COULD BLOCKCHAIN DECENTRALIZE SUPPLY CHAINS? AN EXAMINATION OF DYNAMIC TOKEN DELIVERY MOTIVATION OF MID-TIER SUPPLIERS IN BLOCKCHAIN-DRIVEN SUPPLY CHAIN FINANCE PLATFORMS

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Could Blockchain Decentralize Supply Chains? An Examination of Dynamic Token Delivery Motivation of Mid-tier Suppliers in Blockchain-driven Supply Chain Finance Platforms

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Abstract

Blockchain, or distributed ledger technology (DLT), is expected to enable a highly decentralized and trusted business environment. Yet the business pursuit for profit maximization calls for a more centralized structure and thereby conflicts with the decentralized ideology of blockchain. In the blockchain-driven supply chain finance (SCF) platforms, focal buyer companies can issue "cash tokens" which are blockchain-based electronic invoices/certificates with due days of payment and pay the "cash tokens" to their direct suppliers instead of using traditional open-account techniques. Direct suppliers can hold the "cash tokens" to maturity, use the "cash tokens" as collateral for loans, or pay the "cash tokens" to the upper tier suppliers in goods transactions (we call the last option "token delivery" in the following). Because the "cash tokens" are delivered tier by tier based on transactions, mid-tier suppliers can become a "bottleneck" in the blockchain-driven SCF application. In this paper, we consider the supply chain network as a complex system where firms are self-organized and adaptive to their competitive environment. Via this theoretical lens, we investigate how the mid-tier suppliers' token delivery and supply chain transaction structures interplay over time in the blockchain-driven SCF platforms; meanwhile, how industry characteristics such as the number of firms in each tier and firm size in each tier can influence the interactions. We propose that in the short term, blockchain technology increases mid-tier suppliers' transaction efficiency and thus motivates mid-tier suppliers' token delivery and promotes the decentralization of supply chain transaction structure, i.e., upper-tier suppliers make new transaction links with mid-tier suppliers and focal buyers; in the long term, the more decentralized supply chain transaction structure will in turn negatively affect mid-tier suppliers' token delivery motivation and drive the supply chains more centralized, i.e., the upper-tier suppiers start to face financing difficulties again and

some of the transaction links will diminish. Besides, supply chains with a flatter organizational structure, a larger setup cost gap between mid-tier suppliers and upper-tier suppliers, and a higher operation cost of upper-tier suppliers can remain decentralized longer. We will test our theoretical propositions by a series of simulation experiments in an agent-based model.

Lay Summary

This study aims to make two contributions. First, our study makes a theoretical contribution by closing up a research gap in the field of blockchain-driven SCF platforms. We find a potential “bottleneck” effect of mid-tier suppliers and reveal that even though the benefits of blockchain are obvious in short term, the benefits can diminish in long term due to the dynamically adjusting motivations of mid-tier suppliers. Second, our study makes a practical contribution by demonstrating the vital role of mid-tier suppliers in the long-term success of blockchain-driven SCF. Our findings suggest that blockchain-driven SCF platforms need to develop an effective incentive scheme to encourage the token delivery of mid-tier suppliers and consider industry characteristics when growing their supply chain customer base.

Preface

A version of section 1 has been published as a research idea at a conference. Song, Lingxiao; Nan, Ning; and Wang, Shan, "Could Blockchain Decentralize Supply Chain? A Dynamic Analysis of Token Delivery Motivations of Mid-tier Suppliers in Blockchain-driven Supply Chain Finance" (2019). DIGIT 2019 Proceedings. 10. I generated this research idea and drafted the manuscript for this publication. Prof. Ning Nan helped me proofread and Prof. Shan Wang helped me impletment the interview in the blockchain-driven SCF platform.

In this dissertation, I conducted all the testing and drafted all the manuscripts. My supervisor, Prof. Ning Nan, provided me guidance and helped me proofread some sections.

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Acknowledgments

During my work in the bank industry, I had realized how important and challenging the know-your-customer procedures are when banks manage the credit risks of small and media enterprises. And after I learn about the blockchain technology and its application in the supply chain finance field, I feel very excited and I believe this will be a very prospective solution. I would like to offer my enduring gratitude to my supervisor, Prof. Ning Nan, who has inspired me to continue my work in this field and provided me very detailed and constructive guidance. She taught me the steps for proper research, methodologies, and good writing practices. I also learned how to be a good researcher from her professionalism. I owe particular thanks to Prof. Shan Wang, who gave me a big favor to design the interview questions and implement the interviews in a blockchain-driven supply chain finance platform.

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1. Introduction

Supply chain finance (SCF) refers to financial practices among buyers and suppliers such as inventory financing, trade credit, approved payables finance, or purchase order financing (e.g., Reindorp et al., 2018; Shang et al., 2009; Tunca & Zhu, 2018; Wuttke et al., 2019; Yang & Birge, 2018). SCF expands the function of supply chain management beyond a traditional focus on sourcing, making, and delivering products. It expands a supply chain as a source of inexpensive capital (Rogers et al., 2016). Buyers such as Apple and Walmart use supply chain finance to help optimize the liquidity of their upstream suppliers, and thereby improve buyers' working capital. Suppliers benefit from reduced financial costs (Rogers et al., 2016; Van Der Vliet et al., 2015; Wuttke et al., 2019). Despite its benefits, SCF faces a few challenges, especially in a context involving multitier supply chain networks (Hofmann et al., 2017). First, fraud caused by a lack of information transparency is a major concern in past SCF practices (Beck et al., 2004; Klapper, 2006; Omran et al., 2017). Second, the paper-intensive, manual processes of traditional SCF (Omran et al., 2017; Zhang & Dhaliwal, 2009) have to rely on a large number of intermediaries, which causes low efficiency and high transaction cost (Fellenz et al., 2009; Omran et al., 2017). Third, in multi-tier supply chains, the tier-2 or lower upstream suppliers with the most urgent funding needs often have the least access to SCF due to a lack of direct transaction evidence with focal buyer firms. This, in turn, causes credit waste for focal buyers with considerable credit slack.

Blockchain is expected to be a disruptive technology by enabling a decentralized and trusted economic environment (Beck et al., 2016). Treiblmaier (2018, p. 547) defines a blockchain as "a digital, decentralized and distributed ledger in which transactions are logged and added in chronological order with the goal of creating permanent and tamper-proof records". The central technology associated with blockchain is distributed ledger technology (DLT), which is defined as "the use of decentralized digital trust verification through encrypted digital signatures" (Gomber et al., 2018 p. 237). Pedersen et al. (2019) describe how blockchain works: In general, blockchain is shared among multiple participants. Participants reference each other by their public keys and use their private keys to cryptographically sign transactions. Each successful transaction indicates an update to the blockchain database that is replicated and stored by each participant. Transactions are aggregated and appended to the database in blocks with time stamping and consecutively chained together over time (Cong & He, 2019; Pedersen et al., 2019; Yermack, 2017). Transactions can be automatically managed through smart contracts (Cong & He, 2019; Pedersen et al., 2019; Yermack, 2017). Benefits derived from these functionalities include immutability, nonrepudiation, data integrity and traceability, high-transparency, and high-efficiency (Pedersen et al., 2019).

The benefits of blockchain can potentially solve many challenges faced by traditional SCF. Indeed, blockchain-driven SCF platforms have been increasingly experimented with in recent years. For example, the financing arm of Foxconn, the largest iPhone manufactory, partnered with Dianrong, one of China's top P2P lending platforms, to launch Chained Finance, a blockchain-driven SCF platform for Foxconn's suppliers. The two companies had completed a pilot phase by originating US$6.5 million in loans for small and medium suppliers that were otherwise unable to secure the needed capital (Sawers, 2017; Soo, 2017; Wang et al., 2019a).

However, blockchain-driven SCF platforms also have problems. Within a blockchain-driven SCF platform, "cash tokens" (i.e., blockchain-based electronic invoices/certificates with due date of payment) are authorized by focal buyer companies and then paid to first-tier suppliers who directly transact with the focal buyers. The cash tokens are infinitely divisible. First-tier suppliers can then pass the cash tokens to second-tier suppliers (we call this option "token delivery" in the following), hold the cash tokens to maturity, or use the cash tokens as collateral for loans. As the cash tokens are delivered tier by tier, the upper-tier suppliers must rely on the mid-tier suppliers' token delivery. This causes a "bottleneck" effect of mid-tier suppliers. Unfortunately, SCF platforms typically strive to increase the number of cash tokens authorized by focal firms but neglect effective token delivery of mid-tier suppliers. According to our interviews with a Chinese blockchain-driven SCF platform in the steel industry, even though the authorized cash token amount increased dramatically (from US$14 million to US$286 million in six months after their setup), the majority of tokens were held to maturity by 1-tier suppliers while 2-tier or lower suppliers especially SMEs still had difficulties in obtaining financial support. Only 20% of the authorized tokens were transferred into loans. Thus, how to effectively motivate mid-tier suppliers to deliver cash tokens becomes a significant issue for the long-term success of blockchain-driven SCF platforms.

In this paper, we consider a supply chain network as a complex system where firms are self-organized and adaptive to their competitive environments. The research questions include:

(1) How will the application of blockchain-driven SCF influence the supply chain transaction structures (goods flow) via the mid-tier suppliers' tokens delivery (token flow)?

(2) How will the change of supply chain transaction structures (goods flow) in turn influence the tokens delivery of mid-tier suppliers (token flow)?

(3) Will industry characteristics (e.g., the number of firms in each tier, firm size in each tier, etc.) affect the relationships between tokens delivery and supply chain structures in blockchain-driven SCF?

We propose that in the short term, blockchain technology reduces mid-tier suppliers' transaction cost and financial cost, thus motivates mid-tier suppliers' token delivery and facilitates upper-tier suppliers' liquidity, then promotes the decentralization of supply chain transaction structure, i.e., upper-tier suppliers build new transaction links with mid-tier suppliers or even focal buyers. In the long term, the more decentralized supply chain transaction structure will increase the competitive pressures of mid-tier suppliers and in turn negatively affect mid-tier suppliers' token delivery motivations, and then drive the supply chains more centralized, i.e., the upper-tier suppiers start to face financing difficulties again and some of the transaction links will diminish. We test our theoretical propositions by a series of simulation experiments in an agent-based model (ABM). In this model, supply chain companies are recognized as individual agents with diverse financial and IT characteristics. The token flow and transaction goods flow are viewed as interaction links among agents. Behavior rules are designed in a theoretical lens of cost-benefit analysis based on the agent characteristics and links. With the interaction of goods flow and token flow, characteristics of individual agents will evolve, and then the change of characteristics will, in turn, impact the goods flow and token flow according to behavior rules. The ABM methodology allows us to see the evolution of supply chains over time. A takeaway from our study is that we find the potential "bottleneck" effect of mid-tier suppliers in the blockchain-driven SCF platforms. In the blockchain-driven SCF platforms, even though blockchain technology can decentralize the information, the decentralization of liquidity is still determined by mid-tier suppliers' token delivery. Financial institutions will not provide funding to upper-tier suppliers without the cash token. In other words, without mid-tier suppliers' token delivery, upper-tier suppliers still cannot obtain loans from financial institutions directly and independently.

Extant SCF literature on technology has acknowledged the critical role of IT on intra and inter organization information sharing (e.g., Fairchild, 2005; Blackman et al., 2013; Wandfluh et al., 2015), but detailed analysis of IT factors in SCF remains rare (Bals, 2019). Caniato et al. (2016) identify a need for future research regarding the adoption of IT-enabled SCF platforms. Blockchain-related literature on supply chains mainly focuses on supply chain management (e.g., Cole et al., 2019; Wang et al., 2019b), yet discuss little financing issues. Thus, there is still a research gap in the application of blockchain technology to SCF (Bals, 2019; Wang et al., 2019a).

Our study intends to make three contributions to SCF and blockchain research. First, we provide a dynamic view of the interplay between token flow and goods flow in blockchain-driven SCF platforms. Prior work has a consistent theme that token flow has to match the physical goods flow in a supply chain. We lack knowledge about how blockchain's decentralized token flow will clash or harmonize with physical goods flow. Moreover, when the goods flow changes, it will in turn influence the token flow. Second, our model expands the scope of a supply chain to a multitier network in order to embrace the decentralized characteristics of blockchain. Prior studies on SCF tend to build an analytic model either in dyadic (i.e., focal companies and their direct suppliers) or triple parties (i.e., focal companies, their direct suppliers, and financial institutions). Compared to prior works, our model can capture the unique characteristics of suppliers in different tiers in a granular way. Third, most prior studies tend to revolve around how SCF affects financial costs (e.g., Lekkakos & Serrano, 2016; Tunca & Zhu, 2018; Van Der Vliet et al., 2015). We take a step further and explain three groups of factors: transaction costs, financial costs, and competitive conditions. We hope that our analysis stimulates discussions about the long-term value of blockchain in SCF and provides guidance for the design of blockchain applications in business.

The remaining of the paper proceeds as follows. In section 2, we make literature reviews on supply chain finance, IT development, and economic analysis in the supply chains. Then we describe our research settings in section 3. In section 4, we set up the conceptual model and develop propositions. In Section 5, we demonstrate the robustness of our theoretical results in an extended model through Agent-based modeling (ABM). Section 6 indicates our experiment designs and findings. In section 7, we discuss the theoretical and practical implications and limitations of our research. Section 8 concludes the study.

2. Theoretical Foundation

This study contributes to the literature on the effects of blockchain-driven supply chain finance (SCF) to supply chain networks, exploring the motivations of multi-tier suppliers in a cost-benefit framework. As such, it is related to three domains: 1) SCF business/definition, 2) IT evolvement in SCF, and 3) SCF economic model.

2.1 Supply Chain Finance

2.1.1 Definition of SCF

Supply chain finance is a recent innovative business practice that has been increasingly adopted by buyers and their suppliers (Herath, 2015; Kouvelis & Zhao, 2012; Reindorp et al., 2018; Shang et al., 2009; Tunca & Zhu, 2018; Wuttke et al., 2019; Yang & Birge, 2018). Buyers such as Apple, Dell, Walmart, P&G are using this practice to help optimize the liquidity of their upstream suppliers, and strengthen their financial position by improving their own payment terms. Suppliers benefit as well due to reductions in financial costs (Rogers et al., 2016; Van Der Vliet et al., 2015). Traditionally, supply chain management has been about sourcing, making, and delivering, but now it is about funding, using the supply chain as a source of inexpensive capital (Rogers et al., 2016).

