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RISKS AND OPPORTUNITIES FOR SUPPLY CHAIN FINANCE USING BLOCKCHAIN TECHNOLOGY

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LOYISO KULA, NELLY NATH, HERGEN FRERICHS, VIVEK NAIR

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ACADEMIC DIRECTOR: PROF. MICHAEL L. PINEDO, CAPSTONE DIRECTOR: PROF. RICHARD M. LEVICH, CAPSTONE ADVISOR: PROF. WENQIANG XIAO

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1. Executive Summary

Supply chains all over the world primarily consist of small and medium-sized enterprises (SMEs) located in developing countries. These companies often do not obtain working capital financing as they are located in deeper tiers of supply chains, and their creditworthiness cannot be established. Supply chain finance (SCF) as an instrument of working capital finance does not rely on the supplier's, but on the core enterprise's creditworthiness. Yet, even a digitalized SCF model is usually limited to tier-1 suppliers.

Blockchain technology (BCT) belongs to the key transformative technologies of the fourth industrial revolution, and may provide an infrastructure for secure and efficient transactions in decentralized, and potentially, global networks with a large number of participants. BCT seems to be predestined to mitigate high risks in SCF.

The literature review on BCT applications in SCF reveals a research gap regarding the absence of a systematic and integrated risk assessment. This is the first study, which applies an ISO 31000 conformant risk management framework to assess the risks of a BCT application in SCF based on a business scenario involving a multi-tier supply chain with many SMEs in developing countries, and applying a consortium blockchain.

There are two main results of the study. First, BCT enables the full exploitation of deep-tier financing in SCF. BCT together with smart contracts, Internet of Things (IoT), and cryptocurrency effectively reduces SCF risks by providing an abundance of high-quality information on the blockchain. Second, there is a tradeoff between reducing SCF and BCT risks, depending on the speed of BCT implementation. BCT is still at an early stage of technological development resulting in high BCT risks. These risks need to be mitigated, for example, by limiting the scope of implementation at the beginning, and increasing it only as BCT risks go down over time. The faster BCT is implemented, the more SCF risks can be reduced, and the more BCT risks need to be accepted. Further research regarding the relative riskiness of SCF and BCT risks is necessary to identify the optimal tradeoff.

In the future, BCT is likely to become the backbone of supply chains and SCF relationships. BCT even has the potential to function as a risk mitigant for weak political and economic institutions in developing countries. Our advice to market players is to steadily participate in this developing market with investments that increase with the market's degree of maturity.

2. Introduction, Research Methodology and Literature Review

In the past decade, globalization has spurred massive growth in global trade. Today it is so much easier to exchange information across countries. People are learning and adapting across cultures, cuisines, products, lifestyles, etc. In addition, technological advancements have reached the corners of the world, making it easier for companies to expand globally and offer their products and services to capture potential new markets.

With the massive increase in global trade, investors have an opportunity to invest in the global trade finance gap. According to Asian Development Bank's Trade Finance Gaps, Growth, and Jobs Survey, the global trade finance gap, which is the difference between requests and approvals for trade finance transactions, reached $1.7 trillion in 2020 (Kim et al., 2021, p. 1). The pandemic caused economic and financial uncertainty leading to devastating consequences for global trade. In addition, the survey states that small and medium-sized enterprises (SMEs) suffered heavily as the spread of COVID-19 dried up trade finance, accounting for 40% of rejections in applications (idem). Although the Supply Chain Finance (SCF) mechanism has been in use for a while, during the pandemic, its adoption grew significantly as suppliers could leverage buyer's credit to get account receivables financed in less than 15 days. The need for working capital and liquidity drove the increased adoption of SCF. However, this business model is characterized by inefficient processes and a low level of trust and transparency that has led to increased risk exposure, costs and a lack of financing options for SMEs, especially in multi-tier supply chains. In a study by Surya et al. (2021), the importance of the combination of economic growth and innovation in technology in addressing inefficiencies in the market, in order to increase productivity in organizations, is stressed.

The 4th industrial revolution has been touted as the key to unlocking value in business through technological innovation. Boston Consulting Group lists nine key technologies driving the 4th industrial revolution: "big data and analytics, autonomous robots and vehicles; additive manufacturing, simulation, augmented and virtual reality, horizontal/vertical system integration, the Internet of Things (IoT), cloud, fog, and edge technologies, blockchain and cyber-security" (Rosa et al., 2020, p. 1662, citing Rüßmann et al., 2015). They state that "the integration of these technologies within an industrial context can enable a set of important improvements in competitiveness" (idem). And further to that, John Moavenzadeh, management committee member of the World Economic Forum, presented survey results in a keynote address at the DHL Global Engineering & Manufacturing Summit 2015 that showed

92% of banking and capital markets strategy officers agreed that distributed ledger technology would form the foundation of financial architecture by 2030 (Moavenzadeh, 2015, p. 6). One of the fastest growing types of distributed ledger technology is blockchain technology (BCT). In our study, we will specifically focus on BCT, a "shared decentralized, cryptographically secured, and immutable digital ledger" (Arun, Cuomo and Gaur, 2019, ch. 1) that promises to make possible a paradigm shift in SCF.

Our main research question is: What are the risks and opportunities for SCF using BCT? For the remainder of this chapter, we will unpack the research methodology applied to address this question, and we will present research papers, which define the SCF and BCT ecosystems. In Chapter 3, we break down the SCF ecosystem further, so we can understand the inefficiencies, which are increasing risk exposure, and look at areas where there are opportunities to resolve the risks. In Chapter 4, we explore the features of BCT in the context of SCF, and in Chapter 5, we develop a risk management framework, and study the potential risks in the new technology when applied in the SCF ecosystem. In Chapter 6, we present our conclusions.

2.1 Research Methodology

Our study combines the analysis of existing research with our own expert risk assessment using a standard risk management framework. We apply the international risk management standard ISO 31000 (International Organization for Standardization, 2018) as a risk management framework to analyze the interaction of SCF and BCT risks. To our knowledge, this is the first research paper with an integrated risk assessment of SCF using BCT.

Arun, Cuomo and Gaur (2019, fig. 7.6) develop a generic blockchain model risk framework for the business context that takes the perspective of the network / ecosystem, which we deem to be more appropriate for a management context than for an integrated risk assessment. Matsuo and Sakimura (2021) argue in favor of a holistic management of overall security of blockchain systems that encompasses all technology and security layers, their interconnections, and also interfaces with the outside world (idem, p. 97ff), which is in line with our approach of an integrated risk assessment.

2.2 Literature Review

2.2.1 Supply Chain Finance

Bryant and Camerinelli (2014) define SCF as "the use of financial instruments, practices and technologies to optimise the management of the working capital and liquidity tied up in supply chain processes for collaborating business partners." (idem, p. 5) For the purposes of our paper, we will focus on reverse factoring as the main product of SCF. Bryant and Camerinelli (2014) describe reverse factoring as follows: "Reverse Factoring … allows a Supplier to receive a discounted payment of an invoice or account payable due to be paid by a Buyer. The Buyer approves the invoice for payment and separately finance is raised against the payable by the Supplier from a bank or other finance provider, who relies on the creditworthiness of the Buyer without recourse to the Supplier. The Buyer pays at the normal (or an agreed) invoice due date, although the Supplier has received a discounted payment through the financing facility." (idem, p. 48). Camerinelli (2014), also focused on reverse factoring in his study on the business case for SCF, stating that it is the most popular financial instrument under SCF (idem, p. 7). Bickers (2021) quantifies the volume of SCF at $1.31 trillion in 2020 globally, this certainly confirms the importance of managing risk exposure in this industry to ensure scale and growth. Camerinelli (2014) studies SCF in-depth and the potential opportunities in it, clarifying the different components that will lead to the success of the ecosystem. McKinsey (2015) also studies the commercial opportunities presented by SCF and conducts research with suppliers and buyers to understand where there is scope for improvement of the inefficiencies of SCF. SCF risks for various SCF products are listed in GSCFF (2016). They are closely related to supplier risks discussed in Kara and Firat (2018).

2.2.2 Blockchain Technology

Omran et al. (2017) describe BCT as a disruptive solution which has the power to eliminate financial flow inefficiencies. They compare its ability to make financial transactions more secure, transparent and efficient to the introduction and growth of the internet. Arun, Cuomo and Gaur (2019) study the commercial impact of BCT on a few business models and the opportunities that are presented by BCT beyond Bitcoin. Gupta (2018) states that BCT can potentially transform business through four key features, namely shared ledger, permissions, smart contracts, and consensus (idem, p. 15). Matsuo and Sakimura (2021) acknowledge the benefits of BCT, but also caution us against the accelerated growth of blockchain whilst the technology has not yet reached the level of maturity, which will enable it to replace the current

traditional centralized business structure of data (idem, p. vi). They further state that although the technology seems redundant and hard to scale, it has great potential for permissionless innovation (idem). Staples et al. (2017) have noted other advantages provided by BCT such as integrity and non-repudiation, but cautioned that the technology had limitations for confidentiality, privacy and scalability (idem, p. i). They conclude that the BCT is continuously evolving and further research into the technology will lead to improvements in some of its unknown risks (idem). Pournader et al. (2020) review the literature on BCT in supply chains, transport and logistics published in 2016-2018, primarily in the US and China. While they see the industry at an early stage of development, and acknowledge a certain hype surrounding BCT, they have a positive outlook. For Kramer (2020) one of the main benefits of BCT in supply chains is data integrity which can mitigate compliance risk. Blockchain technology can solve some of the more persistent problems in supply chain management, which typically stem from lack of visibility into product origination, and movement. Key aspects of BCT in supply chains are transparency, validation, automation, and tokenization (idem). World Economic Forum (2022a, 2022b) and ISACA, AICPA and CIMA (2021) provide exhaustive lists of BCT risks.

2.2.3 Supply Chain Finance Using Blockchain Technology

Academic research focuses on the potential role of BCT in mitigating risks in SCF in Asia, with a focus on how the technology can enable participation by SMEs in the economy. Li et al (2020), Yao and Qin (2021), Chen at al (2020) and Du et al (2020) study the existing risks in the current SCF process and propose different BCT frameworks to address these risks. Li et al (2020) propose a conceptual framework for a blockchain-driven SCF platform while Yao and Qin (2021), Chen at al (2020) and Du et al (2020) present case studies of the implementation of BCT in the procurement divisions of large organizations. All of the above authors recognise different vulnerabilities in the SCF ecosystem and observe the impact of BCT in mitigating identified risks, but only Li et al. (2020) try to give a full account of BCT risks. Using a very different approach, a fuzzy cognitive map, Xie and Li (2021) conclude that BCT system risks are the biggest risks of BCT-driven SCF. Hofmann, Strewe and Bosia (2018) identify possible opportunities that could be realized from applying BCT to SCF solutions, specifically approved payables financing. In their study, they take the gaps and inefficiencies identified in SCF and then define a potential blockchain-driven SCF model. Du et al. (2018) investigate the implementation of BCT in a case study at a Chinese conglomerate, identify BCT-specific success factors, and make suggestions how to overcome implementation constraints. Panuparb

(2019) performs a cost-benefit analysis of a BCT-based SCF solution. He shows potential efficiency gains from BCT, but does not at all analyze BCT risk. Further research is reviewed in Liu (2021).

To summarize this introductory chapter, there is a big trade finance gap that particularly affects SMEs in multi-tier supply chains. SCF with its reliance on the buyer's creditworthiness is an attempt to close this gap, but has not been successful so far to provide finance to SMEs in deeper tiers because of a lack of supply chain transparency. BCT as one of the transformative technologies of our time has the potential to serve as a powerful risk mitigant that enables SCF to provide finance across the entire supply chain. There has been a significant growth in research on SCF, BCT, and the interaction of SCF and BCT in recent years. Yet, the review of the literature reveals a research gap that consists of the absence of an integrated risk assessment of both supply chain finance and blockchain technology risk. Our research contributes to closing this research gap. We apply the internationally acknowledged ISO 31000 standard to systematically assess risks of SCF using BCT.

