Entering the world behind the clothes that we wear: practical applications of blockchain technology

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Abstract

This paper investigates blockchain technology from a Triple Bottom Line (TBL) perspective. Transparency is vital for achieving accountability, improving the environmental footprint and ensuring that workers' rights are respected. Blockchain-enabled capabilities provide opportunities to support improved information transparency to sub-suppliers and customers. Case study research is used within the complex multi-tier global fashion industry to explore the application of blockchain technology in enhancing TBL performance. This paper responds to calls from the literature to provide practice-based research on blockchain and supply chain management challenges. The research is based on three technology-based start-ups (at different Technology Readiness Levels (TRL)) and investigates their practical experiences to date, in transforming and advancing supply chain TBL. As this research focuses on the early adoption of blockchain technology within the fashion industry, it demonstrates the practicalities of implementation including its capabilities, operational improvements, challenges and limitations.

Keywords: Blockchain technology, Triple Bottom Line, Supply Chain, Transparency, Fashion

1. Introduction

Sustainability and transparency are fast becoming two of the top priorities within the global fashion industry (McKinsey & Company 2020). High profile environmental and social scandals have led to increased scrutiny of the fashion industry (Macchion et al. 2018; Winter & Lasch, 2016). It is an industry characterized by complex global supply chains, and many studies have investigated the challenges associated with large multi-tier networks (Wilhelm et al. 2016). Transparency is vital for achieving accountability, improving the environmental footprint and ensuring that workers' rights are respected. In the absence of transparency, stakeholders are compelled to expend a substantial amount of resources to determine which companies are socially and environmentally friendly. There is evidence that global apparel companies are starting to adopt supply chain transparency. For example, many have signed the transparency pledge (Transparency Pledge Coalition, 2019) and publicly disclosed information about their Tier 1 manufacturing factories. This disclosure has been hailed a milestone as it signals companies' commitment towards sustainability. Nevertheless, publishing information about first tier manufacturers is not a panacea to social and environmental abuses associated with the fashion industry. For instance, in their analysis of data collected from 100 of the most affluent fashion brands according to the levels of corporate and supply chain transparency, Jestratijevic et al. (2020) found that the type of information disclosed was selectively prioritized. Therefore, besides publishing factory-level information, a mechanism is needed to determine the accuracy, trustworthiness and auditability of the information disclosed.

Recently, blockchain technology has attracted enormous attention among business executives who, according to Deloitte's 2020 global blockchain survey, increasingly see it as integral to organisational innovation (Deloitte, 2020). Although it started as an underlying technology for bitcoin, the business community quickly saw its potential to disrupt and enhance supply chain management (SCM) (Hennelly et al. 2020). Defined as a distributed ledger technology, blockchain consists of a chain of decentralised computer terminals and a network software protocol on a peer-to-peer network of nodes (Wamba et al. 2020). Indeed, blockchain's salient features, such as decentralisation, immutability and auditability, can address critical challenges in supply chains (Min, 2019). Given its features, the potential applications of blockchain technology have been noted in several contexts such as the food industry (Creydt and Fischer, 2019), chemical industry (Sikorski et al., 2017) and healthcare sector (McGhin et al., 2019). Likewise, blockchain technology is increasingly viewed as a potential mechanism for enhancing social and environmental sustainability in the fashion industry (Choi and Luo, 2019, Fu et al., 2018), hence complementing the ongoing information disclosure initiatives. Despite the acclaimed potential applications and the numerous announcements of use cases, Sternberg et al. (2020) note that there are very few successful implementations of blockchain technology solutions in supply chains and there is little empirical evidence on the obstacles to blockchain adoption. This observation is consistent with Wamba and Queiroz (2020) who note that despite the considerable attention that blockchain technology has gained, limited research on blockchain technology exists within the operations and supply chain management (OSCM) field, particularly from a sustainability perspective. Hence, practice-based research has been encouraged to investigate supply chain management challenges related to its implementation (Cole et al. 2019; Kouhizadeh et al. 2020).

Responding to the call for practice-based research, this study draws on three technology-based case studies and answers the following research question: *What are the* *practical experiences and challenges in implementing blockchain technology within the global fashion industry and how does this impact the triple bottom line?*

The study contributes in two ways. Firstly, it provides insights on the operational improvements, experiences and challenges in transforming and advancing sustainability and transparency within the global fashion industry by using blockchain technology. Secondly, it explores the impact blockchain technology has on the triple bottom line, that is, the planet, people and profit. As suggested by Kouhizadeh et al. (2020), such insights are essential for developing key operational governing principles and for guiding the implementation of blockchain technology. As social and environmental sustainability is the '*fashion industry's new must-have, it is increasingly becoming a critical issue for consumers and governments'* (McKinsey & Company, 2020), the insights provided by this study are valuable to both policy makers and managers involved with the fashion industry.

The remainder of this paper is organised as follows. First, a review of the relevant literature is provided in Section 2. The research method is then explained in Section 3, followed by the findings from the three selected cases in Section 4. These are then discussed and lead to four propositions, presented in Section 5. Finally, conclusions are drawn in Section 6, including implications for practice, limitations and opportunities for future research.

2. Literature Review

The literature review is divided into three sections. The first part looks more broadly at blockchain technology for supply chain management. The second section focusses on the potential impact of blockchain technology on the triple bottom line. This is followed by a focus on blockchain technology and sustainable fashion supply chains

2.1 Blockchain technology for supply chain management

Unsurprisingly, blockchain technology has gained traction amongst supply chain management scholars. Notably, the focus of extant literature related to blockchain technology and SCM has been on blockchain's capabilities and issues related to its implementation (Aste et al., 2017; Wamba et al, 2020; Gurtu and Johny 2019; Hastig et al. 2020). Regarding capabilities, blockchain technology is widely acknowledged to enable traceability in supply chains (Hastig and Sodhi, 2020; Casino et al, 2020). The importance of supply chain traceability has long been recognised in the literature (e.g., Jansen-Vullers, 2004). The ability to trace raw materials and products has become critical in almost all industries. For instance, as part of risk management, firms are increasingly encouraged to trace their suppliers beyond first-tier suppliers (Mwesiumo et al. *In Press*). Blockchain technology reliably offers traceability because its distributed databases can be shared across the entire supply network, and the history of all transactions remains forever with permanent footprints (Min 2019).

Related to traceability is blockchain's ability to provide provenance knowledge in supply chains, that is, the information about products' origin, including history on the production processes, modifications, and custody. As global supply complexity increases, provenance knowledge has become an essential element in customers' purchasing decisions (Montecchi et al., 2019). In traditional supply chains, provenance knowledge is typically provided by trusted third-party mechanisms such as certifications and accreditations. However, since blockchain technology provides a documented and fully auditable history of products, it offers reliable provenance knowledge. Thus, blockchain technology primarily addresses the problem of information asymmetry in supply chains. This way, it enables efficient supply chain transparency and visibility (Chod et al., 2020; Sunny et al., 2020). Equally important, blockchain technology enables smart contracts in supply chains (Dolgui et al. 2020). A smart contract consists of rules and policies written in a blockchain, which automatically verifies the fulfilment of specific contractual terms before approving the execution of transactions. Wamba and Queiroz (2020) suggest that blockchain-enabled smart contracts can facilitate efficient decentralised supply chain operations. Intriguingly, some scholars suggest that blockchain technology could be integrated with other digital technologies to maximize value creation in supply chains. For example, Cole et al. (2019) propose that blockchain technology could potentially be integrated with RFID and ERP technologies, while Novo (2018) show that blockchain technology could complement the internet of things. As much as these suggestions are appealing, there is a noticeable research gap on the practical experiences of how best blockchain technology can be integrated with other technologies for maximum value creation.

2.2 Potential impact of blockchain technology on the triple bottom line

According to the natural resource-based view (NRBV) of the firm, the interaction between a firm and its natural environment as well as the world's poor is critical for creating sustainable competitive advantage (Hart 1995; Hart and Dowell, 2011). Thus, to stay competitive, firms must focus not only on profit but also on the planet (environmental sustainability) and people (social sustainability). Consistent with NRBV, McDougall et al. (2019) empirically demonstrate that the focus on pollution prevention, product stewardship, clean technologies, and local philanthropy are key resources for competitive advantage. The extant literature suggests that by enhancing traceability, provenance knowledge, transparency, and smart contracts in supply chains, blockchain technology can offer numerous benefits to supply chains. This section discusses the potential impact of blockchain technology on the triple bottom line: profit, planet and people, corresponding to the impact on economic, environmental and social performance, respectively.

