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Incentive-Driven Information Sharing in Leasing Based on a Consortium Blockchain and Evolutionary Game

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Abstract: Blockchain technology (BCT) provides a new way to mitigate the default risks of lease contracts resulting from the information asymmetry in leasing. The conceptual architecture of a consortium blockchain-based leasing platform (CBLP) is first proposed to facilitate information sharing between small and medium-sized enterprises (SMEs, the "lessees") and leasing firms (LFs, the "lessors"). Then, based on evolutionary game theory (EGT), this study builds a two-party game model and analyzes the influences of four types of factors (i.e., information sharing, credit, incentive–penalty, and risk) on SMEs' contract compliance or default behaviors with/without blockchain empowerment. The primary findings of this study are as follows: (1) SMEs and LFs eventually evolve to implement the ideal "win–win" strategies of complying with the contract and adopting BCT. (2) The large residual value of the leased asset can tempt SMEs to conduct a default action of unauthorized asset disposal, while leading LFs to access the CBLP to utilize information shared on-chain. (3) When the maintenance service is outsourced instead of being provided by lessors, the maintenance fee is not a core determinant affecting the equilibrium state. (4) There is a critical value concerning the default penalty on-chain to incentivize the involved parties to keep their commitments. (5) The capability of utilizing information, storage overhead, and security risk should all be taken into consideration when deciding on the optimal strategies for SMEs and LFs. This study provides comprehensive insights for designing an incentive mechanism to encourage lessees and lessors to cooperatively construct a sustainable and trustworthy leasing environment.

Keywords: small and medium-sized enterprises; leasing; blockchain technology; evolutionary game theory; information sharing

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1. Introduction

Small and medium-sized enterprises (SMEs) typically encounter capital constraints when buying heavy machinery and industrial equipment for manufacturing, such as forklifts, trucks, hoists, etc. [1]. To cut back on the capital expense, leasing an asset from the Original Equipment Manufacturer (OEM) or a Leasing Firm (LF) is a common and economical option to meet the demand for equipment [2]. Leasing has become a popular financing instrument [3].

In general, a lessee (e.g., SMEs) selects the required equipment, and then a lessor can directly lease the asset they manufacture (if the lessor is the OEM) or purchase the requested asset from the OEM for leasing it out (if the lessor is an LF, such as a financial institution or a firm that specializes in leasing), with the lessee paying rent to the lessor in exchange for using the asset [4]. When the leasing service period expires, the lessee may opt to retain, renew, or return the leased equipment depending on the lease's contractual provisions. The leasing business emphasizes the separation of ownership and uses the rights of the leased asset [5].

Compared with purchasing, although leasing is more flexible and cost-efficient for a lessee, the current leasing business could encounter some challenges, such as lacking knowledge about the lessee's credit history, being unable to fully track assets in real time, and failing to discover any default behavior arising from the information asymmetry. Blockchain technology (BCT) stores data in a tamper-proof ledger that can be shared P2P among many nodes without the aid of a reliable third party [6], which can help to transmit data efficiently and accurately among multiple organizations, particularly in the area of equipment leasing (asset management). Hence, in general, the lessee and lessor are encouraged to participate in information sharing on the blockchain.

Nonetheless, it is challenging for lessees or lessors (particularly for SMEs) to develop or participate in a blockchain-based application system (especially for the consortium permissioned blockchain system) due to the budget constraints of the BCT membership fee, heavy data storage (computation) charges, and other barriers [7]. Meanwhile, considering that stakeholders may maliciously handle sensitive data, the participants might be reluctant to share critical information with other parties [8] unless sufficient incentives nudge the lessee. However, previous researchers have not performed a quantitative exploration of stakeholders' BCT-participating behaviors in the context of leasing, where there is a trade-off between the factors of information sharing, credit, incentive–penalty, and risk. On the other hand, although there exists some research relating to the blockchain applied in leasing, the interactive behaviors among lessees and lessors rarely receive adequate attention. Hence, our study aims to bridge this gap by addressing the following research questions.