The term SCF has been used to describe related practices, such as inventory financing, trade credit, approved payables finance, or purchase order financing (e.g., Euro Banking Association, 2014; Reindorp et al., 2018; Shang et al., 2009; Tunca & Zhu, 2018; Wuttke et al., 2019; Yang & Birge, 2018), ranging from single instruments to comprehensive programs aimed at supporting large ecosystems of trading relationships in complex domestic and/or international supply chains (Malaket, 2015). Shang et al. (2009) describe SCF as an emerging practice that aims to improve the performance of a supply chain by integrating material flows with financial flows. Euro Banking Association (2014) defines SCF as the use of financial instruments, practices, and technologies to optimize the management of the working capital and liquidity tied up in supply chain processes for collaborating business partners. Wuttke et al. (2019) focus on the meaning of SCF that is based on reverse factoring, which is commonly understood among managers, with an independent third party (the SCF provider) providing a technology platform to organize all aspects involved. In this paper, we target reverse factoring as well. It is this form of SCF that has gained the most managerial attention so far; annual revenue growth rates have been approximately 20% since 2010, and they are forecasted to be about 15% in the near future (Herath, 2015). (We note that the terms SCF and reverse factoring have, at times, been used synonymously in prior research [(Euro Banking Association, 2014; Herath, 2015; Rogers et al., 2016; Wuttke et al., 2019)].)

In a reverse factoring application, suppliers sell their account receivables to the SCF provider (i.e., banks, financial institutions, SCF platforms) to receive a discounted payment. Upon the delivery of goods and/or services, the buyer signals invoice approval to the SCF provider and pay the payment on the due date eventually (Klapper, 2006; Van Der Vliet et al., 2015; Wuttke et al., 2019). In contrast to traditional factoring, which is initiated by the supplier, reverse factoring in an SCF program has the advantage that the provider bases the risk assessment on the buyer's credit ratings, which are typically higher and more informationally transparent than those of the suppliers (Klapper, 2006; Van Der Vliet et al., 2015). Thus, SCF programs often lead to liquidity improvement and financial cost reduction for suppliers.

2.1.2 IT Evolvement in SCF

This comes to the juncture of SCF business and inter-organizational systems (IOS) migration. An IOS is defined as "an automated information system shared by two or more companies" (Cash & Konsynski, 1985), and "is built around information technology that facilitates the creation, storage, transformation, and transmission of information" (Johnston & Vitale, 1988). Zhu et al., (2006) illustrate a trajectory of firms' migration across inter-organizational systems that are built on standards with relatively different degrees of openness: proprietary systems (e.g., mail, fax, and telephone), partially open systems (e.g., EDI), and open-standard systems (Internet-based IOS). Steinfield et al. (2011) explore the characteristics of IOS that affect information transparency in supply chains in terms of three IOS architectures: point-to-point architecture, private coordination hub architecture, and shared coordination hub architecture. Accordingly, we organize the review of SCF applications by the cross structure between IT standards and IOS architectures (See Table 2.1). Table 2.2 provides definitions of related IOS standards and IOS architectures. From prior work about technologies in SCF, we identify five phases of SCF applications: 1) Paper-based manual SCF; 2) EDI-based SCF; 3) Internet-private coordination hubs SCF; 4) Internet-shared coordination hubs SCF; 5) consortium blockchain-driven SCF. The following parts discuss those five kinds of SCF applications in detail.

	Proprietary Systems	**Partially Open Systems**	**Open-Standard Systems**	
			Internet	**Blockchain**
Point-to-Point Linear Architecture	Paper-based SCF (e.g., Letters of Credit)	EDI-based SCF	NA	NA

Private Coordination Hubs	NA	NA	Internet-Private Coordination Hubs SCF (e.g., online orchestrator-lead SCM)	NA
Shared Coordination Hubs	NA	NA	Internet-Shared Coordination Hubs SCF (e.g., online SCF platform)	Blockchain-driven SCF platform (the focus of this paper)

Table 2.1 SCF categories in terms of IOS standards & architectures

Terms	Definitions
IOS standards	IOS standards are a set of technical specifications that are agreed upon and used by IOS developers to describe data formats and communication protocols, which enable computer-to-computer communications (Zhu et al., 2006). IOS standards differ concerning the process of standards development and the scope of availability (Greenstein, 1990; Zhu et al., 2006).
Proprietary Standards	If a standard is developed and then available only to a closed set of firms that require a private communication platform, it is considered to be a proprietary standard (Greenstein, 1990; Zhu et al., 2006).
Open Standards	If a standard is developed by an open community that uses public communication platforms and software, it is considered an open standard, e.g. TCP/IP as the communication protocol, and XML or ebXML as data standards (Greenstein, 1990; Zhu et al., 2006).
Point-to-Point Linear Architecture	In a point-to-point linear architecture, users are connected in a point-to-point base and information is available to all relevant organizations sequentially and bilaterally (Steinfield et al., 2011).
Interorganizational Coordination Hubs	Interorganizational coordination hubs are standards-based information technology (IT) platforms that are open to use by all qualified members of defined organizational communities (Markus & Bui, 2012), and information is available to all relevant organizations simultaneously (Steinfield et al., 2011).
Private Coordination Hubs	A private coordination hub is usually designed by one dominant company in the supply chain (also called “supply chain orchestrator”) and only its own business partners can participate (Steinfield et al., 2011).
Shared Coordination Hubs	A shared coordination hub usually provides a collaborative platform involving multiple supply chain orchestrators and their partners (Steinfield et al., 2011).

Table 2.2 Definitions of related IOS standard & architecture terms

2.1.2.1 Paper-based manual SCF

Traditional SCF products, such as letters of credit (LCs), have existed for hundreds of years. Banks have served as intermediaries to facilitate the flow of documents (information) and payments related to the flow of goods in trade or to provide assurance relating to the performance or financial obligations of a person or company to another (BAFT-IFSA, 2011). For example, letter of credit is a form letter issued by a bank stating that, on receipt of certain paperwork such as shipping, insurance, and inspection papers, the bank will pay the amount of the LC (Stancill, 1979).

In the aspect of IOS standards, these bank-intermediated forms of SCF are paper-intensive proprietary systems, that are the documentaries, like shipping, insurance, and inspection papers, are possessed by different entities and recorded in different formats, which requires banks to undertake an inspection and assessment manually. Thus, those forms of SCF are relatively low-efficiency and with an expensive financial cost.

In the view of IOS architecture, traditional SCF products, like letters of credit, connect buyers and suppliers bilaterally on a point-to-point basis. Thus, they are unable to link multilateral relationships, with low information transparency in supply chains and information delay issue. Besides, members of a supply chain may face high costs for implementing and maintaining separate connections with different partners (Steinfield et al., 2011).

2.1.2.2 EDI-based SCF

Since the 1960s, large corporations started to adopt EDI to accelerate the communication with suppliers with a focus on digitizing the corporate-to-corporate (B2B) information flows such as purchase orders, shipping documents, and invoices (Euro Banking Association, 2014).

EDI-based SCF differs from paper-based SCF primarily in terms of IOS standards. EDI standards are usually developed by open consortia and thus are considered more open than proprietary standards (Greenstein, 1990; Zhu et al., 2006). Initial EDI standards, often developed and used by an individual company and its suppliers, were more proprietary. Then industry-wide standards lower the asset specificity of EDI compared to proprietary IOS as the content platform supports communications with a larger number of firms in the trading partner base (Emmelhainz, 1993; Yao et al., 2009; Zhu et al., 2006). But in the aspect of IOS architecture, EDI networks are also bilateral linkages (Yao et al., 2009) and on a point-to-point basis (Steinfield et al., 2011).

The evolvement from paper-based manual systems to paperless EDI has been studied extensively in the literature (e.g., Barua & Lee, 1997; Hansen & Hill, 2006; Iacovou et al., 1995; Jelassi & Figon, 1994; Lee et al., 1999; Mukhopadhyay & Kalathur, 1995; Teo et al., 2003; Wang & Seidmann, 1995). In general, although EDI includes such benefits as reduced paperwork and transaction costs, improved information accuracy, timely information receipt, accelerated cash flow, and reduced inventories (Hansen & Hill, 2006; Iacovou et al., 1995; Mukhopadhyay & Kalathur, 1995), EDI process is inflexible, difficult and expensive to maintain (Moore, 2001). Moreover, EDI standards have a complex, hard-to-learn format; and the lack of interoperability is a concern for EDI users (Zhu et al., 2006). Therefore, the trading partner base of EDI is relatively narrow and typically limited to large firms; smaller organizations cannot take advantage of seamless EDI (Markus et al., 2006; Moore, 2001; Zhu et al., 2006).

2.1.2.3 Internet-Private Coordination Hubs SCF

In the early 2000s, online SCF applications, usually as a part of the online supply chain management system (SCMS) led by individual supply chain orchestrators, began to emerge. They attempted to digitize trade and streamline transactions between trading parties, primarily offered as Software-as-a-Service (Daniel & White, 2005; Rogers et al., 2016; Shakir et al., 2007). With this technology, participants can transact digitally with trade data being stored in a centralized-control database, owned and operated by a third-party vendor.

Concerning IOS standards, these online central platforms use open standards and therefore can provide advantages such as low installation costs, reduced complexity, great flexibility, and scalability when compared with EDI standard (Andrew, 2011; Henderson, 2010; Xiao & Hedman, 2019); nevertheless, they introduce issues around data custody, security, and privacy, because a single dominant company or third-party controls and manages all data (Benlian et al., 2018).

Regarding IOS architecture, private coordination hubs feature multilateral relationships and enable real-time information sharing among all participants (Steinfield et al., 2011, Yao et al., 2009). However, they cause adoption problems for smaller, remote, and peripheral members of the supply chain. Since a private hub is set up for a specific supply chain orchestrator, it forces suppliers to bear the costs and inefficiencies of using duplicate procedures and technologies across the companies with which they do business. Moving data and facilitating transactions between different private hubs is still costly, complex, bespoke, and risky (Steinfield et al., 2011).

2.1.2.4 Internet-Shared Coordination Hubs SCF platform

Since the 2010s, Internet-based financial technology (FinTech) SCF platforms, primarily functioning as cloud-based software platforms, began to rise and act as intermediaries in facilitating transactions between focal companies and their suppliers (Rogers et al., 2016).

The main distinction between SCF platforms and SCM-based SCF is the IOS architecture, that SCF platforms involve multiple dominant companies and their suppliers, not just a single dominant company in supply chains. Thus, SCF platforms can be used by suppliers of any buyers participating in the shared coordination hub, reducing some of the interoperability issues that have historically prevented full adoption of point-to-point architecture and private coordination hubs (Steinfield et al., 2011).

2.1.2.5 Blockchain-driven SCF platform

Blockchain technology instigates the most recent and fastest-growing phase of IT applications to SCF. The central technical innovation associated with blockchain is distributed ledger technology (DLT), which is defined as the use of decentralized digital trust verification through encrypted digital signatures (Gomber et al., 2018).

An extensive body of literature has described how blockchains work (e.g., Biais et al., 2019; Chiu & Koeppl, 2019; Cong & He, 2019; Pedersen et al., 2019; Yermack, 2017). In general, blockchain is shared among multiple parties. To perform a transaction, users reference each other through their public keys and use their private keys to cryptographically sign transactions. Each successful transaction on the blockchain indicates an update to the database that is replicated and stored by each participant. Transactions are aggregated and appended to the database in blocks with time stamping and consecutively chained together over time, and can be automatically managed through smart contracts. There are two basic versions of blockchain: the first one is permissionless blockchain, where anyone can access and potentially update the ledger, such as the Bitcoin; the other one is permissioned blockchain (commonly applied in B2B networks, also in SCF platforms), where only a set of trusted validators with known identities has access to the blockchain and can update it, such as Hyperledger (Biais et al., 2019).

In the aspect of IOS standards, blockchain-driven SCF platforms are also open standard systems; thus, they have advantages of low installation costs, reduced complexity, great flexibility, and scalability, just like the Internet. But different from extant Internet-based SCF platforms, a blockchain-driven SCF platform has a higher level of information reliability and verification as a key benefit (Felin & Wilson, 2018), because every participating organization has an exact copy of the same digital ledger; transactions on the shared ledger are immutable, which means every party can be confident that they are dealing with immutable data (Lacity, 2018; Pedersen et al., 2019). Besides, with one version of the truth transparently available to all parties and the application of smart contracts, there are no manual reconciliations, which enables faster transaction time and lower transaction costs (Lacity, 2018; Pedersen et al., 2019).

In the aspect of IOS architecture, extant blockchain-driven SCF platforms are primarily in shared coordination hubs, which means that all related participants can share real-time information without interoperability issues (Felin & Wilson, 2018). Suppliers can enjoy the notion of connect-once-to-connect-to-many, whereby participants require only one interface and a single integration to transact with all other participants across the platform.

According to Euro Banking Association (2014) and PwC (2018), SCF solutions faced several challenges: 1) supplier onboarding problem; 2) only ‘top slice’ suppliers are invited but ‘upper-tier’ suppliers (mainly SMEs) face limited financing or with a high-interest rate; 3) complex and costly manual financing processes; 4) lack of accurate and real-time data; 5) lack of efficient inter-organizational collaboration; 6) lack of trust infrastructure. Table 3 compared the performances of the above five SCF IT solutions about these challenges.