2.2.1 Potential impact on profit

Like other digital technologies, blockchain is advocated for its potential to improve economic performance in supply chains. Since information is the lifeblood of supply chains, effective integration across the supply chain is crucial for value creation (Alfalla-Luque et al., 2013). Thus, any technology that ensures a timely and accurate flow of information should significantly impact supply chain performance. While information management solutions such as ERP systems have traditionally enhanced supply chain integration (Roh and Hong, 2015), blockchain technology takes it to a higher level. As Bai and Sarkis (2018) suggest, blockchain technology meets the essential requirements for enabling effective supply chain integration. Through effective supply chain integration, blockchain technology can lead to positive economic outcomes in several ways such as facilitating faster and cheaper transactions, thereby reducing transaction costs (Montecchi et al. 2019); reducing paperwork, bureaucracy, and potential losses from human error (Deloitte, 2019); preventing fraud and improving forecasting (Yong et al. 2020); and ensuring secure transactions, improved accuracy of record keeping and building customer trust (Wamba et al. 2020).

The role of blockchain technology in minimizing costs can also be explained by transaction cost economics (TCE). According to TCE, a firm's decision to perform an activity internally, have a long-term contract with a supplier, or acquire it on the market through discrete transactions depends on the level of transaction costs (Williamson, 2008). These include costs associated with searching, selection, negotiating and writing contract, monitoring, and enforcement of agreements with suppliers. Thus, TCE predicts that firms are more likely to integrate vertically when transaction costs are high, while market transactions are likely to be preferred when transaction costs are low. Williamson (2008) suggests that the need to make adaptations in exchange relations is the central problem in coordinating economic transactions, and the main source of this problem is uncertainty. There are two forms of uncertainties: environmental and behavioural uncertainties (Rindfleisch and Heide, 1997). Environmental uncertainty refers to the extent to which the circumstances surrounding exchange cannot be specified ex ante, while behavioural uncertainty refers to the extent to which the performance of the exchange partner cannot be verified. Lumineau et al. (2021) suggest that blockchain technology can lower transaction costs associated with behavioural uncertainty. They argue that implementing blockchain technology can reduce costs of identification, gathering information, and evaluation of potential trading partners. Likewise, they contend that since blockchain technology facilitates transparent, real-time, and verified information exchange among transacting parties, it can reduce transaction costs associated with monitoring suppliers and simplifies dispute resolution. In sum, the extant literature emphasises on the potential impact of blockchain on profit through cost minimisation. Following TCE line of reasoning, blockchain technology promises to reduce transaction costs and thus contribute to profit maximisation.

2.2.2 Potential impact on the planet

The planet as a pillar in the triple bottom line framework focuses on environmental sustainability (Fung et al., 2020). NRBV promotes environmental sustainability through three critical strategic capabilities: pollution prevention, product stewardship, clean technology (Hart and Dowell, 2011). These capabilities enable environmental sustainability through waste and pollution reduction, elimination of environmentally hazardous operations, development of environmentally friendly products, and reduction of material and energy consumption. Although the critical role of environmental sustainability for achieving a competitive advantage is widely recognised, limited visibility and traceability across the supply chain are factors that significantly inhibit initiatives to attain it. Thus, any technology that enhances visibility and traceability can enhance environmentally sustainable supply chains. Therefore, it is not surprising that the potential impact of blockchain technology on environmentally sustainable supply chains has attracted considerable attention in the literature. Blockchain technology is credited for its potential to enhance sustainability due to its capability to improve transparency (Saberi et al., 2019).

Bai and Sarkis (2020) suggest that sustainable supply chain transparency can be distinguished into three dimensions: (i) The range of transparency (including the degree of information sharing among supply chain members); (ii) Product transparency such as tracking product components (e.g. raw material origins), tracking product process (from the place of origin to the end customer), tracking product sustainability-related information (e.g. recycling and carbon emissions); and (iii) Participant transparency, including visibility of participant operations, situation information, and participant sustainability conditions. Based on their analysis, they conclude that blockchain technology provides some promise to achieving sustainable supply chains. As for multi-echelon supply chains in the fashion industry, Manupati et al. (2020) suggest that blockchain technology can minimise both total costs and carbon emissions. Related to environmental sustainability, Kouhizadeh et al. (2020) suggest that blockchain technology can potentially benefit the circular economy by facilitating the implementation of its six principles: Regenerate, Share, Optimise, Loop, Virtualise, and Exchange. Equally important, Kouhizadeh and Sarkis (2018) suggest that blockchain technology can make life cycle analysis (LCA) more effective as it supports component identification throughout a product's lifecycle. Amongst other benefits, accurate information about the product life cycle is key to promoting environmental management practices (Udokporo, 2020). Meanwhile Esmaeilian et al. (2020) believe that whilst blockchain contributes to sustainability, there should be incentive mechanisms and tokenisation to promote consumer green behaviour.

2.2.3 Potential impact on the people

Along with the planet (environmental sustainability), NRBV addresses the base of the pyramid as a critical strategic capability for attaining competitive advantage. Khalid and Seuring (2019) refer to the base of the pyramid as "mainly but not solely composed of citizens of so-called developing countries who are dependent on an informal market economy to fulfil their daily needs". More generally, Arnold and Williams (2012, p. 44) refer to it as being composed of individuals who are excluded from "the current system of global capitalism". Elkington (1998) embraces social justice as an imperative for business prosperity in the 21st century. As global supply chains involve numerous actors in the developed and developing economies, delivering social justice across the entire supply chain is critical. In other words, supply chains must take deliberate measures to promote social sustainability. Indeed, malpractices by any actor in a supply chain can easily jeopardise the reputation of other actors in it (Nujen et al., 2021).

Nevertheless, social sustainability continues to be a significant concern in global supply chains (Venkatesh et al., 2020). Typical social sustainability issues include modern slavery, child labour, unfair wages, excessive working hours, unsafe working conditions, and unequal treatment of workers. The extant literature (e.g., Klassen and Vereecke, 2012) recognises that monitoring and controlling social sustainability issues in supply chains is challenging. For instance, when companies use undeclared suppliers it is difficult for stakeholders to monitor and control social sustainability compliance. Therefore, transparency is critical for ensuring social sustainability in supply chains. As Kassoy (2010) noted, sustainability is virtually impossible without transparency. While the extant literature has extensively explored the potential application of blockchain technology in addressing environmental sustainability issues, its potential to address social sustainability has received limited attention (Lim et al., 2021). However, Venkatesh et al. (2020) suggest that blockchain offers a promising future to achieve supply chain social sustainability. They contend that Blockchain technology, together with the Internet of Things and big data analytics, can address social sustainability issues by automating data collection, recording updates, and building tamper-proof record blocks that prevent data manipulation. These activities increase transparency and traceability in supply chains, making monitoring and controlling social sustainability across supply chains possible. Chaudhuri et al. (2021) also recognise the potential application of blockchain technology in addressing social sustainability issues. Their analysis concludes that implementing blockchain-enabled track and trace systems can directly improve social sustainability in supply chains.

2.3 Blockchain technology and sustainable fashion supply chains

The extant literature has reported the potential for the applications of blockchain technology in several sectors. Examples include the application of blockchain technology in food traceability (Kayikci et al. 2020; Rogerson and Parry, 2020; Bumblauskas et al., 2020), blockchain technology-collaboration in pharmaceutical supply chain partners (Epiphaniou et al. 2020), and the potential application of blockchain technology for tracking and tracing in the Gem Industry (Cartier et al. 2018). Of interest to this paper is blockchain's application in the fashion industry, which has also received some attention in the extant literature (e.g., Fung et al. 2020). The growing interest in blockchain's potential applications in the fashion industry is understandable, considering significant problems related to people, planet and profit that remain unsolved. Regarding people, the industry is often associated with social sustainability problems such as modern slavery (Benstead et al. 2020), lower wages (Turker and Altuntas, 2014) and poor working conditions (Bick, Halsey and Ekenga, 2018). As for the impact on the planet, the industry produces nearly 20% of global wastewater and emits about 10% of global carbon emissions (UNECE, 2018). In addition, the fashion industry is criticised for the excessive amounts of water needed to grow cotton and for the release of untreated dyes into local water sources (Bick et al. 2018). As consumers increasingly refrain from products that are related to unsustainable practices, the aforementioned problems are likely to affect the industry's profit. Besides, the problem of counterfeiting in the fashion industry is prominent and it has a direct impact on profit (Meravigila, 2015). Considering all these problems, transparency, traceability, and provenance knowledge are of paramount significance in this industry. As blockchain technology can enable all these aspects, previous conceptual and empirical studies have addressed several issues related to blockchain's application in the fashion industry. The addressed issues include blockchain technology as a facilitator of an emission trading scheme (ETS) (Fu et al. 2018), opportunities for applying blockchain technology in controlling the distribution chain, combating counterfeits, real-time evidence of use and indisputable records of the design process (Burbidge, 2017), a framework for near real-time, cross-chain information sharing with guaranteed authenticity and accuracy, allowing quality defective batches (ElMessiry and ElMessiry, 2018), and blockchain technology as a means to address data quality challenges for sustainable fashion supply chain operations (Choi and Luo, 2019).

