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Mitigating information asymmetry in inventory pledge financing through the Internet of things and blockchain

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Abstract
Purpose – Risks resulted from asymmetric information have become crucial barriers for commercial banks to implement supply chain finance (SCF) – mainly the inventory pledge financing (IPF). At the same time, online financial service providers (OFSPs) are emerging as strong competitors in the SCF market. As a result, commercial banks need to update their traditional SCF business models and alleviate their over-dependence on OFSPs.
Design/methodology/approach – The authors employ a multi-case-study method to investigate how the Internet of things (IoT) and blockchain technologies can be jointly leveraged to mitigate SCF risks. In-depth interviews were conducted to depict the business models and their novel ecosystem to reinforce traditional banks' ability in SCF services.
Findings – From the perspective of information asymmetry, the authors categorize IPF risks into three groups based on the principal-agent theory: collateral, warehousing and liquidity risk. The findings suggest that IoT can primarily improve traditional banks' information acquisition ability, and blockchain can facilitate credible information transformation, enabling banks to acquire knowledge from collaterals. Besides, the e-platform in the new architecture increases banks' involvement in the supply chain and builds a fair network to curtail warehousing risks. The employment of smart contracts and collaborative mechanism ensure process and outcome control in mitigating liquidity risks.
Originality/value – The research contributes to the literature by confirming the role of emerging technologies in reducing information asymmetry risks. Besides, the findings provide valuable insights for practitioners to promote effective practices and approaches in IPF.

Keywords Information asymmetry, Supply chain finance, Inventory pledge financing risks, Internet of things, Blockchain
Paper type Research paper

1. Introduction
Supply chain finance (SCF) has increasingly become a multidisciplinary field at the intersection of logistics, supply chain management and financing (Hofmann and Johnson, 2016). Michael (2007) defines SCF as "*a process of reconfiguring and optimizing costs in an enterprise-led industry chain.*" The development of SCF by banks and other financial institutions could effectively alleviate the financing pressure faced by small- and medium-sized enterprises (SMEs) (Zhu *et al.*, 2019). Among all types of SCF classified by More and Basu (2013), including pre-transportation financing (raw materials financing, order

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financing), in-transit financing (inventory financing) and post-transportation financing (advanced payment financing, accounts receivable), inventory financing model is considered one of the most important models, particularly when global demands on commodities slow down (Yang and Birge, 2013).

Among all the inventory financing models, inventory pledge financing (IPF) refers to suppliers or retailers applying for financial support based on stocks of goods (Qin and Ding, 2011). More precisely, a borrower must deposit and pledge inventory in a warehouse identified by the borrower and approved by a bank. A collateral manager approved by the bank will issue a warehouse receipt in favor of the borrower, who will get loans on the pledged inventory (Song *et al.*, 2016).

Traditional banks are confronted with many challenges that hinder their successful IPF implementation in SCF practices (More and Basu, 2013). Various issues, such as the collusion between warehouses and financing companies, duplicate pledges, fraudulent warehouse receipts and risk prediction errors, have frequently occurred, especially in developing countries such as China (Chen *et al.*, 2010). For instance, in 2012, the "Yangtze River Delta Steel Trade Case" shocked China's banking industry when 1,273 cases of switching pledged steel stocks to other warehouses occurred in Shanghai (Shi, 2018). Current risk avoidance mechanisms in SCF are very likely to fail (Zhang *et al.*, 2015) as SCF involves multi-agents and different sections (Qiu *et al.*, 2014). When SMEs and the third party have advantages to specific information, the collusions between agents could skew the agreement (Lin and Peng, 2021). Thus, the ultimate cause of IPF risks is the information asymmetry between commercial banks and their counterparties (Fang, 2019).

The recent development of Fintech has led to emerging business models, prompting SCF to a more competitive situation with additional financial service providers involved, such as logistic service provider (Hofmann, 2009), online platforms (Song *et al.*, 2018a; Lin and Peng, 2021; Shi *et al.*, 2015), producers (Tsai and Peng, 2017) and distributors (Silvestro and Lustrato, 2014; Martin and Hofmann, 2017). These online financial service providers (OFSPs) can take advantage of their direct access to the transaction information of SMEs to reduce information asymmetry (Song *et al.*, 2018a). Their close cooperation with SMEs could also result in better performance than traditional banks. Therefore, banks must collaborate with these service providers to launch new SCF services to maintain their competitive advantage (Shi *et al.*, 2015).

Cutting-edge technologies such as the Internet of things (IoT) and blockchain can help streamline the information flow along the supply chain by reducing risks in SCF and supporting traditional banks (Chang *et al.*, 2020b; Wamba and Queiroz, 2020). For example, combining IoT technology and the business process of IPF to measure the risks of SCF can significantly improve the accuracy of the credit risk prediction model (Abbasi *et al.*, 2019). Moreover, blockchain technology can increase information transparency of the supply chain and reduce credit and operational risk in SCF (Li *et al.*, 2019). By facilitating trustless technologies such as smart contract, blockchain is changing the interactive effect of human relations (Ali *et al.*, 2020; Frizzo-Barker *et al.*, 2020). Since key developments in economics are related to information and interaction, banks have to utilize these modern technologies or disruptive technologies to strengthen their SCF services in the era of the digital economy (Stiglitz, 2002). However, due to the varying natures of the emerging technologies, how to develop a general business model based on them and find critical points to replicate these models needs to be further explored (Frizzo-Barker *et al.*, 2020).

Prior research has not studied the specific SCF risks to help traditional commercial reduce information asymmetry and curb IPF risks. Besides, it remains unclear how to develop solutions with the IoT and blockchain technologies to narrow the gap between traditional banks and OFSPs. Our paper addresses the research gap and contributes to the literature on IPF risk management. In particular, we study information asymmetry issues existing in the traditional banks and develop SCF solutions based on state-of-the-art technologies to help banks mitigate such issues.

The rest of the paper is structured as follows. Section 2 reviews the prior literature. Section 3 outlines the research methodology and presents an overview of the research model. Section 4 details the case analysis. Section 5 discusses relevant theoretical and practical implications. Section 6 concludes the paper with limitations and future research directions.

2. Literature review

2.1 Information asymmetry risks faced by traditional SCF model

Information asymmetry is one of the most fundamental concepts in the modern economy and is widely studied in many fields such as accounting, finance and supply chain management (Johnson and So, 2018). According to the principal-agent theory, Jost (2001) distinguished two types of information asymmetry based on when they emerge (i.e. time of occurrence): before (adverse selection) or after (moral hazard) the contract is concluded. According to Voigt (2011), moral hazard can be divided into problems of hidden action and hidden information (shown in Table 1). For hidden action, information asymmetry is endogenously determined as the asymmetry emerges from agents' decisions. But hidden information is caused by a lack of equality in information sharing during the post-contract period.