3. Overview of Supply Chain Finance

SCF, with its main product reverse factoring, is a technology solution that allows a financial institution to finance invoices at a discount for suppliers in exchange for short-term net payment credits. SCF is typically applied to open account (O/A) trade terms, whereby the supplier delivers goods before the payment is completed. It contrasts with trade finance, where the supplier usually expects prepayment for the goods before delivery. In trade finance, buyers and suppliers require funding to address the trade cycle funding gap; therefore, both work with their banks in silos. To mitigate the risk, the buyer's bank provides a letter-of-credit (LC) to the supplier's bank upon presenting a bill of lading document as proof of shipment.

SCF bridges the gap between the supplier's needs, who generally wants to get paid early, and the buyer, who typically wants enough time to settle for maintaining a healthy cash flow. SCF is a buyer-led arrangement to optimize working capital and liquidity in supply chain transactions. It is structured with three parties - a buyer, a supplier, and a bank that plays an intermediary role. Bank offers short-term credit to the supplier based on the buyer's creditworthiness, which the buyer pays off later on the due date. SCF is a great financial solution for SMEs as they often struggle with working capital. Solving working capital pressure for SMEs has been a key concern in academics and industrial circles. The high cost of financing

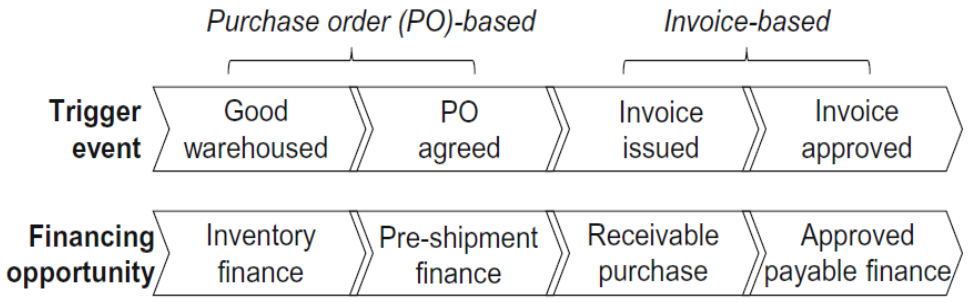
for SMEs is challenging and leads to supplier instability negatively affecting the overall supply chain.

From an investment aspect, SCF opportunities include inventory financing, purchase order financing, receivables financing, and approved payables financing. Besides working capital management, the global shift to open account trade and SME liquidity needs is driving the demand for approved payables financing. There is a big opportunity in SCF, but lack of standardization, compliance, risk of fraud, cost of KYC, and accounting treatment have become barriers to adoption at scale. Moreover, especially with global trade, there are more challenges like assessing third-party risk, geopolitical risk, business continuity, supply chain visibility, disruption risk, etc. Therefore, it is important to build a sustainable SCF solution with technology that provides transparency and allows data exchange between all parties involved.

3.1 Opportunities in Supply Chain Finance

SCF opportunities are available at various stages in the supply chain events. Figure 1 gives a good example of SCF triggered events and corresponding financing opportunities.

Figure 1: SCF Opportunities



Source: Hofmann, Strewe and Bosia (2018), p. 16, adapted from Bryant and Camerinelli (2014), p. 136

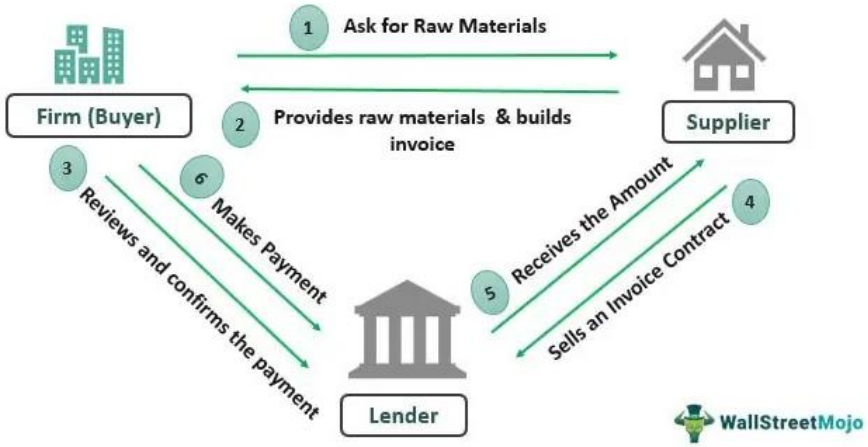
Figure 2 gives an overview of SCF financing types. Approved payable financing is the most widely accepted financing instrument based on our literature review. Reverse factoring belongs to the product category of approved payable financing (Hofmann, Strewe and Bosia, 2018, p. 17f). Figure 3 explains supply chain interactions in reverse factoring. In this paper, the scope of risk assessment and mitigation measures are limited to account payable financing.

Figure 2: SCF Financing Types

Inventory Finance	Pre-Shipment Finance	Receivable Purchase	Approved Payable Finance
It is a form of credit that sellers can avail by pledging their existing inventory as a collateral. A purchase order may (as assumed in Figure 1) or may not exist.	Pre-shipment financing is available to sellers when they receive a purchase order from a buyer. The financing includes raw materials, wages, packing, and other costs associated with the seller's working capital.	Using receivable purchases, sellers get immediate payment for receivables relating to a single or multiple buyers by selling them to their bank. To reduce the risk of pooled receivables, the bank may require insurance from the seller.	In approved payable financing, the seller qualifies to get financing for account receivables as soon as the buyer approves the invoice. Here, the buyer assumes the risk and the bank pays the seller based on the buyer's creditworthiness.

Source: Own figure

Figure 3: Supply Chain Interactions in Reverse Factoring



Source: Thakur and Vaidya (2022)

3.2 Supply Chain Finance Risk Profile

Big organizations and cash-strapped suppliers may benefit from SCF, but the model is exposed to many risks. Transparency and reliability are the major concerns. In addition, the international nature of trade makes it more difficult to manage risks. The key SCF risks are outlined below:

- ***Deep-tier financing risk:*** This is the risk that only Tier-1 suppliers obtain financing, and companies in deeper tiers do not obtain financing, because transparency in deeper tiers is perceived as low, and costs of information as high.

- ***Performance and dilution risk:*** Performance risk is the risk that a supplier is not able to meet its obligations under a contract (deliver goods of agreed quality in agreed time frames). Dilution risk is the risk a receivable is reduced in value (e.g. due to returns, credit notes, commercial disputes) except due to the supplier's default. (GSCFF, 2016, pp. 79, 86). Fraud risk is not included in this risk type.
- ***Double financing risk:*** This is the risk that a supplier fraudulently uses receivables more than once to obtain financing. We collect under this header any kind of fraud risk that is caused by forging, or misusing documents (like invoices, warehouse receipts, etc.). (GSCFF, 2016, p. 80) In the literature, the term transaction authenticity risk is also used to describe this risk type (Li et al., 2020).
- ***Sleeping risk:*** This is the risk where supply chain finance helps that bank loans look like trade credit in a borrower's balance sheet. This is a risk from poor disclosure that obscures a company's underlying health, and results in mispricing of risk and misallocation of capital. In times of a crisis, banks withdraw their funding faster, and in a more concentrated manner than dispersed trade creditors would. (Wass, 2020)
- ***KYC/AML risk:*** This is the risk of not adequately following regulations and laws to thoroughly identify a customer, and to identify money laundering activities. This risk causes financial institutions to refrain from lending to SMEs in developing countries.
- ***Supply chain disruption risk:*** This is the risk of disruption of larger parts of or the entire supply chain due to events at one supplier, or due to external events (port/transportation delays, natural disaster, geopolitical problems, trade route disruption etc.).
- ***Operational risk:*** This is the risk of failure of systems, processes, and people in face of the high complexity of supply chain networks and associated financing relationships.
- ***Credit risk:*** This is the risk that the borrower is not willing or able to repay a loan due to a lack of company liquidity or company capital. This risk type excludes risk from fraudulent activities. In SCF, a bank's credit decisions are usually based on a credit risk assessment of the core enterprise that guarantees any loans to suppliers. Credit risk of the suppliers indirectly forms part of the credit risk of the core enterprise. Mou, Wong and McAleer (2019) empirically investigate core enterprise, and Du et al. (2019) supplier credit risk.

3.3 Risk Mitigation Using Digitalization of Supply Chain Finance

Integration of supply chain actors and financial institutions by leveraging the power of data and technology can speed up part of the supply chain movements. It can improve processes to

help manage costs, comply with new regulatory requirements, set pricing strategies, and maintain resiliency in the overall supply chain. E-invoicing is the most well-known form of digital data exchange which automates manual processes, reduces errors, speeds up financing approvals and captures early payment discounts. Real-time cash flow forecasting software accurately predicts future flows for supporting better decision making and helping buyers plan for cash surpluses and funding gaps. New innovations from e-procurement to e-invoicing and data-driven decision making, are enabling actors in the supply chain to work together and exchange information and money in a way that was not previously possible. This can help reduce some risks and speed up the overall process, but an efficient, low-risk SCF solution requires traceability in supply chain movements, effective collaboration and data sharing (transparency) between the parties involved.

3.4 Interview with Taulia

During this research, we conducted an interview with Andy Lee, Director, Distribution – North America and the Asia Pacific at Taulia, LLC. Taulia is a leading working capital management Fintech company headquartered in San Francisco, California. In April 2020, Taulia partnered with J.P. Morgan to extend financing solutions to their clients and recently, in March 2022, SAP acquired Taulia.

Based on the interview, we discovered that Taulia's main products revolve around e-invoicing (i.e., taking paper invoices and making them electronic), dynamic discounting (allowing buyers to take advantage of costs of goods sold (COGS) reduction via paying early their vendors for a decent discount), SCF (using 3rd party money i.e., banks or other liquidity providers to pay suppliers early) as well as account receivables and inventory finance. Taulia's artificial intelligence (AI) powered platform transforms a paper invoice into a digital invoice once the supplier uploads the receipt. It reduces the risk of human error and possible delays. Taulia gets a credit line from partner banks or investors to pay suppliers early for an early payment option. According to Andy, *"Knowing the buyers on Taulia's platform, lenders are comfortable in giving credit lines for SCF. It's for Taulia to decide where to use these funds. In this arrangement, early payment is made when the buyer approves the invoice, and the buyer owns the risk of payment. Example: For Novartis, Taulia can pay Novartis suppliers, and agreement is made between Taulia and Novartis to cover for the assets. So, Novartis takes the responsibility for payments made by Taulia."*

According to Andy, Taulia is strong in SAP ERP systems, but they are also evaluating blockchain and other technologies. He mentioned one of the issues with current SCF is that big banks focus on top-tier suppliers based on creditworthiness and where return on capital is higher. That is one main reason for SMEs to go to a Fintech. He also mentioned that the SCF model has inherited risks such as double payment risk. A legal problem in the US is that SCF is treated as an asset type transfer, since the lender buys the receivable from a supplier. The asset cannot be certified if it has been bought by someone else, and if it is certified, it is a legal issue. BCT is particularly helpful in maintaining authenticity as data is immutable. Taulia is also looking at blockchain to develop multi-tier/deep-tier financing solutions.

4. Prospects of Blockchain Technology in Supply Chain Finance

After having shown opportunities and risks in SCF, this chapter is dedicated to prospects of BCT in SCF. The chapter starts with the presentation of key features of BCT in a business setting that significantly differs from the Bitcoin cryptocurrency setting. Then, the risk profile of BCT will be analyzed, again with a focus on a business setting. Finally, applications of BCT in SCF will be discussed. At the end of the chapter, conclusions will be drawn that prepare for the following risk assessment.

4.1 Key Features of Blockchain Application in Business Setting

BCT provides a "shared, decentralized, cryptographically secured, and immutable digital ledger" (Arun, Cuomo and Gaur, 2019, ch. 1) "that facilitates the process of recording transactions and tracking assets in a … network" and that addresses "the need for an efficient, cost-effective, reliable and secure system" (Gupta, 2018, p. 3). Transactions cover digital assets as well as financial, and physical assets. BCT has the potential to alleviate market frictions in the form of information, interaction, and innovation frictions (idem, p. 22). There is a natural fit of BCT and SCF as both are network-based.