Overall, the existing studies emphasize blockchain's potential to enhance the economic, social and environmental performance of fashion supply chains. However, they also suggest that blockchain's implementation in the fashion industry is challenging due to various barriers. For instance, Fu et al. (2018) note that funding and effort are needed to build the blockchain, operate the ETS, designate the auditors, and establish the carbon emission evaluation standards. Financial cost as a barrier is also noted by Choi and Luo (2019), who suggest that the cost of implementing effective blockchain technology can outweigh the benefits. Further, research into how companies are encouraging actors within the supply chain to adopt blockchain has been identified as urgent e.g., through incentivisation such as sharing implementation costs (Cole et al. 2019). Fu et al. (2018) and Choi and Luo (2019) argue that since blockchain's implementation in the fashion industry will positively affect society's welfare, governments should step in and finance such projects. Besides the financial barrier, it is also plausible to consider other challenges related to blockchain's implementation. Saberi et al. (2019) categorise such barriers into intraorganisational (e.g., lack of management support and commitment and resistance to change), interorganisational (e.g., challenge in integrating sustainable practices among supply chain partners and unwillingness to disclose information), technical (access to technology and immutability challenge of blockchain technology) and external barriers (e.g., lack of rewards and encouragement programs and lack of external stakeholders' involvement). While extant studies related to blockchain's application in the fashion industry offer valuable insights, they are mainly conceptual. At this stage, we need more real cases and practical experiences that can allow us to explore ways to support better implementation of blockchain technology in the fashion and other industries.

3. Research Method

3.1 Research Design

Given the lack of both academic and managerial knowledge regarding blockchain technology, as cited earlier, empirical research is needed. This study is therefore exploratory and aims to understand the practical experiences and challenges in implementing blockchain technology within the global fashion industry from a triple bottom line perspective. Case study research was deemed appropriate as it lends itself to exploratory research (McCutcheon & Meredith 1993; Yin, 2018). More than one firm has been selected to provide breadth, ensuring that views are captured from multiple perspectives whilst increasing validity and aiding in preventing researcher bias (Barratt et al., 2011; Yin, 2018). A case is defined as a company and data has been collected from three companies. As outlined by Voss et al. (2016), multiple case studies can range from three and above. Given the immaturity of blockchain adoption within the fashion industry, three pioneering companies have been included in this research. This research focuses on the perspective of blockchain technology start-ups as these companies are at the forefront of enabling the adoption of blockchain within the fashion industry.

The selection criteria are as follows; companies should be a blockchain technology company operating within the fashion industry, provide access to multiple sources of information to aid triangulation and the firms should have experience in implementing blockchain within the fashion industry for sustainability purposes. All cases have been named as opposed to being anonymised to improve transparency and reliability of the research. Three start-up technology companies (see Figure 1 for summary) based in Sweden, Italy and Germany have been selected for this research. The companies have either developed a smartphone app or platform using blockchain technology to collect supply chain information. Additionally, they are able to use this data to allow consumers to scan a purchased product using their smartphones or access verified information pre purchase on a commercial website. The case companies are at different Technology Readiness Levels (TRL), allowing a cross-comparison between the enablers and barriers for the implementation process, and the assessment of how this technology supports sustainability.

Semi-structured interviews have been used, supplemented by company documentation, company webinars, websites, and news articles to provide triangulation. Each company has also provided demonstrations of their technology either during interviews and/or via videos (and for one of the cases, 1TrueID, one of the researchers saw this at their launch event). Additionally, the team have either visited commercial websites to access real-time information for products and/or downloaded the case company apps to test the functionality of the blockchain technology. In the instance of PaperTale, each researcher had a t-shirt so that they were able to scan and access the corresponding data within the app. Figure 1 provides an overview of the data collection process for each case company (including details of primary/secondary data) along a timeline. We have also shown how this has helped us to develop the propositions presented in the discussion section of this paper (Section 5) .

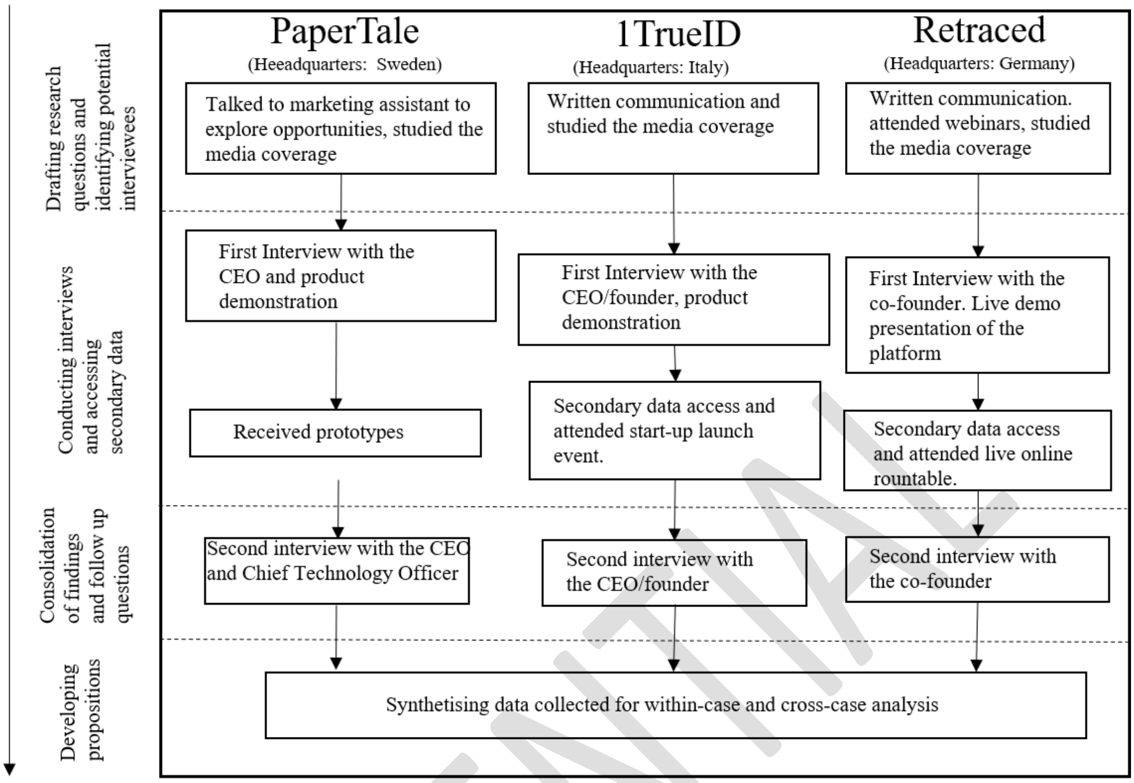

Figure 1, Overview of data collection process

Interviews were conducted in stages. During the first stage, semi-structured interviews have been used by preparing questions to ensure coverage of key topics (see Appendix). Follow up interviews were conducted during the second stage to probe further and or clarify any initial points raised. This is an abductive study, and the prior literature was therefore constantly compared to empirical observations. Additionally, data analysis was conducted in parallel to the interview phase to be receptive to new results and allow more in-depth sets of questions to be developed in the second stage (Voss et al. 2016). The questions had an open-ended format ensuring areas could be explored as they developed during the interview. The questions were split into themes (general-company/product background, operational, supplier/retailer/customer adoption and product demo). The key topics covered business and product features, technology, sustainability, challenges and supply chain collaboration. As the case companies are start-ups, there was also emphasis on their starting story and future plans to fully understand their journey and experience to date. A summary of the data collected is provided in Figure 1. The founders of each company were identified as key informants as they could reliably answer the set of questions (Voss et al. 2016). These interviewees were the most knowledgeable in the company and able to provide in depth information on all of the key topics. Additionally, as the companies are start-ups, they have very small teams. However, an additional interviewee (Chief Technology Officer) was identified in PaperTale (see Figure 1), to supplement the data provided by the founder. To help guard against interviewees' subjectivity and bias, information was triangulated with secondary data for all three cases (see Figure 1). For Retraced, as only the founder was interviewed, additional data was obtained from pre-recorded webinars and an online round table discussion. For 1TrueID, as only the founder was interviewed, additional data was obtained from one of the researchers who attended the company's launch event. In order to improve rigour and increase validity, a set of questions were prepared in advance and sent to each interviewee together with a document providing an overview of the research. More than one researcher was present during each interview allowing inter reliability to be checked. One researcher took the lead whilst the others present could independently take notes and also contribute if deemed necessary (Eisendhardt, 1989) Interviews were video recorded and subsequently transcribed after each interview.

