to mean DLT. There are a number of different DLT, including Ethereum, a global, distributed applications platform suited to the deployment of smart contracts (Zheng et al. 2018), executed automatically when conditions are proven to have been met on a blockchain-enabled system (Abeyratne and Monfared 2016). A full discussion of DLT and their types is outside the scope of this paper; reviews exist elsewhere (e.g. Mueller-Bloch et al. 2019). Blockchain has broadly been used according to one of three models: public, private and consortium.

A public blockchain is created as a decentralised network where each participant - or node - records transactions on a public ledger. Sets of transactions accumulate and are placed into a group - or 'block' - which is put into an algorithm to generate a unique hash code related to that dataset at a particular point in time. This hash code forms the first piece of data in the next set of transactions forming the next block. As transactions accumulate, the list grows as blocks are added 'forming a chain' [figure 1] (McConaghy et al. 2017).

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Private blockchains are operated by one organisation, which grants limited visibility rights to chosen parties (Wang, Hugh Han, et al. 2019). Consortium blockchains are similar but have multiple rather than a single owner (Lin and Liao 2017). Public blockchains enable any "miner" (creator of a block) access to the blockchain, with anyone able to read its contents (Guo and Liang 2016), a form often referred to as 'permissionless' (McGinn et al. 2018). Private and consortium blockchains, limited in the number of nodes by permissions granted by the owner(s), restrict visibility at the cost of a small degree of immutability (Kshetri 2018), and an attack on the system would only need to breach the few systems on the blockchain in order to corrupt the data. These 'permissioned' blockchains accept additional blocks onto the blockchain through consensus mechanisms (Bergman et al. 2019). Public blockchains operate a 'proof of work' (PoW) mechanism in which a node adding a block must, through use of an algorithm known to miner systems, prove to other nodes that it is responsible for the new block (Dinh et al. 2018). At this point a majority must accept this in order for the block to be approved (Yu et al. 2018). Visible to anyone, public blockchains may have a high number of nodes, which increases security because an attacker would need to access a significant number of nodes in order to change data on the blockchain and then approve that change with a majority of 'votes' (Lin and Liao 2017), though there are other potential failure points in many configurations of blockchain (Gramoli 2017). The number of nodes in a public blockchain makes the system less efficient compared to private and consortium blockchains, because the majority required to approve each additional block is higher than the few (or single) in a consortium (or private) blockchain (Yermack 2017).

Supply chains usually use permissioned blockchains (Cole et al. 2019) because of considerations that permissionless blockchains would undermine traditional supply chain system logic by decentralising data management to produce immutability (Li et al. 2018). Using the lack of extensive PoW protocols across a widely distributed network, nodes could potentially collude with a single supplier to undermine the blockchain (Apte and Petrovsky 2016).

Blockchain potentially offers the upstream visibility in supply chains that consumers are increasingly demanding, for example by logging data on whether specific fish have been legally caught or identifiable diamonds legally mined (Francisco and Swanson 2018). This is largely a result of the decentralised, consensus-based trust mechanism underpinning the technology (Hackius and Petersen 2017), which aids performance management of key SCM processes through simultaneous immutability and transparency (Kshetri 2018).

The visibility provided by blockchain solutions aids decision making (McConaghy et al. 2017) by enabling stakeholders to see timely, accurate, reliable information while reducing the number of data sources that create decision points (Saaty and Ergu 2015). Kshetri (2018) claims that blockchain can be deployed without the need for devices or tag-attachment processes and offers unit-level identification, though provides no justification of this. It is possible using biochemical tracing. For example Oritain (www.oritain.com) developed biochemical fingerprinting allowing verification sample testing to be undertaken throughout the supply chain, but this is a complex solution. Data automatically transmitted by RFID technologies can be captured, stored and shared using blockchain systems, which deliver visibility at the unit level to enhance trust (Zelbst et al. 2019). However, barcodes and QR codes remain dominant (Parreño-Marchante et al. 2014) as RFID tags are relatively expensive (Segura-Velandia et al. 2016) and the various types are incompatible (Mo and Lorchirachoonkul 2012).