Bitcoin is the most famous BCT implementation that has shown that a fully digitalized network with anonymous participants can function on a global scale without centralized oversight and without transaction intermediaries. Yet, Matsuo and Sakimura (2021) confirm that Bitcoin and BCT are not equivalent. The success of Bitcoin is also due to other design characteristics (idem, pp. 20, 40). According to Gupta (2018), some key design characteristics of Bitcoin are public access, full transparency of transactions, anonymity of participants, and a special consensus mechanism, and immutability.

In business networks (e.g. supply chain networks), public access and full transparency of the complete database lead to network inefficiencies, risk of cyberattacks, and risk of information loss to competitors, the media, and other players. Full anonymity is generally not desirable for business, and not possible for legal, and regulatory reasons (Arun, Cuomo and Gaur, 2019, ch. 1). The Bitcoin consensus mechanism is tailored to homogeneous transactions and decentralization of transaction validation. The transaction throughput is low, and energy consumption is high (Matsuo and Sakimura, 2021, pp. 59f, 64). In a business network, transactions are heterogeneous and numerous. Not every network participant is able to perform a validation. A consensus mechanism with trusted parties, a higher throughput and less energy consumption is required (Arun, Cuomo and Gaur, 2019, ch. 1). Immutability is less efficient in a business context as transaction errors are more common.

Additional considerations in a business context are the use of smart contracts, the interface between blockchain and the physical world, and network ownership and control. Smart contracts are digital contracts that are automatically executed based on the fulfillment of predefined conditions without any human intervention. The use of smart contracts presupposes the legal validity of transactions on the blockchain. An intelligent design of smart contracts can significantly increase the efficiency of a business network. The interface between blockchain and the physical world is important as digital representations of physical assets on the blockchain (like their quality, and their location) need to be correct. The same is true for off-chain financial flows, i.e. financial flows that are not performed using a cryptocurrency. Network ownership and control needs to be answered both from a business and a legal perspective. The choice of business model has a big influence on the governance of the network, and on the incentives and benefits for network participants (cf. four business models for blockchain networks in Arun, Cuomo and Gaur, 2019, Fig. 4.2).

BCT business applications are commonly designed as permissioned blockchains (Gupta, 2018, pp. 10, 15). This means that access to the BCT network is restricted, that not all transaction details can be seen by all network participants, and that there is no anonymity. There is the possibility of granting special permissions, e.g. for auditors or regulators (idem, p. 10). Other BCT characteristics like decentralization, single source of truth, use of cryptography and immutability stay in place. The consensus mechanism needs to be agreed on in view of the particular circumstances (Gupta, 2018, p. 17). Matsuo and Sakimura (2021) recommend that a

private blockchain with a trusted third party can be more efficient than with a Bitcoin-like consensus mechanism (idem, pp. 56, 107).

Pournader et al. (2020) cluster the BCT in supply chains around the key terms technology (interface of blockchain with physical world, IoT), trust (strengthening security of data flows and IoT data), trade (a.o. transfer of funds within a network), and traceability / transparency (questions regarding inventory movements) (idem, p. 2067). According to them, the particular value of BCT lies in the prevention of data and transaction fraud thanks to continuous validation. Smart contracts increase speed and transparency of transactions. Transparency and traceability alleviate dispute resolution, regulatory compliance, sustainability, and supply chain risk management (idem, p. 2065). Cryptocurrencies allow P2P instant money transfers at a global level (idem, p. 2075).

The discussion in this section has shown that the optimal set-up of a BCT application for a business network is a permissioned blockchain, whose specific design needs to be tailored to the specific application. BCT applications in supply chain networks provide particular benefits and have a positive outlook (Pournader et al., 2020). Yet, BCT comes with its own risks that need to be weighed against the benefits.

4.2 Risk Profile of Blockchain Application in Business Setting

BCT is a risky emerging technology. While the Bitcoin implementation has proven its viability since its going live in 2009, this holds particularly true for new BCT implementations in a business setting. World Economic Forum (2022a) provides a risk identification checklist for both public and permissioned blockchains with five categories, 18 subcategories, and 70 risk-related questions:

- Technology risks refer to performance, security, integration, and data privacy.
- Strategic risks are paramount as blockchain still is a young technology that affects the very way of doing business (network view rather than individual company view). They are categorized into value proposition and incentive model, brand and reputational, and change management..
- Financial risks refer to the funding and the benefit model, to network-internal controls in the absence of intermediaries, to accounting and financial reporting, and to the protection of consortium intellectual property.

- Legal and regulatory risks are present with respect to cross-jurisdictional regulations, legal conflicts between consortium parties, antitrust, and AML and KYC.
- Operational risks refer to governance and control, auditability, and all issues around ownership of assets on a blockchain (associated with anonymity, immutability, interoperability, etc.).

World Economic Forum (2022b) furthermore ranks blockchain security risks: 1) Decentralization, 2) Confidentiality, 3) Endpoints, 4) Availability, 5) Nodes, and 6) Smart contracts. It regards decentralization in BCT networks as the biggest security risk as it contradicts the centralized approach of traditional security governance. Availability risk is the only risk that is larger in a permissioned than in a public setting as the number of validating nodes is smaller, and as there is an entity responsible for access control.

ISACA, AICPA and CIMA (2021) provide an exhaustive list of information risk items in permissioned blockchains: 1) Governance; 2) Infrastructure; 3) Data; 4) Key Management; and 5) Smart Contracts. There are 38 subcategories with 125 items. This list can be seen as complementary to World Economic Forum (2022a) providing more detail on the technology risk in permissioned blockchains.

The Internet of Things (IoT) may be a solution for risks at the interface of blockchain and the physical world (e.g. when implementing blockchain in supply chain applications). The idea is that events in the physical world are automatically and securely identified by IoT sensors and reported to the blockchain, where smart contracts are automatically executed in response to new information (Hofmann, Strewe & Bosia, 2018, p. 71). On the other hand, taking into account IoT adds a further risk dimension to the analysis. Iqbal et al. (2021) identify IoT security constraints based on hardware, software, and communication limitations, give an overview of IoT security risks, and state that IoT security is more challenging than conventional network security (idem, p. 173f). World Economic Forum (2020) states that IoT is more vulnerable to attack and harder to defend than traditional networks due to the very high number of interconnected IoT devices and networks, security vulnerabilities in edge devices like routers, and the lack of industry-wide security protocols. BCT risk assessments need to take into account IoT-technology risks.

For supply chain networks, Pournader et al. (2020) summarize the following limitations of BCT: constraints on transactional throughput, latency, and size; the need to integrate

blockchain systems with common data management systems; the immutability that makes it difficult to correct data errors; the potential loss of private keys; and high implementation costs. (idem, p. 2073) They see smart contracts as a high-risk choice necessitating external validation by intermediaries in real-world applications (idem, p. 2064).

There is a large body of literature on BCT risks. Any analysis of the benefits of using BCT to mitigate risks in SCF needs to take BCT risks into account. If the mitigation effect of BCT on SCF risks is larger than new BCT risks, there is a business case for BCT in SCF. In the next section, specific applications of BCT in SCF are presented and analyzed.

4.3 Blockchain Application in Supply Chain Finance

In this section, past research on BCT applications in SCF will be assessed with respect to the questions, which SCF risks are presented, which BCT configurations are used to mitigate these risks, which BCT risks are presented, and what is the overall risk assessment.

Li et al. (2020), Yao and Qin (2021), Chen et al. (2020), and Du et al. (2020) discuss similar approaches to the application of BCT in SCF. The authors largely agree on risks in the traditional SCF setup, employ similar implementations of BCT to mitigate these risks, and come to similar conclusions. They differ in the extent of discussing BCT risks. None of them performs an overall risk assessment of applying BCT in SCF.

Li et al. (2020) identifies as SCF risks: transaction authenticity risk, deep-tier financing risk, and operational risks (leading to high risk control costs). Yao and Qin (2021) specify that operational risk is particularly borne by the core enterprise that might not sufficiently manage its supplier guarantees, and point out that there are risks of disputes over ownership of goods, and of collusion between core enterprise and suppliers. They add payback risk, i.e. arising from the fact that the financial institution is unable to directly monitor the collection of accounts receivable, and emergency / contingency risk regarding the entire supply chain. Chen et al. (2020) stress fraud risks from incorrect and forged documents. Du et al. (2020) indicate the information asymmetry between core enterprise and other supply chain (SC) participants, and point out that SCF risks arise from the short history of the business in China, and from the lack of a sound credit trading system in China.

In all four papers, a consortium blockchain / alliance chain is implemented. A consortium blockchain / alliance chain is a permissioned blockchain, in which the consensus mechanism

is controlled by a few SC participants (core enterprise, financial institution, third-party logistics company, regulatory agency). The upstream and downstream SC participants that actually obtain finance are granted access to the blockchain, but do not participate in validating new information. (Li et al., 2020). Chen et al. (2020) mention that query permission can be public or limited to particular participants.

As a consensus mechanism, Du et al. (2020) apply Byzantine Fault Tolerance, Chen et al. (2020) Practical Byzantine Fault Tolerance, and Li et al. (2020) Redundant Byzantine Fault Tolerance. Yao and Qin (2021) apply Proof of Authority. All of these are tailored to permissioned blockchain settings, and are much more energy-efficient than Bitcoin's Proof of Work. The consortium blockchain is characterized by high processing speed. Du et al. (2020) report a throughput of >1000 transactions per second with a confirmation delay of four seconds. Smart contracts are or can be used for financial transactions. IoT is or can be used to monitor characteristics and flow of physical goods. (Li et al., 2020)

The core enterprise generally acts as guarantor for loans to SC participants. The financial institution extends loans and for this purpose checks the authenticity and reputation of the borrower by analyzing past trading records, real-time order status, and real-time inventory information stored on the blockchain. The logistics company warehouses pledged goods, and keeps respective information up-to-date on the blockchain. A regulatory agency might perform an additional vetting of borrowers. (Li et al., 2020) The BCT platform can be seen as custodian of cash, information, and goods flow (Chen et al., 2020).

The four authors generally agree on the scope of products: advance payment, purchase order, accounts receivable, and inventory / warehouse receipts pledge financing.

BCT mitigates SCF risks primarily because of the abundance of high-quality, immutable, cryptographically secured, real-time information on the blockchain regarding SC participants, financial, and goods flows (prospectively, including IoT-traceability) that is easily accessible to all authorized participants (transaction authenticity risk, fraud risk, risks from information asymmetry). Authorized parties can actually monitor one another. (Li et al., 2020, Du et al., 2020) This information covers the entire supply chain including deeper tiers allowing the split of trade receivables along the supply chain such that financing is made available to lower tiers (deep-tier financing risk) (Li et al., 2020). This information also allows the installation of early warning systems (Yao and Qin, 2021) (emergency / contingency risk). Operational risks are or

can be further reduced by smart contracts, and IoT (Chen et al., 2020). The participation of government regulatory authorities and insurance companies can further reduce risks and regulatory costs (Du et al., 2020).

Li et al. (2020) identifies the following BCT risks: low level of digitization, lagged infrastructure construction, insufficient relevant laws, lack of motivation of core enterprises to participate, security and legal issues of smart contracts, cost of financial institutions with various SCF blockchains, and authenticity of information before uploaded to the blockchain. Chen et al. (2020) identifies the risk that documents and physical goods legally do not match. Du et al. (2020) offer homomorphic encryption as a solution to the privacy risk that arises in a permissioned blockchain as identities of parties must not be encrypted, while confidential transaction data needs to be encrypted.

Chen et al. (2020) and Du et al. (2020) report on the successful business implementation of their respective blockchains. Chen et al. (2020) use the commercial BCT application Xuper (https://xuper.baidu.com) in the Chinese auto retail industry. Ye, Liao and Luo (2020) report on Tencent's "We Chain" as another business implementation of an alliance chain targeting micro enterprises in supply chains. Special characteristics of "We Chain" are that it views itself as an open platform, that the platform acts as funding provider and that funding sources include an Asset Backed Security platform.