3.2 Data Analysis

Pattern-matching logic was adopted, and data has been analysed to identify themes within the data (Braun and Clarke 2006). The coding scheme was compared between the members of the research team. The data has first been analysed through within-case analysis followed by cross-case analysis (Eisendhardt, 1989). We accounted for construct validity, internal validity, external validity and reliability throughout the research process

(Yin, 2018) which is summarised and presented in Table 1.

Table 1, Measures taken to enhance validity and reliability

Tests of research design quality	Data collection	Data analysis
Construct validity	• Semi-structured interviews have been used, supplemented by company documentation, websites, news articles, product demonstrations, webinars and attendance at a launch event and roundtable discussion to provide triangulation (Yin, 2018). • Interviews conducted with highly knowledgeable informants from different countries to provide different perspectives. (Eisenhardt and Graebner 2007). • Multiple researchers involved throughout all stages of the research.	• Data analysis conducted in parallel to interview phase to be receptive to new results and allow more in-depth sets of questions to be developed (Eisenhardt, 1989). • Established and maintained a chain of evidence (Yin, 2018).
Internal validity	• n/a	• Research framework from literature. • Pattern matching among cases (Yin, 2018). • Cross-case synthesis (Yin, 2018). • Triangulation of data between interview data, secondary data and observations/webinars/ demonstrations. • Thematic analysis based on pattern matching and explanation building logic (Braun and Clarke 2006). • The coding process was carried out separately by two different researchers.
External validity	• Gathering data on the case context (Gibbert et al. 2008). • Multiple cases of different organisations to prevent researcher bias (Voss et al. 2016).	• Analytical generalization (Yin 2014). • Extensive intra-case analysis (Eisenhardt 1989).
Reliability	• Semi-structured interview guide included in case study protocol (Yin, 2018). • Interviews conducted by more than one of the research team (Eisendhardt, 1989). • Case study protocol and database used (Yin, 2018). • Case identity provided rather than anonymised (Yin, 2018). • Physical/tangible evidence (Yin, 2018).	• All interview transcripts analysed by interviewer (Yin 2018).

4. Findings

4.1 Within-case analysis

The within-case analysis led to the identification of the operational improvements and limitations arising from the implementation of blockchain technology. The analysis involved developing a full understanding of each case company's background and journey, challenges and future plans. Each case has been analysed from a triple bottom line perspective to determine social, environmental and economic impacts. This is presented below followed by a cross case analysis in Section 4.2.

4.1.1 PaperTale Overview

PaperTale is a technology start-up founded in 2019 and headquartered in Sweden. The company currently has 14 people within their team. It is mainly a self-financed venture, although they received seed funding from the Swedish Government when they first started. This was described as 'negligible' by the founder and he explained that the partners have also invested in the company. In addition to this, the company have set up its own factory in Pakistan. This is a separate entity but established around the same time as the PaperTale venture. The factory produces for other brands and is therefore a source of cash flow for PaperTale. PaperTale has developed an app which relies on the blockchain technology, allowing customers to scan a product using their smartphones to access supply chain information. The features of the app are provided in Table 2. Having access to their own factory has also allowed PaperTale to create their own 'proof of concept' collection of T-shirts, to both test the technology and demonstrate its functionality to consumers, brands and suppliers. On the sleeve of the t-shirt is a small plastic button (NFC tag). The owner of the T-shirt needs to download the PaperTale App and scan the tag. This allows the customer to access the information. Having successfully launched their proof-of-concept collection, PaperTale is now moving into what is described as their ‘pilot stage’ to show the viability of their technology, which involves working with other brands and factories. Based on discussions with the company, the researchers assessed that they are at TRL 3 (proof of concept). The long-term vision is for their product to become an industry standard and therefore set an expectation that all garments have verified transparent supply chains. PaperTale uses a combination of public and private blockchain. Both public and private blockchain are decentralized peer-to-peer networks, in which each node maintains a copy of a shared add-only ledger of digitally signed transaction. However, while anyone can enter and participate in a public blockchain, with participation usually incentivized, a private blockchain requires an invitation and must be validated by the network starter (e.g. the app or platform provider). Table 2 provides an overview of the PaperTale app.

Table 2, Summary of Paper Tale App

App Function	**Overview**	**Verified Information**
Product Journey	• Journey of product including fibre formation, yarn formation, textile formation, dyeing and garment production. • Asset Transfer included- movement/transportation of raw materials and finished product.	Environmental impact for product journey (currently not for asset transfer)- Water consumption and CO2 emissions
Meet the Craftsman	• Images of craftsman e.g. machine operator, cutting operator, finishing quality inspector. • Option to visit factory website.	Gender Age 18+ Minimum Wage View Payroll
Claim Ownership/ Compensate	• PaperTale allocated $2 for customer to compensate impact. • Customer enters code to show ownership of product and authorise.	$2 dollar payment for: 1 Tree 1 School Day

4.1.2 1TrueID Overview

1TrueID is a technology start up founded in 2017 through investment from its co-founders and headquartered in Italy. At the beginning of 2020, 1TrueID have received funds from Lombardy Region to support its project. 1TrueID is a patented solution to trace goods, verify authenticity of items and engage the customers who bought them. This is based on the first world model of supply chain blockchain developed from one of the co-founders in late 2009. 1TrueID have developed an app allowing customers to verify authenticity, declare ownership and access verified information on a product's origin and production process through their smartphone. This is achieved through scanning a smart label with an NFC or RFID tag or a QR-code, that is attached to the product. 1TrueID also allows companies to monitor their products in real time throughout the supply chain, guaranteeing their traceability. The company mainly works with luxury brands and has won a number of awards for their blockchain solution. Based on discussions with the company, the researchers assessed that they are at TRL 6 (technology demonstrated in relevant environment). 1TrueID relies on a public blockchain. Table 3 provides an overview of the 1TrueID app.

Table 3, Summary of 1TrueID App

App Function	**Overview**	**Verified Information**
Owner-product journey	• Journey of product. • Authenticity. • Interaction with brand (including during production process e.g., customer can customise product). • Declaration of ownership. • After sales involvement with brand. • Sustainable Development Goals data.	Secure digital identity (Digital DNA ©). The information provided depends on the specific brand needs.
Brand	• Each product has secure ID. • Traceability and geolocation of products. • Item user relationship data. • Interaction with customer (including during production process e.g.,	Secure digital identity (Digital DNA ©). The information provided depends on the specific brand needs.

	customer can customise product).

4.1.3 Retraced Overview

Retraced is a German technology start-up founded in 2018 with a mission to "*redefine the way we consume by providing easy access to honest information about the products around us*' and a '*vision to foster supply chain transparency to ensure better working conditions and more sustainable manufacturing practices*'(Company Website). The Founder describes themselves as a "*sustainability management platform*". It uses blockchain technology to collect data in the supply chain of fashion brands. Their business model is based on two pillars, internal transparency (data collection/ internal management) and external transparency (communication to customers). Table 4 provides a summary of their platform. Out of the 50 brands currently using the platform, 25 are using it for internal transparency and 25 for external transparency. It allows brands to show the end customers how their purchase impacts the environment and the lives of the people involved with production. Meanwhile, by providing better transparency, it allows businesses to better plan the production and identify any potential bottleneck in the supply chain network. Retraced benefited from seed funding and have grown through investment. They piloted the technology using a small shoe brand prior to launching to other businesses. Based on discussions with the company, the researchers assessed that they are at TRL 5 (technology validated in relevant environment). Retraced uses Hyperledger fabric which is permission based blockchain meaning not everybody has access to it or can participate. Table 4 provides an overview of the Retraced platform in terms of internal and external transparency.