Product labelling solutions all integrate with and complement blockchain solutions, offering a level of visibility not previously possible (Francisco and Swanson 2018). With product recalls, for example, "currently, if a retailer faces a foodborne disease outbreak, retailers have a difficult time figuring out where the bad ingredients came from and to which stores they were delivered" (Dobrovnik et al. 2018, p.28). Since goods cargoes currently involve significant paperwork, existing systems are at risk of tampering (Kshetri 2018). The substitution of documents in a traditional supply chain can go unnoticed because volumes of paperwork are too great to be constantly rechecked and different products might look alike. Mislabelling of fish, for example, is hard to detect because species might not be detectable by sight (Pramod et al. 2014). A blockchain-enabled system could counter this introducing unit-level visibility to traceability making counterfeiting and fraud more difficult. Blockchain does this "by providing a robust system to trace origin, certifying authenticity, tracking custody, and verifying integrity of products" through the secure recording and collation of data on each unit (Montecchi et al. 2019, p.284).

2.4 Uses of blockchain in supply chains to date

The immaturity of blockchain technology applications in supply chains means there are few cases available to analyse (Dobrovnik et al. 2018). The following examination of uses of blockchain in the supply chain literature thus addresses conceptual models as well as reported cases of trials and projects.

Countering fraud (the protection imperative)

Among the main issues addressed thus far in the literature is fraud, particularly regarding the counterfeiting of goods. The use of blockchain in this respect is in the protection of intellectual property, specifically in the realm of digital art. McConaghy et al. (2017) discuss a use case for safeguarding creators and ensuring attribution of any image used. Another example lies in the context that recent years have seen scandals in the food industry including supplier fraud, as in the case of the 'horsemeat scandal' in Europe (Agnoli et al. 2016), poisoning, such as the milk formula case in China (Xiu and Klein 2010), and a rise in environmental and social claims in controversial products such as palm oil (Oosterveer 2015). The complexity and risk involved in food requires more rapid response (Lindgreen and Hingley 2003), and blockchain is potentially well-suited to offering the visibility required (Ringsberg 2014).

Food supply chains are seen as vulnerable, and of the blockchain cases in the literature, US supermarket Walmart's is the most high-profile (Kamath 2018). Initially tracking pork in its Chinese supply chains (Zhao et al. 2016), the company believes that the visibility offered by blockchain guarantees both better sourcing control and enhanced risk management: "Even in the event of contamination, the greater controls and visibility offered by Blockchain enable the contamination to be traced to the source for proper corrective actions" (Biggs et al. 2017, p.9).

There are other food risks which blockchain might also mitigate. Biswas et al. (2017) cite the annual $15bn cost of fraudulent wines (5% of the global market) as evidence of the need for the visibility that blockchain could offer supply chains. Their proposed system uses a consortium protocol to ensure that information is kept to a limited number of partners, in this case the entire supply chain from vineyard to retailer. This end-to-end approach means "anyone in the supply chain can trace the origin, production and purchase history of each individual product… [and] can verify the provenance and authenticity of the purchased wine by inputting the product ID in the system. After receiving the product ID, the system first identifies the batch of wine and then traces back all transactions made by different entities in the supply chain for the corresponding item" (Biswas et al. 2017, p.5).

Such fraud is not limited to higher-value products such as wines. Rejeb (2018) develops a similar concept for Ghanaian tilapia, an often mis-sold white fish. The concept works by using mobile technology to input environmental conditions at the farm level onto a blockchain and then using RFID tags to track products through the supply chain, giving the consumer visibility of product provenance.

The value of counterfeit pharmaceuticals ($200bn per year globally) and associated safety concerns have led to interest in blockchain-enabled visibility in the industry(Clark and Burstall 2018). Though details of active trials of blockchain in pharmaceuticals supply chains are not currently found in the literature, Tseng et al. (2018) conceive of a system of unit-level visibility in order to improve regulatory checks by appointing government agencies and large pharmaceutical companies to roles which verify data inputs.

Customer demand (the market imperative)

A significant motivation for companies investing in blockchain for SCV is increasing consumer demand for information about product origins (Casado-Vara et al. 2018). The internet has enabled greater information sharing for customers (Wilson and Clarke 1998), and blockchain offers the potential for the kind of visibility that can be corroborated by the system (Abeyratne and Monfared 2016). The level and quality of visible data that this might offer could increase service quality to consumers, creating greater value (Wang, Singgih, et al. 2019).

Wang et al. (2019, p.71) posit that customers "increasingly demand to know how, when and where products are sourced and processed." The desire for enhancing visibility has led to trials of blockchain in supply chains.Ffor example Verhoeven et al. (2018, p.12), report that Bext360 is using the technology to assure the provenance of their coffee harvest because, "the 'classic' approach of tracking and tracing is expensive, imprecise, and does not address the consumers' demand for visible transactions on the supply chain."