Du et al. (2018) investigate the implementation of a BCT in a case study at a Chinese conglomerate with 400 subsidiaries and 15,000 suppliers that concerns the introduction of an automated blockchain-based transactions system and a direct payments wallet system between the core enterprise, subsidiaries, and suppliers, which in a next step allowed small suppliers to obtain bank financing. The authors identify the following blockchain-specific success factors: 1) As for most people blockchain is equivalent to Bitcoin, a specific effort needs to be undertaken to educated all people concerned by about the specificities of the specific business implementation; 2) As blockchain is a new technology, unexpected implementation constraints need to be expected and mitigated; 3) Blockchain implementation requires a company culture of working with start-ups, an entrepreneurial spirit within the company, and a corporate strategy supportive of digital transformation. As to the need to overcome implementation constraints, the authors suggest to start with use cases that do not introduce big behavioral changes, and to advance incrementally. They recommend being careful with use cases with frequent transactions, as blockchain technology is less efficient at processing large amounts of

data than centralized databases, and to proceed in a sandbox mode to account for unknown risks.

Omran et al. (2018) analyze blockchain-driven SCF using reverse factoring and dynamic discounting as examples. They identify similar SCF risks as the preceding authors, and state that especially SMEs, particularly in deeper tiers, suffer from financing risk. BCT mitigates these risks by providing efficiency, transparency, and autonomy. The authors present additional thoughts not mentioned by preceding authors. Information on the blockchain not only allows the rating of the creditworthiness of formerly disregarded SMEs, but credit ratings can be dynamically adapted and automatically evaluated depending on the documented behavior of the SME on the blockchain. Furthermore creditworthiness can be made dependent on other vertical and horizontal attributes of the supply chain in addition to borrower attributes (e.g. customer orders within pull oriented supply chains). Overall, BCT may lead to a reduction of financial risks, and also to an improvement of overall supply chain performance. Besides banks, logistics companies may play an elevated role in the future making cross-functional offers (logistical and financial services). Omran et al. (2018) identify the following BCT risks that have not been mentioned by preceding authors. A performance risk is that in non-network configurations centralized IT-systems process data faster than blockchain systems. Therefore, full appreciation of BCT necessitates a paradigm shift towards a network view, which represents a strategic risk. Even in a network configuration, BCT is more applicable in "responsive and multi-echelon supply chains, where trustworthiness and availability of information as well as autonomy of decision-making processes results in higher cost savings" than in "stable supply chains with higher levels of vertical integration and focus on efficiency" (idem, p. 13f).

There are several papers that show how SCF risks can be successfully mitigated by BCT. Only Li et al. (2020) try to give a full account of BCT risks. We have not found any research where a full-scale risk assessment based on a risk management framework has been done. In the next section, we will carry out such a risk assessment.

5. Risk Assessment of Blockchain Application in Supply Chain Finance

A risk management framework conforming with ISO 31000 is developed (section 5.1), and applied to assess the risks of a BCT application in SCF. The risk assessment is an expert assessment based on the business scenario that is described in section 5.2. The risk assessment

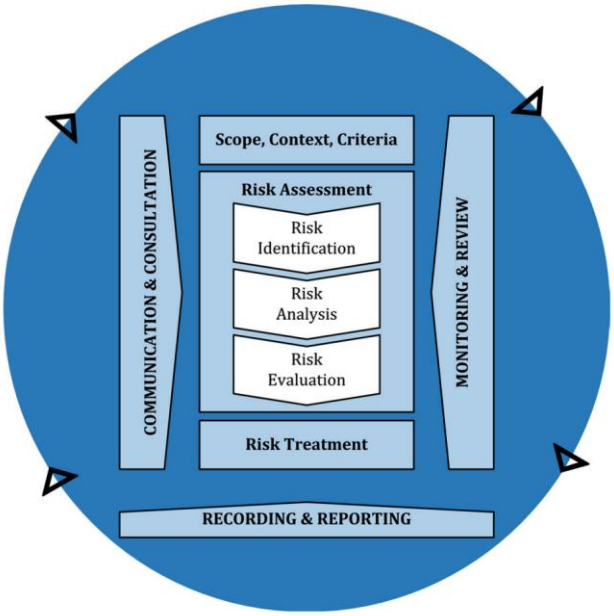
starts with the evaluation of risks in SCF without taking into account a BCT application (section 5.3). It continues with the evaluation of the BCT application before and after applying mitigating actions (section 5.4). It concludes with the evaluation of SCF with the BCT application (section 5.5). All details of the risk assessment can be found in the Risk Register (Appendix-1).

5.1 Risk Management Framework

The industry and academia utilize many risk management frameworks and approaches for risk management. The International Organization for Standardization (ISO) has developed the international risk management standard ISO 31000, which organizations widely use to manage their risks (ISO, 2018). ISO 31000 can be customized to any organization and is not industry- or sector-specific. This paper utilizes risk management principles, process, and framework of ISO 31000 to understand SCF risks and develop the SCF risk profile. The risk management framework will also facilitate developing an updated risk profile after implementing BCT in SCF, considering all the new risks that come with implementing BCT.

Figure 4 illustrates the ISO 31000 risk management process. In this study, the process phases "Scope, Context, Criteria", "Risk Assessment", and "Risk Treatment" are applied.

Figure 4: ISO 31000 Risk Management Process



Source: International Organization for Standardization (2018), p. V

As per ISO 31000, the scope of all risk management activities needs to take account of organizational objectives, and the risk criteria are defined based on these objectives (idem, p. 10). In SCF using BCT, we differentiate between the following types of organizations: the core enterprise ("Buyer"), upstream and downstream SC participants ("Supplier"), financial institutions ("Financer"), and a Fintech ("Fintech") providing the BCT platform. All organizations follow their own profit maximization objectives, and share the objective of maximizing the supply chain's success. The risk assessment is organized by the risk register template shown in Figure 5.

Figure 5: Risk Register Template

Risk Title	Risk Likelihood	Risk Impact							
		Operational		Financial		Legal & regulatory		Reputation	
		Scale	Score	Scale	Score	Scale	Score	Scale	Score
Risk-1	H	H	9	M	6	L	3	NA	0
Risk-2									
Risk-3									

Source: Own figure

In the risk assessment, all SCF and BCT risks are identified by reviewing the respective literature, analyzed, and evaluated. A comprehensive understanding of SCF and BCT risks considers the underlying vulnerabilities, and the level of exposure or susceptibility to unforeseen external events by evaluating risks based on the likelihood of their occurrence and its impact on the business. Each identified risk is allocated to a risk likelihood category. Three risk levels (low, moderate, high) are available. Figure 6 shows the definitions for the three risk levels.

Figure 6: Risk Likelihood Definitions

Risk likelihood scale	Risk likelihood definition
High	Highly likely to occur (once a year)
Moderate	Fairly likely to occur (once in five years)
Low	Unlikely to occur (once in ten years)

Source: Own figure

Furthermore, identified risks are assessed with respect to four risk impact categories that are derived from the organizations' objectives: operational, financial, legal and regulatory, and reputational. For each risk impact category, there are three risk levels (low, moderate, high).

For each identified risk, it is possible that a specific risk impact category does not apply. In that case, no assessment is done for that category. Figure 7 gives an overview of the definitions of the risk impact categories.

A probability score is assigned to the risk based on the likelihood of its occurrence. A score of three (3) is assigned to highly likely risk events, two (2) to moderately likely events, and one (1) to less likely events. Similarly, for risk impacts a score of three (3) is provided to events with high impact, two (2) for moderate impact, and one (1) for low impact events.

Figure 7: Risk Impact Category Definitions

Risk Impact categories	Risk Impact scale definition		
	Low	Moderate	High
Operational	Late or inconsistent delivery of business objectives. Minor disruption to ongoing operations.	Partial delivery of business objectives. Disruption to ongoing operations.	Non delivery of key business objectives. Threat to future business credibility. Loss of ability to continue ongoing operations.
Financial	Negligible revenue impact	Financial impact to the particular business line (additional cost, opportunity loss)	Financial impact that attracts the attention of the board and stakeholders / regulators
Legal & Regulatory	Minor regulatory or legal penalties / losses	Major regulatory or legal penalties / losses	Regulatory agencies seize control of assets or are granted absolute decision-making authority
Reputation	Reputation damage within region	National reputation damage	International reputation damage

Source: Own figure

The risk severity score is established as per the risk heat map provided in Figure 8, by multiplying probability and impact scores. Risk heat maps are generated for each risk impact category.

Figure 8: Risk Heat Map and Risk Severity Score Template

HEAT MAP		**Risk Impact**		
		L (1)	**M (2)**	**H (3)**
Risk Likelihood	**H (3)**	3	6	9
	M (2)	2	4	6
	L (1)	1	2	3

Source: Own figure

The risk profile is determined based on each risk impact category's total risk severity score. Figure 9 shows how risk profiles can be used to compare different risk scenarios. In this example, for each of the risk impact categories, the sum of risk severity scores for the SCF-scenario is compared with the sum of risk severity scores for the SCF with BCT-scenario. The change to the overall risk severity is examined and comprehended for further recommendation.

Figure 9: Risk Profile Template

Source: Own figure

In the following section, we set the context for the risk assessment by defining a business scenario.

5.2 Business Scenario for the Risk Assessment

The business scenario is designed to address a constellation, in which a BCT application in SCF is expected to provide the largest benefits compared with a digitalized centralized database solution. At the same time, this business scenario is expected to reveal the largest risks resulting from the size and complexity of the assumed supply chain.

The business scenario is a BCT application in SCF for a multi-tier inter-company supply chain with a large number of SMEs in developing countries as supply chain participants requiring finance ("Supplier"). This could either be a domestic supply chain in a large developing country like China, or an international supply chain with many Suppliers located in developing countries. The business scenario assumes a core enterprise ("Buyer") in the supply chain. While it is not important whether this core enterprise is located in a developed or in a developing country, it is assumed that it is a large company with a well-functioning organization, with effective systems, and processes. Finance is assumed to be provided by financial institutions

or capital markets ("Financer"). Again it is not important where these are located, but it is assumed that financial institutions are large companies with a well-functioning organization, with effective systems, and processes. Financial institutions are assumed to be well-diversified, such that financing the supply chain in question does not pose a concentration risk. The same holds for capital markets financing. The BCT application is provided by a Fintech company ("Fintech"), for which the development, implementation, and management of BCT applications represents a key activity. The Fintech works for a diversified portfolio of customers.

The stylized BCT application tailored to the use in SCF is characterized by the following:

- Restricted access: Only permitted parties obtain access. Access management is done by prespecified parties (e.g. core enterprise, platform manager). Access rights are layered trading off optimal role fulfillment, and protection of confidential information. In addition, encryption is used to protect confidential information.
- Decentralized with limited transparency: The complete database of transactions is distributed across the network. The blockchain is not fully transparent due to access right restrictions. Query rights need to be defined. Ownership of the database is not determined. The database is controlled by a prespecified consortium (e.g. core enterprise, financial institution, logistics company, regulator).
- No anonymity: All participants can be uniquely identified using cryptographic authentication procedures.
- Consensus: Transactions are validated by the prespecified consortium using proof of authority, practical byzantine fault tolerance, or another mechanism appropriate for consortium blockchains.
- Immutability: Both the state and the updating process of the blockchain are protected against fraudulent changes.
- Smart contracts, IoT-devices, and cryptocurrencies: Possible, but not obligatory.
- Technical performance: Is better than that of a public blockchain like Bitcoin, but worse than that of a centralized database application.

With this business scenario as the basis, expert ISO 31000 risk assessments of SCF with and without BCT are performed in the following sections.

5.3 Risk Assessment of Supply Chain Finance

The risk assessment starts with the evaluation of risks in SCF without taking into account a BCT (Appendix-1, sheet-1). For each of the SCF risks identified in chapter 3.2 the risk owner is determined, the risk likelihood is assessed, and the risk impact is scored.

Figure 10 shows the results of the High/Moderate/Low-(H/M/L)-scoring of the SCF risk assessment. The Buyer bears performance, operational, and supply chain disruption risks. The Supplier bears dilution, operational, and supply chain disruption risks. The Financer bears deep-tier financing, double financing, sleeping, KYC/AML, operational, and credit risk.