Table 4, Summary of Retraced Sustainability Platform

Platform Function	Overview	Verified Information
Internal Transparency (data collection/ internal management)	• Users have their own profile on the platform allowing suppliers or brands to access information. • Digitally track supply chain through collecting documents that prove different transactions via digital signatures and time stamps.	• The data includes certifications, audits and other information such as emissions and resource usage and product location.
External Transparency (communication to customer)	• Consumer friendly 'badges' that the brand can display on their product page. • Product journey and company information. • Verification of documents or certifications from companies within the supply chain. • The data displayed is all pulled from the platform.	• Example badges include fair payment, fair working conditions, social engagement, sustainable materials, no hazardous chemicals, low water usage, and environmental engagement. • Product journey is provided in the form of steps and processes (e.g. yarn processing fabric processing and manufacturing), including company name, addresses and distance travelled. • Certificates (e.g. Global Organic Textile Standard GOTS) are listed and explained- There is also the ability to click to see proof and access an image of the certificate. • Photos are also provided of the different facilities.

4.2 Cross case analysis

The cross case analysis followed the within case analysis leading to the identification of similarities and differences between the cases which are presented in the following section, with supporting evidence from semi-structured interviews and secondary data analysis. The findings are presented in four subsections, Impact on planet and people, Impact on profit, Challenges and Integration with other technologies.

4.2.1 Impact on planet and people

The case companies have all developed a product that improves supply chain transparency. From a social and environmental perspective, they allow supply chain information to be shared with the end customer. PaperTale refer to developing '*a consumer focussed*' product for sustainability which is able to educate consumers and allow them to see if a product is made with the lowest possible impact. Through blockchain technology, transparency is achieved but the companies are aware that to be effective, they need to effectively translate this information to the end customer. PaperTale highlights this in the following quote "*we need to educate in a friendly way. We are still trying to figure out our communication but I believe the knowledge is power."* Retraced have already started to explore how to best communicate transparency to customers. The co-founder explains "*There is no point in publishing the blockchain code. This looks great but no one is able to understand the code. You can only read the time stamp and that's it. The transparency that we would like to provide the customer is about the right data at the right time. The right time is when the customer makes the purchasing decision, either at the store or online purchase, and the right data means types of data that the consumers can work with. For instance if I tell the consumer that this product has a certain certificate at tier 1 level, this might not be understandable. So what we try to do is to translate all the certificate and data from the products to easily understandable measures or claims*." Their solution has therefore been the use of badges on product websites as detailed in Table 4.

It is evident that the case companies are placing emphasis on 'storytelling' as a means of sustainability education and communicating their blockchain capabilities. This is highlighted by the Retraced co-founders in secondary data "*track-and-trace capabilities that allow each shoe to tell its own story, reveal every face behind the product that has helped bring it to market and show the origin of its raw materials*." They add "*we wanted to focus more on the people who produce our products. A transparency solution was important to us, such as being able to scan the shoe and then see who worked* *on it, the history of how the shoe was made, as there are about ten people working on each pair of shoes, and also to be able to see where the materials come from*" Similarly, the founder from PaperTale highlights "*we want to give the human experience, there are people on the other side of the world making these* [clothes]*".* With consent there is also the ability to display the workers photo in the PaperTale app (or an avatar if consent is not given). The founder explains that you have to '*bring the human aspect to the consumer'* adding *'The workers are really excited about it, they want to be heard'.* The founder of 1TrueID discusses the benefit of storytelling. Emphasis is placed on using storytelling to improve the relationship between the customer and the brand. This is exemplified from the following quote "*Storytelling triggers the interaction with the customer, offering a new shopping experience and after-sales involvement.[…]In fact, from a storytelling point of view, "narrating" the product from its first phase of realisation allows* [the brand] *to involve the consumer more by establishing an immediate brand-customer relationship*." There is however consideration that circularity can also be achieved through using the technology to both build relationships and further understand the product lifecycle. The founder explains *"Because you can trace the product from the raw material, according to a cradle to grave philosophy and you can trace it so that you can really know how to reduce it or recycle it at the end of its life. And at the time that you have a digital identity, you can have precise data about how it is used and how it is recycled'.* PaperTale also involve the customer in the post purchase journey of the product. This is achieved through the customer claiming ownership and compensating their impact. PaperTale admit that this is their own definition of compensation and they have therefore allocated $2 to this feature. This payment equates to the donation of planting one tree and one school day for a child. The owner claims that this is part of the education process "*we could have launched without this feature but this helps educate the customer and involve them in the product journey*".

All three companies highlight the advantage of blockchain providing verified information. This level of transparency, including for example working conditions and worker data relating to age, gender and payment, could help to reduce the risk of exploitation. The founder of 1TrueID argues "*thanks to the blockchain, 1TrueID allows companies to monitor their products in real time throughout the supply chain, guaranteeing their traceability "* Similarly, the co-founder of Retraced highlights *"One of the key advantages of blockchain is the inability to remove data. A brand cannot for example request that data relating to child labour can be removed. They are however able to request that they leave the platform*". The system is therefore not fool proof but as the founder of PaperTale explains, it provides a solution that ensures '*Every step has to be verified'.* For example, Retraced digitally tracks the supply chain by collecting documents that prove different transactions via digital signatures and time stamps. The co-founder explains "*We also digitally track suppliers. We collect documents that prove different transactions. Which is very relevant for our US brands that work with us to ensure that the cotton they purchase does not come from certain regions in China. So they need to have the document trail of all transactions."*

Insights are also provided regarding the challenges of collecting and sharing sensitive data such as worker information. One example is collecting worker data. For their proof-of-concept range, PaperTale discovered that not all workers had their own smartphone and therefore developed a kiosk in the factory to enable workers to verify their salary payments. Until PaperTale work with an external factory they are also unsure how willing they will be to share salary information. They decided to publish confirmation that the workers were paid above the minimum wage. The founder explained that the ability to do this and encrypt the actual figure was seen to "*calm the industry down*" adding "*Nobody knows what the salary is. It is above the law that is what matters*". In contrast, Retraced have not provided this level of detail for end customers of the larger brands that they are working with due to the large amount of people involved in the garment production stage. Concerns were also expressed regarding emotionalising the product and falling victim to potential greenwashing.

4.2.2 Impact on Profit

It is evident from the findings that blockchain technology can lead to economic benefits for both brands and suppliers. Firstly, suppliers can benefit from improved efficiency. Initially, PaperTale was going to market their concept to brands. However, they were surprised at the level of interest from factories. The founder explains that "*no one is paying for sustainability but the demands are more and more so the factory sees* [blockchain as] *a way out of that*". Similarly, Retraced believe the real user of their platform is the suppliers as they input the data. The co-founder argues "*As long as I make my solution from a perspective of a brand I will never be able to on-board the suppliers, because they will see this as an additional effort. It is important to understand and get the perspectives of the suppliers to see what their issues are when it comes to compliance of sustainability management. And if you can solve their issue then they will input the data willingly, they will be incentivised".* The platform is therefore not built from a brand perspective, although they may pay [for accessing the platform], the supplier enters the data and it therefore has to be an attractive proposition for them. The Retraced co-founder therefore claims that the platform is "*a promising business case for suppliers*". By uploading information to a platform and connecting complex supply chains, this eliminates the need to provide information to individual parties. The co- founder clarifies "*We normally put it this way, if a company's suppliers are based on our platform and if* *you upload your profile once every eight weeks which takes about a few minutes, that means all the suppliers will access your updates information and will leave you alone. This is a business case because regardless they need to provide all these data to each individual supplier multiple times*." This is referred to as "*network synergy*" resulting in improved efficiency and reducing the amount of communication required via email and telephone, when a new document is required across the supply chain. The internal transparency that Retraced is able to achieve therefore makes supply chain data collection more efficient and effective, benefiting both suppliers and brands. The Retraced co-founder states "*The major issue is that brands do not have access to supply chain data and the reason behind this is the lack of resources, time and money for data collection. Retraced provide a 'step by step approach'. They allow companies to gain an overview of their supply chain, establish where there are compliance gaps and risks and then identify what needs to be addressed".* Although PaperTale argue that their product is not supposed to replace certificates, they believe that they will provide a solution that will eliminate some the current work that is carried out by brands internally and their over reliance on reports. The following quote from the founder underlines this "*We are a threat to* [brand's] *sustainability departments* […] *If there is no disease no documents are needed.* […] *Sustainability departments are surviving on reports*"