Information asymmetry has been extensively studied in business areas in recent years. For instance, Johnson and So (2018) found that asymmetric information could influence most interactions between economic agents and be measured in the financial market. Moreover, information asymmetry leads to two normative issues: equality imbalance and efficiency losses (Landes and Néron, 2018). Chowdhury *et al.* (2018) also proved that asymmetric information brings inequalities in the financial market, and the inefficiency and dis-integrity breed speculators. In SCF, when banks' intuition is not adequate, and incentives for third-party service providers are not enough, the SMEs and the third-party service providers may take advantage of their information superiority and collude to defraud banks to obtain loans (Lin and Peng, 2021). Based on the principal-agent theory, Qiu *et al.* (2014) summarized possible information asymmetry risks in SCF. They believed that information risks exist between commercial banks, loan enterprises, the third service providers, or the core enterprises, between the third service providers and loan enterprises and between loan enterprises and logistics enterprises. Among all the operational risks in IPF of SCF: external fraud, internal fraud, loss and damage of pledges and operational errors of employees, the most significant losses are from external fraud, and how to intelligently identify and avoid the fraud risk of pledges is necessary (Wang *et al.*, 2019).

Researchers categorized pledged inventory risks into price fluctuation risk of the collateral, warehousing risk and liquidity risk (Sheng and Wu, 2012; Liu *et al.*, 2020). The collateral risk is brought by the collateral whose price fluctuates randomly. In general, a debtor could get a loan merely equivalent to a portion of the inventory value, known as the advance rate or the loan-to-value ratio (Li *et al.*, 2020). Due to banks' scant knowledge of goods, they cannot reasonably estimate the stocks' value, especially those with heavily

Table 1. Classifications of information asymmetry

	Hidden characteristics	Hidden characteristics	Hidden characteristics
Source of information asymmetry	Exogenous	Exogenous	Endogenous
Time of occurrence (before or after arriving a contract)	*Ex ante*	*Ex post*	*Ex post*
Type of information asymmetry	Adverse selection	Moral hazard	Moral hazard

Source(s): Cited from Voigt (2011)

fluctuating prices. Fu *et al.* (2017) found that there were over-stock phenomena of debtors in terms of securing the inventory financing availability for the future and concluded that a low loan-to-value ratio hurts SMEs' benefits. It is thus evident that adverse selection leads to the damages of interests of the two parties.

The warehousing risk occurs when collateral in a warehouse is lost or damaged, or a borrower replenished a warehouse with defective goods when the warehouse is taking the custody responsibility (Sheng and Wu, 2012). As a result, the value of collateral cannot equal the value of original stocks. The risk may also happen when a warehouse colludes with a borrower to cheat a bank by transporting inventory out of the warehouse or duplicating the pledge in multiple banks. The main reason for this risk is that banks cannot confirm collaterals due to lagged information, and they can only restrain warehouses and SMEs with a "blacklist" mechanism (Wang *et al.*, 2019).

Liquidity risk happens when a debt-financed firm fails to afford the loan obligations, and the pledged inventory must be sold to the market by banks or warehouses to repay the loan (Li *et al.*, 2020). However, the process of collateralized property foreclosure is costly and time-consuming (Le and Nguyen, 2019). However, banks can hardly recover total amounts from collateral liquidation due to the high cost of liquidation in disputes between banks and warehouses or between warehouses and third parties (Le and Nguyen, 2019).

2.2 Online SCF developed by OFSPs

Many online supply chain finance (OSCF) models have emerged with the development of FinTech (Lin and Peng, 2021). OSCF adopters include three leading types: B2B/C2C platforms, manufacturers or downstream buyers and professional service providers or IT system providers (Chen *et al.*, 2019). The revolution of information technology helps improve the accessibility of these novel funding channels to SMEs due to the new characteristics of these OSCF modes (Tsai and Peng, 2017). For example, the operation of OSCF runs faster, the operation process is based on standards, the relationship of related industries along the chain is closer, and the dependence on collaterals and financial costs are lower.

Compared with traditional banks, OFSPs that run OSCF excel in data collection, information processing, big data analysis and information sharing. Traditional banks have a scientific mechanism in risk assessment and prevention (Chen *et al.*, 2019), emphasizing different points in SCF business. Traditional banks rely more on the credit of focal enterprises, while OFSPs focus on the credit level of business background and the authenticity of a transaction. In other words, traditional banks care more about the "main body credit," but OFSPs stress the importance of "electronic credit" (Deng and Chen, 2017). Thus, many commercial banks tend to cooperate with OFSPs by leveraging OFSPs' flexible information structure. For example, China Construction Bank was cooperating with Treasure Island (a B2B platform) to jointly launch the OSCF business (Lin and Peng, 2021). Bank of China was teaming with JD (an e-commerce platform) to explore a variety of Internet-based financial products and services (Tsai and Peng, 2017). The cooperation not only improved their operation and service efficiency but also made financial services more feasible.

However, the cooperation between banks and OFSPs also has its limitations. Commercial banks heavily rely on the e-platform, and a lack of effective incentive mechanisms in the cooperation will increase collusion between the e-platform and loan borrowers (Lin and Peng, 2021). Besides, the online enterprises are more scattered in wide regions and diverse industries, which increases the difficulty in credit investigation and reduces the stability of the supply chain. In addition, if OFSPs emphasis too much on "electronic credit" and neglect "main body credit" to pursue convenience and speed, borrowers may enhance their levels of site membership via fictitious online transactions, abnormal trading and fake customer reviews to defraud loans (Deng and Chen, 2017). Thus, merely seeking OFSPs' electronic help with credit auditing on SMEs in SCF business is not the perfect solution to traditional banks' dilemma.

Consequently, how to construct an ecosystem by strengthening their risk assessment efficiency and risk prevention ability is of great significance for commercial banks. However, most analyses of the IPF risks are scattered and not from the perspective of comparison with OFSPs' leading solutions. Thus, a new research direction is needed.

2.3 The IoT and blockchain technologies

New technologies can increase information transparency of supply chains and reduce credit risks of SMEs (Lyu and Zhao, 2019). IoT is now extended to the Internet of everything or the industrial Internet. Five technologies are widely used for the deployment of successful IoT–based products and services: radio frequency identification (RFID), wireless sensor networks (WSN), middleware, cloud computing and IoT application software (Lee and Lee, 2015). IoT-enabled technologies can help financial institutions get immediate information by remotely using GPS, embedded mobile video surveillance terminal, electronic fence, RFID and other relevant applications (Abbasi *et al.*, 2019). Through continuously capturing data from everyday activities, IoT-enabled technologies allow businesses to get timely and accurate information for better operation and decision making (Xu *et al.*, 2014; Joseph *et al.*, 2017; Uden and He, 2017).