There are two unique advantages of blockchain-driven SCF platforms. First, blockchain provides a trust infrastructure, where transactions and asset ownerships are immutable and traceable, which is very essential for financial institutions' onboarding and their KYC process to control customers' credit risks. For example, even though traditional B2B platforms provide informations about the products, logistics and payments, the data reliability and traceability are not enough for the financial institutions to meet the requirements of the Basel Accord. Banks still need to spend a significant amount of time and human resource validating the transaction information. Besides, due to the data asymmetry among financial institutions, tranditional SCF certificates (such as the Letter of Credits) can be collateralized multiple times at different financial institutions. In the blockchain-driven SCF platforms, with the DLT and time stamps, transaction information and financing information is traceable and immutable; thus financial institutions can easily follow the transaction processes and avoid the multiple collateral problems, which will facilitate the KYC process and save the due diligence cost dramatically. Second, the blockchain-enabled tokenization of focal buyer's credit allows the focal buyer to deliver credits, which provides upper-tier suppliers with low-cost financing. Traditonal SCF solutions usually reach out to the direct suppliers, while the n-tier suppliers still have difficulties in obtainging financial supports. In a blockchain-driven SCF application, focal companies can issue "cash tokens" which can be seen as a blockchain-based electronic invoice and the "cash tokens" can be divided infinitely, and then be delivered to mid-tier suppliers and upper-tier suppliers based on transactions in supply chains. Using cash tokens issued by high credit level focal buyers as collateral, upper-tier suppliers are capable to obtain loans from banks at a lower interest rate.

	Ideal SCF Solutions	LCs	EDI	Cloud SCM	Cloud SCF platform	Permissioned BCT SCF platform
1	Easy, fast, and cheap supplier onboarding process			√	√	√
2	Multitier suppliers with a low financial cost					√
3	Automated process		√	√	√	√ (better)
4	Accurate, real-time data sharing			√	√	√ (better)
5	High inter-organizational collaboration and interoperability				√	√
6	Trust infrastructure/ data immutability and traceability					√

Table 2.3 Comparison of performance in different SCF IT solutions

2.2 SCF Economy

One stream of the literature in the SCF economy primarily uses analytical models to revolve how SCF affects financing costs, especially for SMEs with limited access to financing. Tunca & Zhu (2018) focus on the buyer intermediation in SCF. They build a game theory model to show that buyer intermediated financing can reduce financial interest rates, increase order fill rates, and boost supplier borrowing. Lekkakos & Serrano (2016) find that SCF can release more than 10% of the supplier's working capital as the SME suppliers get paid earlier. Van Der Vliet et al. (2015) use simulation optimization to explore how payment terms allow buyers and suppliers to benefit from SCF. They find that payment term extension induces a non-linear financing cost for the supplier, beyond the opportunity cost of carrying additional receivables. Furthermore, the size of the payment term extension depends on demand uncertainty and the cost structure of the supplier.

Another stream of SCF research relevant to our study is the exploration of drivers and strategies of SCF adoption. Wuttke et al. (2019) uncover key drivers of supplier adoption speed in SCF applications on organizational motivation. The authors combine efficiency motive drivers with legitimacy motive drivers and find that suppliers with more limited access to financing tend to adopt SCF faster. Also, suppliers adopt SCF faster if such adoption is associated with more pronounced reductions in their financing costs. Legitimacy motive drivers also impact supplier adoption speed. Specifically, mimetic and normative pressures accelerate the speed at which suppliers adopt SCF, while coercive pressures seem to have such an effect only when the buyer's stakes are high. Liebl et al. (2016) focus on the objectives of SCF which include extending days payable outstanding, the reduction of supplier default risk and process simplifications. Besides, they identify that the number of integrated suppliers, dependence of suppliers on their buyers, spread between internal refinancing and SCF costs and the diversity of target agreements strongly influence these objectives and the adoption of SCF. Wuttke et al. (2016) use a diffusion model to obtain insights regarding a buyer's optimal SCF adoption in terms of timing and payment terms. They find that initial payment terms and procurement volume affect the optimal timing of SCF adoption and optimal payment term extensions; the buyer’s influence on suppliers affects the optimal introduction timing, but not optimal payment terms. They also suggest that some buyers should hold off on SCF adoption.

2.3 Summary of Literature Review

Extant SCF literature on technology has acknowledged the critical role of IT on intra and inter organization information sharing, but detailed analysis of IT factors in SCF remains rare. Blockchain-related literature on supply chains mainly focuses on supply chain management, yet little discussing about financing issues. Thus, there is still a research gap of the application of blockchain technology to SCF.

First, prior work has a consistent theme that information flow has to match the physical goods flow in a supply chain. They cannot explain how the information flow will change the physical goods flow in the blockchain-driven SCF, i.e., the interactions between information flow and goods flow. Blockchain technology has a unique advantage that it can create a highly trusted, decentralized information environment. Thus, the information flow in blockchains (i.e. “tokens”) not only have information value but also have financial value. It enables the liquidity availability of upper-tier suppliers and further influences the supply chains’ goods flow. And more interestingly, this is not a static process. The changes in goods flow can in turn affect the mid-tier suppliers’ token delivery behaviors and then influence the upper-tier suppliers’ liquidity. This paper explains how the token flow and goods flow interact and evolve in the blockchain-driven SCF platforms.

Second, our study builds a model on multitier suppliers. We classified three levels of supply chain participants: focal buyers, mid-tier suppliers, and upper-tier SME suppliers. Prior studies tend to build an analytic model either in dyadic (i.e., focal buyers and their direct suppliers) or triple parties (i.e., focal buyers, their direct suppliers, and financial institutions), very few in multitier supply chain networks. However, suppliers in different tiers should possess unique characteristics. Upper-tier suppliers are usually SMEs with a higher level of competitive pressure (Choi & Hartley, 1996). Besides, upper-tier suppliers usually face financial constraints (Cragg & King, 1993; Raymond, 2006) and thus less stable than mid-tier suppliers. SME managers with financial constraints have increased willingness to take on new risks (Bromiley, 1991), as managers of stressed organizations make riskier choices (Tversky & Kahneman, 1981).

Considering the relatively low setup cost, SMEs are more likely to make expansion when they obtain extra liquidity.

Third, most prior researches tend to revolve around how SCF affects financing costs, but we explore the motivations of suppliers in blockchain-driven SCF by three kinds of factors: transaction costs, financial costs, and competitive conditions. Our study is at the junction of SCF business and information technology. Blockchain-driven SCF is not only a financial innovation but also an information technology innovation. Extensive studies have demonstrated the significant role of IT in SCF applications and a key benefit is reduced transaction costs. We view transaction costs and financial costs as internal factors; meanwhile, organizations' decision-making is also influenced by the external environment, i.e., competitive conditions. Thus, our conceptual framework is more comprehensive than prior studies.

Finally, the long-term applications of SCF are still understudied by prior researches. Most prior studies demonstrate the short-term benefits of SCF applications towards suppliers (e.g., Lekkakos & Serrano, 2016; Tunca & Zhu, 2018; Van Der Vliet et al., 2015), very little researches considering the dynamic characteristics of supply chain participants and market power (Iacono et al., 2015). Our study focuses on the long-term dynamics of supply chain participants and the competitive environment, which can facilitate the long-term development of blockchain-driven SCF.

3. Research Setting

According to our interview at a Chinese blockchain-driven SCF platform in the steel industry, the process of a blockchain-driven SCF platform is illustrated in Figure 3.1. This platform is in a buyer-lead SCF architecture where focal buyers initiate the process of financing and the finance is done with the focal buyers' credit risk. This platform focuses on the accounts payable finance service for the mid-tier and upper-tier suppliers. In each transaction, cash tokens are issued by focal buyers and then paid to their direct suppliers based on the transaction amount. The cash tokens can be seen as blockchain-based electric invoices with due days of payment and are infinitely divisible. The first-tier suppliers can continue delivering the cash tokens to the second-tier suppliers (i.e., token delivery), or hold the cash tokens to maturity, or obtain loans from financial institutions in advance within the number of cash tokens, and so forth. Since the cash tokens are delivered tier by tier through transactions, upper-tier suppliers (usually SMEs who need loans most) must depend on the mid-tier suppliers' token delivery.

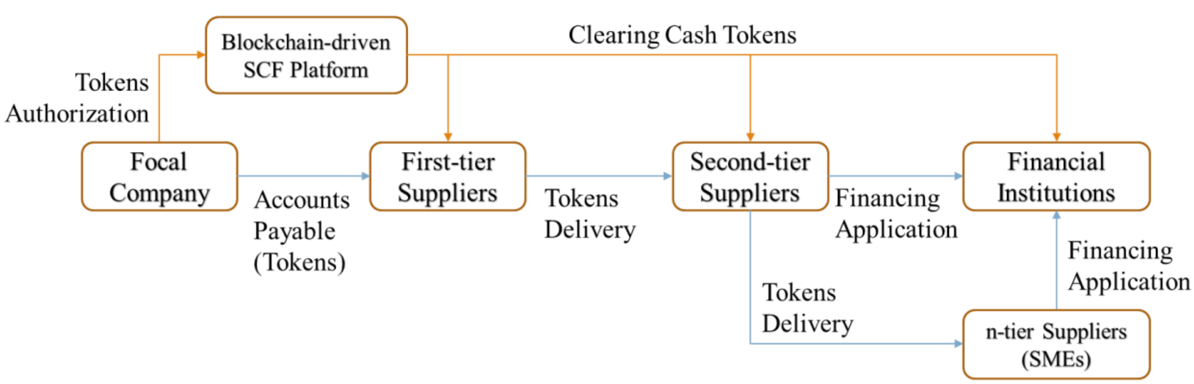


Figure 3.1 Business process in blockchain-driven SCF platforms

In this process, we define three tiers of supply chain companies according to their firm size, financing ability, transaction position, and permissioned authority in the blockchain-driven SCF platforms.

(1) Focal buyers: Large companies with high credit ratings, high financing capability, and low financing interest rate. Focal buyers are usually the most central and powerful firms in the supply chains. Only focal buyers are capable of authorizing cash tokens.

(2) Mid-tier Suppliers: Suppliers that are usually medium sized companies with moderate credit ratings and financing capability, but they are capable of obtaining loans from banks directly with a moderate financial cost. They are usually direct suppliers or the second-tier suppliers of focal buyers. They can choose to deliver the cash tokens, or not (i.e., holding the cash token to maturity or financing from banks directly).

(3) Upper-tier Suppliers: Suppliers who are usually SMEs and unable to obtain loans from banks without the authorized cash tokens. They are usually in the upper-tier of the supply chains and can only get the tokens from mid-tier suppliers.

	Firm Size and Financing Ability	**Supply Chain Position**	**Permissioned Token Ability**
Focal buyers	Large companies with high financing ability	Focal companies (0-tier)	Authorization
Mid-tier suppliers	Medium-size firms with moderate financing ability	1 or 2-tier suppliers	Delivering the tokens or holding tokens to maturity or financing
Upper-tier suppliers	SMEs with very low financing ability	At the end of supply chains	Holding tokens to maturity or financing

Table 3.1 Summary of the three-levels supply chain participants

In the blockchain-driven SCF platforms, one advantage is their decentralized ability to finance upper-tier suppliers and thus to improve the liquidity of the whole supply chains.

However, in this process, we can see that upper-tier suppliers token availability still depends on mid-tier suppliers' delivery. In other words, even though blockchain technology helps to increase information transparency, reliability, and improve transaction efficiency, the decentralization of liquidity is still built on the centralized supply chain transaction structure. Thus, there comes to a negotiation between the decentralized blockchain structure design and centralized supply chain network structure; and one of the most important roles is the mid-tier suppliers. Our study will further explore how the tokens flow and goods flow interact in the blockchain-driven SCF platforms over time.

4. Conceptual Model and Proposition

4.1 Conceptual Model

In this section, we analyze how the mid-tier suppliers' token delivery motivations change over time in a cost-benefit framework including internal factors (transaction costs and financial costs) and external factors (competitive conditions), with the theoretical lens of transaction cost theory, industrial organization (IO) economics, and slack resource literature.

First, blockchain-driven SCF is a technological innovation (Wuttke et al., 2019); thus, we try to frame our conceptual model and develop the propositions by drawing upon the literature which explores the drivers of technology adoption and utilization at the firm level, especially in a B2B network. One key idea in this research stream is that firms tend to join B2B networks due to two primary motivations: efficiency or legitimacy (e.g., Grewal et al., 2001; Liu et al., 2016; Son & Benbasat, 2007; Wuttke et al., 2019). The efficiency-oriented perspective, drawing on transaction cost theory (Williamson, 1981), suggests that organizations adopt B2B applications based on the rationalistic expectation of enhancing the economic efficiency or decreasing costs of their transactional processes. On the other hand, according to institutional theory (DiMaggio & Powell, 1983), organizations that embrace the legitimacy-oriented perspective as their primary motive for adopting B2B applications put greater emphasis on social norms and institutional expectations. Prior studies identified three specific types of external institutional pressures facing an organization: mimetic, coercive, and normative pressures (DiMaggio & Powell, 1983; Grewal et al., 2001; Son & Benbasat, 2007).

However, in our research framework, we focus on the perspective of efficiency-oriented explanation, i.e., transaction costs. We view mid-tier suppliers' token delivery as one kind of IT utilization in the post-adoption period, rather than IT adoption. Factors strongly influential in explaining the initial adoption of an IT innovation may be less influential in explaining its continued use (Son & Benbasat, 2007). According to Klonglan et al. (1970), sociological variables are superior to economic variables in explaining initial adoption, but economic variables best explain continued use. Likewise, within the context of IOS, the findings of studies on EDI adoption (Chwelos et al., 2001) and on EDI usage (Son et al., 2005) reveal that trading partner pressures heavily and positively influence EDI adoption, but not EDI usage. Liu et al. (2016) direct an empirical study and find that at the stage of utilization, the relationship between institutional factors and supply chain technology utilization is less significant or even negligible. Thus, we assume that in blockchain-driven SCF platforms, mid-tier suppliers have a strong motivation to deliver cash token when token delivery can enhance their economic efficiency.

Second, through an extensive literature review, we find that, besides transaction costs, prior studies on SCF also tend to build economic models around how SCF affects financing costs (e.g., Lekkakos & Serrano, 2016; Tunca & Zhu, 2018; Van Der Vliet et al., 2015). SCF is not only a technology innovation but also a financial innovation. Prior researches have provided solid evidence that SCF is a win-win solution to both buyers and suppliers concerning financial costs. Thus, we frame our conceptual model by involving financial cost as well.