There are also human rights-related reasons for firms seeking assurance that they can offer customers ethical products. Both consumers (McClenachan et al. 2016), and business (Gold et al. 2015), fear forced and child labour. Other forms of corporate malpractice may be addressed by enhanced corporate social responsibility. Labour issues such as 'modern slavery' are best addressed by giving consumers specific, detailed information relating to product veracity. Provenance has trialled blockchain in products such as fish and leather goods for consumer information demands, including human rights issues in Indonesia. The company used mobile phones and smart tags to collect data to go onto the blockchain, simultaneously meeting consumer demands for enhanced visibility and contribute to sustainable development (Kewell et al. 2017).

2.5 Residual issues identified in the blockchain literature

While the number of trials in the literature is limited thus far, both extant pilots and broader conceptual papers have identified real and potential issues with blockchain's use for visibility in supply chains.

First, digitisation is required. Existing ERP systems have integration problems that blockchain would not necessarily solve (Abeyratne and Monfared 2016), which would, for both connectedness and security, require integration along the whole supply chain (Rejeb 2018). This causes problems in areas of the world that lack necessary infrastructure (Kshetri 2018), creating gaps in the supply chain in which reliable data are unavailable, opening the process to questions as to the trustworthiness of all information provided to the end consumer. The problem leads Motta et al. (at press) to suggest that confidence in blockchain is as much a social as a technical issue.

Assuming the need for full-technology integration can be overcome, two issues remain. Interoperability of fully-digitised supply chains is not assured (Casino et al. 2019). The 'fully-digitised supply chain' cannot be fully digital in the case of physical goods. Errors and fraud can enter the digital supply chain at the interface between the physical and digital. Apte and Petrovsky (2016) highlight that the data on the blockchain cannot be guaranteed to match the physical good. Babich and Hilary (2019) offer a specific example, demonstrating that blockchain might be entirely accurate when used to verify the provenance of a product or the conditions in which it is harvested, but that authenticated certification is only true at the moment of attestation. Conditions may change immediately, rendering blockchain-enabled verification outdated even before the certificate has been seen by a customer. As O'Leary (2017, p.141) explains, "unfortunately, visibility itself does not make a transaction correct, and the 'threat' of visibility (as a preventive or detective control) does not ensure that the transaction is correct" because fraud and human input error remain significant problems.

Second, governance in blockchains necessitates compromise. On a public blockchain governance may be problematic because the blockchain has no 'owner', while on a private blockchain the owner is the governor (Wu et al. 2017). On a consortium blockchain there could be trade-offs between how much access to give entities on the blockchain and the sensitivity of some of that data (O'Leary 2017). Such issues could take time to resolve. The current industry standard system - Electronic Data Exchange – has been waiting over 30 years for the industry to agree a standard (Dobrovnik et al. 2018). Pass and Shi (2017) foresee a need to ensure that oligopolistic control of a blockchain system by a few powerful parties does not undermine trust.

The limited evidence of live cases and conceptual models of blockchain for SCV provide a foundation for examining the subject. Our case studies allow us to both challenge and build on this groundwork. The paper's research questions are thus: How are firms using blockchain for supply chain visibility in the food industry? What are the challenges?

3. Methodology

Context

The supply chain literature shows that response to consumer demand is a driver of competitive advantage (e.g. Mason-Jones and Towill 1997). Supply chain managers relied on traceability systems for data about products in supply chains, and food scandals in the 1990s introduced traceability requirements to food regulations (Karlsen et al. 2013). Traceability, "the ability to identify the origin of an item or group of items, through records, upstream in the supply chain" (Schwägele 2005, p.166) is key in locating product problems in supply chains (Resende-Filho and Hurley 2012). Consumers increasingly demand more information about products, particularly around food sustainability (Govindan 2018), that current traceability systems cannot deliver. Visibility is a capability that offers firms both the opportunity to present information to customers (Busse et al. 2017) and also enhance the decision-making of supply chain firms (Yang 2014). Visibility provides the "capability to use information to initiate and inform action" (Parry et al. 2016, p.231), providing consumers the information they require. Blockchain could be an enabler for visibility, and this work therefore sets out to investigate this technology.

To explore uses of blockchain for enhancing SCV, case studies were carried out. The case study method was adopted for its use in answering 'how' and 'why' questions (Yin 2014). The units of analyses are four firms using blockchain in their supply chains. Agridigital is a provider of blockchain services to the agriculture industry; Techrock, provider of a blockchain solution to tainted infant formula; the World Wildlife Fund's (WWF) Pacific fisheries division focuses on sustainable fishing with the help of blockchain provider TraSeable; Demeter (the Greek goddess of the harvest and growth and a pseudonym given to an anonymised firm here) has successfully used blockchain-enabled smart tags to authenticate wine and offer consumers vineyard-to-retail store visibility.