At the same time, blockchain technology is recently argued to have the potential to disrupt business and financial services in the way the internet disrupted off-line commerce as the latest "disruptive innovation" (Frizzo-Barker *et al.*, 2020; Cong and He, 2019; Pan *et al.*, 2019). Blockchain is defined as "a comprehensive information technology with tiered technical levels and multiple classes of applications" (Swan, 2015). Even though disruptive technologies are considered rarely "positive" or "negative" (Pinch and Bijker, 1984), blockchain can reduce the possibility of fake or false records and secure information systems and digital records on all the computers in the blockchain network (Berdik *et al.*, 2021). As a novel technology, blockchain has great potential to offer significant advantages for promoting direct communication among multiple parties involved in the supply chain without customized services provided by third parties (Swan, 2015; Hughes *et al.*, 2019; Chang and Chen, 2020). In this way, blockchain can mitigate informational asymmetry and improve consensus quality, leading to a wider range of economic outcomes (Cong and He, 2019). Existing blockchains can be broadly categorized into a public blockchain, alliance blockchain and private blockchain. Among the blockchain technologies, smart contracts are *"digital contracts allowing terms contingent on a decentralized consensus that is tamper-proof and typically self-enforcing through automated execution."* They can "*augment contractibility and enforceability on certain contingencies*" regardless of lock-in requirements of money transfer or the automated payment after product or service exchanges (Cong and He, 2019). To be specific, contractual clauses are written in a series of codes, and the contract will be executed when redefined terms of the contract are verified, and an event or a function is triggered. Hasan *et al.* (2019) proposed a blockchain-based solution for shipment supply chain management and utilized the smart contract to manage the interactions between the sender and receiver of the shipment. This solution could largely improve product visibility, tracking and process automation in global trade and logistics activities.

As IoT sensors and blockchain become increasingly popular every day, organizations are looking to integrate IoT with blockchain to improve business processes and accelerate growth (Joshi *et al.*, 2018). The combined effect of blockchain and IoT can bring wonders (Malik *et al.*, 2021). For example, since blockchain can help existing IoT solutions enable secure and trustless messaging between devices in an IoT network (Banafa, 2017), the integration of blockchain and IoT technologies was used for food traceability systems in the agriculture industry (Lin *et al.*, 2018). As data gathered by IoT devices may contain confidential or private information, it is good to store and share sensitive data on the blockchain to help trusted stakeholders monitor the status of goods. UPS and FedEx developed blockchain pilot projects to enhance their logistics systems. Furthermore, AI and big data technologies can be leveraged to analyze on-chain data and provide near real-time analytics and recommendations to relevant stakeholders through customized dashboards (Rabah, 2018; Sultana *et al.*, 2021; Varsha *et al.*, 2021).

2.4 Research gap and framework

There are very few studies about facilitating traditional commercial banks' SCF services to convergence IoT and blockchain technologies. It remains unclear how the integration of blockchain technology and IoT could be effectively designed and implemented to address issues such as data security and trust (Song *et al.*, 2018b). The lack of research makes it challenging for the financial industry to adopt and implement these practices. Chang *et al.* (2020a) reported that knowledge hiding in blockchain was common. Many banks have pressing questions to be answered; for instance, how can new technologies enable traditional banks to solve information asymmetry hindering IPF development, and how can traditional commercial banks develop and implement the SCF business model to face the challenges of OFSP. Prior research has not analyzed the IPF risks from the information view to provide measurements for mitigating the risks using state-of-the-art technologies.

To address the research gap, we derived a research framework based on the main risk categories and the SCF solution strategy proposed by Blackman *et al.* (2013), as shown in Figure 1. Information asymmetry between banks, loan borrowers and warehouses includes adverse selection, hidden information and hidden action. The barriers in communication induce collateral, warehousing and liquidity risk in IPF, as we summarized from the literature. According to Song *et al.* (2018a), OFSPs have superior solutions due to their information acquisition ability, network structure and process control capability. Based on this framework, our research helps identify effective strategies and provides valuable insights.

3. Methodology

The purpose of this paper is to address and mitigate the information asymmetry issue in IPF by leveraging new technologies. Since the applications of IoT and blockchain and the

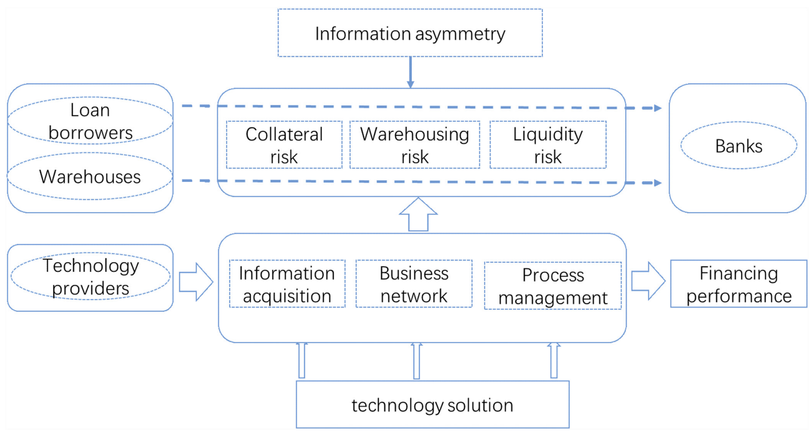

Figure 1.
The research framework

integration of the two are still in the exploratory stage, a qualitative analysis is more practicable. Given the novel, innovative and phenomenological nature of this research, we think in-depth case analysis is appropriate for our study (Eisenhardt and Graebner, 2007; Yin, 2009). While case studies are useful for depicting dynamic processes and summarizing valuable experiences, appropriate cases need to be identified to answer our research questions (Xiong *et al.*, 2021). The "purposive sampling" method was adopted to select two IPF cases from China for several reasons. First, China has been progressively promoting SCF recently and experienced a lot of trust crises in IPF. Thus, it is necessary to strengthen symmetric information sharing and trust-building among players in SCF. Secondly, China is very active in embracing IoT and blockchain technology. Thus, there are a lot of novel application scenarios in China that can be shared with the communities to improve existing practices. We consulted P Commercial Bank (P Bank is the pseudonym as requested), which specializes in implementing SCF. P Bank is the first group to cooperate with OFSP and adopt the IoT and blockchain technologies in SCF businesses. Thus, P Bank is the industry leader in implementing SCF, and they recommended two novel cases to us as successful examples in IPF. The first case focuses on implementing IoT in solving data collection and inventory verification, while the second one investigates IPF by integrating the IoT and blockchain technology.

We adopted the triangulation approach to better understand the two cases, which combines three research methods: field research, in-depth interview and second-hand material searching. First, the research group performed a field investigation in selected financial institutions by observing their communication process, recording the bank officer's operations and conducting a test run for event-triggered risks. In addition, we visited the focal company and SMEs to check their facilities, business operation process and related credit information to verify the information collected from the financial institutions. Thirdly, we conducted semi-structured interviews with practitioners from every party involved in the target supply chain. All the selected interviewees were senior managers or program managers who were directly involved in these cases, and their ages were primarily around 30–50 years old. To limit memory errors and increase accuracy, we cross-examined the informants' descriptions and asked at least two respondents for each question. The interview process lasted for several months, from August to December of 2019 for the first case and September to October 2020 for the second case. We established a rigorous procedure for interviews by preparing several lists of questions for different interviewees. For bank clerks, our questions focused on their concerns on IPF, their willingness to accept technologies, the effectiveness of technologies, risk control method and data analyzing process; for focal enterprises, we mainly asked for the purpose of starting the IPF, the warehousing process and the information collecting and sharing process; for borrowers, we explored the difference between application processes of traditional banks and those of banks that adopted the IoT platform/Blockchain platform; for technology solution providers, we were interested in the operation processes, technologies' functions and challenges. All the questions were verified by interviewing two or more workers from each unit or department. Finally, we collected public information from Internet news, corporate websites and meeting minutes. Since both focal enterprises in our study are large companies, we found rich online resources available such as the organizational news and reports for our case analysis. The data resources are shown in Appendix.