Last but not the least, as transaction costs and financial costs are usually generated within the transactions, we view transaction costs and financial costs as internal factors. However, organizational decision-making is also influenced by the external environment, i.e. competitive conditions. Barney (1986) suggests that research in business strategy usually is aimed at developing normative theories that firms can apply in choosing strategies that generate high returns on investments (Henderson, 1979; Porter, 1980). Much of this research rests on the observation that the nature and character of the competitive conditions facing a firm determines a firm's strategic selection, as well as the return potential of those strategies (Barney, 1986). According to the industrial organization (IO) economics (Caves, 1980; Porter, 1980, 1981), returns to firms are determined by the structure of the industry within which a firm finds itself. The key attributes of an industry's structure that are thought to have an impact on firm returns include: 1) the existence and value of barriers to entry, 2) the number and relative size of firms, 3) the existence and degree of product differentiation in the industry, and 4) the overall elasticity of demand for the industry (Porter, 1980, 1981). Industries with large barriers to entry, a small number of firms, a large degree of product differentiation, or low demand elasticity allow firms to earn higher returns than firms in industries without these attributes (Barney, 1986). The relationship between the structural characteristics of industries and performance of firms have come to be known as the structure-conduct-performance (SCP) paradigm, for firm conduct (i.e., strategy) and performance are presumed to follow directly from an industry's structural attributes (Porter, 1981); meanwhile, the relationships among structure, conduct, and performance are not unidirectional and that industry structure is in turn influenced by firms' conduct and performance (Scherer & Ross, 1990). Thus, we frame competitive conditions into the conceptual model, and with the SCP paradigm, explore how the tokens delivery influences the competitive conditions faced by mid-tier suppliers and how the change of competitive conditions, in turn, affects the mid-tier suppliers' tokens delivery.

Figure 4.1 shows our conceptual model and Table 4.1 explains the relationships in it.

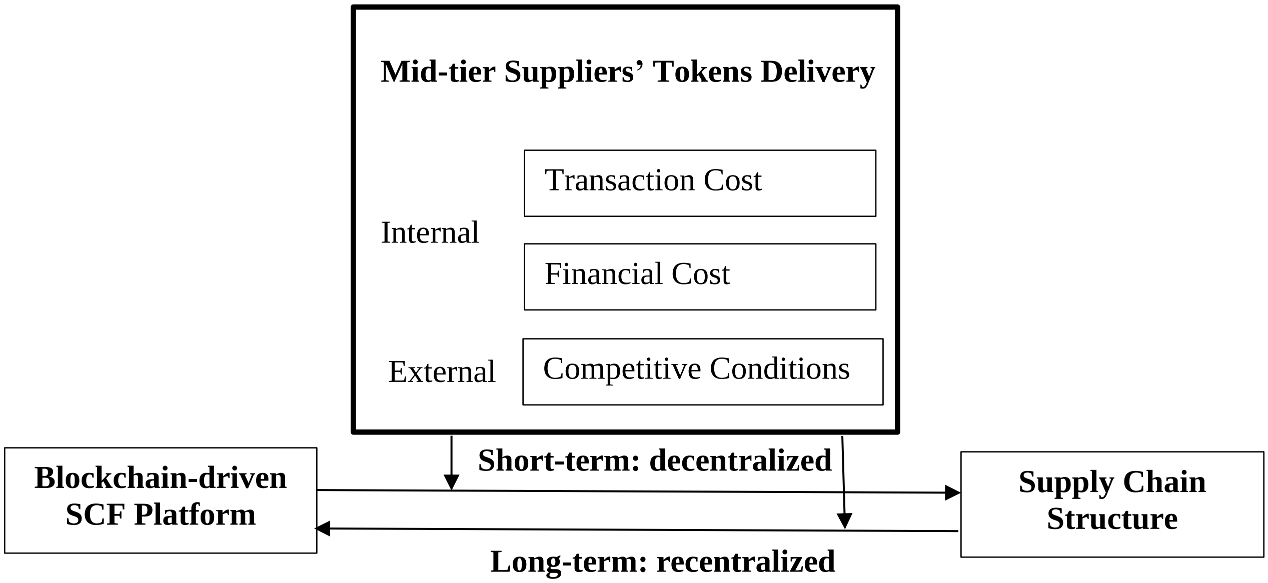


Figure 4.1 Conceptual Model

	Internal Factors (Benefit)	**External Factors (Cost)**	**Overall Effects on Supply Chain Structure**
Short-term (P1)	Transaction costs and financial costs decreased	Competitive pressures fluctuate	Decentralized
Long-term (P2)			Recentralized

Table 4.1 Summary of relationships in the conceptual model

4.2 Proposition Development

In short term, we posit that the mid-tier suppliers' token delivery motivations are mainly influenced by internal factors.

According to transaction cost theory (Rindfleisch & Heide, 1997; Williamson, 1981), transaction costs are the "costs of running the system" and include such ex-ante costs as drafting and negotiating contracts and such ex-post costs as monitoring and enforcing agreements (Coase, 1937). Transaction costs include both the direct costs of managing relationships and the possible opportunity costs of making inferior governance decisions (Rindfleisch & Heide, 1997). Transaction costs refer to the effort, time, and costs incurred in searching, creating, negotiating, monitoring, and enforcing a service contract between buyers and suppliers (J.T., 1992). Williamson's microanalytical framework rests on the interplay between two main assumptions of human behavior (i.e., bounded rationality and opportunism) and two key dimensions of transactions (i.e., asset specificity and uncertainty).

In the context of IOS, many researchers have developed both conceptual models and empirical studies under transaction costs theories to explore how IT contributes to transaction effectiveness and efficiency and then affects the firm's governance structure. For example, Malone et al. (1987) suggest that electronic commerce leads to greater use of markets, rather than hierarchies, because these markets have relatively lower transaction costs. They explained that on the one hand, new information technologies have greatly reduced both the time and cost of communicating information, which they called electronic communication effects; on the other hand, electronic coordination can be used to take advantage of the electronic brokerage effect (i.e., electronic markets can electronically connecting many different buyers and suppliers in a fast, convenient and inexpensive way and thus significantly decrease buyer searching costs) and the electronic integration effect (i.e., information technology is used to change and lead to tighter coupling of the processes that create and use the information). Hess & Kemerer (1994) developed empirical research on computerized loan origination systems supporting this assertion. Son & Benbasat (2007) identified that firms often adopt B2B e-marketplaces due to expectations about improved transaction efficiency and effectiveness.

Blockchain-driven SCF is technological innovation. In section 2, we have summarized the IT development in SCF, described how blockchain works, and made a comparison between the different IT solutions. In general, blockchain-driven SCF platform is capable of providing faster, more transparent, and decentralized transaction structures. Huber (1990) sets forth a framework about the effects that advanced communication and decision-aiding technologies have on organizational intelligence and decision making. According to his framework, the key IT's impacts on organization intelligence and decision making include increasing information accuracy, increasing efficiency, reducing communication costs, and broadening communication scope (Huber, 1990; Malone, 1997). Similarly, compared with traditional SCF (i.e., LCs, EDI-based SCF, Internet-based SCF), blockchain-driven SCF platforms' impacts on mid-tier suppliers' transactions are summarized in table 4.2.

Impacts	**Traditional SCF**	**Blockchain-driven SCF**
Information Accuracy/ Reliability/ Transparency	**Low**: Central controlled, Fake risk	**High**: Distributed ledger technology (DLT) Data immutability
Efficiency	**Low**: Intermediate-based transactions Partially automated process	**High**: Point-to-point transactions (Disintermediate) Just-in-time automated processes (Smart contracts)
Communication Cost	**High**: Relatively low interoperability Manual process involved	**Low**: High interoperability Automated processes
Transaction Scope	**Narrow**: 1-2 tier suppliers	**Broad**: Upper-tier suppliers

Table 4.2 Impacts Comparison of Traditional SCF and Blockchain-driven SCF

Consistent with Malone et al. (1987), we propose that blockchain-driven SCF platforms also have electronic information effects, information breakage effect, and information integration effect and thus capable to reduce mid-tier suppliers' transaction costs. First, in the aspect of electronic information effects, with the application of DLT and smart contracts blockchain-driven SCF can realize just-in-time information sharing in high information accuracy and transparency. Second, in the aspect of information breakage effect, blockchain-driven SCF platforms can connect not only 1 or 2 tier suppliers but also upper-tier suppliers with low onboarding and communication costs. Thus, supply chain participants can find business partners and make transactions in a faster, safer, and less expensive way. Third, in the aspect of information integration effects, blockchain-driven SCF platforms can realize the integration of goods flow, information flow, and cash flow in supply chains. All those characteristics of blockchain-driven SCF help to decrease opportunisms and uncertainties in transactions and thus decrease transaction costs between firms.

Regarding financial costs, prior studies have agreed that SCF is a win-win solution for both buyers and suppliers on financial costs reduction (e.g., Lekkakos & Serrano, 2016; Tunca & Zhu, 2018; Van Der Vliet et al., 2015; Wuttke et al., 2019). For buyers, the SCF solution makes it possible to extend payment terms and thus reduce working capital; for suppliers, SCF provides a more accessible and cheaper financing source than traditional bank financing. In this paper, compared with traditional SCF, blockchain-driven SCF has a broader transaction scope where the cash token can not only reach 1 or 2 tier suppliers but also upper-tier suppliers. According to our research setting, we assume that mid-tier suppliers are normally medium or large size firms with moderate financing ability and interest rate; but upper-tier suppliers are usually SMEs with limited financing options and high-interest rates. Thus, we postulate that the financial cost reduction and liquidity improvement benefits should become more and more significant as the cash token is delivered deeper and deeper in the blockchain-driven SCF platforms.

Proposition 1 (a): *In the short term, the application of blockchain-driven SCF reduces mid-tier suppliers' transaction cost and financial cost, thus positively incentivizes mid-tier suppliers to deliver tokens and facilitates upper-tier suppliers' liquidity.*

As we described, one unique advantage of blockchain-driven SCF platforms is that the high-level data reliability and verification enable trusted tokenization of focal companies' credit. Through token delivery of mid-tier suppliers, upper-tier suppliers can get low-cost financing readily and quickly. In other words, blockchain-driven SCF increases upper-tier suppliers' financial liquidity significantly.

Prior slack resource literature has stressed the importance of resource slack as a driver of firms' growth (e.g., Bamford et al., 2000; Cooper et al., 1994; Penrose, 1959). Slack is a financial capability which can be diverted or redeployed to develop other internal capabilities in firms (George, 2005; Nohria & Gulati, 1996). Thus, it is central to the development of every firm (Dollinger, 1995). Scholars have shown that financial slack facilitates the growth of firms developing new products (Mishina et al., 2004), and influences managerial risk-taking (Steensma & Corley, 2001). Thompson (1967: 150) suggests that slack endows a firm with the ability 'to take advantage of opportunities afforded by the environment,' and some empirical researches also find that slack is positively associated with firms' expansive aggressiveness (Ang & Straub, 1998; Jensen, 1989; Rauh, 2006). Financial resource slack refers to liquid financial resources that are "in excess of what is needed for a firm to meet its current commitments and support current sales levels," and provides management with flexible resources to take advantage of growth opportunities (Mishina et al., 2004). The availability of slack resources facilitates decisions that do not necessarily respond to short-term demands but focus on new paths (Hutzschenreuter et al., 2007; Nohria & Gulati, 1996; Simsek et al., 2007). Slack resources can offer managers leeway to explore emerging opportunities by increasing their confidence in their ability to execute new courses of action (Ajzen, 1991; Hutzschenreuter et al., 2007). Resource slack may enable organizations to divert attention away from "firefighting" and enable them to focus on expansive thinking and risky, innovative ventures with potentially high payoffs (Voss et al., 2008), and to pursue new projects, improve processes, or develop new markets (Simsek et al., 2007).

In our research setting, upper-tier suppliers are usually SMEs with distinct characteristics from big companies. First, in the aspect of resources, small businesses usually suffer from resource poverty (WELSH & A., 1981), because small businesses tend to be clustered in highly fragmented industries with many competitors which are prone to price-cutting as a way to build revenues. In the context of IS, lots of prior researches mentioned that small businesses have limited financial sources and low levels of IT sophistication (e.g., Cragg & King, 1993; Mehra et al., 2014; Raymond, 2006; Street & Meister, 2017). Second, in the aspect of competitive characteristics, Dean et al. (1998) argue that smaller businesses more actively initiate competitive challenges, and are also seen as being quicker and nimbler in executing their challenges, due to structural simplicity, streamlined operations and by limiting their competitive moves to narrow domains (Chen & Hambrick, 1995). Other reasons include a lack of structural inertia (Hannan & Freeman, 1984), entrepreneurial-oriented and/or risk-seeking leadership (Hitt et al., 1991; Woo, 1987), faster decision speed (Chen & Hambrick, 1995), and targeted innovation (Hamermesh et al., 1978). In contrast to large firms that may view low amounts of financial slack as insufficient to support new initiatives (Tseng et al., 2007), SMEs may perceive a lack of financial cushion as additional pressure to find a way to survive. The result is an increased willingness of SME managers to take on new risks (Bromiley, 1991), as managers of stressed organizations make riskier choices (Kahneman & Tversky, 1979). In a word, upper-tier suppliers are normally in a highly competitive and unstable market structure with a relatively high expansive aggressiveness compared with mid-tier suppliers.

Besides, MacDonald (1985) finds that firms are more likely to enter industries that are related to their primary activities. In a supply chain, firms usually collaborate to finish the final goods productions and sales. For example, in the steel industry, supply chain participants should include various mining companies, coal/iron/other industrial materials processing companies, steel mills, steel processing companies, etc. The activities among supply chain firms are related, especially among adjacent buyers and suppliers. Vertical expansion can facilitate companies to control inventory, lower transaction cost and uncertainty, and improve bargaining powers in the supply chains.

Thus, we propose that upper-tier suppliers are more likely to make expansions, i.e. building new transactions with new mid-tier suppliers to grow sales, or even with the focal buyers, when they get excess financial liquidity. Under this situation, the supply chain structure is decentralized by the blockchain-enabled token delivery.