Figure 10: SCF Risk Assessment - H/M/L-Scoring - Pre Mitigation

SCF Risk Assessment - H/M/L Scoring							
Risk ID	Risk Title	Risk Owner	Risk Likelihood	Risk Impact			
				Operational	Financial	Legal &	Reputation
1	Deep-tier financing risk	Financer	H	H	H	H	M
2	Performance risk	Buyer	H	M	M		
3	Dilution risk	Supplier	H	H	H		H
4	Double financing risk	Financer	H		M	H	
5	Sleeping risk	Financer	H	H	H		M
6	KYC/AML risk	Financer	H	M	H	H	M
7	Supply chain disruption risk - Buyer	Buyer	M	H	H		
8	Supply chain disruption risk - Supplier	Supplier	M	H	H		
9	Operational risk - Supplier	Supplier	H	H	H		L
10	Operational risk - Buyer	Buyer	M	M	M	M	M
11	Operational risk - Financer	Financer	L	L	L		
12	Credit risk	Financer	L	M	M	M	M

Source: Own analysis. **Notes:** H = High, M = Moderate, L = Low

Of the twelve SCF-risks seven obtain a high risk, three a moderate, and two a low risk likelihood. High risk likelihoods for deep-tier financing, performance, dilution, double financing, and KYC/AML risks result from the fact that the Supplier is an SME located in a developing country. Sleeping risk obtains a high risk likelihood due to the difficulty of assessing the Buyer risk profile as account payables are not fully disclosed in the financial statements. Operational risk is high for Supplier (SME in developing country), moderate for Buyer (sophisticated large company), and low for Financer (sophisticated diversified large company). Supply chain disruption risk is moderate for both Buyer and Supplier as they are both hit equivalently, while the Financer is protected due to diversification. Credit risk has a low risk likelihood due to strict banking regulations.

Risk impacts range from no score to high scores with most scores in the financial and operational risk impact categories. Deep-tier financing risk shows high operational, financial, and legal and regulatory impacts, and moderate reputational impacts as there is inadequate data to assess the creditworthiness of deep-tier suppliers, and high fraud/compliance risk. In fact, risks are so high that Financers avoid this risk altogether. Dilution risk is characterized by high financial, operational, and reputational impacts as it hits the Supplier, i.e. an SME in a developing country with low liquidity and capital and whose international reputation is at stake. KYC/AML risk shows high financial and legal and regulatory, and moderate operational and reputational risk impacts as impacts are expected to be significant for Suppliers, i.e. SMEs in developing countries. Sleeping risk has high operational and financial, and moderate reputational impacts as a risk event poses an existential threat to the Buyer, which would lead to high losses at the Financer. Operational risks of the Supplier as well as supply chain disruption risks at the Buyer and at the Supplier have high operational and financial risk impacts as these can lead to existential threats to the companies. Double financing risk has a high legal and regulatory and a moderate financial risk impact assuming the Supplier is an SME from an emerging market. Credit risks have moderate impacts across all impact categories due to diversification and the existence of reserves. Similarly, moderate risk impacts are expected for operational risks at the Buyer (a well-organized large company). Operational risks at the Financer have low operational and financial impact due to strict regulations. More detailed risk descriptions, including causes and effects, and scoring justifications are given in Appendix-1, sheet-1.

Figure 11: SCF Risk Assessment - SCF Risk Heat Map - Pre Mitigation

SCF Risk Heat Map - Pre Mitigation

Operational		Risk Impact		
		L	M	H
Risk Likelihood	H	0	2	4
	M	0	1	2
	L	1	1	0

Financial		Risk Impact		
		L	M	H
Risk Likelihood	H	0	2	5
	M	0	1	2
	L	1	1	0

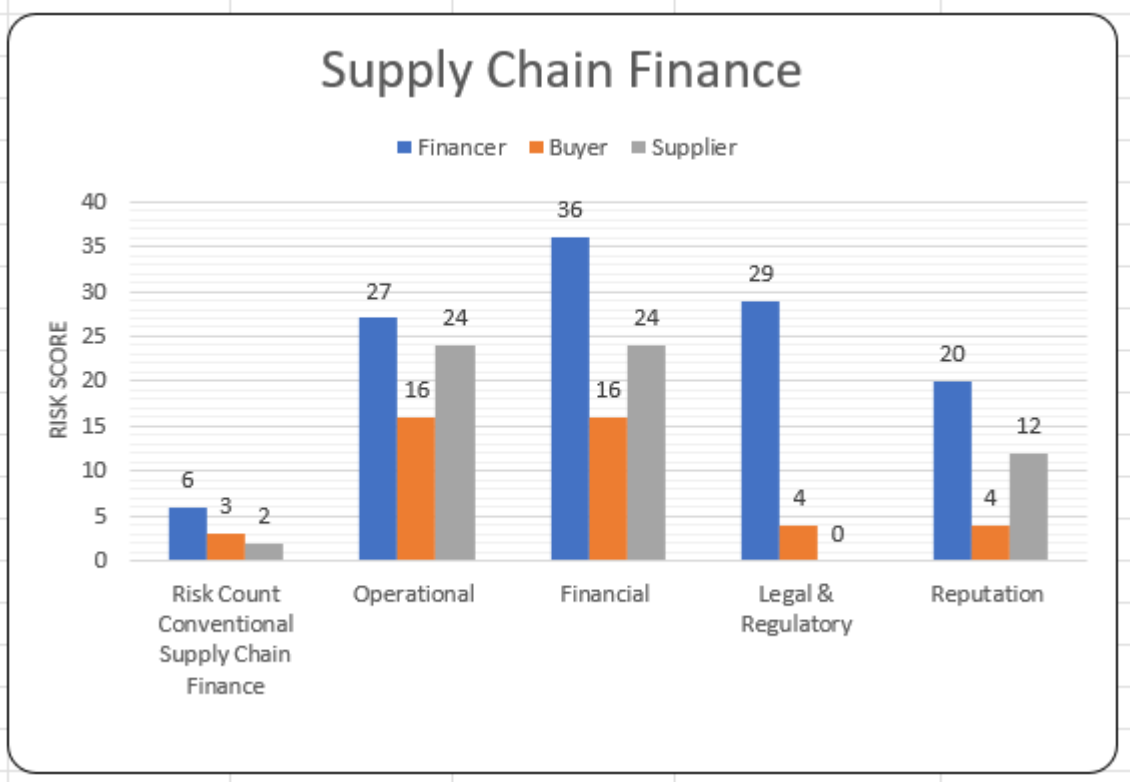
Legal & Regulatory		Risk Impact		
		L	M	H
Risk Likelihood	H	0	0	3
	M	0	1	0
	L	0	1	0

Reputation		Risk Impact		
		L	M	H
Risk Likelihood	H	1	3	1
	M	0	1	0
	L	0	1	0

Source: Own analysis. **Notes:** Risk Heat Map represents the number of risks at different significance levels (Red, Yellow & Green) for each risk impact category. H = High, M = Moderate, L = Low.

Figure 11 shows the H/M/L-scoring in the form of a risk heat map for each risk impact category. Entries in nine out of twelve red fields in the heat map indicate that SCF risks without mitigation can be regarded as high. Applying the risk multipliers given in Figure 8, risk severity scores add up to 76 for financial, 67 for operational, 36 for reputational, and 33 for legal and regulatory risk impacts. Figure 12 shows the distribution of risk severity scores by risk impact category and risk owner. Financers, buyers, and suppliers are subject to significant operational and financial risk impacts. The Financer has the highest risk exposure across categories, followed by the Supplier, and the Buyer. Legal and regulatory risk is particularly concentrated at the Financer.

Figure 12: SCF Risk Assessment - Risk Scores by Risk Owner - Pre Mitigation



Source: Own analysis

The conclusion of the SCF risk assessment before mitigation is that SCF is characterized by high risks concentrated in the financial and the operational risk impact categories and mostly exposing the Financer.

5.4 Risk Assessment of Blockchain Application

The risk assessment continues with the evaluation of the BCT application before and after applying mitigating actions (Appendix-1, sheet-2 and sheet-3 (Risk ID 13-20)). For the BCT

risks identified in chapter 4.3 an analogous expert risk assessment is performed as for the SCF risks in the preceding section. For the optimal fit with the business scenario, risks found in the literature were clustered into eight categories. The focus is on technology risk, which is divided into the dimensions general, security, smart contracts, and IoT. Furthermore, there is strategic risk, and finance-, legal-, and operations-related network risks.

Figure 13 shows the results of the H/M/L-scoring of the BCT risk assessment before mitigation actions. The Fintech bears the technology risks as no other party in the supply chain network has the necessary competence to manage this risk. The Buyer bears the strategic risk, and the finance-, legal-, and operations-related network risks as the core enterprise dominating the supply chain.

Figure 13: BCT Risk Assessment - H/M/L-Scoring - Pre Mitigation

BCT Risk Assessment - H/M/L Scoring							
Risk ID	Risk Title	Risk Owner	Risk Likelihood	Risk Impact			
				Operational	Financial	Legal & Regulatory	Reputation
13	Technology risk - General	Fintech	H	M	M	M	L
14	Technology risk - Security	Fintech	H	M	M	M	M
15	Technology risk - Smart Contracts	Fintech	H	M	M	M	L
16	Technology risk - IoT	Fintech	H	M	M	M	L
17	Strategic risk	Buyer	H	M	M	L	L
18	Finance-related network risk	Buyer	M	M	M	M	
19	Legal-related network risk	Buyer	H		M	M	M
20	Operations-related network risk	Buyer	M	M	L	M	

Source: Own analysis. **Notes:** H = High, M = Moderate, L = Low

Of the eight BCT-risks six obtain a high, and two a moderate risk likelihood. The risk likelihood for technology risk events is generally high due to the abundance of potential infrastructure, data, integration, and security issues. The cryptocurrency markets have shown that smart contracts have not become a robust technology so far. This is caused by their self-enforceability, which excludes any fault-tolerance. IoT-security risks are paramount due to the lack of industry-wide security protocols and the large number and large variety of devices that are difficult to protect cost-efficiently. The strategic risk likelihood is high, which already can be seen from the fact that the market has difficulties to get started. Stating the value proposition and effectively incentivising every Supplier poses a significant challenge. The legal risk likelihood is high due to the size of the supply chain with many Suppliers located in developing countries. Legal conflicts between Supplier and Buyer and within the consortium are likely because of unclear legal liability in a permissioned network.

Risk impacts range from no score to moderate scores with a predominance of moderate scores that are evenly distributed between the operational, financial, and legal and regulatory risk impact categories. Moderate reputational impacts are expected only for data security and legal events. Moderate risk impacts for both the Fintech and the Buyer are due to the fact that it is assumed that the BCT application is introduced to the entire supply chain at once. The consequence of that assumption is that any risk event can have an impact on the entire supply chain network. Impacts are not assessed as high as the Fintech is assumed to have sufficient diversification in its pool of customers, and as the BCT application does not affect production in the supply chain, but only financing. More detailed risk descriptions, including causes and effects, and scoring justifications are given in Appendix-1, sheet-2.

Figure 14 shows the H/M/L-scoring as a risk heat map for each risk impact category. Risks are concentrated in the red high likelihood / moderate risk impact-field indicating that BCT risks before mitigation can be regarded as high. It is noteworthy that there are less risks in red fields than in the SCF risk analysis done in the preceding section. Risk severity scores add up to 42 for financial, 41 for legal and regulatory, 38 for operational, and 24 for reputational risk impacts.