This research adopted the open coding method for the coding process (Gioia *et al.*, 2013), which explicitly shows the dynamic process of IPF. The coding processes were analyzed by one of the authors and checked by another bilingual professional to preserve informants' original meaning and intent, then discussed with the other co-author for improvements until all these authors reached agreements. According to the coding result of the NVivo software, there were 37 third-level nodes, and we named the third-level nodes according to the interviewers' expression. Then we combined the theories with the third-level nodes to name the second-level nodes, which helped us better understand the usage of IoT and blockchain technology in mitigating IPF risks. In the end, we summarized the second-level nodes and sorted out 12 first-level nodes. The coding result of the first case is shown in Appendix.

4. Case studies

4.1 Case one: use of IoT technology

4.1.1 Background of the case. YangHong Warehouse Company Ltd. in Jiangsu province of China provides liquid chemical warehousing and petroleum warehousing services to chemical manufacturers and retailers. YangHong is a subsidiary of Hong Chuan Zhi Hui (002930), a Shenzhen Stock Exchange-listed company, one of China's largest methanol warehousing service providers. YangHong owns 77 storage tanks and cooperates with more than 1,000 retailers. However, there is a similar financial shortage bottleneck for YangHong's customers, who are small- or medium-sized private-owned companies. These retailers are unable to provide guarantees or mortgage assets to obtain traditional banks' credits, and bank regulators do not favor their imperfect financial systems. As a large-sized warehousing service provider, YangHong tried to explore SCF by taking advantage of their full information of the partners along the supply chain.

P Bank was reluctant at first with several concerns. Firstly, since many SMEs were cooperating with YangHong, and a large sum of trading was happening every day, it was difficult for P bank to acquire detailed information of these transactions and accordingly credit these SMEs. Secondly, methanol production needed dynamic warehousing. The turnover rate of the inventory was high, thus monitoring the collateral movement, checking the damages or losses of underlying assets and ensuring the replenishment of infective goods were beyond the financier's capability. Thirdly, within the traditional SCF business model, inadequate depiction of SMEs' operations, slow crediting process and high labor-cost filed inspection would inevitably lead to risky and inefficient business. The lack of additional constraints raised the possibility of SMEs' defaults and probably bred opportunistic behaviors of YangHong and SMEs.

4.1.2 IPF solution with IoT. To prevent possible IPF risks, P bank, YangHong and Sample Technology Co. Ltd (HK1708) cooperated in taking advantage of the IoT solutions. Sample Technology is a company providing IoT solutions, smart city systems and logistics services. They upgraded the warehouses of YangHong with IoT equipment, rebuilt the back-office system and developed an IoT architecture with three layers for the warehouse: the perception, transportation and application layer (see Figure 2). The bottom layer was composed of various sensors inside the warehouse. They were used to collect data about liquid PH value, temperature, density, weight, volume and other measures. Then the information was transported into the cloud immediately. After the data was filtered, processed and analyzed, important outcomes, such as the condition of the liquid, the quality of the liquid and whether it could match the requirement of P Bank, were sent to the application layer.

It is worth mentioning that they also installed a set of monitoring instruments that were used to control the operation of the warehouse and allowed bank officers to remotely monitor the chattel in an emergency. If an owner of the underlying goods applied for financial support in the online system, the goods would be transported into a designated warehouse. After sensors verified the goods, the platform would automatically lock the inventory by shutting all the input/output gates of pipelines. Then the IoT system would start to supervise the inventory and continuously reflect data until a new electronic command was issued from the system. All the operations during that period could be recorded and sent to bank officers. Thus, the IoT architecture standardized the workflow with real-time information verification and automatic inventory monitoring (shown in Figure 3).

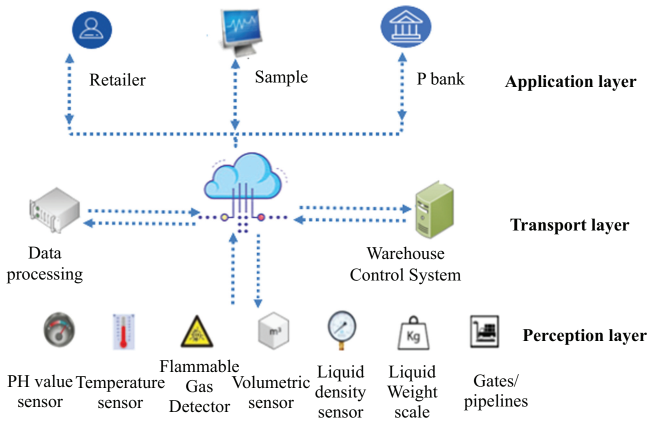

Figure 2. The architecture diagram of IoT

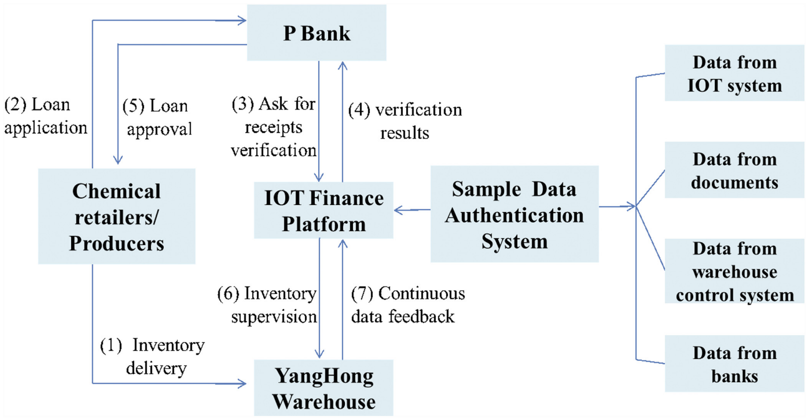

Figure 3. The workflow of inventory pledge financing

To alleviate the credit risks and promote financing efficiency, P bank and YangHong set up a membership list based on their credit risk model to select qualified retailers according to P bank's credit model. Table 2 shows the selection criteria for the applicants. All the loan processing activities, including application, verification, reviewing, disbursing and real-time data transformation, took place automatically on the platform for eligible members. After verifying these members' inventory, P Bank could approve their loan applications in 2 h.