Proposition 1 (b): *In the short term, mid-tier suppliers' token delivery makes highly-centralized supply chain transaction structure more decentralized.*

However, we argue that a dynamic competitive condition and token delivery motivations of mid-tier suppliers change over time. According to industry organization (IO) economics, the key attributes of an industry's structure that are thought to have an impact on firm competitive conditions include: 1) the existence and value of barriers to entry, 2) the number and relative size of firms, 3) the existence and degree of product differentiation in the industry, and 4) the overall elasticity of demand for the industry (Porter, 1980, 1981). In this paper, we suggest that the change of supply chain structure mainly influences the number and relative size of mid-tier and upper-tier suppliers and thus influence the competitive conditions of upper-tier and mid-tier suppliers (See Table 4.3, here we make the qualitative analysis first).

	Number of upper-tier suppliers	**Firm size of upper-tier suppliers**	**Number of mid-tier suppliers**	**Firm size of mid-tier suppliers**	**Competitive Pressure – Mid-tier**
Short-term	Increase	-	-	-	Decrease
Long-term	Decrease	Increase	Increase	-	Increase

Table 4.3 Competitive conditions of upper-tier and mid-tier suppliers

Wuttke et al. (2019) found that suppliers with more limited access to financing and with larger estimated financial cost reductions adopt SCF faster. The reduction of both transaction costs and financial costs will attract more suppliers to join the SCF platform. But considering upper-tier suppliers are with more limited financing sources and higher original financial costs, the number of upper-tier suppliers will increase much faster than mid-tier suppliers, which leads to higher competitive pressure in upper-tier suppliers. According to Porter (1980, 1981), the competitive pressures increased in suppliers have a positive influence on the competitive conditions of buyers. Thus, we propose that in short term, the competitive condition of mid-tier suppliers will improve with the adoption of blockchain-driven SCF platforms, and thus positively incentivize mid-tier suppliers' token delivery, which is consistent with *Proposition 1 (b)*.

However, as we described above, the supply chain structure can be decentralized by the blockchain-enabled token delivery. Some of the upper-tier suppliers can make expansion and grow into mid-tier suppliers, thus the number of mid-tier suppliers will increase, which will lead to higher competitive pressure for the mid-tier suppliers. For the upper-tier suppliers, improved financial slack helps them to make expansion and thus increase their firm size or even grow to mid-tier suppliers; on the other hand, through serious competition in short term, some weak upper-tier suppliers are probably failed and only strong companies survive. Thus, the number of upper-tier suppliers should decrease. In summary, with the increased firm number in mid-tier suppliers, the increased firm size, and decreased firm number in upper-tier suppliers, the mid-tier suppliers' competitive pressure will rise and then negatively influence their token delivery motivation.

Without mid-tier suppliers' token delivery, the liquidity of upper-tier suppliers will become limited again. Then, upper-tier suppliers are difficult to expand production and build new transactions. They may also not have enough financial liquidity to support the established transactions before. Thus, the upper-tier suppliers will probably decrease their original transactions and the supply chain structure will become more centralized again.

Proposition 2: *In the long term, the more decentralized supply chain structure will in turn increase the competitive pressure of mid-tier suppliers, and thus negatively affect the mid-tier suppliers' tokens delivery and upper-tier suppliers' liquidity. Then the supply chain structure will become more centralized gradually.*

The dynamic changes of mid-tier suppliers' competitive conditions, token delivery motivations, and supply chain structure are summarized in figure 4.2.

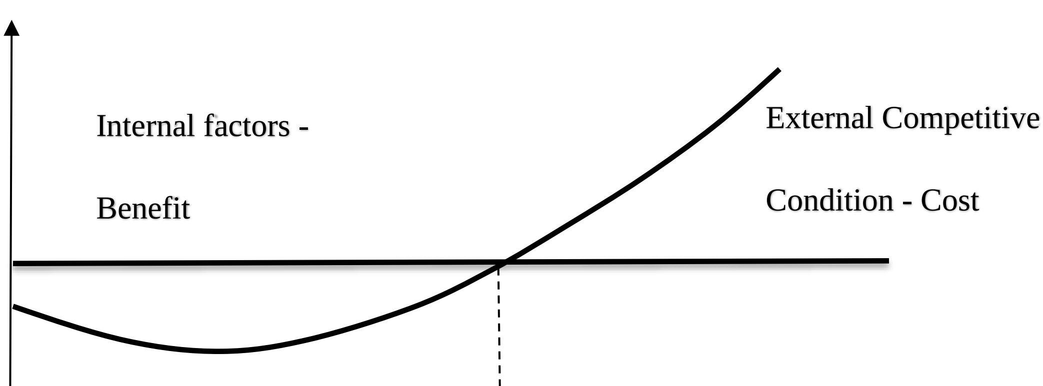


Figure 4.2 Dynamic changes of mid-tier suppliers' competitive conditions, token delivery motivations and supply chain structure

5. Complex Adaptive Systems and Agent-Based Model

Complex adaptive system (CAS) theory is an ideal overarching framework for our development of a testable model of the propositions presented earlier. Complex adaptive systems are defined as "systems composed of interacting agents described in terms of rules. The agents adapt by changing their rules as experience accumulates" (Holland 1995, p. 10). CAS studies focus on nonlinear dynamic changes and views interactions as the source of the changes (Nan, 2017). Examples of a CAS include a natural ecosystem, a group of competing companies, and the traffic actions of vehicles, etc. CAS theory has proved a valuable framework in many management theory development studies (e.g., Haki et al., 2020; Malgonde et al., 2020; Nan, 2011; Nan, 2017; Sandberg et al., 2020).

In this section, considering the multilevel, interactive, and dynamic natures of supply chain networks, we conceptualize supply chain networks as complex adaptive systems, which has been demonstrated by prior studies as well (e.g., Harvey, 2016; Nair & Reed-Tsochas, 2019; Statsenko et al. 2018; Zhao et al. 2019). By thinking of supply chain networks as CAS, we can interpret the supply chain network patterns in a bottom-up way and develop experimental manipulations that are more likely to be flexible and effective. But the CAS theory integrates rather than replace the cost-benefit theories used to develop our propositions. In other words, the behavior rules of firms in our CAS model are primarily based on economic theories.

5.1 CAS Conception of Blockchain-driven SCF

When examining a complex adaptive system, three concepts become essential: agents, interactions of agents, and an environment (Nan, 2011). Under our research setting, we consider the enterprises comprising the supply chain networks as agents; the tokens delivery and goods transactions among supply chain firms as interactions; and the supply chain structures as the environment. The key illustrative points are summarized in Table 5.1.

	Description of CAS	**Blockchain-driven SCF Illustrations**
Agents	Agents are individual actors or basic entities of actions. Agents are described by attributes and behavioral rules.	Individual supply chain firms work together based on shared norms and economic rules.
Interactions	Interactions are mutually adaptive behaviors among agents. Interactions can be viewed as a function of agents, connections, and flows.	Supply chain firms can select suppliers, decide tokens delivery, and goods transactions.
Environment	The environment is the medium for agents to operate in and interact with (Epstein and Axtell 1996). It is defined by structures and structures characterized by the topography of an environment.	The supply chain network centrality and competitive conditions in the supply chain networks are dynamic.

Table 5.1 Mappings between CAS and blockchain-driven SCF

5.1.1 Agents

As defined above, *agents* are "individual actors or basic entities of actions in CAS" (Nan, 2011). According to this definition, individual supply chain firms in different tiers should be considered as agents that constitute the nodes in the supply chain network. By conceptualizing supply chain firms as agents in blockchain-driven SCF platforms, we can apply the concepts of *attributes* and *behavioral rules* in specifying the mechanisms underlying mutually adaptive interactions among supply chain firms.

Attributes are the internal states of agents. They mainly play three important roles in CAS: first, they provide yardsticks for the fitness of agents (fitness refers to the ability of an agent to achieve a positive payoff during interactions); second, attributes enable agents to select interaction partners and form relational links; third, similarity among attributes allow agents to aggregate into classes (Nan, 2011). In section 4, we developed the propositions in a cost-benefit framework, with the theoretical lens of transaction cost theory, industrial organization (IO) economics, and slack resource literature. Accordingly, the attributes of supply chain firms can be embodied by some financial indicators, such as financing efficiency (e.g., accounts receivable turnover, cash turnover), transaction efficiency (e.g., inventory turnover), operation income, costs, etc. Building on the earlier description of the three roles of attributes in a CAS, using financial indicators as attributes has three specific contributions. First, financial indicators can measure companies' operational and financial performance during the application of blockchain-driven SCF platforms. For instance, the transaction efficiency indicates the ability of firms in realizing productivity gains and the financing efficiency indicates the ability of firms to obtain liquidity. Second, financial indicators make otherwise identical supply chain firms distinguishable, facilitating selective interactions among firms; meanwhile, financial indicators make it more convenient to simulate the firms' behaviors in a cost-benefit framework. Third, financial indicators can reflect the similarities shared by firms in the same tier or industry, which facilitate us to develop manipulations.

Behavioral rules are "the schemata governing agents' attributes and behaviors. They can be considered as a set of input/output statements linking an agent's perception of the world to changes in its internal state or actions" (Nan, 2011). The behavior rules among supply chain firms can be embodied by the basic economic rules associated with the cost-benefit variation. Cost-benefit models have been widely used to analyze people's or organizations' behaviors in both IS and economic studies (e.g., Arazy & Woo, 2007; Hahn et al. 2009; Jen-Hwa Hu et al. 2017). In the blockchain-driven SCF platforms, firms' behaviors can be unfolded into three aspects: blockchain-based information sharing (i.e., using tokens to settle the payments [tokens delivery] or not [holding tokens to maturity]), obtaining liquidity (i.e., using tokens as the collateral to get loans from financial institutes), and making goods transactions (i.e., delivering goods to support production). Among those three behaviors, blockchain-based information sharing enables the tokens financial value. Companies can easily get loans from financial institutions with tokens. Then firms can use the funding to support their goods transactions. In a word, blockchain-enabled information sharing (tokens delivery) is the start of this process, the destination of supply chain firms is to make goods transactions, and obtaining liquidity is an intermediate action to support goods transactions. In this study, one of our goals is to evaluate the success of blockchain-driven SCF application among firms, i.e. whether the application of this platform can help upper-tier suppliers obtain liquidity and then facilitate the whole supply chain networks. And mid-tier suppliers' tokens delivery is a key action. Thus, our focus is the mid-tier suppliers' token delivery and we will use goods transaction amount variation to model mid-tier suppliers' token delivery motivation because goods transaction is the final goal of supply chain firms. We assume that firms only conduct behaviors leading them to get more benefits and fewer payoffs. Accordingly, firms will deliver tokens only if delivering tokens can boost their goods transaction amounts.

5.1.2 Interactions

Interactions refer to "the mutually adaptive behaviors of agents" (Nan, 2011). In the blockchain-driven SCF platforms, due to the data immutability, traceability, and high-transparency, tokens authorized by focal buyers can almost be viewed as a kind of "digital currency”. Thus, we unpack the interactions among supply chain firms into two types: tokens links (tokens flow) and transaction links (goods flow).

In the aspect of token links, mid-tier suppliers can choose to deliver tokens to upper-tier suppliers, or not (i.e., holding the tokens to maturity, or using the tokens as the collateral to obtain loans); upper-tier suppliers can get loans from the financial institution with obtained tokens. In the aspect of transaction links, supply chain firms can select transaction partners and determine their transaction amounts, choose to move into new markets or quit from current markets. Besides, the relationships among these firms vary as reflected in their transaction positions. Companies in the same tier usually have a competitive relationship. Agents’ attributes can be changed by the interactions over time. By examining the interactions between individual-level characteristics and behaviors, we can explore the emergence of collective-level supply chain structure patterns.

5.1.3 Environment

Environment is “the medium for agents to operate in and interact with (Epstein and Axtell 1996). Environmental structures provide important conditions for actions and interactions to unfold; meanwhile, it can be modified by the ongoing interactions of agents” (Nan, 2011). Researchers often discuss environmental structures from the institutional properties of organizations, such as enterprise culture, strategies, and work requirements (DeSanctis & Poole, 1994; Nan, 2011; Orlikowski, 1992). However, as we argued in section 4, we view supply chain firms’ behaviors and interactions as IT utilization in the post-adoption period and will focus on the perspective of efficiency-oriented explanation. Thus, In the blockchain-driven SCF platforms, we conceptualize the supply chain network competitive conditions as the environment, i.e., the number of firms each tier, the centrality of transaction links and token links among supply chain firms. Typically, significant dynamism exists in the competitive conditions of supply chain firms which necessitates constant adaptation. The interactions between tokens flow and goods flow can influence the competitive conditions; meanwhile, the dynamic supply chain competitive conditions will in turn affect the tokens flow and goods flow.

5.2 Agent-based Model Design

Agent-based modeling (ABM) is a good quantitative theory development tool that helps researchers to test the bottom-up causal path proposed by literature-based theorization (Nan, 2017). “By coding the theoretical premises into parameters and algorithms of a computer program, ABM serves as a flexible tool for researchers to conduct ‘what if’ analyses (i.e., counterfactual conditionals) and obtain implications of theoretical propositions that are not easily envisioned in literature-based theorization” (Nan, 2017). Besides, “researchers can statistically analyze numeric data generated by ABM simulations to verify whether the patterns of the causal paths are distinguishable from the patterns of random effects” (Nan, 2017). This ensures the reasonability of our theory propositions.

In our conceptual model, supply chain firms are defined as basic entities that interact with one another. The mid-tier suppliers’ token delivery motivations are affected by their transaction costs and financial costs variation; meanwhile, they are influenced by the dynamic competitive environment. The conceptual model is built on a cost-benefit framework and reflects the relationships between tokens flow and goods flow in the supply chains.

Consistent with the conceptual model, the agent-based model design is based on a cost-benefit framework as well. It includes one focal buyer agent, which can also be viewed as a group of core companies. The number of mid-tier suppliers and upper-tier suppliers is adjustable, through which we can feature different industries or various initial supply chain structures.

When it comes to the conception of transaction costs and financial costs, prior SCF literature usually analyzes transaction costs and financial costs of supply chain firms in the view of monetary value. However, the blockchain-driven SCF platforms not only save supply chain partners' monetary cost, but also improve their financing efficiency and transaction efficiency, e.g., reducing the cycle time of financing requests/activities/loan applications, reducing the time used to check accuracy and reliability of transaction information, and facilitating to settle contract disputes. We know that time has monetary values. Firms can make more transactions and generate greater income if they have higher financing efficiency or transaction efficiency. Thus, the monetary value and temporal value should be convertible between each other; and in order to simplify our agent-based model, we use firms' transaction efficiency/ability to conceptualize the transaction costs variation and firms' financing efficiency/ability to conceptualize the financing costs variation. Besides, we standardize these two factors (i.e., the values are set from 0 to 1 to represent the abilities), because we will focus on the variations of these two factors over time, and standardization makes it easier to make comparisons between different companies. Companies with higher financing efficiency and higher transaction efficiency are capable of getting more orders and increase their transaction incomes.