The collective case study approach allowed us to study a contemporary issue in its context or, importantly in this particular research, in its many contexts (Stake 1995). This means that the understandings gained from the study are meaningful and relevant to their settings (Farquhar 2012), take account of the open system in which businesses operate, with its broad, differing influences (Leca and Naccache 1988), and allow for increased generalizability (Yin 2014).

Sample

We used a mixed strategy to find firms to approach for interviews. We began by using industry contacts to discover firms of interest within our network, as well as using other desktop methods such as searching business networking websites and reading industry news for stories on organisations already using blockchain in their supply chains. We then used snowball sampling (Farquhar 2012), asking interviewees if they knew of anyone that we should talk to about blockchain and SCV. The latter method proved fruitful as it often came with an introduction to the prospective respondent.

The method led to us approaching 73 organisations. Of these, we received 42 responses, from which we were able to proceed and conduct 28 interviews with 15 firms (nine of which we subsequently interviewed for a second time), which we categorised as: providers of blockchain for SCV; their customers; and commentators on the technology, including journalists and management consultants. A semi-structured interview technique was used to focus on important issues that arose during the course of conversations as respondents raised them (Finley 2018). These interviews included questions regarding the individuals' capacity in working with blockchain, the opportunities firms have found in their supply chains, and the major challenges they discovered. We followed these questions up where appropriate for specific examples and detail.

From these interviews, we came to understand that there is significant concern in many firms regarding the sharing of information regarding their supply chain work with blockchain. Organisations were concerned about the commercial sensitivity of their trials, seeking to prevent 'second-mover advantage', where rivals wait to see how early technology adopters err before learning from those mistakes (Hoppë 2000). Other firms were found not to have developed a technology at all, rather their blockchain 'vapourware' was a marketing device to make them sound advanced. Seven firms engaged in detailed discussions with us, two of which were later prevented by technology partners from providing us with enough information for inclusion. Of the remaining five, two were in partnership, which gave us useful insights into the technology provider-user relationship and are dealt with together in a joint case study. The remaining three also provided a depth of information, enabling us to present four cases, although one would not grant us permission to name them. Following the interviews, emails and archival data were used to elucidate important points.

Data analysis

An inductive analytical approach was used, characterised by Kennedy and Thornberg (2018, p.52) as a "series of empirical cases to identify a pattern from which to make a general statement". Inductive research begins from an agnostic position, allowing ultimately generalisable themes to emerge from the data (Abbasi 2012) and since our research was exploratory, this method offered the freedom to discover from, rather than search within, data.

Interviews were conducted by one or two interviewers and the notes read by four researchers and coded independently for themes. Discussions around each researcher's codes surfaced relevant themes which were used in the analysis. That the four case studies come from the food industry reflects the inherent risks in that sector's supply chains (Lindgreen and Hingley 2003). We guard against limiting the paper's findings to food alone, however, as some of the challenges our cases highlight are blockchain-specific rather than unique to the industry.

4. Case studies

1. Agridigital

1.1 Company background

AgriDigital is an Australian agricultural commodity management platform provider and supply chain financier founded in 2015.

1.2 Product and rationale

Agriculture is one of the least digitised industries. Many farmers record data such as pharmaceuticals administered to animals on pencil and paper. AgriDigital has reacted to increasing consumer demand by creating a verification system using blockchain.

1.3 System and benefits

In response to increasing customer demand around product provenance, Agridigital offers assurance of the veracity of the organic status of agricultural products. This is because, as a senior manager asserts, Agridigital "want to verify marketing claims rather than get all the data." To do this, farmers collect a range of data on a web application. Myriad data sources are available, but only those data directly pertaining to organic status (i.e. the customers' interest) are recorded. These are data from stages of growing the cereal (seed used, weather, fertilizer), through production (milling location, other cereals milled there), and transport (times and locations), and are matched to pre-identified and verified operational practices.

These data are then bundled into assertions, each representing a claim established as important to proving the organic status of the product. Each assertion is then hashed and recorded on a layer of a private Quorum blockchain. In order to track shipments, Agridigital uses RFID-enabled weighbridges, which detect and weigh tagged vehicles, adding time, weight, and location data onto the blockchain. A web application is then used at the point of packaging to determine the true/false organic status of the product.