4.1.3 Case and data analysis. In IFP business, OFSPs deal with adverse selection by taking advantage of their platform's dominant position in the supply chain and their information system to extensively access SMEs' transaction and logistics information (Shi *et al.*, 2015). Banks in traditional SCF could only rely on "hard information" such as warehouse receipt as a major information channel which hinders their popularity among SMEs. Compared with conventional inventory monitoring models, the new architecture equipped with IoT facilities improves P bank' information acquisition ability. With IoT devices collecting data, the collateral is easily recognized, and the quality of underlying assets is efficiently checked. Moreover, the facilities could standardize the inventory checking process and provide P bank varieties of product information. The solution alters traditional banks' dependence on paper

Category number	First level index	Second level index
1	Corporate quality	Assets
		Liability
		Profits
		Sales amount
		Sales growth rate
2	Corporate management	Operation history
		Leadership quality
		Management quality
		Employee quality
		Financial disclosure quality
3	Supply chain operation	Supply chain stability
		Industry growth rate
		Rank in the field
		Price stability
		Operating turnover rate
		Default rate of the supply chain
		Vulnerability of the supply chain
4	Operation history on the platform	Trading period
		Trading frequency
		Trading volume
		Counterparty qualification
		Counterparty credit rating

Table 2.
Criteria index for membership

receipts to ascertain pledged assets and improves the consistency of information and goods flow.

In traditional IFP, traditional banks cannot take immediate action due to slack business structure and simple bilateral relationship, leading to the warehouses' hidden actions. Nevertheless, OFSPs embed SMEs into their business network, and through the connected storage management system, they can realize process management on inventory in OSCF (Song *et al.*, 2018a). To update the traditional IFP, P bank leverages the interconnection of IoT information networks. Immediate information transportation enables banks to access chattel timely and allows real-time online monitoring to replace field inspection. Moreover, upgrading the in-trans system reduces bank's labor costs and allows banks to manage inventory efficiently. With IoT-embedded systems, risk signals can be acknowledged much sooner and increases the possible cost of hostile manipulation or inventory arbitrage. All these measures enhance financers' ability to recognize hidden actions of the counterparty.

More importantly, the architecture accelerates the financing processing of SMEs. It speeds up the credit rating workflow and the loan approval process by linking the information system with banks' back-office system. Due to real-time communication that makes dynamic warehousing feasible, and SMEs could enjoy the convenience of dynamic warehousing loan service. The speedy loan approval increases the cooperation stickiness of core enterprises, SMEs and banks. SMEs have strong incentives to maintain stable and successful partnerships with commercial banks. The IoT–based IPF also improves commercial banks' involvement in the supply chain and their knowledge in valuing the underlying asset when it comes to liquidation.

In conclusion, the IoT–based IRF solution enriches traditional banks' risk management solutions. Commercial banks could utilize state-of-the-art technologies to build an e-platform for transparent, standard and efficient communication. The e-platform allows commercial banks to embed it into SMEs' business and alleviate traditional SCF business models. However, the IoT architecture also has limitations. It cannot solve all IPF risks, and the liquidity risk is still an obstacle in promoting the IPF. Due to the warehouse's reluctance to involve in the liquidation process, traditional banks lack a bridge connecting with the market and a mechanism to secure their rights from the information standpoint. Additionally, the case is mainly based on SMEs' business credit rather than core enterprise' credit according to the selection rules. Thus, the credit of the core enterprise has not been fully exploited. Finally, this IoT architecture is merely suitable for a standard commodity such as sugar and chemical products. For non-standard commodities such as electronic commodities and semi-manufactures, the architecture is not applicable. However, a variety of commodities and more generic solutions are needed to promote IPF.

4.2 Case two: joint use of IoT and blockchain technology

4.2.1 Background of the case. Xiao Wei Yun Lian Blockchain Company, Ltd. (X blockchain company) provides mediator services with blockchain and IoT technologies. Their team started to explore IoT technologies in SCF in 2011. They are now a leading company in implementing IoT and blockchain technologies in China. X blockchain company and P Bank set an excellent example by providing IPF solution services to Baoshan Iron and Steel Company Ltd. (600019). Warehouses of Baoshan have standardized warehousing management processes and advanced WMS (Warehouse Management System), which are used to custody large-scaled raw materials, such as steel, plastic, sugar, etc. First, P bank requested to connect to the warehouses' WMS to collect daily information related to specific chattel. To verify the information of underlying assets matching electronic receipts, P bank and Baoshan introduced a set of IoT equipment (RFID, electronic fence, video surveillance, etc.). Thus, information collected from IoT could be used to verify the electronic receipts generated by the WMS before they were transferred into digital certificates. Additionally, since Baoshan is a large-scale state-owned company, they have an excellent credit rating in P bank and excellent indicators of corporate solvency, profitability and operating capacity. Baoshan has hundreds of suppliers and downstream, and these SMEs stick by Baoshan. These characteristics decided that Baoshan could be the core enterprise to provide a credit base for transferring receipts between retailers and commercial banks. Thus, the promise that Baoshan would be responsible for the assets underlying, and any damages or losses of the inventory would be compensated by Baoshan was appended to the blockchain as a smart contract.

4.2.2 IPF solution based on the convergence of IoT and blockchain. After establishing fundamental trust, the next step was to build a credible information-sharing platform where the receipts could be transferred among relevant stakeholders. X blockchain company provided an alliance blockchain architecture with four nodes located in the Shanghai notary public office, Suzhou notary public office, Nanjing notary public office and X company. The notary public offices are government authorized organizations to provide neutral, authentic and legal information to the public. To ensure the information on the blockchain was secure and indelible, the peer nodes of the network were simultaneously recording information. The blockchain included three layers: the application layer for operations by users, the Fabric Hyperchain layer for information storage and smart contract and the scheduling layer for information transferring (shown in Figure 4). The electronic receipts of the pledged inventory could also be transferred, split and sold, and in particular, used as securitized cash. All the processes related to receipts, including receipt issuing, receipt pledging, pledge releasing and pledge written-off, had to be uploaded to the blockchain. Thus, trustworthy information could be introduced to every party along the chain, and the ownership of the receipts could be transferred to any participants on the chain. Since banks, warehouses, retailers, guarantee agencies and partners in related industries joined the chain to share digital trust, the ecosystem was built. All the transactions were recorded, and P bank could monitor the trade

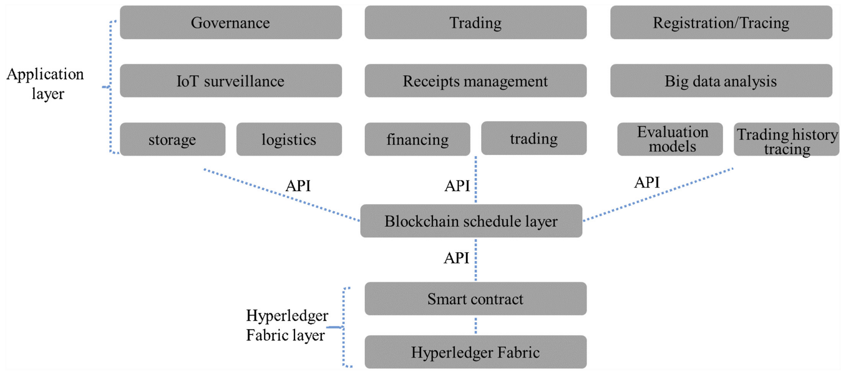

Figure 4.
The architecture of the X blockchain

flow. They could also consistently obtain overall supply chain activities between financed SMEs and their customers through the platform.