It is also evident that blockchain technology helps to create a new value proposition for suppliers. The PaperTale founder claims "*the biggest reason they* [factories] *are seeing* [the PaperTale app] *as their marketing and PR- this is something that is directly going to the consumer and factories are normally at the backstage".* For example, Cotton Australia are listed on the product journey for the proof of concept t-shirts and are therefore becoming a visible entity. He adds *"They* [factories] *see this* [Papertale] *as something they can use to raise the price* [...] *It is a different approach than* *certificates because certificates put more pressure on them and then in the end they lose money.* Similarly, there is also the opportunity for suppliers to capitalise from their use of the Retraced platform. Retraced are currently running a pilot project with a supplier in Pakistan to differentiate themselves by using traceability to add value, enabling them to sell their product at a higher price to brands. Attention was however drawn to the implications that transparency can have on tax issues which would directly impact profit. The co-founder of Retraced explains. "*This also has implications on rule of origin for tax calculation. We have been contacted by tax advisers in the context of tax fraud. Often the suppliers have a number branches in a number of countries doing different steps and are vertically integrated where there seems to be revenue and profit shift.*"

From a brand perspective, both PaperTale and 1TrueID highlighted the benefit of their product for also gaining access to consumer data (in addition to improving sustainability goals). PaperTale is still deciding how best to commercialise their technology. The financial model is also a challenge with regards to who pays for their product. PaperTale would like to charge per unit (i.e. garment) with the premise that the brand could charge more for a transparent product and gain from increased customer engagement. There is also potential to further capitalise on the ability to interact with customers through the app and with consent, access consumer behaviour. The founder argues "*The value here is 2 ways, data collection from the supply chain is very big value for brands, you can know your impact, comply with legislation, show proof e.g. no modern slavery. From consumer side* [there is] *even more valuable data- you are able to see consumer behaviour, plan better collections." S*imilarly, 1TrueID draw attention to the commercial benefit from a brand perspective. In fact, out of the three case companies, 1TrueID have explored this area the most. The founder argues "*greater transparency of information also brings benefits in terms of communication and branding: in fact, 1TrueID allows you to create* *strong engagement between customers and brands*". One of the main advantages for the brands is related "*not only to statistical information regarding the interactions between the consumer and his products, but also to the history of purchases made by customers and create a customer profile card to facilitate future sales*". There is therefore the option to digitally schedule reorders due to access to individual customer purchase history data. Another benefit is adding value through customisation. The founder gives the example of their technology being used to support the specialised production of a collection of haute couture shirts. This enabled them to offer "*an innovative service to customers that would allow them to introduce them to the individual stages of the manufacturing of their shirt and to be able to customize their garment".* Additionally, 1TrueID place emphasis on the security advantages that their product is able to offer. The founder highlights "*In order to prevent counterfeiting of products and prevent their sale on unofficial markets / channels, the solution also allows you to verify the authenticity of the items".* This therefore has economic benefits for both the brand and the customer.

4.2.3 Challenges

The findings reveal that all case companies have encountered challenges at different stages of their journey and some of these remain ongoing. One of the main obstacles is improving understanding and awareness of blockchain. The co-founder of Retraced argues "*We need to create sufficient awareness* [of blockchain] *and make the market and industry ready, educate the consumers to demand more, educate the governments to request more and make the overall standards higher".* The case companies highlighted the adaptability from brands as a current key limitation. It is apparent that this is for a number of reasons. The PaperTale founder claims "*To create a new workable concept is a big challenge. Technology has not been an issue, lack of awareness is".* He also argues that brands are "*worried or sceptical*", *"reluctant for this level of transparency*" and have a "*lack of understanding of the technology"* adding *"blockchain technology is not easy to grasp".* Similarly, the founder of 1TrueID adds "*The biggest challenge is that, as soon as a brand understands that this is a feasible solution, they should also understand that it is not free of charge. But it costs a lot in terms of not only of money, but of resources it needs to dedicate to traceability, to smart contracts to all the aspects that are involved in order to have trustable data in the blockchain. So, most of the projects are standing in the line because we made a pilot or a capsule, but when we have to scale to the entire supply chain of the brand, this type of solution is complex, it is not simple."* Similarly, the co-founder of Retraced refers to the '*digitalisation backlog'* in the industry adding that "*As long as the digital foundation is not set along the supply chain, there is no way we can scale and utilise the potential of this* [blockchain] *technology"*. To achieve this, all entities within the supply chain need to participate (farmers, suppliers, brands, certifiers etc.). Currently, it is for example difficult to request that a farmer hosts their own blockchain node due to lack of access to technology.

Despite blockchain capabilities providing verified information. The findings highlight the risk of tampering of data. Including certifiers in the network would help minimise this risk. For example, Global Organic Textile Standard (GOTS) or testing laboratories could verify organic cotton with a digital signature. The Retraced co-founder acknowledges that *"there will always be a way to trick the system, but all we need to do is to make it expensive enough to not make it worth doing".* This is achieved by including multiple confirmation and verification stages along the supply chain. He clarifies "*If you provide wrong information and it has a digital signature with it, there will be a backlash down the line if the cotton is tested and found out that it is not organic".* It is therefore too costly and risky to do this, but there are still limitations in the technology. The Retraced co-founder gives the example of identifying child labour in the supply chain

"Unless we have cameras installed in every corner there will not be a way to monitor this". Additionally, auditors can be bribed and certificates can be bought. *"This is a perfect example that the blockchain by itself is not the solution, it is just a way to move towards the right direction and right idea of working in the supply chain and how things should work."*

Retraced also highlights the challenge relating to ensuring brands can leave their platform. Data is stored using an ID number which relates to the different companies within the supply chain. As the blockchain cannot be deleted, the connection has to therefore be cut between the company name and ID. The co-founder explains "*We need to make sure the brands can properly off board from our platform otherwise we are breaking all the confidentiality regulation in the world* [...] *this is one of the biggest limitation of using blockchain to its full potential because the regulatory landscape is a barrier".*

4.2.4 Integration with other Technologies

All three case companies highlighted the importance of integration with other technologies. This is underlined in the following quote from the founder of 1TrueID "*Blockchain without other technologies is nothing, nothing else than a ledger. So, blockchain needs other technology, it's a must because without it's inconsistent".* The case companies' blockchain solutions are based on the integration of different technologies such as QR Codes, Rain technology, Near Field Communication (NFC) and Bluetooth low energy (Btle). These integrate with Enterprise Resource Planning (ERP) systems. All three companies are using NFC smart tags that can be attached to garments and scanned to access supply chain data. There is also potential to capitalise on other technologies to make these more sustainable. For example, the PaperTale proof of concept collection used a plastic NFC tag. They are now in the process of developing 3D printed tags from recycled plastic from the North Sea, manufactured locally in Sweden.

The case companies also discuss exploring industry 4.0 technologies to help improve their systems. One such example is the use of smart contracts. Retraced is designed in a way to collect data from many platforms and systems around the world. They are currently exploring ways to use smart contracts and working with farmers in Pakistan, to see how they can digitalise their input data via the Retraced business app. The co-founder refers to this as '*a real digital interaction'* between the two parties. They could then build a smart contract enabling a payment transaction to be automatically paid through the system, as soon as the receipt of the cotton is confirmed. The co-founder explains "*We could trace the physical goods moving downwards within the supply chain and the money moving upwards. We could monitor the amount of money flowing in the supply chain and verify that there has been fair payment of goods and eliminating the risk of not being paid*".

Another opportunity is to connect to manufacturing machines to collect data such as water consumption, chemical consumption, emission rates and waste within each stage of the supply chain. This is however expensive and it is argued there is not yet the business case for this depth of information and tracing. The Retraced co-founder stresses "*Right now we are trying to avoid any hardware in the supply chain at all cost. It is not scalable. We are looking for a solution that is expandable as fast as possible. From an impact perspective but also from economic perspective."*

Integration with other technology is also identified as a means overcoming some of the challenges encountered. For example, as identified in the previous sub section, there are challenges with verifying the certificates uploaded onto the Retraced platform. A future ambition is therefore connecting platforms as this eliminates the need for data entry duplication. There is also the potential for artificial intelligence (AI) to be used to check and verify certification. The Retraced co-founder however argues that there is resistance from the certification organisations "*It is very difficult to convince them that we are not going to digitalise their business away and replace their organisation, in fact the data is going to be used to everybody's advantage within the supply chain*". There are however some certifiers that are willing to be part of the platform but the founder claims "*technically they are not there yet, their systems are not designed to be digitally integrated and share data*".

5. Discussion

This section aims to synthesise the research findings and extends the existing literature by presenting four theoretically informed propositions. As the prevalence and interests of firms in adopting blockchain technology increases, in this study we attempt to shed further light on the TBL implications of blockchain technology, with a particular focus on the fashion industry. We believe that blockchain, as an emerging and novel technology, is creating new business and financial opportunities for supply chain networks. Despite efforts in recent years to investigate the impacts of blockchain on supply chain sustainability (Kouhizadeh et al. 2020; Saberi et al 2019; Esmaeilian et al. 2019; Kouhizadeh et al. 2021; Gurtu and Johny 2019), further contributions are required to provide practical insights to support the theoretical body of current literature. Our findings show that the adoption and implementation of blockchain technologies in the fashion industry can enhance the companies' performance with respect to the three pillars of the TBL, as the case companies are on the positive trajectory towards improving sustainability.