1.4 Remaining problems

While AgriDigital has proven blockchain able to provide visibility along the supply chain, the firm highlighted three challenges. First is the human input element. Error and corruption in data entry are compounded in blockchain-enabled systems because the technology's inbuilt trust mechanism can mean data being accepted unhesitatingly. A senior manager asserts that "blockchain seems to bring with it a 'halo of truth' which leads to a lack of questioning of the data". Second, the technology will not fulfil its potential unless supply chains are fully digitised beforehand. While this presents practical problems in certain industries, not least agriculture, a senior manager does believe that products can be developed simultaneously with technological solutions to embed blockchain and fully leverage its potential. Finally, the senior manager believes that using blockchain in small networks is "simply a thought exercise," and that once the supply chain is fully digitised, as many nodes as possible within that network must be added to the blockchain infrastructure in order to maximise both the volume of relevant data and the security of the network. An issue inherent in this logic, and given the immaturity of privacy solutions at a chain as well as transactional level, is that all sub-contractors would need to be nodes in a 'maximised' network, putting at risk the commercial sensitivity not only of contractors' identities, but also their data, including price and contractual data, though this may be overcome in time as the technology matures.

2. Techrock

2.1 Company and background

Chinese company Techrock is both a developer and user of blockchain for SCV. The firm was founded in 2013 by two friends with first-hand experience of counterfeit consumables in China.

2.2 Product and rationale

Techrock's main product offers assurance to parents regarding the provenance of infant formula, a major concern following contamination of powdered milk products with melamine, a poison which affected 300,000 babies in 2008 (Gong and Jackson 2012). The firm works with producers of infant formula and other health-related goods to secure their products.

2.3 System and benefits

Techrock's products are protected by smart packaging. A small wire is embedded in the product label which acts as an antenna for an RFID tag. The tag is readable by a consumer's smartphone app, which authenticates the product within two seconds of being scanned. Every scan of the tag creates a new authentication key. The antenna communicates the new key to Techrock, where it is stored on a public Hyperledger-based blockchain. The app first tells the customer that the product is authentic, then provides details such as date and location of production, a picture of what the product should look like, and a list of every scan of the tag, including their own. This offers the consumer confidence in the safety of the product because, by opening the can, a consumer breaks the wire in the label.

By storing authentication keys on its blockchain, Techrock guards against counterfeiting and helps to assure customers that the product they are purchasing is authentic. The smartphone app scan allows the consumer to guarantee that the product has not been corrupted.

2.4 Remaining problems

A senior manager acknowledges, however, that challenges remain. First, while this system works as designed for infant formula, food supplements, and vitamins, the cost of the solution may be high for relatively cheap products. Parents are perhaps uniquely willing to pay significantly higher retail prices for the type of assurance offered by Techrock's solution. Second, in some markets, the firm believes, there is an inherent lack of trust between consumers and businesses, which have overpromised trustworthiness previously. This makes communicating the benefits of the technology simultaneously essential and very difficult. Finally, at time of initial interview, the technology used by Techrock was prevented from working on iPhones, although this issue has since been overcome.

3. World Wildlife Fund (WWF) and *TraSeable Solutions*

3.1 Company name and background

TraSeable Solutions is a Fijian provider of blockchain services founded in 2017 working in partnership with WWF on a project to provide sustainable management of tuna in the Western and Central Pacific.

3.2 Product and rationale

The two organisations partnered to create one of the first ventures to use blockchain to tackle the problems of illegal fishing. The system seeks to provide data enabling local fishing companies to take advantage of developed countries' demand for catches that are sustainably certified and from fisheries free of human and labour rights abuses, as fisheries have been identified as being high-risk for modern slavery.

3.3 System and benefits

TraSeable enables its customers to collect details on harvests such as location, crew details, catch logs, and fishing ground analytics using a smartphone app. Location and route data are logged in parallel with satellite tracking data which are automatically documented on the firm's public Ethereum blockchain. During processing, shipments are tagged with QR codes and data recorded with a web application capturing each critical process, providing visibility of details such as cold storage conditions. These data can then be shared with the end consumer, who can use their smartphone to scan a QR code on the packaging to view details about catch and processing location, and other third parties for uses such as processing permit applications and recording audits.

3.4 Remaining problems

While this technology enhances supply chain transparency and visibility and has had a positive impact on environmentally and socially sustainable fishing, problems remain. First, remote areas of the Pacific often have neither the digital infrastructure nor the hardware to facilitate automated data collection at this level. This means that human data entry is required and the threat of error or fraud persists. This is particularly the case for what the organisations view as 'opaque and diffuse' Southeast Asian fisheries that consist of thousands of vessels delivering to hundreds ports and processing facilities subject to little monitoring and oversight. Second, at a macro level, blockchain currently lacks adequate data and input standards, creating governance issues and prevent learning from one trial being communicated effectively elsewhere.