After recording more than 3,000 transactions among 200 retailers over three years, the deposited data enabled P Bank to leverage the information to evaluate these retailers. First of all, in the blockchain application layer, trading details were deposited related to the pledge during the business development process. The information of buyers and sellers, trading frequency of the borrowers, trading history of the warehouse receipts, producer of the underlying assets, and market price fluctuation were recorded. Later, information would be transported to P Bank' back-office system. Based on P bank's rich risk assessment experience, evaluation models including SMEs' business operation evaluation, the pledge value analysis and credit history analysis were used to comprehensively evaluate borrowers. After the standard credit rating process, banks could decide on customized interest rates, loan-to-value ratio and loan period. Since the evaluation result was automatically produced, the loan approval procedure now took only three days, 4–12 days shorter than before.

More importantly, Baoshan company, X company and SMEs all had strong incentives to boost cooperation with P Bank. For Baoshan company, the blockchain-based SCF could help them prolong the payment period to their suppliers or extend their customer base by providing value-added services. Besides, P bank offered high rewards and penalties to Baoshan company. If any collusion between Baoshan company and SMEs was founded, Baoshan had to shoulder the responsibility to compensate for the gap between the loan amount and liquidation value of the underlying assets. In contrast, if Baoshan company refused to conspire with SMEs and informed P bank, P bank would reward Baoshan with high rewards. From the perspective of SMEs, their upstream and downstream were all on the chain, their strategic partners would acknowledge any default behavior, so the cost of a breach of contract was high. In X company's case, they could benefit from the authentic ecosystem and obtain incomes from stable users' fees, so they did not have destructive motivations.

Finally, although technologies were expeditious in information collecting, verification, transferring and sharing, incentive mechanisms were needed to solve disputes in dealing with defaults. To reduce the burden of P Bank, several mechanisms were introduced to prevent the liquidity risk. First, the Futures Exchanges were adopted since Baoshan has a few warehouses, which are exchange-approved warehouses. If the commodity could be used to back a future contract, it would be delivered to a specific warehouse. If the inventory could not meet the strict specifications of the Futures Exchanges, a guarantee agency would be brought in to pay for the debts in case of the borrower's default (see Figure 5). Then, the dispute could be minimized between the guarantee agency and the loan borrowers. All the measures were written to the contract and submitted to the blockchain, which has legal rights to avoid endless haggling and shifting of responsibility between stakeholders. The smart contract between P bank and Baoshan company and the smart contact between P bank and the guarantee agency could be triggered by the default event and predetermined items. Then the repayment transfer would be executed automatically to reduce tedious procedures and inconvenience of traditional procedures. Moreover, the smart contract avoided artificial tampering and manipulations of the paper-type contracts since the blockchain nodes chronically recorded every single operation. As a result, unnecessary arguments and disputes were greatly decreased.

4.2.3 Case and data analysis. In contrast with the IoT–based IPF model, this model promotes an ecosystem that integrates all the participants, which provides a more general SCF model for all commercial banks. In traditional SCF, banks have difficulty obtaining borrowers' operation information and transaction information, while OFSPs outperform traditional banks in information acquisition (Chen *et al.*, 2019). However, in this converged technology-based model, to improve the validity of the receipts before they are appended to the blockchain, IoT technologies are devised to enhance the visibility of the goods flow and information flow. Blockchain later enables efficient digital transferring of the warehouse receipts in a reliable environment. Besides, they built a platform where retailers and financial institutions can activate the receipts' transactions on the chain. Due to frequent transactions with upstream and downstream, the transmission of information penetrates each link in the supply chain operation. With data accumulated as a data pool, banks can access SMEs' transaction information, which could be used to further analyze SMEs' operation, leading to easier estimation of inventories' risks. The in-time analysis further speeds up loan approval processes and dynamic IPF.

Moreover, the convergence of IoT and blockchain assembles the custody responsibility and supervisor responsibility of warehouses. The incentive mechanism strengthens the consensus between financiers and warehouses to curtail collusion opportunities and sets a

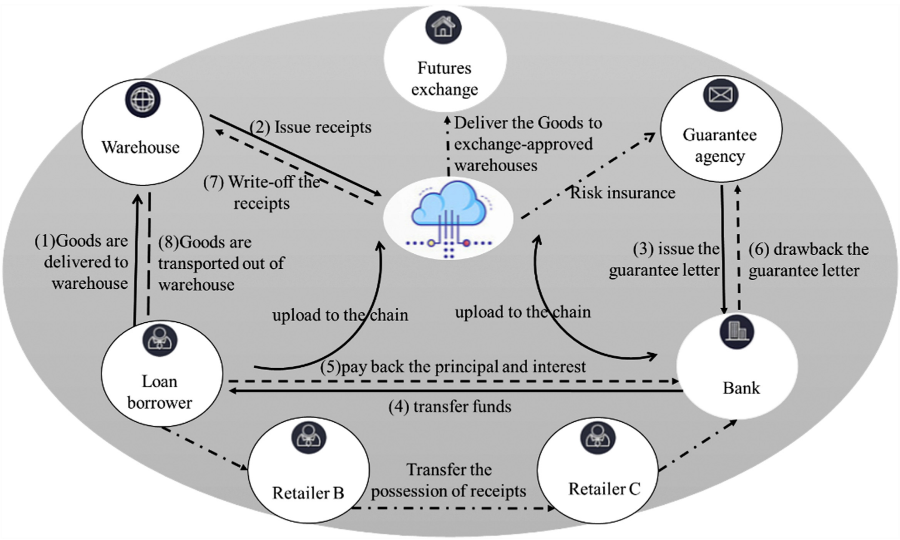

Figure 5.
The workflow of the inventory pledge financing on the X blockchain

foundation for spreading trust culture along the supply chain. At the same time, the binding relationship between SMEs and participants on the chain is regarded as a kind of strong tie (Song *et al.*, 2018a), which can restrict SMEs' opportunistic behavior and reduce their default intention. Due to the unbalanced status between OSFPs and borrowers, X company establishes a fair network structure for all involved parties along the chain. Beyond the dependence on focal companies' credit as in traditional SCF, the trustworthy and cooperative partnership between banks, technology providers, focal enterprises and SMEs acts as additional constraints in the blockchain-powered SCF model.