Tokens are another important factor in our conceptual model. Even though tokens are the embodiment of information, their immutability, traceability, and high-transparency features enable them to have financial values. Thus, we consider tokens as a kind of digital currency and tokens can positively affect firms financing efficiency. Besides, in section 4 we have indicated that blockchain-driven SCF platforms have electronic information effects, information breakage effect, and information integration effect and thus capable to reduce firms' transaction costs and improve firms' transaction efficiency. Accordingly, in our agent-based model, we argue that firms can get higher financing efficiency and transaction efficiency depending on their token amount.

According to the behavior rules of firms, in blockchain-driven SCF platforms, mid-tier suppliers' tokens delivery determines the tokens' availability to upper-tier suppliers. We use token delivery motivation as a key antecedent to mid-tier supplier's token delivery behaviors. We argue that the token delivery motivation is determined by the firms' transaction income variation. If one company cannot realize at least the same amount of transaction income in one period compared with last period, then this company will change its token delivery motivation. We model mid-tier suppliers' token delivery motivation as a function of their transaction incomes because realizing goods transaction is the final goal of firms, and transaction incomes are not only affected by firms' financing efficiency and transaction efficiency but also influenced by the competitive conditions, which is consistent with our conceptual model. In our conceptual model, we analyze the competitive condition dynamics in two aspects: the number of firms in each tier of a supply chain and firm sizes. In the agent-based model, the number of firms in each tier is a consequence of the change of supply chain structures; and the firm size is measured by firms' equity. We assume that the total demands of focal buyers are constant. If the number of mid-tier suppliers increases (decreases), their competitive pressure will rise (drop) accordingly; then individual mid-tier suppliers' transaction incomes will be negatively (positively) affected. If the equity gaps between mid-tier suppliers and upper-tier suppliers decrease (increase), the competitive pressure in mid-tier suppliers will rise (drop) accordingly; then individual mid-tier suppliers' transaction incomes will be negatively (positively) affected.

Regarding the interactions in our ABM, transaction links and tokens links in supply chain networks are not static. In the conceptual model, we indicate that upper-tier suppliers with financial slack are more likely to make expansions including making new transactions with other mid-tier suppliers or becoming mid-tier suppliers to make transactions with focal buyers. Accordingly, in the agent-based model, upper-tier firms can build new transaction links with mid-tier suppliers with the possibility of their increased financing ability; meanwhile, upper-tier suppliers will decrease their transaction links with the likelihood of dropped financial abilities. Besides, if an upper-tier supplier's equity can reach the setup cost of mid-tier firms, then this upper-tier supplier will enter the market of mid-tier suppliers and make transaction links with the focal buyers directly. If mid-tier supplier's equity can reach the setup cost of the focal buyer, then this mid-tier supplier will become a new focal buyer and make transaction links with other mid-tier suppliers. Regarding the token links, firms will build token links with their suppliers only if their token delivery motivations are positive.

Finally, our conceptual model demonstrates how the supply chains centralities vary over time. Consistent with the conceptual model, we use the standard tokens links degree and the standard goods transaction links degree to conceptualize the supply chain network centrality. Table 5.2 summarizes the key elements in our agent-based model.

Element	Conceptual Definition	Computational Representation
Agents	**Focal buyers, Mid-tier suppliers, Upper-tier suppliers**	**The agent characteristics are as follows:**
Tier	Firms' transaction positions in the supply chain network, 0-n	0 represents focal buyer, 1 represents mid-tier suppliers, 2 represents upper-tier suppliers
Financing efficiency/ability*	The ability to get loans from financial institutions	The Financing Efficiency of focal buyers equal to 1; for mid-tier suppliers, the Financing Efficiencies are randomly set from 0.5 to 1; and for upper-tier suppliers, the Financing Efficiencies are randomly set from 0 to 0.5. At the end of each period, update the upper-tier suppliers' "Financing Efficiency = Financing Efficiency last period * (1 + Δ Tokens Amount / Tokens Amount last period)".
Transaction efficiency/ability*	The ability to complete goods transactions in each period	The Transaction Efficiency of focal buyers equal to 1; for mid-tier suppliers, the Transaction Efficiency is randomly set from 0.5 to 1; and for upper-tier suppliers, the Transaction Efficiency is randomly set from 0 to 0.5. Transaction Efficiency = Transaction Efficiency last period * (1 + Δ Tokens Amount / Tokens Amount last period)
Transaction incomes	Firms' total income per period (goods amount)	We assume the goods demand of focal buyers is a constant value. Firms divide the goods demand to their direct suppliers weighted by the direct suppliers' Sum of Transaction Ability and Financing Ability.
Tokens Amount	Total tokens obtained in each period	Tokens are authorized by core companies, through which upper-tier suppliers can easily get funding from financial institutions. Tokens are delivered tier by tier.
Equity	Accumulated profits over time periods	Equity measures enterprises profit residuals, positively related to company size. The initial values are set according to industrial data. Equity = Initial Equity + Transaction Income - Fixed Cost per Period
Token Delivery Motivation	Firms' intension to deliver tokens to their direct suppliers	Token delivery motivation determines whether this company will deliver tokens; Boolean value, 1 represents that this company will deliver tokens to its suppliers; -1 represents not.

		Focal buyers' motivation equal to 1 constantly. For mid-tier suppliers, the initial values are 1; IF Δ Goods amount is negative, THEN token delivery motivation will change, with the possibility of (Δ Goods Amount / Goods Amount of last period).
Set-up Cost	The minimum cost of entering the market in each tier	Constant value, set by tier
Fixed Cost per Period	The operational cost of producing goods per period	Constant value, set by tier
Interactions	**Goods Transaction links, Tokens links**	**The interaction rules are as follows:**
Deliver goods	Firms build goods transaction links with their selected suppliers	IF the focal buyer receives raw materials THEN the focal firm can continue production. Goods Flow influences the Transaction Incomes of firms.
Deliver tokens	Firms build tokens links with their selected suppliers if their tokens delivery motivation is positive.	IF enterprises' token delivery motivation is positive, THEN this company will send tokens to its suppliers, i.e. building token links between this company and its suppliers. Tokens delivery amount equals to goods delivery amount of this link. IF enterprises' token delivery motivation is negative, THEN this company will stop deliver tokens, i.e. the existed token links will disappear. Tokens flow influences the Tokens Amount of firms.
Make New Transactions	Firms will increase transaction links with financial slack	IF upper-tier suppliers' Equity > Setup Cost of middle enterprises, THEN upper-tier suppliers build direct transaction link with the focal buyer. IF upper-tier suppliers' Token Amount > 0, THEN with the possibility of "Δ Financing Ability", this upper-tier supplier will build a new transaction link with one middle enterprise.
Decrease Transactions	Firms will decrease transaction links without enough financial liquidity	IF upper-tier suppliers' Financing Ability decrease, THEN this upper-tier supplier will delete one transaction link with one middle enterprise with the possibility of "Δ Financing Ability".
Environment		

Supply chain structure transformation	Supply Chain Network Centrality	Standard token links degree, which is calculated by “Number of token links / Full network links amount”
		Standard transaction links degree, which is calculated by “Number of transaction links / Full network links amount”

***Note:** Because the tokens have identical influences on “Financing efficiency/ability” and “Transaction efficiency/ability” in our agent-based model, we only use one parameter “Total Ability” to represent these two factors in the coding.

Table 5.2 Summary of agent-based model designs

6. Experiments and Findings

6.1 Procedure of a Simulation

At the beginning of a simulation session, one focal buyer agent was created, which can also represent a group of focal buyers. We set an "enterprise number tier rate" to determine the total number of mid-tier suppliers relative to the focal buyer, and the total number of upper-tier suppliers relative to the number of mid-tier suppliers. This ratio also represents the initial structure of this supply chain network; a high tier ratio indicates a flatter structure. Besides, the setup cost and fixed cost of focal buyers are set as constant values. We use "setup cost tier rate" and "fixed cost tier rate" to adjust the setup cost and fixed cost of mid-tier suppliers and upper-tier suppliers. The detailed rules are shown in Table 6.1. Then transaction links are randomly settled between the focal buyer, mid-tier suppliers, and upper-tier suppliers. Considering the benefits are more significant at the beginning, the initial token delivery motivations of all firms are positive. Thus, the tokens links are settled as same as the transaction links. A simulation session runs through 500 clock ticks. A clock tick represents a complete transaction cycle which begins with the focal buyer's order placement, continue to goods production and token delivery among multi-tier suppliers, and finally end with focal buyer receiving goods and clearing the payment. We assume this is also the time period between two adjacent order placements of the focal buyer. During each clock tick, every firm tries to max their transaction incomes by executing its behavioral rules: deliver tokens or not, make new transactions or give up current transactions. Supply chain structures (tokens links and goods transaction links) could change as a result of the firm's adaptations. At the end of a clock tick, the average of mid-tier suppliers' tokens delivery motivations, the number of tokens links, and the number of transaction links are calculated as the outcome measures. We finally obtain a time series of the three outcome measures from tick 0 to tick 500 for each simulation.

6.2 Experiment Design

In reference to our research questions, the first two questions regard a general relationship between the token flow and the goods flow in the blockchain-driven SCF platforms; the third research question explores how the industry characteristics can influence the relationships between the token flow and goods flow over time. In order to answer the first two questions, we have developed propositions 1 and 2 in section 4 through qualitatively theoretical analysis; and we will make quantitively analysis using the full simulation dataset in this section. Regarding the third research question, three sets of simulations were implemented to gain insights into the effects of industry characteristics, i.e., the enterprise numbers tier rate which represents the initial supply chain organizational structure (a higher rate indicates a more flatting organizational structure), setup cost tier rate which indicates the firm size gaps between buyers and suppliers, and fixed cost tier rate which represents the operation cost gaps between buyers and suppliers, respectively. The treatment of each simulation is detailed in Table 6.1. This experiment design resulted in a total of: 3 (enterprise number tier rate) * 3 (setup cost tier rate) * 3 (fixed cost tier rate) = 27 simulation treatments. Each simulation treatment was repeated 30 times (810 simulation sessions).

Industry characteristics	**Experiment Treatments**
Enterprise number tier rate	Varying the *enterprise number tier rate* from 3 to 9 using 3 increments. The number of the focal buyer is set as 1. Mid-tier suppliers' number equals *"Focal buyer number * enterprise number tier rate"* and upper-tier suppliers' number is *"Mid-tier supplier number * enterprise number tier rate"*.

Setup cost tier rate	Varying the *setup cost tier rate* from 3 to 9 using 3 increments. Focal buyer setup cost is set as a constant value. Mid-tier suppliers' setup cost equals *"Focal buyer setup cost / setup cost tier rate"* and upper-tier suppliers' setup cost is *"Mid-tier suppler setup cost / setup cost tier rate"*.
Fixed cost tier rate	Varying the *fixed cost tier rate* from 3 to 9 using 3 increments. The focal buyer's fixed cost per period is set as a constant value. Mid-tier suppliers' fixed cost equals *"Focal buyer fixed cost / fixed cost tier rate"* and upper-tier suppliers fixed cost is *"Mid-tier suppler fixed cost / fixed cost tier rate"*.

Table 6.1 Summary of experiment treatments

6.3 Findings

We use the full simulation dataset to generate the standard token links degree and standard transaction links degree graphs over time (Figure 6.1). These simulation results largely consistent with our propositions. In beginning, both tokens link degree and transaction links degree climb but level off over time. Meanwhile, the mean of mid-tier suppliers' tokens delivery motivation goes down at the beginning and levels off over time (Figure 6.2).

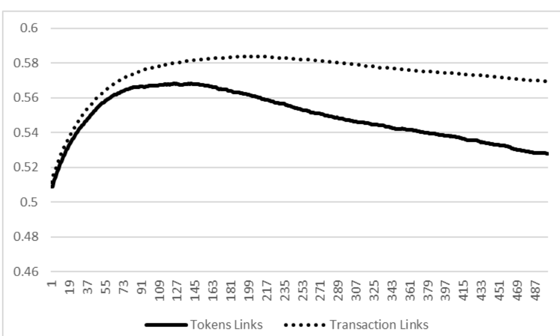


Figure 6.1 Standard token link degree and transaction links degree over time

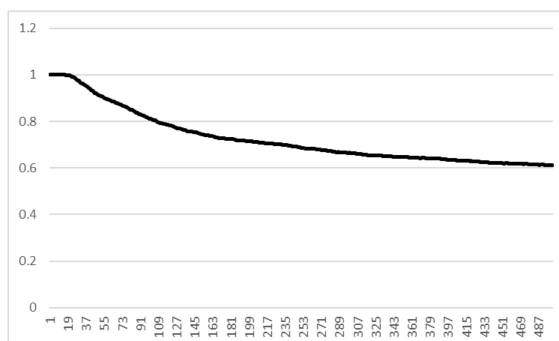


Figure 6.2 Average mid-tier suppliers' token delivery motivation over time

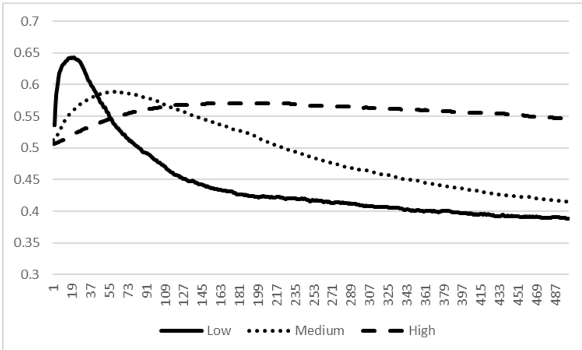
In reference to our proposition 1, in short term, most mid-tier suppliers have a positive token delivery motivation and thus upper-tier suppliers can get tokens from mid-tier suppliers, which will increase the financing ability of upper-tier suppliers. With the boosted financial slack, upper-tier suppliers have a higher possibility to improve their transaction efficiency, make new transactions with mid-tier suppliers, or even make a transaction with the focal buyer. Accordingly, Figure 6.1 shows that in the first 100 ticks, both the tokens links degree and transaction links degree keep rising (i.e., the supply chain networks become more decentralized). Meanwhile, in Figure 6.2 the average mid-tier suppliers' tokens delivery motivations are highest at the beginning.