4. Demeter

4.1 Company name and background

Demeter is the pseudonym we have given a European firm initially engaged in traceability in the food industry pre-blockchain, which has now pioneered the technology for authentication and SCV for several consumer goods.

4.2 Product and rationale

The firm has successfully trialled blockchain for wine veracity. Among the world's most counterfeited goods, mislabelled wine is a problem which harms both corporate value through suboptimal products being seen as the producer's responsibility, and also public health, since ingredients added to fake wines may be harmful.

4.3 System and benefits

Demeter has partnered with a wine producer which uses web applications to collect data on its product. The firm uses a modular, reusable label with an RFID tag, which is scanned at each node to provide traceability and visibility. Data captured include growing conditions, grape variety and handlers of the wine in the supply chain. This has allowed the partnership to track over 10,000 bottles of wine. Data are stored on a public Ethereum blockchain, which allows consumers to use a smartphone app to scan a QR code on the label. The app will inform them immediately through a colour-coded response whether the bottle is authentic. Their device will then provide data on the product's journey from vineyard to store.

The firm uses a combination of factors to enhance trust and security in the network. First, to prevent collusion, Demeter works on an n+1 premise, whereby if there are two (=n) parties to a transaction, three other parties must have the data on their systems. Second, from a transactional perspective, blockchain can provide the focal firm with a "mass balance" to ensure that the total value of transactions matches the final balance, but without giving it all transaction data, a result called "zero knowledge truth".

4.4 Remaining problems

A senior manager at Demeter believes that the greatest barriers to wider blockchain adoption are twofold. First, the technology's underpinning of cryptocurrencies and the associated negative media that has attracted gives consumers an adverse view of blockchain. Ironically, a trust issue with blockchain - the 'trust machine' - seems to exist. The secrecy in which most blockchain trials are held is holding affirmative information back from consumers, both preventing them from learning the technology's capabilities and making them wonder why information is being kept from them. Second, those convinced by blockchain's ability to provide SCV have started from a position that all data needs to be stored on blockchains. Demeter believes that this is not only unnecessary, but expensive and time-consuming. Critical, sensitive data relating specifically to the problem blockchain is being used to solve should go onto the blockchain; non-essential data can be stored locally and shared as required.

5. Discussion and conclusions

We ask how firms are using blockchain for SCV, and what the challenges are. The supply chain literature indicates that a lack of visibility hinders effective SCM (Bartlett et al. 2007). Processes are prevented from working optimally (Petersen et al. 2005); potentially critical data are unavailable (Christopher and Lee 2004); data fragmentation creates information asymmetry, hampering productivity and creating trust imbalances (Wang and Wei 2007). The emergent literature on blockchain as a tool for visibility in supply chains suggests that the technology has the potential to solve some of these problems, though caveats remain (Abeyratne and Monfared 2016).

Evaluating blockchain's use as a visibility tool in SCM, we have conducted four in-depth case studies on firms operating in agriculture, infant formula, fisheries, and wine. Our findings verify some of the claims made in the extant literature, including confirmation of specific models. These include the need to design a system that reduces the potential for Sybil attacks outlined by Apte and Petrovsky (2016), addressed by Demeter's n+1 procedure. Dobrovnik et al.'s (2018) claim that unit-level visibility offers profitability generated from customer-centricity is borne out by Techrock's business model. The WWF-TraSeable joint venture partially advances the need for better sourcing control highlighted by Biggs et al. (2017) while also reducing the potential for labour abuses in fisheries (Gold et al. 2015). Biswas et al.'s (2017) anti-counterfeit model for wines shares results with Demeter. All four of our cases demonstrate Kshetri's (2018) assertion that blockchain offers both immutability and transparency, while WWF-TraSeable, Techrock, and Demeter all support the position that unit-level visibility is possible. All of our cases highlight the need for end-to-end supply chain digitisation (Abeyratne and Monfared 2016).

The paper also challenges certain ideas. Kshetri (2018) suggests that blockchain removes the requirement for tagging technologies. While this is potentially the case in limited instances, we find tags essential in all our cases. Similarly, while Casado-Vara et al. (2018) posit that consumer demands on product provenance are driving blockchain's implementation for SCV, our cases demonstrate that assurances regarding product security are also key. Finally, the idea that supply chains for physical goods cannot be fully digitised (Apte and Petrovsky 2016) are partially challenged by Techrock's vertically-integrated business model, which removes certain boundaries, though admittedly not all.