First, we consider the impacts on the firms' profitability. Evidence from three in-depth case studies indicate that the "profit" dimension of TBL can materialise in a number of ways. It can improve the efficiency of the operations by reducing the repetitive administrative tasks with respect to updating certifications and audit data. For instance, by uploading information to a platform and connecting complex supply chains, this can eliminate the need to provide information to each company separately. Also referred as "*network synergy*", it results in improved efficiency and reduction in the amount of communication required via email and telephone to monitor the supply chain. In addition, by including intermediaries (such as certifiers), the efficiency of time-consuming auditing can be improved and costs can be lowered as blockchain can eliminate manual operations thus reducing the need for additional staff and time (Gurtu and Johny, 2019). The results show that blockchain also improves the efficiency by driving down the transaction costs by using digital signatures, time stamps and smart contracts which enable an automatic payment transaction through the system as soon as the receipt of the product is confirmed. This supports the works of Lumineau et al. (2021) which used the Transaction Cost Theory to highlight that blockchain technology can reduce costs. Blockchain therefore facilitates transparent, real-time, and verified information exchange amongst transacting parties, reducing transaction costs associated with monitoring suppliers and simplifies dispute resolution. Further supporting the findings of Bai and Sarkis, (2020), our results also show that transparency and information sharing technologies can be utilised to improve competitiveness. For example, suppliers and brands can use blockchain as a marketing tool to promote their sustainability credentials and differentiate their product from the competition. This new value proposition was most prevalent for suppliers.

Consistent with NRBV, evidence also shows that blockchain can impact the social and environmental aspects of TBL in multiple ways (McDougall, et al. 2019). All three case studies have shown that their blockchain solutions are consumer oriented with a priority of addressing their social and environmental concerns whilst educating customers and allowing them to assess the impact of the product that they purchase. As a result, blcokchain may help promote sustainable consumption and help to empower consumers with information to help inform their purchasing decisions. The cases have shown how blockchain is able to provide visibility of the working conditions for the people who manufacture products, ensuring that workers' rights are respected whilst bringing the human aspect to the consumer. In addition, storytelling (i.e. communicating the product journey) can improve the relationship between the customer and the brand. These findings are in contradiction with the study in the fashion industry by Choi and Luo (2019) that asserts blockchain can improve social welfare but lead to a reduction in supply chain profit. Moreover, our analysis partially rejects the following assertion by Saberi et al. (2019) "*Blockchain technology in the supply chain will more effectively manage economic and environmental (ecological) sustainability rather than social sustainability in the supply chain.*" Our findings have shown that Blockchain has the potential to help improve social sustainability through improved supply chain transparency and the ability to verify fair payment and working conditions. The technology can then be used to communicate this information to the end consumer.

In terms of environmental sustainability, the contribution of blockchain to the "planet" dimension of TBL has been well explored in the literature (Kouhizadeh et al. 2020; Saberi et al 2019; Esmaeilian et al. 2019; Kouhizadeh et al. 2021). Manupati et al (2020) asserts that blockchain approaches within a multi-echelon supply chain in the fashion industry can minimise both total costs and carbon emissions. Our results also indicate that companies' environmental related performance can be improved through increased transparency (carbon footprint, chemicals used), visibility, smart contracts, and distributed relationships. This is further supported by McDougall et al. (2019) who have highlighted the importance of improving environmental performance to remain competitive. The above discussion leads to the first group of research propositions centred on TBL performance:

Proposition 1: The adoption and implementation of blockchain technologies improves companies triple bottom line performances in the fashion industry.

> **Proposition 1a**: The adoption of blockchain technology impacts the "Profit" aspect of triple bottom line indirectly through reducing the operations cost (e.g. by improving efficiency and reducing repetitive tasks such as uploading certifications) and enhances competitiveness by offering a differentiation opportunity through the promotion of sustainability credentials.

> **Proposition 1b**: The adoption of blockchain technology impacts the "People" aspect of triple bottom line through providing transparency on labour conditions and offers the ability to verify fair payment and working conditions.

> **Proposition 1c:** The adoption of blockchain technology impacts the "Planet" aspect of the triple bottom line through providing transparency and certification on information relating to the carbon footprint, water and chemical usage.

Whilst the above discussion expands on the contribution of blockchain on TBL, there still remains some challenges that companies encounter when adopting this technology. Our findings provide empirical evidence to support the barriers proposed by Saberi et al. (2019). In particular, the findings provide evidence of interorganisational barriers amongst supply chain partners and technical barriers. For example, integrating sustainable practices amongst supply chain partners and an unwillingness to disclose information has previously been identified as an issue. However, our findings found adaptability from brands rather than suppliers as a limitation. Suppliers were willing to share information due to the value propositions highlighted above. There is however still an overall lack of industry awareness about the technology and its abilities. Further, this is a disruptive technology that challenges the status quo, not only through making all supply chain partners visible but by changing current practices e.g. current monitoring practices for achieving sustainability. Our study also highlighted the reluctance of some certifiers to share data. As the experience and knowledge of blockchain is growing, there is also a realisation of the technical challenges. For example, the integration of new and legacy supply chain systems (Bai and Sarkis, 2020). Our findings also identify the digitalisation backlog in the industry, impacting both the scalability of blockchain technology and the ability to use it to its full potential. This leads us to propose the following:

Proposition 2: The digitalisation backlog, lack of industry awareness and immutability are the key barriers for the adoption and implementation of blockchain technology in the fashion industry impacting scaleability wihtin the supply chain and brand adoption.

One way to facilitate the ongoing endeavour to leverage blockchains in the supply chain (Saberi et al. 2019) is by highlighting the value proposition of this technology within the supply chain. However, similar to Kouhizadeh et al. (2020), we also believe that industrial regulations for blockchain incentivisation is needed to drive the adoption and implementation penetration of blockchain technology. The findings for example highlighted the role that governments can play in improving sustainability standards. We also identified that for successful adoption and implementation of blockchain technology within the supply chain, all parties need to be encouraged by an incentivisation mechanism. Examining the incentivisation of blockchain technology adoption in the supply chain was identified by Cole et al. (2019), as one of the key themes for future research into blockchain technology. Our findings further support the works of

Esmaeilian et al. (2020) in their study of designing incentive mechanisms and tokenisation to promote consumer green behaviour. In this study we have also shown that the companies can obtain buy-in across the supply chain by highlighting the value proposition (speed and efficiency and TBL performance improvement). Additionally, as highlighted in the previous sub section, which has considered the impact on profit, both brands and suppliers can capitalise on the new value proposition, using improved transparency to differentiate themselves from competition, potentially through rising prices and accessing customer information. Our findings therefore demonstrate how the start-up case companies are encouraging suppliers and fashion brands to adopt the use of blockchain technology This leads us to propose the following:

Proposition 3: The barriers to adoption and implementation of blockchain technology are overcome if the value propositions are highlighted for different parties in the supply chain as an incentivisation mechanism and this helps to improve their competitiveness.

Finally, our study has highlighted the importance of integration with other technologies. The litereature has identified this as one of the technical challenges/barriers that hinders full adoption of blcokchain technology (Cole et al. 2019). Our research provides empirical insights on the integration of blockchain technology with other technologies by providing examples such as integration with ERP, the use of smart contracts, 3D printing and AI. The use of other technologies supports the blockchain infrastructure. For example the internet of things can facilitate information sharing while RFID and NFC tags helps track the physical movement of raw materials/garments. The case firms identified integration with other technologies as a means to overcome some of the challenges encountered (e.g. facilitating information sharing amongst all supply chain parties). This has not been discussed at length in the literature and the case companies are only benginning to explore the potential to further innovate, as their businesses grow.

However, from their development to date, there is already evidence that from a TBL perspective, integration with other technologies can have an impact on people, planet and profit. This leads us to the final proposition :

Proposition 4 The integration of other technologies complements blockchain adoption and implementation (e.g. by facilitating information sharing and tracking the physical movement of raw materials) and acts as a contributor towards achieving Triple Bottom Line targets whilst overcoming associated challenges.