(1) How can the blockchain technically drive information sharing and storage between the SME (the "lessee") and LF (the "lessor")?
(2) How to incentivize excellent lessees to share more information while expecting that rational lessees and lessors can both maximally benefit from the leasing business empowered by BCT.
(3) How can the lessee and lessor adjust their behavior strategies to ensure that all parties' payoffs reach equilibrium through continuous trial-and-error learning?

To address these questions, we need to accomplish the following research objectives. First, a conceptual architecture of a consortium blockchain-based leasing platform (CBLP) is devised, suitable for information sharing among SMEs and LFs in a P2P distributed network. Secondly, we employ evolutionary game theory (EGT) to formulate a game model, taking fully into consideration the four kinds of factors (i.e., information sharing, credit, incentive–penalty, and risk) that affect the leasing strategies involving the two game parties (lessee and lessor). Finally, the main impacting results are discussed in-depth, and policy implications are provided on the ground.

In addition, compared with other similar works investigating BCT strategies using the evolutionary game, the novelty and contributions of this study can be summarized as follows:

(1) Our evolutionary game model is developed on the blockchain-based leasing business (specifically the operating lease) in manufacturing, which pays more attention to the SME's leasing behavior (i.e., making the rental payment, reverting the leased asset, maintenance responsibility, and asset monitoring) dynamically changes with the BCT adoption/non-adoption strategy. This study can mitigate the shortcomings of today's leasing management.
(2) We provide a more comprehensive analysis demonstrating that the four factors of "information sharing, credit, incentive–penalty, and risk" dynamically impact the lessee's complying performance on the LC and the lessor's decision-making on BCT adoption. More importantly, we carefully consider technical barriers faced by the organizational players when implementing BCT, such as on-chain and off-chain storage overheads, leasing transaction verification overheads, and credit assessment in BCT.
(3) Based on the game analysis, our experimental results can support LFs (the "lessor") in comprehensively understanding how SMEs (the "lessee") meet the obligations in the

LC and give some implications to policymakers when designing a proper incentive mechanism on the lease.

The remainder of this paper is structured as follows: Section 2 provides a theoretical background of the leasing business, BCT, leasing empowered by BCT, and the evolutionary game integrated with BCT. Section 3 exhibits the CBLP composed of SMEs and LFs. Section 4 states the problem description. Section 5 builds the game model. Section 6 provides a mathematical analysis of the model stability. Section 7 conducts a numerical simulation. Some recommendations and policy implications are provided in Section 8.

2. Literature Review

The following subsections will give an overview of crucial terminologies (i.e., leasing and BCT), the state of the art of BCT-based leasing, and BCT strategies using evolutionary game theory, which serve as a solid theoretical background for this study. After that, the main challenges in conventional leasing are highlighted.

2.1. Definition of Leasing

SMEs typically need to decide between leasing and buying an expensive heavy asset (such as real estate, transportation equipment, industrial equipment, etc.). In recent years, leasing assets has become a popular financing tool for SMEs to solve capital problems in the supply chain [9]. According to the Accounting Standard IAS 17, "a lease is an agreement whereby the lessor conveys to the lessee in return for payment or series of payment the right to use an asset for an agreed period of time" (see, e.g., European Commission, 2012) [10]. From an accounting perspective, there are two types of lease, a capital lease and an operating lease [11]. In a capital lease, the lessor transfers the ownership of the asset to the lessee at the end of the lease. In contrast, an operating lease only allows the lessee to have the right to use the assets. Still, it requires the asset to be reverted to the lessor, such that the lessor will either re-lease the asset in another LC or sell it to release the residual value. At present, the operating lease dominates the leasing market.