Our proposition 2 postulates that in long term the expansion of upper-tier suppliers will increase the competitive pressure of mid-tier suppliers, which can induce mid-tier suppliers to change their token delivery motivation. Without tokens obtained from mid-tier suppliers, upper-tier companies' financial ability will become insufficient to support their expansion activities. Thus, upper-tier suppliers, which are unable to get tokens, will decrease their newly-build transactions with mid-tier suppliers and the supply chain structure starts to become more centralized. Consistent with this proposition, we can see that with the rising of tokens links degree curve (i.e., supply chain network becomes decentralized), the average mid-tier suppliers' tokens delivery motivation goes down (Figure 6.2); and after around 100 ticks, the average mid-tier suppliers' tokens delivery motivation goes below 0.8, then the token links degree curve starts to fall (i.e., supply chain networks become more centralized). And interestingly, as the supply chain network starts to become more centralized, the dropping of the average mid-tier suppliers' tokens delivery motivation also slows down and the supply chain network centrality leads to a new balance.

Besides, although both the tokens links degree curve and transaction links degree curve start to flatten after a while, the descending slope of tokens links degree curve is steeper than the transaction links degree, showing that although mid-tier suppliers decrease their tokens delivery to upper-tier suppliers in long term, the prior-built transaction links remain. On the one hand, some upper-tier suppliers have grown bigger and made transactions with focal buyers, thus they can maintain powerful financing ability even without mid-tier suppliers' tokens delivery. On the other hand, when the supply chain network starts to become more centralized, some mid-tier suppliers are likely to recover delivering tokens, then the supply chain transaction network will achieve a new balance, where the network centrality is more decentralized than the initial statues but more centralized than the peak of decentralization.

Research Questions	Propositions	Findings
(1) How will the application of blockchain-driven SCF influence the supply chain transaction structures (goods flow) via the mid-tier suppliers' tokens delivery (token flow)?	**Proposition 1 (a):** In the short term, the application of blockchain-driven SCF reduces mid-tier suppliers' transaction cost and financial cost, thus positively incentivizes mid-tier suppliers to deliver tokens. **Proposition 1 (b):** In the short term, mid-tier suppliers' token delivery makes highly-centralized supply chain transaction structure more decentralized.	Figure 6.1 shows that in the first 100 ticks, both the tokens links degree and transaction links degree keep rising (i.e., the supply chain networks become more decentralized). Meanwhile, in Figure 6.2 the average mid-tier suppliers' tokens delivery motivations are highest at the beginning.
(2) How will the change of supply chain transaction structures (goods flow) in turn influence the token delivery of mid-tier suppliers (token flow)?	**Proposition 2:** In the long term, the more decentralized supply chain structure will in turn increase the competitive pressure of mid-tier suppliers, and thus negatively affect the mid-tier suppliers' tokens delivery and upper-tier suppliers' liquidity. Then the supply chain structure will become more centralized gradually.	In Figure 6.1 and 6.2, with the rising of tokens links degree and transaction links degree (i.e., supply chain network becomes decentralized), the average mid-tier suppliers' tokens delivery motivation goes down; and after around 100 ticks, the average mid-tier suppliers' tokens delivery motivation goes below about 0.8, then the token links degree curve starts to fall (i.e., supply chain networks become more centralized). As the supply chain network starts to become more centralized, the descending slope of the average mid-tier suppliers' tokens delivery motivation flattens and the supply chain network centrality reaches a new balance.

Table 6.2 Summary of general findings



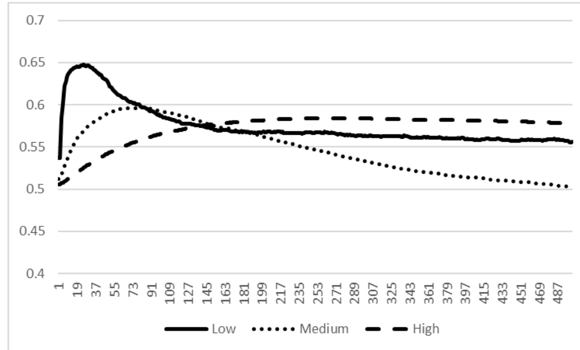
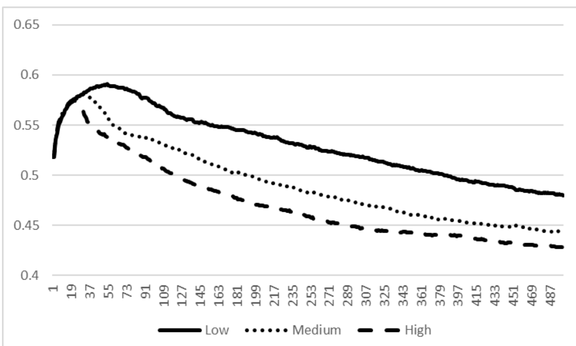


Figure 6.3 Standard token link degree with varying enterprise number tier rate

Figure 6.4 Standard transaction link degree with varying enterprise number tier rate



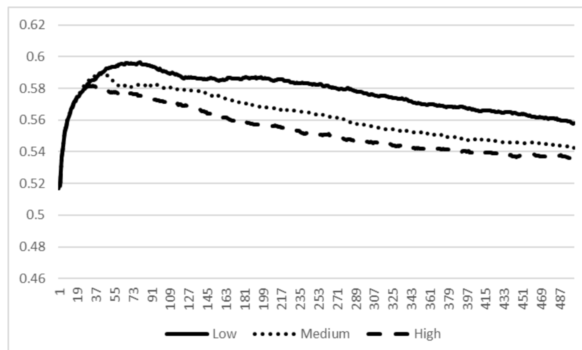
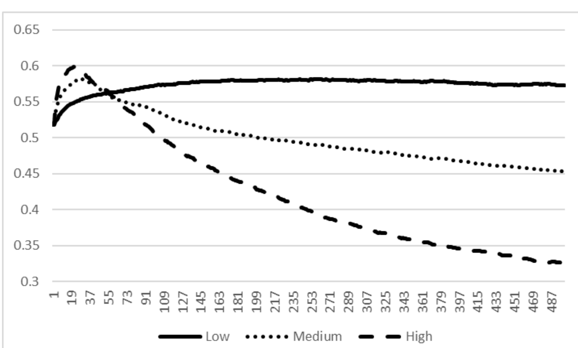


Figure 6.5 Standard token link degree with varying setup cost tier rate

Figure 6.6 Standard transaction link degree with varying setup cost tier rate



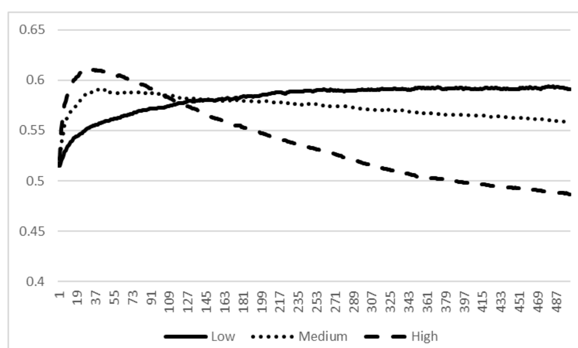


Figure 6.7 Standard token link degree with varying fixed cost tier rate

Figure 6.8 Standard transaction link degree with varying fixed cost tier rate

According to the industry characteristics, the agent-based model produces a precise view of the effects of enterprise number tier rate, setup cost tier rate, and fixed cost tier rate on standard token links degree and standard transaction links degree over time (See Figure 6.3 to Figure 6.8). With varying enterprise number tier rate, setup cost tier rate, and fixed cost tier rate, the thresholds of standard tokens links degree curve and standard transaction links degree curve appear at different times.

First, in our agent-based model, the number of lower-tier suppliers is set by multiplying the number of upper-tier firms with the enterprise number tier rate; thus, a higher enterprise number tier rate represents a more flatting supply chain organizational structure. The simulation shows that a higher enterprise number tier rate produces slower increases in token links centralization in the short run, and the threshold appears earlier under a lower enterprise number tier rate. We can see that when the enterprise number tier rate is high, the curve almost flattens into a horizontal line. Different enterprise number tier rates have similar effects on transaction links degree. In other words, the blockchain-driven SCF platform should have a better performance in a more flatting supply chain network, and the supply chain network with a more flatting organization structure is more likely to stay decentralized in the long term.

Second, the setup cost tier rates have no apparent effects on token links centrality and transaction links centrality in the short term. However, higher setup cost tier rates indicate more rapid decreases in token links degree and transaction degree in the long run. In our agent-based model, we set the lower-tier suppliers' setup cost by dividing the upper-tier firms' setup cost by the setup cost tier rate; thus, a higher setup cost tier rate indicates a lower setup cost gap. In other words, supply chains with bigger setup cost gaps are more likely to stay decentralized for a long time.

Third, in our agent-based model, the lower-tier suppliers' fixed operation cost is set by dividing the upper-tier firms' fixed operation cost by the fixed cost tier rate; thus, a higher fixed cost tier rate indicates a lower upper-tier suppliers' fixed operation cost. The simulation shows that a higher fixed cost tier rate produces more fast increases in token links degree in the short run, and the threshold appears earlier under a higher fixed cost tier rate. The transaction links degree indicates similar results. Thus, if the upper-tier suppliers have higher operation costs, the SCF platforms are more likely to perform well in the long run.

In sum, supply chain networks with flatter structures, higher setup cost gaps, and higher upper-tier supplier operation costs are more likely to preserve the decentralized statue in long term. And blockchain-driven SCF platforms should develop supply chain customers with these characters to get a more sustainable performance.

Research Question	Proposition	Findings
(3) Will industry characteristics (e.g., the number of firms in each tier, firm size in each tier, etc.) affect the relationships between tokens delivery and supply chain structures in blockchain-driven SCF?	**Proposition 3 (a):** In blockchain-driven SCF platforms, initial supply chains flatting degree can positively affect the threshold of the supply chain structure change, i.e., supply chains with more flatting structures can keep the more decentralized statue in a much longer time period.	Figures 6.3 and 6.4 show that higher enterprise number tier rate can produce slower increases in token links degree and transaction links degree in the short run; and the threshold appears later under higher enterprise number tier rate.
	Proposition 3 (b): In blockchain-driven SCF platforms, the setup cost gaps between mid-tier and upper-tier suppliers can positively affect the threshold of the supply chain structure change, i.e., supply chains with higher setup cost gaps can keep the more	Figures 6.5 and 6.6 show that higher setup cost tier rates indicate more rapid decreases in token links degree and transaction degree in the long run.

	decentralized statue in a much longer time period.	
	Proposition 3 (c): In blockchain-driven SCF platforms, upper-tier suppliers' fixed operation cost can positively affect the threshold of the supply chain structure change, i.e., supply chains with high fixed operation cost upper-tier suppliers can keep the more decentralized statue in a much longer time period.	In Figures 6.7 and 6.8, a higher fixed cost tier rate produces more fast increases in token links degree and transaction links degree in the short run, and the threshold appears earlier under a higher fixed cost tier rate.

Table 6.3 Summary of findings regarding industry characteristics

6.4 Model Validation

Validation is typically aimed at verifying the reasonableness of the simulation results. In this study, we find two blockchain-driven SCF application cases with different industry characteristics to verify our simulation results.

First, the model simulation is performed with a low enterprise number tier rate (i.e., a centralized supply chain structure), a moderate setup cost tier rate (i.e., a moderate setup cost gap between mid-tier suppliers and upper-tier suppliers), and a low fixed cost tier rate (i.e., a high fixed operation cost of upper-tier suppliers). This treatment mimics the environment of the steel industry as observed by our interview in a blockchain-driven SCF platform. This platform has 13 focal buyers and 105 active suppliers. The authorized token amount rises from US$3 million to US$200 million in five months after the platform's setup. However, the majority of tokens are held to maturity by first-tier or second-tier suppliers while upper-tier suppliers still have difficulties in obtaining financial support. 122 financing transactions completed in this platform and only around 24% of the authorized tokens (US$48 million) are transferred into loans. We calculate the cumulative financing percentage over five months after its setting up in Figure 6.9. Accordingly, the simulation results also produce a rapid increase at the beginning but an early drop of the token links degree curve and transaction links degree curve (Figure 6.10 and Figure 6.11).

In the second case, we set the agent-based model with a high enterprise number tier rate (i.e., a flatting supply chain structure), a low setup cost tier rate (i.e., a big setup cost gap between mid-tier suppliers and upper-tier suppliers), and a moderate fixed cost tier rate (i.e., a moderate fixed operation cost of upper-tier suppliers). This treatment mimics the environment of the auto retail industry as observed by Chen, J. et al. (2020). They introduced a blockchain-driven SCF platform in the auto retail industry (Zhi-lian-che-rong in China) with a good performance. It has over 600 active enterprise users that adopt this platform to run their financing business. 3296 financing transactions completed in this platform and the financing amount reached about US$80 million. Consistent with the case findings, the simulation results for the auto retail industry also produce a better platform performance, i.e. the token links degree and transaction links degree keep rising over time (Figure 6.10 and Figure 6.11). Although this result cannot prove that the model is a true representation of reality, it provides evidence that the computational model can assist to gain insights into our research questions.