Figure 14: BCT Risk Assessment - BCT Risk Heat Map - Pre Mitigation

BCT Risk Heat Map - Pre Mitigation

Operational		Risk Impact		
		L	M	H
Risk Likelihood	H	0	5	0
	M	0	2	0
	L	0	0	0

Financial		Risk Impact		
		L	M	H
Risk Likelihood	H	0	6	0
	M	1	1	0
	L	0	0	0

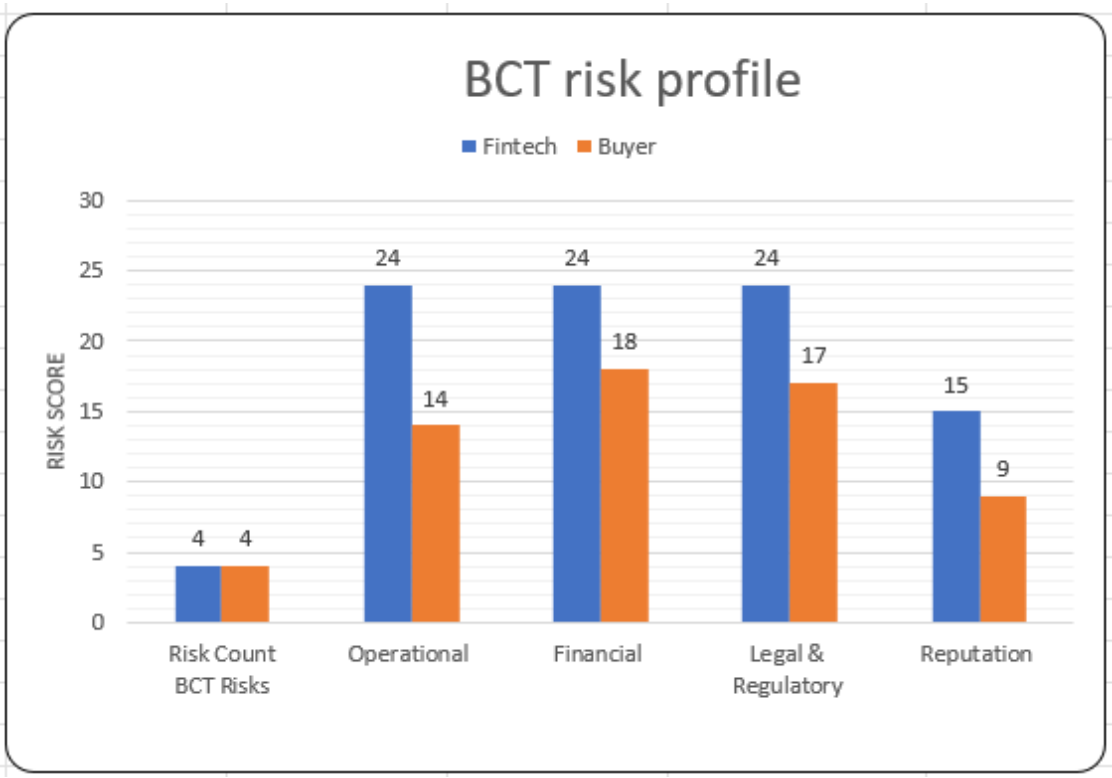
Legal & Regulatory		Risk Impact		
		L	M	H
Risk Likelihood	H	1	5	0
	M	0	2	0
	L	0	0	0

Reputation		Risk Impact		
		L	M	H
Risk Likelihood	H	4	2	0
	M	0	0	0
	L	0	0	0

Source: Own analysis. **Notes:** Risk Heat Map represents the number of risks at different significance levels (Red, Yellow & Green) for each risk impact category. H = High, M = Moderate, L = Low.

Figure 15 shows the distribution of risk severity scores by risk impact category and risk owner. BCT risk severity scores are generally higher for the Fintech than for the Buyer reflecting the predominance of technology risk in BCT.

Figure 15: BCT Risk Assessment - Risk Scores by Risk Owner - Pre Mitigation



Source: Own analysis

The conclusion of the BCT risk assessment before mitigation is that BCT is characterized by high risks spread out across the operational, financial, and legal and regulatory risk impact categories and exposing both the Fintech and the Buyer. As these high risks will not be hedged away by SCF risks, mitigation actions are considered with the goal to improve all risk severity scores to green. The following risk reduction measures are applied:

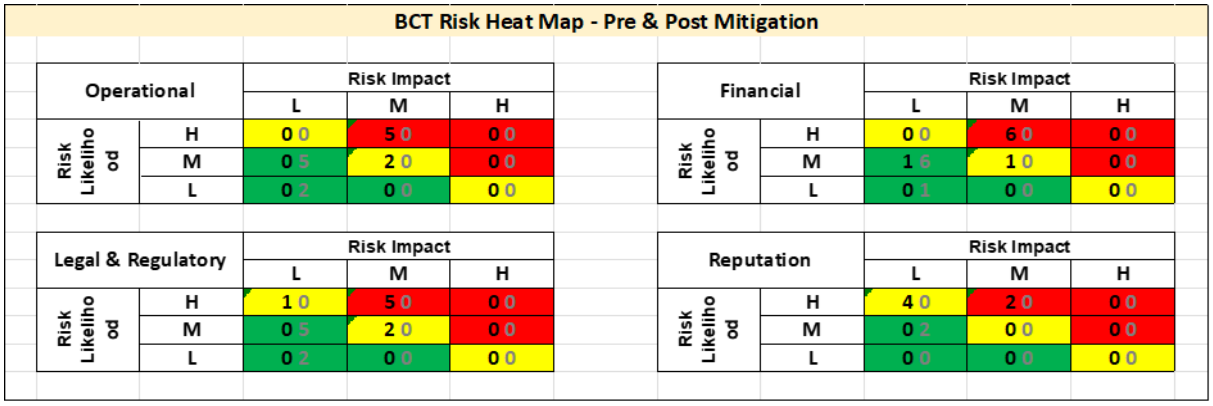
- Implement pilot project with limited scope (geographically, domestic / international, size of consortium, number of Suppliers requiring finance)
- Limit the amount of highly confidential data on the blockchain
- Run blockchain in addition to legacy systems to ensure redundancy
- Limit the use of smart contracts
- Limit the use of IoT-devices

Limitations are lifted incrementally. As a risk avoidance measure, cryptocurrency should not be used at the outset. As a risk transfer measure, insurance ought to be acquired as a protection against negative events (e.g. technology breakdowns, cybersecurity events, legal actions) to the extent it is available and cost-effective.

While the nature of limitations necessary to obtain risk mitigating effects can be clearly described, it is much more difficult to determine the degree of limitation that is necessary to turn a red risk severity score into a green risk severity score. The degree of limitation necessary will depend largely on the specific situation at hand. Yet, as there will be a large degree of uncertainty around any judgment, a reasonable strategy is to start with far-reaching limitations at the outset, lift the implementations incrementally depending on the results of a continuous risk monitoring. For the following, we assume such a stepwise approach with a conservative starting point (but without fixing the specific starting point).

Figure 16 shows that mitigation actions lead to a reduction of all risks to a green level. Risk severity scores go down from 42 to 13 for financial, from 41 to 12 for legal and regulatory, from 38 to 12 for operational, and from 24 to 4 for reputational risk impacts. More details are given in Appendix-1, sheet-3 (Risk ID 13-20).

Figure 16: BCT Risk Assessment - BCT Risk Heat Map - Pre & Post Mitigation



Source: Own analysis. **Notes:** Risk Heat Map represents the number of risks at different significance levels (Red, Yellow & Green) for each risk impact category. Black font represents pre mitigation risks and grey font represents post mitigation risks. H = High, M = Moderate, L = Low.

The BCT application after mitigation actions can be implemented in SCF without exerting risk-increasing effects. The downside is that many benefits of the BCT application will be limited at the beginning. More benefits will only be obtained in the course of incrementally expanding the scope of the implementation over time towards a full implementation across the entire supply chain.

5.5 Risk Assessment of Supply Chain Finance with Blockchain Application

The risk assessment concludes with the evaluation of SCF with the BCT application (Appendix-1, sheet-3 and sheet-4). The mitigating effects of the BCT use in SCF are as follows:

- Increase of quantity and quality of information: Information on the blockchain includes information on Suppliers (e.g. KYC), information on financial flows (e.g. invoices, collateral pledges), and information on physical flows (e.g. warehouse receipts, GPS coordinates of goods, quality of goods). Information on financial and physical flows is fully integrated. All documents are digitally signed. Once on the blockchain, the information is cryptographically secured and immutable. Information covers all historical information and in addition real-time information. The information is accessible to all authorized parties subject to access restrictions. The information can be automatically analyzed by AI / machine learning algorithms.
- Use of smart contracts: Once agreed, smart contracts run fully automatically, and reduce operational and fraud risks, while increasing efficiency.
- Use of IoT-devices: IoT-devices further improve the quantity and quality of information. To the extent that the data transfer is cryptographically secured and automatized, IoT-devices reduce operational and fraud risks.
- Use of cryptocurrency: The use of a cryptocurrency in a supply chain further simplifies financial flows, and reduces operational risks, while increasing efficiency.

Figure 17: SCF Risk Assessment - H/M/L-Scoring Post Mitigation

SCF Risk Assessment - H/M/L Scoring after mitigation							
Risk ID	Risk Title	Risk Owner	Risk Likelihood	Risk Impact			
				Operational	Financial	Legal &	Reputation
1	Deep-tier financing risk	Financer	L	L	L	L	L
2	Performance risk	Buyer	L	L	L		
3	Dilution risk	Supplier	L	H	H		H
4	Double financing risk	Financer					
5	Sleeping risk	Financer					
6	KYC/AML risk	Financer					
7	Supply chain disruption risk - Buyer	Buyer	M	M	M		
8	Supply chain disruption risk - Supplier	Supplier	M	H	H		
9	Operational risk - Supplier	Supplier	M	H	H		L
10	Operational risk - Buyer	Buyer	L	M	M	M	M
11	Operational risk - Financer	Financer	L	L	L		
12	Credit risk	Financer	L	M	M	M	M

Source: Own analysis
Notes: H = High, M = Moderate, L = Low

Figure 17 shows the H/M/L-scoring after mitigation actions. There are no high risk likelihoods any more. Risk impacts stay high for dilution, supply chain disruption (Supplier), and operational (Supplier) risk. The specific mitigating effects of the BCT application regarding the identified SCF risks are as follows:

- Deep-tier financing risk: Information on the blockchain helps assess credit risk of deep-tier Suppliers more precisely. Credit ratings can be dynamically adapted and automatically evaluated depending on Supplier behavior on the blockchain. Furthermore, creditworthiness can be made dependent on other vertical and horizontal attributes of the supply chain in addition to borrower attributes (e.g. customer orders within pull oriented supply chains) (Omran et al., 2018). Suppliers have the capability to build a positive track record on the blockchain. This is particularly helpful for SMEs in developing countries that cannot prove their creditworthiness otherwise. BCT furthermore allows the splitting of trade receivables along the supply chain, which makes bank financing available to borrowers in deeper tiers. All these benefits from the use of blockchain helps deep-tier Suppliers to obtain financing with and without guarantees from the Buyer. The Buyer may actually be removed as a "financial intermediary". As a result, there are opportunities for the Financer to extend short-term credit to Suppliers beyond Tier-1, for the Buyer to improve health of and visibility within the supply chain, and for the Supplier to obtain access to working capital finance at a lower interest rate.
- Performance risk: BCT mitigates supplier underperformance, low quality of raw materials, lack of quality checks and quality assurance by providing the full audit trail of data, and by creating an everlasting means of record keeping. Bad performance can be easily detected in historical data. An early warning system can be designed and implemented that analyzes real-time data. The application of IoT-devices acts as an additional trigger for notification of consignment delays, thus reducing operational impact. As a result, performance reliability can be determined, risk likelihood and risk impacts drop to low.
- Dilution risk: Dilution can be easier detected in historical data. An early warning system can be designed and implemented that analyzes real-time data. Smart contracts can be used to reduce moral hazard. As a result, risk likelihood drops to low, while risk impacts stay unchanged.
- Double financing risk: Double financing and other document fraud can be easily identified by automatically analyzing all financial and physical flows real-time. Auditability, immutability and transparency of BCT helps prevent information and fraud risk. As a result, the risk is avoided altogether.
- Sleeping risk: A company's reliance on bank credit disguised as trade credit can be effectively analyzed given historical and real-time information on financial and

physical flows on the blockchain. An early warning system can be installed to detect changes in financing behavior. With respect to the supply chain in question, the risk is avoided altogether.