Furthermore, to prevent liquidity risk, introducing the smart contract locks up all the partners for agreement negotiation, responsibility and claiming and promoting negotiation efficiency among stakeholders. In contrast with the traditional SCF model, banks do not need to resort to costly legal proceedings to recover all the losses. A smart contract enables P bank to realize the behavior control and process control by ensuring the transferring of repayment. Moreover, in the blockchain-based IPF model, all the involvers are shouldering responsibilities. The assignment is clearly devised, and the collaboration is efficient in the structure. Thus, the multi-part collaborative mechanism strengthens the outcome management, and smart contract ensures the process management, which used to be OFSPs' strengths (Song *et al.*, 2018a).

5. Discussion

5.1 Theoretical implications

The prior literature about SCF risks mainly focuses on operational and credit risk measurement (Li *et al.*, 2019; Abbasi *et al.*, 2019; Lyu and Zhao, 2019). Very few prior studies focus on inventory financing risk, especially from the viewpoint of information. Based on the principal-agent theory, our research analyzes the IPF risks. According to Jost (2001), information asymmetry is classified into three categories: adverse selection, hidden information and hidden action. Correspondingly, we explicitly separate IPF risks into three main categories: collateral, warehousing and liquidity risk. The dimensions extend the research of Brindley (2004), focusing on analyzing pledge loan credit contracts from an information angle. Asongu and Odhiambo (2018) concluded that increasing the number of information-sharing channels could reduce information asymmetry and significantly promote financial access.

Besides, to reduce information symmetry, it is crucial to innovate traditional banks' SCF model, especially when OFSPs are emerging as strong competitors with their natural advantages in addressing information asymmetry. OFSPs' dominated SCF model is "supply chain-oriented," and they directly involve in the supply chain cooperation with their IT platforms (Song *et al.*, 2018a). Although traditional banks are "focal enterprise-oriented," they are advanced in risk assessment and prevention (Deng and Chen, 2017). Due to natural genetic defects, it is also difficult for traditional banks to set up e-commerce platforms to engage in SMEs' direct transactions (Shu *et al.*, 2020). Meanwhile, over-dependence on OFSPs may result in many drawbacks, such as the OFSPs' failure to fulfill their duties on information auditing, SMEs' deliberate frauds on e-platform and loans and banks' passive position in the business (Lin and Peng, 2021). Thus, our study contends that traditional banks can leverage IoT and blockchain technologies to build an ecosystem and compensate for their lack of embeddness in the supply chain. As well known, OSCFs' business is restricted to retailers and traders who are SMEs on the e-commerce platform. But the blockchain-based model could embed into commodities and industrial products so that the business model could contest with OSCF.

Following the framework in investigating SCF solutions suggested by Blackman *et al.* (2013), our research analyzes the changes of traditional banks in three aspects: component information acquisition, business network structure and process management (see Figure 6). First, according to Mohr and Spekman (1994) and Voigt (2011), the quality of the conveyed information, the effectiveness of communication, and the extent and frequency of information sharing play an important role in a supply chain relationship. By taking advantage of IoT and blockchain, traditional banks' information acquisition ability can be primarily improved since IoT helps collect real-time information, and blockchain helps preserve and transfer information in a credible environment. The information quality of the chattel is largely improved. Thanks to the authentic and stable information flow, the technology-supported SCF can reduce and control collateral risk after the data accumulation of inventories.

Moreover, although banks cannot embed themselves into SMEs' operations similar to OFSPs to reduce hidden action, they could set up an SCF alliance with the help of core enterprises and the technology service providers. More importantly, the alliance is different from the network structure of OSCF, which the OFSPs dominate, and SMEs are vulnerable members of the network. In the blockchain and IoT facilitated ecosystem, the focal company, SMEs, technology providers and banks share equality and trust. With information accumulated on the platform, commercial banks could enhance their familiarity with SMEs' operation, cash flow situation and integrity. SMEs enjoy the convenience and efficiency of the loan approval process brought by timely communication. Especially in the second case, all the participants are motivated to sustain a cooperative relationship and avoid opportunistic behavior in the ecosystem. With the technology service providers' help, efficient communication between banks, SMEs and warehouses can enhance the mechanism to control warehousing risk.

Furthermore, to curtail liquidity risk, both outcome and process control measures are needed (Song *et al.*, 2018a). First, smart contracts could be used to automate the transfer process in every stage and to ensure the fulfillment of all the repayments. Therefore, SMEs' income and account are under monitor during the loan process, which is easier for banks to control SMEs' cash flow and assess their ability to repay the loan. Second, outcome control is strengthened by the clear division of each one's responsibility. If low-credited SMEs default,

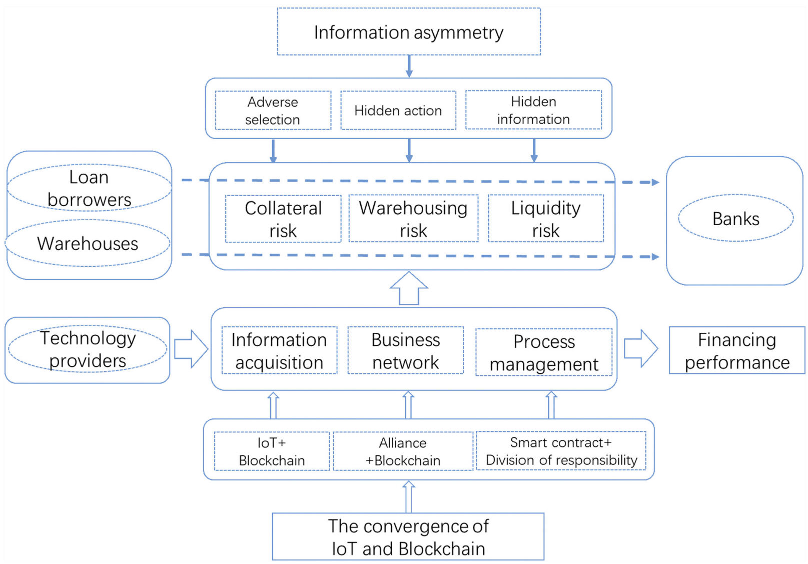

Figure 6.
Technology-based SCF business model framework

commercial banks could introduce focal companies, guarantee companies and technology providers to share liquidation risks.

5.2 Practical implications

IoT architecture or technology will not benefit companies unless it is tied to a specific purpose and business outcome (Gerhard, 2020). The findings from the two case studies offer valuable insights to practitioners, financial institutions and policymakers. The first case has an advantage in timely and continuous information communication, while the second case centers on the model structure. Considering that the first case is only suitable for standard commodities, the replication of the model is more difficult than the second case, which has no limitations on inventories. Most importantly, the second case is focused on the collaboration relationship and the ecosystem. Additionally, as alliance blockchain becomes prevalent supported by mature technology and low cost, the trust can be constructed to become the base for adopting and sustaining blockchain-based SCF, and the business model could be extended to a lot of industries.