The Demeter case demonstrates that unit-level data allows for product recalls in the event of contamination and simultaneously makes such events less likely. By capturing data as they are created, Demeter's solution allows stakeholders to see what has happened at and between each node and make informed decisions based on that flow of information. Similarly, Techrock's pioneering use of blockchain offers the end consumer specific data on the package in their hands to alert them to issues. In this case, the vertically-integrated model used by Techrock potentially reduces supply chain risk by decreasing the number of nodes in the chain. And despite Agridigital's claim that consumers do not want to be overwhelmed by data, but simply validate the veracity of firms' marketing claims, the company's use of blockchain offers a level of visibility that not only enriches SCM but also allows consumer-facing organisations to offer data to suit both customer needs and product requirements.

The WWF-TraSeable project provides a working demonstrator of Rejeb's (2018) conceptualisation of blockchain's use for targeting mis-sold fish. In both labelling fish at the point of catch and using satellite data to verify vessel routes, WWF and TraSeable have countered human rights abuses in fisheries at the same time as providing product provenance. The project therefore demonstrates that a well-designed use of blockchain can tackle multiple SCV problems simultaneously.

However, while these cases advance the argument for blockchain as a tool for SCV, they each offer problems that will interest both users and researchers. We have categorised these residual issues thus: issues of trust; boundary issues; issues of governance; and consumer issues. Issues of *trust*, divided by questions of both scarcity and excess, threaten the development of the technology, its adoption as a tool for SCV, and its value once implemented. We find, through barriers identified by Demeter, that the secrecy in which trials have been conducted to date is hampering the sharing of problems and best practice, potentially leading to duplication of effort. Allied to this is the perception that previous systems, and business in general, have previously over-promised on trust, creating a wariness that advocates for blockchain will need to overcome. Once blockchain has been implemented, care will need to be taken that data stored on blockchains is not treated unquestioningly. As a senior manager at Agridigital suggests, there is a potentially dangerous tendency to view "immutability as infallibility."

Allied to issues of trust are *boundary* issues: problems of connection between the physical and the blockchain worlds. Interviewees were almost unanimous in declaring that full digitisation of the supply chain is a precondition for the adoption of blockchain. Without that requirement, human data entry onto blockchains retains the potential for error and corruption discussed by O'Leary (2017), and leaves all of the data on the blockchain open to doubt.

Issues of *governance* centre on the lack of standards around blockchain. Identified by WWF-TraSeable, we find that without agreed protocols, data entered onto blockchains could be inconsistent in terms of level of detail, comparability, and which supply chain nodes are included on a blockchain. The difficulty of knowing how much data to put onto a blockchain is also a governance challenge. For all data to be automatically entered onto a fully-digitised blockchain, all nodes must be included. This creates three problems. First, it endangers the identity of actors within the supply chain. Second, the difficulty of masking commercially sensitive data increases with the volume of data. Finally, the quantities of data produced in supply chains could require significant computing power, even given the potential to hash images (Patel 2018). The latter issue leads a senior manager at an internet governance institute interviewed for the research to suggest that blockchain's future lies predominantly with corporations tracking huge quantities of goods, such as Amazon and FEDEX.

Consumer issues include the usability of blockchain-stored data to the general public, and willingness to pay. We find that a lack of inter-operability prevents some consumers from accessing data stored on blockchains specifically for the buying public. The Techrock case highlights that non-traditional actors might need to become supply chain partners. If a company develops a technology which uses blockchain but is unavailable to a significant proportion of the mobile phone-using market, the potential value to the developer is reduced. On the other hand, the same case highlights a use for blockchain in which the extra cost required to develop a product using the technology is taken on by the consumer. This may only hold for high-risk goods such as infant formula, and potentially high-value status goods.

6. Implications

6.1 Theory implications

In contributing to theory, this paper first highlights a gap in the impact of blockchain on the shifting role of agency in digitally-integrated supply chains. The findings from the cases show that blockchain is most likely to succeed in supply chains which are sufficiently digitised to enable data to be collected and stored on a single, supply chain-length system. Supply chains linked by features such as supplier trust enable their constituent parts to better manage risk (Li et al. 2015). Monitoring of supplier sustainability practices enhances focal firm performance (Shafiq et al. 2017). We find that the potential visibility offered by blockchain could enhance trust by easing supply chain friction, reducing the role of a focal firm from monitor to destination. Our major contribution is therefore that, while sustainability responsibilities may have produced 'double agency' (Wilhelm et al. 2016), blockchain potentially shifts the role of agent to technology solution provider as visibility blurs inter-firm boundaries.