- KYC/AML risk: KYC/AML-information is collected and analyzed only once, and is reused by other authorized participants. Borrowers are continuously and automatically monitored with respect to their behavior on the blockchain using appropriate early warning and analysis tools. As a result, the risk is avoided altogether (cf. Rijanto (2021), who shows for thirty projects that the highest perceived usefulness of BCT in SCF is seen in the solution of KYC problems (idem, p. 3087)).
- Supply chain disruption risk: Information on the blockchain allows the design and implementation of early warning systems for the detection of supply chain disruptions, supporting supply chain risk management activities (Babich and Hilary, 2020, p. 234). The Buyer can use this information to make arrangements with an alternative Supplier not likely to be impacted by a given supply chain disruption (dual supplier strategy). For a single Supplier supply chain disruption risk represents an external risk factor beyond the Supplier's control. As a result, risk likelihoods do not change, but risk impacts for the Buyer drop from high to moderate.
- Operational risk: The operational risk of the Financer as a large diversified financial institution remains unchanged at a low level. The BCT application reduces the risk likelihood of operational risk of the Buyer from moderate to low, and of the Supplier from high to moderate, while risk impacts remain unchanged.
- Credit risk: Transparency with BCT will be beneficial for credit risk assessments. The credit risk assessments of the Financer are formed with respect to Tier-1 Suppliers, taking into account payment guarantees by the Buyer. The BCT application improves the information on these Suppliers, but not enough to change the risk likelihood and the risk impacts.

For the evaluation of SCF with the BCT application, there are two scenarios:

1. 100% BCT implementation: BCT risks are disregarded and the BCT application is implemented for 100% of the supply chain network without any risk-reducing limitations. As a consequence, the risk-mitigation of the BCT application regarding the SCF risks is 100% effective. (Appendix-1, sheet-4)

2. Conservative starting point BCT implementation: The BCT application is implemented using a stepwise approach with a conservative starting point. Risk-reducing limitations on scope, smart contracts, IoT and so on are in place, and they are lifted only incrementally. While a specific starting point will not be proposed in this paper, a first implementation step covering, for example, 10% of a full blockchain implementation for the supply chain in question, would mean that the risk-mitigation of the blockchain application regarding the SCF risks is 10% effective. (Appendix-1, sheet-3).

Figure 18 shows the risk heat map of the SCF risk assessment before mitigation actions , and after the 100% BCT implementation. As SCF risks are substituted with BCT risks, a decrease in the high risk likelihood / moderate risk impact category comes with an increase in the high and moderate risk likelihood / moderate risk impact categories. As a result, financial, operational, and reputational impacts slightly decrease from 76 to 68, from 67 to 64, and from 36 to 34, respectively, while legal and regulatory impacts clearly increase from 33 to 46.

Figure 18: SCF + BCT Risk Assessment - Risk Heat Map - 100% BCT

SCF Risk Heat Map - Pre & Post Mitigation (include residual BCT risks - 100% implementation)

Operational		Risk Impact		
		L	M	H
Risk Likelihood	H	0 0	2 5	4 0
	M	0 0	1 3	2 2
	L	1 3	1 2	0 1

Financial		Risk Impact		
		L	M	H
Risk Likelihood	H	0 0	2 6	5 0
	M	0 1	1 2	2 2
	L	1 3	1 2	0 1

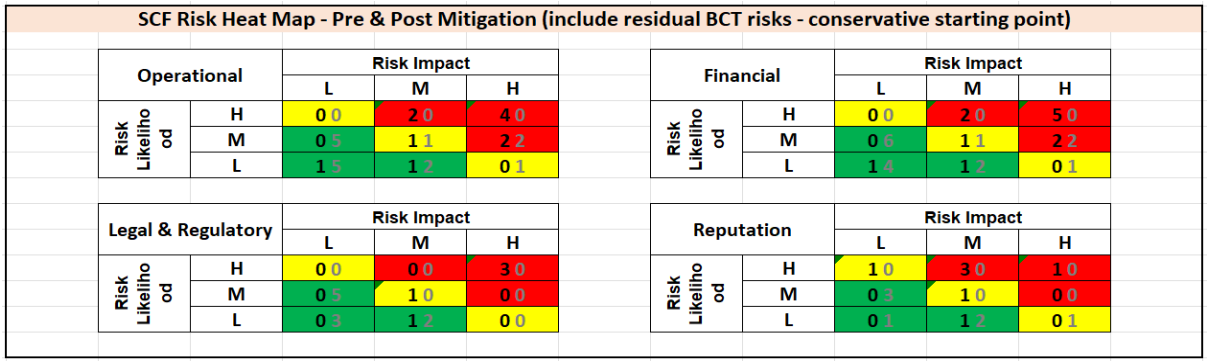
Legal & Regulatory		Risk Impact		
		L	M	H
Risk Likelihood	H	0 1	0 5	3 0
	M	0 0	1 2	0 0
	L	0 1	1 2	0 0

Reputation		Risk Impact		
		L	M	H
Risk Likelihood	H	1 4	3 2	1 0
	M	0 1	1 0	0 0
	L	0 1	1 2	0 1

Source: Own analysis. **Notes:** Risk Heat Map represents the number of risks at different significance levels (Red, Yellow & Green) for each risk impact category. Black font represents pre mitigation risks and grey font represents post mitigation risks. H = High, M = Moderate, L = Low.

Figure 19 shows the risk heat map of the SCF risk assessment before mitigation actions, and after the conservative starting point BCT implementation. As expected a clear risk decrease can be seen in most red fields. The risk severity scores decrease from 76 to 39 for financial, from 67 to 38 for operational, from 36 to 14 for reputational, and from 33 to 17 for legal and regulatory risk impacts. The conservative starting point-implementation of the blockchain application leads to a net risk decrease within the scope of the blockchain implementation.

Figure 19: SCF + BCT Risk Assessment - Risk Heat Map - Cons. Starting Point BCT



SCF Risk Heat Map - Pre & Post Mitigation (include residual BCT risks - conservative starting point)

Operational		Risk Impact		
		L	M	H
Risk Likelihood	H	0 0	2 0	4 0
	M	0 5	1 1	2 2
	L	1 5	1 2	0 1

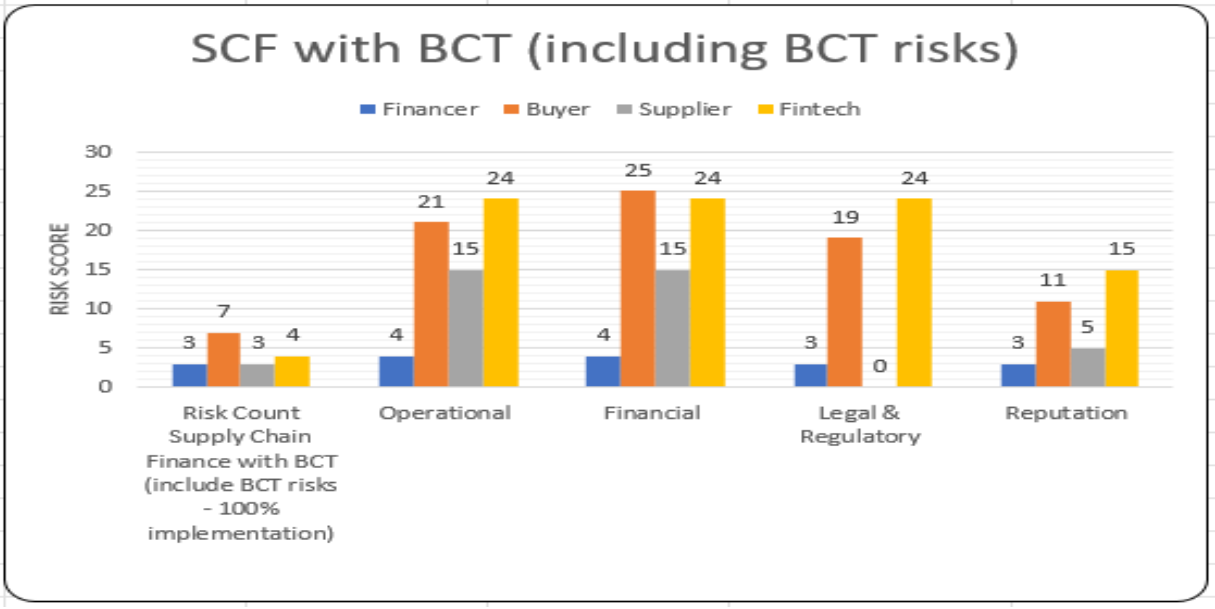
Financial		Risk Impact		
		L	M	H
Risk Likelihood	H	0 0	2 0	5 0
	M	0 6	1 1	2 2
	L	1 4	1 2	0 1

Legal & Regulatory		Risk Impact		
		L	M	H
Risk Likelihood	H	0 0	0 0	3 0
	M	0 5	1 0	0 0
	L	0 3	1 2	0 0

Reputation		Risk Impact		
		L	M	H
Risk Likelihood	H	1 0	3 0	1 0
	M	0 3	1 0	0 0
	L	0 1	1 2	0 1

Source: Own analysis. **Notes:** Risk Heat Map represents the number of risks at different significance levels (Red, Yellow & Green) for each risk impact category. Black font represents pre mitigation risks and grey font represents post mitigation risks. H = High, M = Moderate, L = Low.

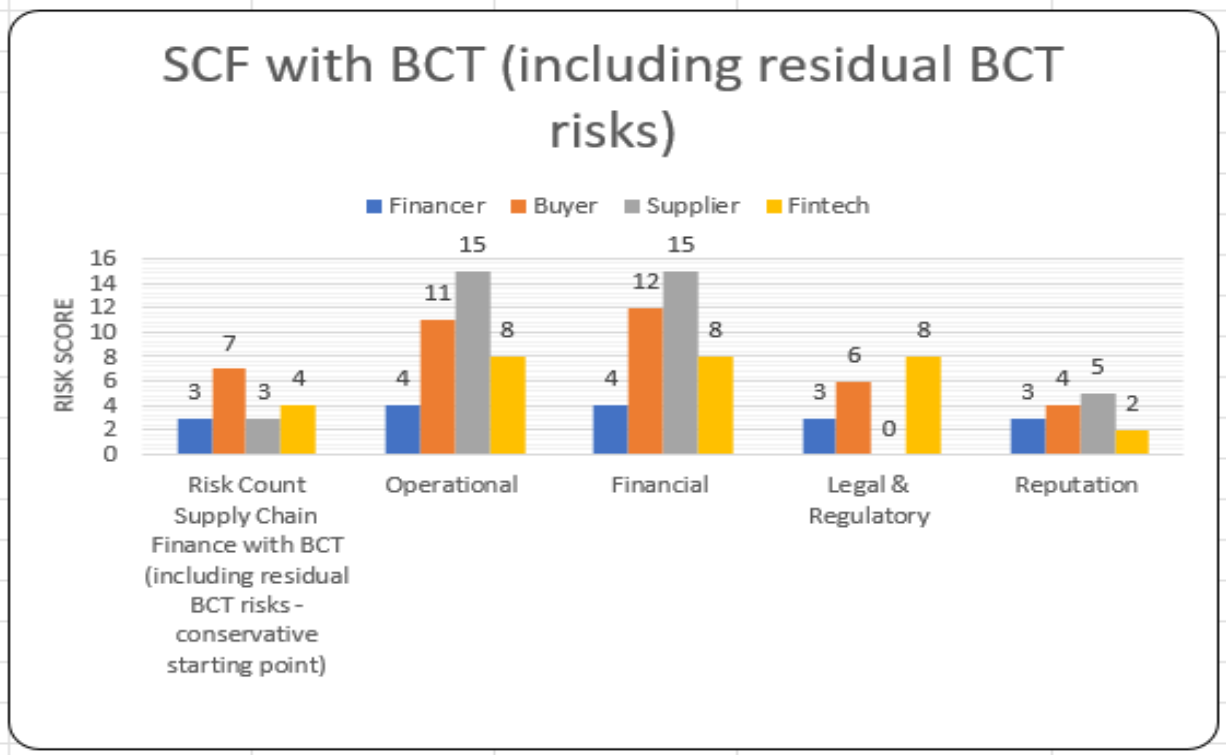
Figure 20: SCF + BCT Risk Assessment - Risk Owner - 100% BCT



Source: Own analysis

Figure 20 shows the distribution of risk severity scores across risk owners for the 100% BCT implementation. The risk severity scores for the Fintech and the Buyer are very high across all risk impact categories. Figure 21 shows the same information for the conservative starting point BCT implementation. The risk severity scores of Fintech and Buyer are much lower. The main risk severities are borne by the Supplier followed by the Buyer and by the Fintech in the financial and the operational risk impact categories. The Fintech and the Buyer are subject to legal and regulatory impacts. The risk severities of the Financer are lowest, and distributed across all four categories.