But there are several implications for managers who consider establishing similar technology-based IPF models. First, it is crucial for a significant number of SMEs to join the blockchain platform. Starting with the core enterprises in the supply chain can mobilize SMEs to join the blockchain. When more SMEs' upstream and downstream members are on the chain, traditional banks could easily acquire, extract, synthesize and disseminate the information in the data pool. Second, the digital information flow must be consistent with the goods flow. Thus, information collected from IoT sensors and WMS should be precise and be uploaded to the blockchain in a timely manner. Third, the data accumulated on the chain should be fully exploited. After filtering the sensitive information, the data should be mined by banks to enrich the credit risk assessment model and improve lending actions to maximize the performance.

6. Conclusion

Our study provides valuable insights to explain how the IoT and blockchain can be converged to address information asymmetry and mitigate IPF risks. Our work is timely in that it provides a solid foundation for synthesizing the risks of IPF and a feasible solution to compete with OFSPs. Based on the principle-agent theory, we classified the information asymmetry into three groups (adverse selection, hidden information and hidden action), coincidently explaining the collateral risk, liquidity risk, warehousing risk in IPF. Through multi-case analysis, we propose that IPF risks could be addressed from the information perspective by using emerging technologies like the IoT and blockchain. With the rapid growth and development of the IoT and blockchain, they have become helpful in providing high-quality information acquisition, building a fair business network and sponsoring effective process management. The results can help commercial banks evaluate whether they should adopt these technologies and how to embed these models into their SCF business.

A limitation of this study is that we only provided two case studies to help understand the impact of these emerging technology solutions on SCF. More case studies or a large-scale survey study from multiple data sources will be helpful to generalize the findings. As far as future work is concerned, it is interesting to design and develop customized data mining and visualization approaches to analyze SCF when more IoT data becomes available. We also plan to investigate the regulation issues of managing SCF on blockchain in the future. We will recommend strategies and best practices for businesses and individuals to regulate and transform existing SCF. Finally, it is also important for organizations to adopt suitable strategies for implementing IoT and blockchain technologies across the supply chain, obtaining buy-in from key actors and getting support from technology providers.

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Appendix

Data sources	Case 1	Case 2
Technology solution provider	Chief Executive Officer (CEO) of Sample Technology	The CEO of X Blockchain company
	Chief Finance Officer (CFO) of Sample Technology	The program leader
	The IoT platform architect	The blockchain platform architect
	UI designer	The marketing manager
	(JiangSu Province)	(Zhejiang Province)
P Bank	Chief Risk Officer (CRO) of P Bank	The Chief Manager of SCF Department
		Senior program leader in SCF Department
	(Shanghai)	(Shanghai)
Focal company	The program leader in YangHong	A senior manager of Baoshan Company
	A wenior warehouse manager	A warehouse manager of Baoshan Company
	(Jiangsu Province)	(Shanghai)
SMEs	The entrepreneur of R Mechanical Company	The finance representative of Y company
	The finance representative of D Biology CO. LTD	The entrepreneur of Y company
	(Yangtzi River area)	(Yangtzi River area)
Observations	Participant observation of the IoT Platform operation	Participant observation of the X blockchain operation
	Participant observation of the warehousing process	Participant observation of the warehousing process
	Participant observation of the credit analysis and reporting workflow	Participant observation of the credit analysis and reporting workflow
Secondary data	Templates of the case data:2	Template of the case data: 4
	video introducing of the case:2	PowerPoint introducing of the case: 3
	News related to the case:5	News related to the case: 8

Table A1. Data sources of the two cases

First-level codes	Second-level codes	Original quotes
Challenges in adopting the traditional IPF	*Inferior position on information acquisition*	*YangHong and SMEs' interests are strongly interdependent, while we are at an unfair information disadvantage in this business model. (The program leader of P Bank)*
	Adverse selection risks of the traditional IPF	*Over-relying on the hard information, such as the profit ability, financial reports and pledged goods, we could not accurately give credit to methanol companies. The market of this industry is very dynamic . . . (Chief Risk Officer(CRO) of P Bank)*
	Hidden information of the traditional IPF	*We cannot visit the premises very often and check the quality of the liquid chemicals as experts. (The program leader of P Bank)*
	Hidden action risks of the traditional IPF	*The biggest challenge is that commercial banks do not trust chattel mortgage mode after the steel pledge crisis happened in 2012. They are afraid of duplicate collateral and fraudulent receipts . . . (Chief Executive Officer(CEO) of Sample Technology)*
Efficient information acquisition	*Transparent information sharing*	*The process control is transparent, strict, and in a timely manner, and it heavily alleviated the difficulties in our job and reduced the supervision cost of the warehouse. At the same time, the whole process is easy to understand . . . (A senior warehouse manager)*
	Frequent information sharing	*The sensors could continuously verify the inventory and send the result to the platform immediately. (A senior warehouse Manager)*
	Extent information sharing	*In the traditional SCF method, banks could only "observe", could not "dip our fingers in" or "poke out noses into". But now the whole process is transparent to them, which gives banks a strong sense of security. (Chief Finance Officer(CFO) of Sample Technology)*
	Efficient information sharing	*All the documents are electronic invoices, the system could verify the goods and the invoices. The IoT platform is very convenient and it dramatically improved the efficiency to get a loan. (The Entrepreneur of R Mechanical Company)*
Cooperative network structure	*Engagement of participates*	*Based on the data collected from IoT system and the database of YangHong, we set up a credit model to credit all the customers on the list. The credit evaluation model is quite different with traditional ones . . . (Chief Risk Officer(CRO) of P Bank)*
	Motivation of the cooperation	*We used to run frequently between warehouses and banks for a few weeks to get a loan. But now the loan application process is much simpler than before, the IPF model is very popular among methanol producers and traders like us. (The finance representative of D Biology CO. LTD)*
	Barriers to wreck the collaboration	*Without instructions to release the pledge from the platform, the goods are impossible to be shipped out. Even with the help of the warehouse manager, any abnormal operations of the warehouse will be noticed and recorded. The cost to do any manipulation on the warehouse receipts is very high. (The program leader of the Sample Technology)*

(*continued*)

Table A2.
Coding result of IoT–based IPF model

First-level codes	Second-level codes	Original quotes
	Supervisor of the cooperation	*Banks used to be the last one to find the troubles about inventory, but now we could check all the operations of the warehouse and the inventory owners on the pledged goods. (The Program Leader in YangHong)*
Challenges of the IPF model	*Liquidation risks to be solved*	*Even though we do not worry a lot about collusion risks and evaluation uncertainties of the inventory, we still need to face liquidation risks of pledged goods. (The Program Leader in P Bank)*
	The credit of core enterprise to be fully exploited	*Actually we do not like the fact that focal companies stand by and shoulder little responsibility in the game when default happens. Since they take a certain amount of commission in the loan process, they should . . . (Chief Risk Officer(CRO) of P Bank)*
	Limitation on commodity varieties	*This IoT facilities are specially designed to liquid chemical warehouses, such as ethanol, methanol . . . (The IoT Platform Architect)*

Table A2.

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