Drawing together the four propositions, we now present an empirically informed framework, Figure 2, to illustrate the relationship between adoption and implemetation of blockchain technology and improvement in TBL performance. The framework also suggests that companies can integrate other industry 4.0 technologies to complement the adoption and implementation of blockchain in the fashion industry, which can ultimately contribute to improving sustainability performance.

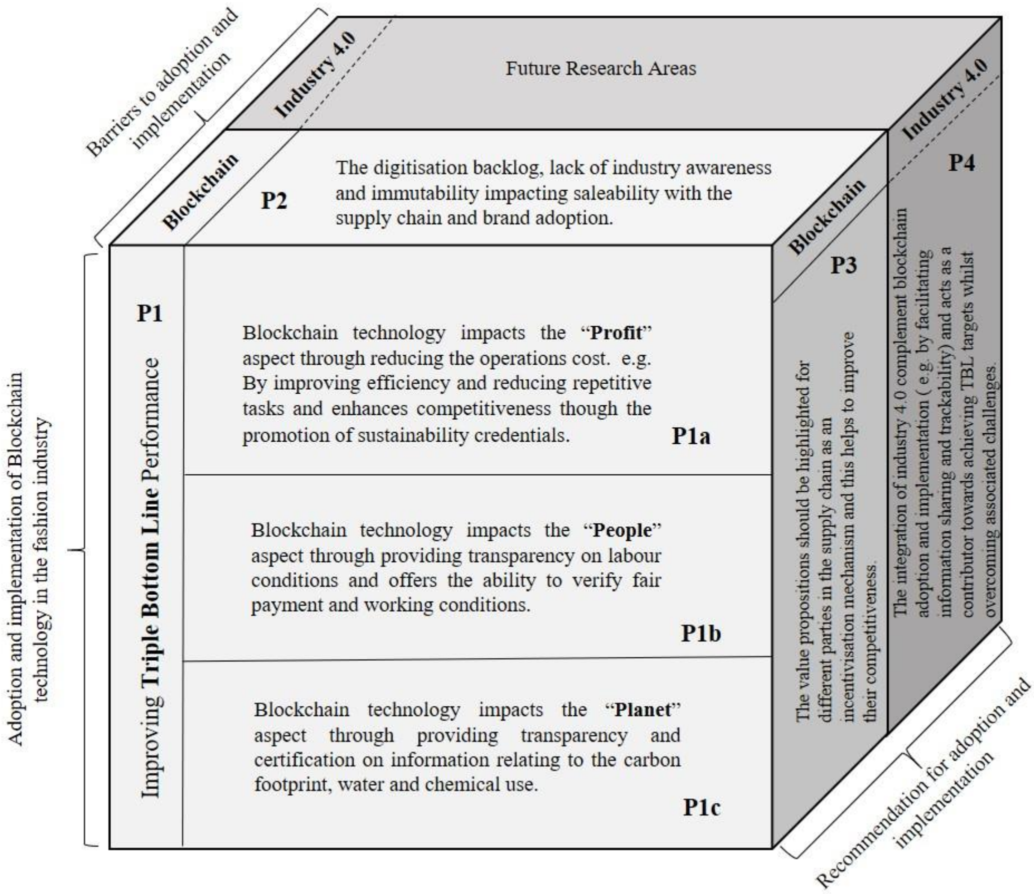

Figure 2, Research propositions and future research areas framework

6. Conclusion

This research addresses an important gap in the literature by empirically investigating how to improve operational efficiency and effectiveness through blockchain applications and whether it is possible to apply this within the global fashion industry. The immature state of the OSCM literature means that there is an opportunity for this research to help shape its adoption. The following subsections outline the theoretical contribution and managerial implications. This is followed by research limitations and suggestions for future research.

6.1 Theoretical contribution

The findings highlight blockchain capabilities and demonstrate how the start-up case companies are encouraging fashion brands to adopt the use of blockchain technology, including the operational improvements and limitations arising from this. he case companies have shown that the use of blockchain technology is a strong enabler of sustainability in fashion supply chains, since it increases traceability and transparency. Through blockchain technology, the case studies have improved supply chain monitoring, information sharing and enabled final customers to become more knowledgeable about the real impact that their clothes have on the environment and the workers involved during production. Thus, consistent with NRBV, the findings suggest that blockchain technology supports the implementation of both social and environmental sustainability. From an economic perspective, the study has shown that blockchain technology can improve efficiency and reduce costs (as explained by transaction cost economics (TCE).. We have also highlighted its potential to develop new value propositions through improving sustainability performance to increase prices and gain competitive advantage. Our findings highlight the importance of the integration of blockchain with other digital technology solution providers, major players in the fashion industry and, more importantly, amongst all the different actors in the supply network. It is however important to recognise that blockchain technology by itself is not the solution, but it facilitates transparency and traceability. It’s success is dependent on a willingness to share the right data and this therefore takes effort and dedication throughout the supply chain rather than being seen as a solution to fix for all sustainability issues.

6.2 Managerial Implications

This paper will be of benefit to different stakeholders particularly those in the fashion indsutry, aiding the improvement of sustainability through the implementaiton of blockchain technology. As this research focuses on the early adoption of blockchain technology within the fashion industry, it provides practical insights and highlights opportunities into its capabilities and how it can be used to improve transparency and sustainability. The findings are of benefit to multiple stakeholders including but not limited to blockchain technology firms (i.e. the case firms in this study), brands, multi-tier suppliers and other related parties such as auditors and certifiers. The research also has implications for managers in other sectors, who may be similarly considering blockchain application, particularly those operating in complex multi-tier supply chains. Additionally, the research has policy implications by highlighting the role governments can play in supporting blockchain implementation and improving sustainability standards.

The research highlights how blockchain technology can improve transparency and traceability for all parties involved. Evidence provided from the case firms provides an overview of some of the solutions available either through the use of smartphone applications or in the case of Retraced, a sustainability management platform. These improve transparency and traceability providing for example, product journey information, carbon footprint and worker data. The findings highlight improvements in efficiency, removing duplication and reducing costs. There is also focus on the ability to use blockchain to communicate and educate the end customer through storytelling. Further, this can facilitate relationship building and facilitate access to valuable customer data.

The benefit for supply chain entities is achieved by creating new value propositions allowing both brands and suppliers to capitalise on improved sustainability through translating this into higher prices and differentiation from competitors. There is therefore an opportunity to change the business model, benefiting for all those involved. Through incentivisation, parties can better understand blockchain's capabilities. It can for example replace legacy systems and old working practices reliant on monitoring and duplication of data, to better manage compliance. However, to fully reach its potential all parties need to participate. For example, the benefit of incorporating auditors and certifiers has been highlighted e.g. reducing data duplication and minimising risk. However, challenges were also identified as some of these organisations are either reluctant due to concerns that their services will no longer be required or their systems are not currently compatible to share data. Cooperation amongst supply chain partners is therefore encouraged.

6.3 Research limitations and future research directions

The research focuses on the fashion industry and is from the perspective of the technology providers. Although this provides a unique perspective, as they are the starting point of blockchain implementation in supply chains, future research could include different stakeholders. As blockchain implementaiton in the fashion industry is sitll in its infancy, very few brands and suppliers have started to adopt its use. The study could therefore be extended to brands and suppliers as they start to adopt blockchain tehcnology. Longitudianl studies. could follow this journey and further understand how blockchain impacts the TBL and the associated challenges encountered along the way. This would also facilitate research into integration with other technologies. As more companies adopt blockchain technology there will also be the opportunity to further investigate whether it promotes sustainable production and consumption. Finally, the four propositions presented could be verified through larger scale studies to further understand blockchain capabilities.

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Appendix

Interview Protocol

General- company/product background

1. Introduction, company background (size, number of employees, sector), business model and how it operates.
2. Funding and starting story (motivation).
3. Different features of the business including sustainability (what kind of data is being recorded in blockchain) and who is responsible for capturing the data?
4. Overview of product – function and verified information available.
5. What are the biggest challenges that the company has faced (from initial idea to date)?
6. Collaboration along the supply chain – how important is this to implement blockchain technology effectively?
7. Future plans.

Operational

1. Type of blockchain used. Public vs private.

2. What capabilities of blockchain do you use (smart contracts, traceability, tracking, security for transaction, transparency, auditability)
3. What other technologies are required to facilitate the implementation of your technology (interoperability how easy is it to integrate with other technologies out there).
4. Challenges of implementation/scale up (data availability).

Ssupplier/retailer/ customer adoption

1. Current engagement with suppliers and retailers – how many have adopted use of product and future plans.
2. What are the challenges of convincing suppliers/ retailers/ customers to use your service (main barriers for wider adoption).

Product Demo

1. Overview of functionality
2. Information captured and shared