Figure 21: SCF + BCT Risk Assessment - Risk Owner - Cons. Starting Point BCT



Source: Own analysis

To connect our final analysis with our starting point, we compare Figure 21 (SCF + Conservative starting point BCT implementation) with Figure 12 (SCF without BCT). There is a significant reduction in SCF risks for the Financer, the Buyer, and the Supplier. The risk reduction is least accentuated for the Buyer. In particular, the Buyer's legal and regulatory risks increase, and reputational risks remain unchanged. This is caused by the additional BCT risks that the Buyer needs to take on. The Fintech enters into the picture as the risk owner of the residual BCT technology risks. Pre and post mitigation risk profiles for each risk owner can be found in Appendix-2.

The conclusion of this risk assessment is that the 100% BCT implementation does not produce risk-decreasing effects, and can therefore not be seen as a risk mitigation for SCF risks. The conservative starting point BCT implementation effectively reduces SCF risks, and does not add any significant new risks. Overall, the implementation of BCT in SCF will mitigate SCF risks only to a limited extent at the beginning. It will fully mitigate many of the SCF risks to a green level for those parts of the supply chain that are covered by the BCT implementation. Yet, high BCT risks make it impossible to go for a 100% BCT implementation at once. Only to the extent that BCT risks can be managed down in the future, limitations on the BCT implementation in SCF can be lifted. It follows that there is a tradeoff between reducing SCF

and BCT risks, respectively, depending on the speed of BCT implementation. The faster BCT is implemented, the more SCF risks can be reduced, and the more BCT risks need to be accepted. In our analysis, we only showed the two extremes of this trade-off, the 100% BCT implementation, and the conservative starting point BCT implementation, respectively. Under the assumption that the further development of BCT in the coming years will lead to a reduction of BCT risks, particularly, of technology risks, a full implementation of a BCT application in SCF will significantly reduce SCF risks.

6. Conclusion

Globalization is driven by global trade, and global trade needs global trade financing. The growth of global trade is slowed down by a large global trade finance gap. Particularly, SMEs in developing countries is often denied trade financing as their creditworthiness cannot be established. Many of these SMEs are participating in supply chains. SCF has been developed to address working capital finance needs within supply chains. The defining characteristic of SCF as opposed to working capital finance, or trade finance is that its goal is to optimize financing across a supply chain network. In SCF, the creditworthiness of a supply chain's core company ("Buyer") is usually transferred to lower the borrowing costs of other less creditworthy supply chain companies ("Suppliers"), often SMEs that do not have optimal access to bank loans. Unfortunately, the SCF business model does not live up to expectations. Financing risks are perceived as high, and SMEs in deeper tiers of multi-tier supply chains often do not benefit from this financing technique at all. The complexity and intransparency of international supply chains that are often predominantly located in developing countries keeps the reach of SCF limited to tier-1 suppliers. BCT belongs to one of the key technologies of the 4th industrial revolution. As an infrastructure for secure and efficient transactions in a decentralized network with a large number of participants, it seems to be predestined to be implemented to improve the functioning of supply chains, and of SCF.

The literature review shows that SCF, BCT, and also the application of BCT in SCF are active research areas. Chinese researchers most actively work on the analysis of BCT in SCF. Many supply chains and a lot of SMEs are located in China. The level of fraud in SCF is perceived as high, and legal and economic institutions are perceived as not being fully supportive of the SCF business model. A few research papers report on practical BCT implementations in SCF in China. The literature review reveals a research gap at the intersection of SCF and BCT. While the potential mitigating effects of BCT on SCF risks are documented quite well, only Li

et al. (2020) gives a detailed account of BCT risks. None of the papers performs an integrated risk assessment of both SCF risks and BCT risks. This study contributes to the research with such an integrated risk assessment. Based on the study of existing research, an expert risk assessment is performed using the international risk management standard ISO 31000. To our knowledge, this is the first research paper with a systematic and integrated risk analysis of SCF with BCT that conforms with ISO 31000.

Before performing the risk assessment, an overview of SCF is given and prospects of BCT in SCF are discussed. As part of the SCF overview, SCF opportunities are described, and a list of SCF risks is given: deep-tier financing risk, performance and dilution risk, double financing risk, sleeping risk, KYC/AML risk, supply chain disruption risk, operational risk, and credit risk. Digitalization helps mitigate some SCF risks, but is insufficient to decisively reduce the deep-tier financing risk. An expert interview with one of the leading working capital management Fintech Taulia confirms this view. Regarding prospects of BCT in SCF, the optimal set-up of a BCT application for a business network is a permissioned blockchain, whose design characteristics need to be tailored to the specific application. The risk profile of BCT is characterized primarily by its early stage of development. Risks can be categorized into: technology risk, legal and regulatory risk, strategic risk, operational risk, and financial risk. These risks can be further split into a large number of subcategories, especially regarding technology risk. In a supply chain setting, IoT-related risks also need to be taken into account.

The scope of the ISO 31000 conformant risk assessment of BCT in SCF comprises the following stylized organizations in a supply chain: Supplier, Buyer, Financer, and Fintech. All parties are assumed to maximize their own profits, and additionally to maximize profits of the supply chain network. Risk scoring criteria are defined by three-level scales (low, moderate, high) for risk likelihoods and risk impacts, respectively. Risk impacts are scored regarding four risk impact categories (operational, financial, legal and regulatory, reputational). Risk severities are summarized in risk heat maps, and risk profiles are used to compare risk severities across risk scenarios. The context of the risk assessment is defined by a business scenario that involves a multi-tier supply chain with a large number of SMEs in developing countries as Suppliers requiring finance. The Buyer is a large well-run company, the Financer a large well-run and well-diversified financial institution. The BCT application is provided by a specialized Fintech with a diversified customer portfolio. The specific BCT application is a permissioned consortium blockchain with the optional use of smart contracts, IoT, and cryptocurrencies.

The risk assessment proceeds in three steps: 1) risk assessment of SCF (without BCT), 2) risk assessment of BCT before and after mitigation actions, and 3) residual risk assessment of SCF with BCT.

For the risk assessment of SCF (without BCT), of the twelve identified SCF-risks seven obtain a high, three a moderate, and two a low risk likelihood. Risk impacts are concentrated in the financial and operational risk impact categories and mostly expose the Financer. The main reason for high risks is the fact that Suppliers are SMEs located in developing countries, which actually causes the Financer to avoid deep-tier financing entirely. This can be regarded as a market failure. Risk severity scores add up to 76 for financial, 67 for operational, 36 for reputational, and 33 for legal and regulatory risk impacts.

For the risk assessment of BCT, a total of eight BCT risks were identified, half of them technology risks borne by the Fintech, and half of them strategic and other risks borne by the Buyer. Of the eight BCT-risks six obtain a high, and two a moderate risk likelihood. Risk impacts are evenly distributed between the operational, financial, and legal and regulatory risk impact categories exposing both the Fintech and the Buyer. The main reason for high risks is the early stage of BCT technology development leading to an abundance of technology-related concerns. Risk severity scores add up to 42 for financial, 41 for legal and regulatory, 38 for operational, and 24 for reputational risk impacts.

BCT risks can be fully mitigated employing a mix of risk reduction (limiting scope and highly confidential data, ensuring system redundancy, limiting smart contracts and IoT), risk avoidance (no cryptocurrency), and risk transfer measures (buying insurance). Limitations are lifted incrementally as BCT risks go down in the course of the technological life cycle. The degree of limitation necessary to obtain green risk severities cannot be reliably determined. Therefore, a conservative starting point needs to be chosen with incremental lifting of limitations based on continuous risk monitoring. Mitigation actions lead risk severity scores to go down from 42 to 13 for financial, from 41 to 12 for legal and regulatory, from 38 to 12 for operational, and from 24 to 4 for reputational risk impacts.

For the risk assessment of SCF with BCT, mitigating effects of the BCT application in SCF include the increase of the quantity and the quality of information on the blockchain, further supported by the use of smart contracts, IoT-devices, and cryptocurrency. Most notably, BCT fully mitigates the deep-tier financing risk to a low risk likelihood, and low risk impacts. The

Financer benefits from extending the short-term credit to suppliers beyond tier-1, the Buyer obtains visibility regarding the movement of shipments/deliverables, and the Supplier gets access to working capital at a lower interest rate. BCT mitigates performance risk to a low risk likelihood, and low risk impacts, and dilution risk to a low risk likelihood, and unchanged risk impacts. Double financing risk, sleeping risk, and KYC/AML risk are completely avoided by the implementation of BCT. Risk impacts of supply chain disruption risk are lowered from high to moderate for the Buyer. Operational risk likelihoods are reduced by one notch for both the Buyer and the Supplier.

With a 100% BCT implementation, SCF risks are substituted with BCT risks, and risks overall do not decrease. Risk severity scores compared with SCF risks (without BCT) slightly decrease from 76 to 68 for financial, from 67 to 64 for operational, and from 36 to 34 for reputational risk impacts, while they clearly increase from 33 to 46 for legal and regulatory risk impacts. With a conservative starting point BCT implementation, a clear risk decrease can be observed. Risk severity scores decrease from 76 to 39 for financial, from 67 to 38 for operational, from 36 to 14 for reputational, and from 33 to 17 for legal and regulatory risk impacts. The conservative starting point BCT implementation leads to a net risk decrease within the scope of the BCT implementation.

There are two central results from the integrated risk assessment in this study. The first is that BCT extends the reach of SCF into the deeper tiers of multi-tier supply chains, and enables SCF to provide financing to a vast number of SMEs in developing countries. BCT together with smart contracts, IoT, and cryptocurrency effectively reduces SCF risks by providing an abundance of high-quality information on the blockchain. The second is that there is a tradeoff between reducing SCF and BCT risks, depending on the speed of BCT implementation. BCT is still at an early stage of technological development resulting in high BCT risks. These risks need to be mitigated, for example, by limiting the scope of implementation at the beginning, and increasing it only as BCT risks go down over time. The faster BCT is implemented, the more SCF risks can be reduced, and the more BCT risks need to be accepted. In our analysis, we only showed the two extremes of this trade-off, the 100% BCT implementation, and the conservative starting point BCT implementation, respectively. Other choices are possible. BCT risks can be hedged to a lower degree, allowing for a quicker implementation, leading to a faster coverage of larger parts of a supply chain, and resulting in lower SCF risks. The optimal

level of BCT risk mitigating actions depends on the risk severity of SCF risks relative to the risk severity of BCT risks.

More research is needed regarding the following points: 1) The expert risk assessment is done by the authors based on an extensive review of the literature, and discussions with industry experts. In a next step, the risk assessment should be done by a more representative group of experts, and market participants; 2) The extent of BCT limitations needed to mitigate high risks is not precisely specified. The relative riskiness of SCF and BCT risks is not clearly determined, and the optimal tradeoff is not identified; 3) There are simplifying assumptions that all risks are completely identified, and that SCF and BCT risks can be added.

The further development of BCT is likely to reduce BCT risks changing the tradeoff between SCF and BTC risks, and allowing additional BCT implementation steps in SCF. In the future, BCT is likely to become the backbone of supply chains and SCF relationships. SCF may not have to rely on the Buyer's creditworthiness any more as it will be possible to easily establish the Supplier's creditworthiness. BCT even has the potential to function as a risk mitigant for weak political and economic institutions in developing countries. Our advice to market players is to steadily participate in this developing market with investments that increase with the market's degree of maturity.

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