6.2 Policy implications

For policy, the visibility offered by blockchain potentially extends to auditors and authorities. The records that firms maintain, which we find are as much for product safety as they are for confirming marketing claims, can be shared simply by granting permission for relevant third parties, whether they are partners or tax, customs, or certifications organisations. Policy makers might therefore opt for access for various financial and legal reasons.

6.3 Managerial implications

Blockchain could significantly enhance SCV. While this ability has long been desired in SCM, demand for it has grown with public problems in supply chains. Supply chain traceability systems enable firms to view the 'when' and 'where' that Wang et al. (2019) discuss, but not 'how' products are processed. As consumers have become increasingly insistent, firms have made claims and adopted certifications the veracity of which the end customer has never been able to verify.

In order for consumer hunger for knowledge on product provenance to be sated, several changes must be made to supply chains. First, without full digitisation, the potential for error and fraud may mean customers cannot be satisfied and firms cannot trust upstream processes (Montecchi et al. 2019). Second, as RFID tags were very expensive when first used in product traceability (Balocco et al. 2011), full-visibility blockchain solutions can be expensive, potentially limiting their use to lower-volume, higher-value goods. Decisions will need to be made around consumer willingness to pay or corporate disposition to absorb costs to reduce risk. Finally, consortia will need to decide how to govern their blockchain networks. Collusion may be as great a risk as external systems attacks, and all parties involved will need to evaluate their appetite for knowledge within their supply chains against the overall benefits to each party, the network as a whole, and the consumer.

While this study offers findings that can be generalised, particularly with regard to issues still to be overcome, it is limited to the extent that we can describe successes by the specific use cases investigated. We urge firms engaged in pilots, trials, and projects to be more open to sharing findings, if not the process, so that outcomes might be added to the embryonic body of real case data available. The possibility remains, as a senior consultancy manager interviewed for this research asserts, that such "technological solutions do not solve the problem before them, but do become an incremental part of that solution." Learning from the difficulties of implementation is likely to be accelerated by a more open, trusting ecosystem developing around the trust machine.

6.4 Future Work

There is currently an issue of access to data around blockchain implementations in supply chains, and much of the literature is concerned with modelling uses of the technology in this field (e.g. Madhwal and Panfilov 2017; Dobrovnik et al. 2018). Firms deploying blockchain solutions is an important area of investigation to both test our findings and build further conclusions. In this regard, we offer several potential areas for further enquiry. First, we suggest further individual case studies in other sectors would enable detailed insight into a blockchain-empowered supply system. Second, longitudinal studies to develop insights of the reasons for (and barriers to) adoption of the technology, the various stakeholders involved, and locations and/or institutions that accept and use the technology. Finally, there is significant scope for interdisciplinary study of blockchain's potential to be used for good. Global challenges, particularly those of a wider significance, e.g. palm forest devastation, child and forced labour, and inputs to food products. Supply chain researchers can address these problems, often with collaborators in related fields, employing blockchain as part of the solution.

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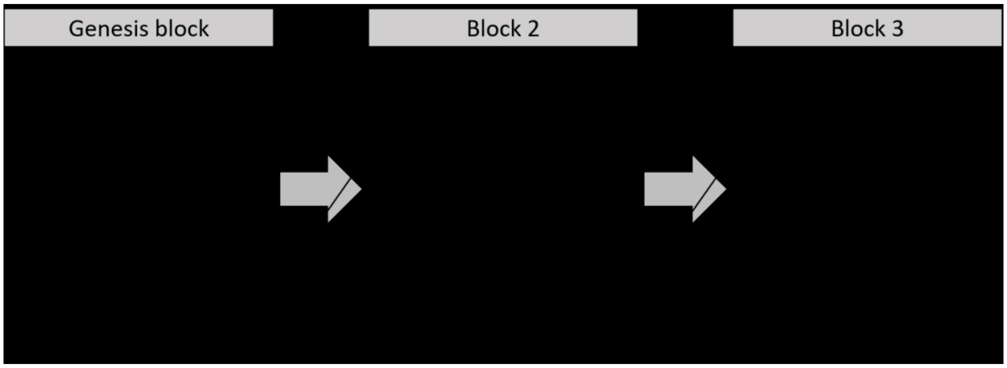

Figure 1: structure of a blockchain