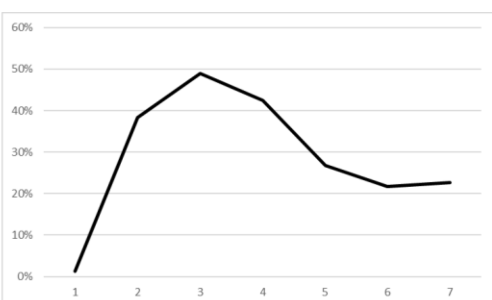


Figure 6.1 Cumulative financing percentage in a steel industry blockchain-driven SCF platform

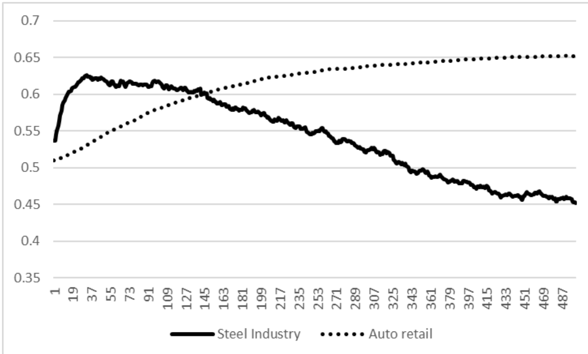


Figure 6.10 Token link degree simulation results in the steel industry and the auto retail industry

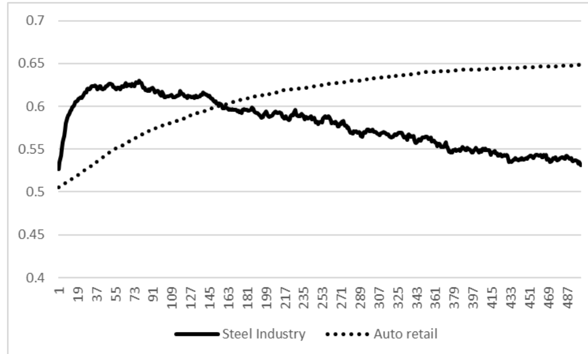


Figure 6.11 Transaction link degree simulation results in the steel industry and the auto retail industry

7. Discussion

This study views the supply chain network as a complex adaptive system where firms are self-organized and adaptive to their competitive environments. Via this theoretical lens, we investigate how the application of blockchain-driven SCF (information flow) can influence the supply chain transaction structures (goods flow) via the mid-tier suppliers' tokens delivery and how the change of supply chain transaction structures can in turn influence the token delivery of mid-tier suppliers. Besides, we investigate how some industry characteristics (i.e., initial supply chain flatting degree, firm size (setup cost) gaps, and fixed cost gaps) affect the relationships between tokens delivery and supply chain structures in the blockchain-driven SCF.

We propose that in the short term, blockchain technology reduces mid-tier suppliers' costs and thus motivates mid-tier suppliers' token delivery and promotes the decentralization of supply chain transaction structure; however, in the long term, the decentralized supply chain transaction structure will in turn negatively affect mid-tier suppliers' token delivery motivations and drive the centralization of a supply chain. We test our theoretical propositions by a series of simulation experiments in an agent-based model (ABM). In this model, supply chain companies are recognized as individual agents with diverse characteristics. The transaction goods flow and token flow are viewed as interaction links among agents. Behavior rules are designed in a theoretical lens of cost-benefit analysis based on the agent characteristics and links. With the interaction of goods flow and token flow, characteristics of individual agents will evolve, and then the change of characteristics will, in turn, impact the goods flow and token flow according to behavior rules. The AMB methodology allows us to see the evolvement of supply chains in a bottom-up way.

A takeaway from our study is that blockchain-driven SCF does not fully realize the decentralized ideology of blockchain. In blockchain-driven SCF platforms, even though blockchain can decentralize the information flow, the liquidity availability of upper-tier suppiers is still determined by mid-tier suppliers' token delivery. Without mid-tier suppliers' token delivery, upper-tier suppliers still cannot obtain low-cost loans from financial institutions directly and independently. In this section, the implications and limitations of the CAS model of blockchain-driven SCF use are discussed.

7.1 Theoretical Implications

This paper is one of the first blockchain-driven SCF studies. According to an extensive literature review, research in the domain of supply chain finance with blockchain is still limited (Hofmann et al., 2017; Wang et al., 2019). Extant SCF literature on technology has acknowledged the critical role of IT on intra and inter organization information sharing (e.g., Fairchild, 2005; Blackman et al., 2013; Wandfluh et al., 2015), but detailed analysis of IT factors in SCF remains rare (Bals 2019). Silvestro & Lustrato (2014) mention technological challenges such as proprietary systems hinder SCF adoption. Caniato et al. (2016) identify a need for future research regarding the adoption of IT-enabled SCF platforms. Blockchain-related literature on supply chains mainly focuses on supply chain management (e.g., Cole et al., 2019; Wang et al., 2019b), little discussing the financing issue. Thus, there is still a research gap in the application of blockchain technology to SCF (Bals, 2019; Wang et al., 2019a). Our study is going to fill this research gap and tries to uncover the unfit between the centralized supply chain transaction structure and decentralized blockchain ideology in the long term. We reveal that even though the benefits of blockchain are obvious in the short term, the benefits can diminish in the long term due to the dynamically adjusting motivations of mid-tier suppliers.

First, prior work has a consistent theme that information flow has to match the physical goods flow in a supply chain. They cannot explain how Blockchain's decentralized information flow will change the physical goods flow in the blockchain-driven SCF, i.e., the interactions between information flow and goods flow. Blockchain has a unique advantage that it can create a highly trusted, decentralized information environment. Thus, the tokens not only have information value but also have financial value. The decentralized information flow enables liquidity decentralization and further influences the supply chain structures. And more interestingly, this is not a static process. The changes in supply chain structures can in turn affect information flow and liquidity decentralization. This paper explains how the decentralized information flow and the centralized supply chain structure interact and evolve over time.

Besides, the long-term applications of SCF are still understudied by prior researches. Most prior studies demonstrate the short-term benefits of SCF applications towards suppliers (e.g., Lekkakos & Serrano, 2016; Tunca & Zhu, 2018; Van Der Vliet et al., 2015), very little researches considering the dynamic characteristics of supply chain participants and market power (Iacono et al., 2015). Our study focuses on the long-term dynamics of supply chain participants and the competitive environment, which can facilitate the sustainable development of blockchain-driven SCF.

7.2 Practical Implications

Our study makes a practical contribution by demonstrating the vital role of mid-tier suppliers in the application of blockchain-driven SCF; meanwhile, we analyze the influences of industry characteristics on the long-term application of blockchain-driven SCF. We suggest blockchain-driven SCF platforms developing effective incentive plans to enlarge tokens delivery of medium-tier suppliers, such as token-delivery-based interest rebate, etc. Besides, according to our experiment findings, the blockchain-driven SCF platforms should have better performances in the supply chain network with a more flatting organizational structure, higher setup cost gaps, and higher upper-tier supplier operation cost. Accordingly, to get better performance, the blockchain-driven SCF platforms can develop their customers in industries with these features, such as the retail industry; and avoid industries such as heavy manufactory. Third, our study makes a managerial contribution by designing an agent-based model as a tool for blockchain-driven SCF platforms to capture mid-tier suppliers' dynamic motivations in a cost-benefit framework. On this basis, blockchain-driven SCF platforms could use the real data doing further analysis to support their decision making and adjust their marketing strategy.

7.3 Limitations

While the CAS lens focuses our theorization on a cost-benefit framework to explain the dynamic tokens flow and goods flow interactions between firms, this study ignores other possible drivers of firms' behaviors, such as bargaining power of suppliers, barriers to new markets, demand fluctuations, and business model innovation. Meanwhile, considering our research is focusing on the IT post-adoption period and to quantitively analyze the supply chain firms' behaviors, we assume that the supply chain firms are in a complete competition environment and do not include variables reflecting social norms and institutional expectations such as the mimetic, coercive, and normative pressures in the supply chain networks. Finally, this study proposes a theoretical explaination towards the potential problem of the blockchain-driven SCF platforms; however, the long-term data in the blockchain-driven SCF platforms are not available currently. Future research could explore how factors outside the boundary of our theory development can modify the insights gained from this study and collect more industrial data to do further analysis.

8. Conclusion

This study provides researchers and industrial managers a dynamic view of the long-term use of the blockchain-driven SCF platforms. In order to operate the blockchain-driven SCF platforms more successfully and sustainably, the blockchain-driven SCF platforms should pay more attention to incentive the mid-tier suppliers' token delivery and are better to choose supply chains that have more flatting structures, bigger firm size gaps, and higher upper-tier supplier operation costs. Otherwise, the blockchain-driven SCF platforms should reconsider the reasonability of current financing processes in the platforms. IT is a tool, but the determinant should be the rules, i.e. how to apply IT into the business models. In this case, even though blockchain is viewed as a decentralized technology, the business design of blockchain-driven SCF is still based on the centralized supply chain transaction structure. In other words, even though blockchain technology helps to increase information transparency, reliability, and improve transaction efficiency, the design of blockchain-driven SCF does not fully realize the decentralized ideology of blockchain technology.

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Appendice: Pseudo-Code of the Agent-Based Model

Let the model user set the *Enterprise Number Tier Rate*

\\ This is an experimental treatment for proposition testing

Let the model user set the *Setup Cost Tier Rate*

\\ This is an experimental treatment for proposition testing

Let the model user set the *Fixed Cost Tier Rate*

\\ This is an experimental treatment for proposition testing

Setup firms {

\\ This procedure creates firms and defines their attributes.

Create 1 focal buyer with *Tier* = 0, *Total Ability* = 1, *Token Delivery Motivation* = 1, *Transaction Amount per Period* = 500, *Setup Cost* = 10000, *Fixed Cost per Period* = 250

Create numbers of mid-tier suppliers regarding the *Enterprise Number Tier Rate*, with *Tier* = 1, *Initial Total Ability* is set randomly between 0.5 to 1, *Initial Token Delivery Motivation* = 1, *Setup Cost* is set according to *Setup Cost Tier Rate*, *Fixed Cost per Period* is set regarding *Fixed Cost Tier Rate*, *Initial Equity* is equal to *Fixed Cost per Period*, *Initial Token Amount* = 0.

Create numbers of upper-tier suppliers regarding the *Enterprise Number Tier Rate*, with *Tier* = 2, *Initial Total Ability* is set randomly between 0 to 0.5, *Initial Token Delivery Motivation* = 1, *Setup Cost* is set according to *Setup Cost Tier Rate*, *Fixed Cost per Period* is set regarding *Fixed Cost Tier Rate*, *Initial Equity* is equal to *Fixed Cost per Period*, *Initial Token Amount* = 0.

}

Setup transaction links {

\\ This procedure set up the initial supply chain transaction links

Ask each mid-tier suppliers create a transaction link with the focal buyer

Ask upper-tier suppliers to create transaction link with mid-tier suppliers randomly

}

Setup token links {

\\ This procedure set up the initial supply chain token links

Ask each firm [

IF Token Delivery Motivation > 0 [

Ask my-links [set color green]

 ]

]

}

Calculate mid-tier suppliers' Transaction Amount and Tokens Amount {

// Focal buyer divide goods demand to the mid-tier suppliers weighted by the mid-tier suppliers'

Total Ability

Ask focal buyer [

  IF this focal buyer has transaction links with mid-tier supplier [

   Set sum-total-ability = sum [Total Ability] of linked mid-tier suppliers

   Ask each linked mid-tier supplier [

Set in-transaction-amount = in-transaction-amount + Total Ability * in-transaction-amount / sum-total-ability

Set tokens Amount = Tokens Amount + Total Ability * in-transaction-amount / sum-total-ability

Set token link color as green

]

]

]

}

Calculate upper-tier suppliers' transaction amount and tokens amount {

//// Mid-tier suppliers divide the goods demand to the upper-tier suppliers weighted by the upper-tier suppliers' Total Ability

Ask mid-tier suppliers

[

IF this mid-tier supplier have transaction links with upper-tier suppliers [

Set sum-total-ability = Sum Total Ability of linked upper-tier suppliers

Ask each linked upper-tier supplier [

Set in-transaction-amount = in-transaction-amount + Total Ability * in-transaction-amount / sum-total-ability

IF mid-tier suppliers' tokens-delivery-incentive = 1 [

Set tokens Amount = Tokens Amount + Total Ability * in-transaction-amount / sum-total-ability

```
        Set token link color as green
      ]
    ]
  ]
 ]
}
```

```
Calculate Tokens Delivery Motivation {
// This procedure update mid-tier suppliers' token delivery motivation according to their
transaction amount variation
  Ask mid-tier suppliers [
   IF transaction-amount < last-transaction-amount and random-float 1 < (last-transaction-
amount - transaction-amount) / last-transaction-amount
   [
   IFELSE Tokens Delivery Motivation = 1
     [Set Tokens Delivery Motivation = -1]
     [set Tokens Delivery Motivation = 1]
   ]
 ]
}
```

```
Update mid-tier suppliers' and upper-tier suppliers' Total Ability {
//This procedure update suppliers' Total Ability according to their Tokens Amount variation
```

```
  Ask mid-tier and upper-tier suppliers
  [
    IF Transaction Amount > 0
    [
    Set Total Ability = Initial Total Ability * (1 + Δ Token Amount / Token Amount of last
period)
      IF Total Ability > 1 [ Set Total Ability = 1]
    ]
  ]
}

Update firms' Equity {
// Firms' Equity will be updated at each period end, profit residuals
  Ask each firm
  [
  Set Equity = Equity + Transaction Amount – Fixed Cost per Period
  ]
}

Make New Transactions {
//This procedure let upper-tier suppliers make new transaction link with mid-tier suppliers or
focal buyer
Ask upper-tier suppliers [
```

Set P = Total Ability – Initial Total Ability

IF random-float 1 < P [This upper-tier supplier will create transaction link with one of the mid-tier suppliers which are not the upper-tier supplier’s transaction partners before]

IF Equity > Setup Cost of mid-tier suppliers

[This upper-tier supplier will create a transaction link with the focal buyer]

]

}

Decrease Transactions {

// This procedure let upper-tier suppliers delete new-built transaction link with mid-tier suppliers or focal buyer

Ask upper-tier suppliers

[

IF Total Ability < max Total Ability and random-float 1 < (max Total Ability - Total Ability)

[Ask one of this upper-tier supplier’s transaction link die]

]

}

Calculate Supply Chain Network Centrality {

Set Standard token links degree = Number of token links / Full network links amount

Set Standard transaction links degree = Number of transaction links / Full network links amount

}

Record-result {

\\ This procedure will collect all the data we need in this simulation experiment

Record each mid-tier supplier's Token Delivery Motivation

Record current Network Centrality

Record current experimental treatment

Record current clock tick

}