Concerning the determinants in default actions of the LC, Kaposty et al. [12] defined an LC as having defaulted when the lessee becomes insolvent or the lessor terminates the contract due to an overdue payment owed by the lessee. The latter case is considered in this study. Difficulty in repossessing the leased asset is also one of the results of defaulting [13]. Altman et al. [14] discovered that a lessee with poor creditworthiness defaults more easily, resulting in higher default losses. On the other hand, Kysucky and Norden [15] revealed that reducing information asymmetry between the lessee and lessor could motivate the lessee to maintain its reputation to obtain future leases. In addition, an exhaustive inspection of asset maintenance and disposals plays an essential role in contract defaults [12]. However, the current leasing system lacks the ability to reliably record real-time information (including the documents) about the leased asset's operational activity, which hampers the lessor's ability to ensure the lessee's compliance with the LC.

2.2. Blockchain Technology (BCT)

Blockchain Technology (BCT) was initially proposed by Satoshi Nakamoto, and it enables transactions to be encapsulated in data blocks and appended to a ledger as a chain structure [16]. It allows distributed and mutually distrustful nodes validate transactions through consensus mechanisms while utilizing cryptography (i.e., public–private key encryption and hash functions) to ensure data integrity. By its nature, blockchain technology makes transactions synchronous, non-reversible, immutable, and traceable in distributed databases, enabling organizations to store and share reliable data without double-checking [17]. Blockchain technology can effectively solve the problem of information asymmetry [18] and monitor the asset's operation in real time, which helps the lessor to alleviate the default risks caused by a low-credit lessee [19]. Therefore, it is beneficial to encourage SMEs (the "lessee") to use BCT and energetically participate in information sharing.

BCT is generally classified as the permissionless blockchain and the permissioned blockchain [20], depending on whether or not nodes are granted to participants in a blockchain network [14,17]. The permissionless blockchain, also called public blockchain, is open access, allowing any node to participate in the consensus procedure, such as Bitcoin and Ethereum. The permissioned blockchain can be further categorized into private permissioned blockchain, in which whitelisted participants in one organization are selected in advance to join the invitation-only network, and a consortium permissioned blockchain, which is operated under the control of several authorized organizations allowing the identifiable participants to execute certain on-chain actions, such as Quorum, Hyperledger Fabric, and Corda. The consortium blockchain is becoming popular with enterprises, where a group of companies collaboratively use the blockchain to improve business processes. Any organization can apply to join the blockchain network, but only authorized organizations granted membership are allowed to write or read information on-chain [21]. This study is dedicated to introducing a consortium permissioned blockchain jointly maintained by the OEM, SMEs, LFs, third-party maintenance centers (MCs), and regulators. At present, blockchain has been widely used in many industries for sharing information, such as supply chain [22], energy [23], healthcare [24], industrial manufacturing [25], smart cities [26], and online education [27].

2.3. BCT Application in Leasing

Currently, there is relatively limited research on the application of BCT in the leasing business. Most research focuses on how BCT fosters information exchange through the lifecycle of the leasing process and improves the efficiency and transparency of leased asset management. For instance, to address the issues of lengthy negotiation cycles and cumbersome financing procedures caused by information asymmetry, IBM proposed a crane leasing model based on the IBM Blockchain Platform that requires the identity of the leased crane to be registered on the blockchain and leasing transactions to be recorded on the leasing blockchain [28]. Leased physical aircraft can be tokenized via blockchain, facilitating asset management [13]. In addition, several researchers are particularly interested in BCT-based car-leasing. Auer et al. [29] developed a prototype blockchain-IoT-based car-leasing platform, demonstrating that the blockchain can facilitate collaboration among stakeholders to some extent while relying on the appropriate balance among factors such as security, authenticity, traceability, scalability, etc. It also emphasizes considering storing car-renting events on- or off-chain to support scalability, as agreed by Faber et al. [30]. To address the problem of inefficiency in delivering and searching records, Agyekum et al. [31] used Ethereum to construct a car-leasing platform that enables the transfer of ownership of a leased car by invoking a transaction on the blockchain, hence helping the regulator to clearly monitor every leasing transaction.

The aforementioned cases imply the following potential benefits of the blockchain applied in leasing: (1) Stakeholders (such as lessors) spend less time verifying the leasing information's authenticity on-chain, since the blockchain can record lease contracts and financial transactions in a non-editable way, which reduces the credit investigation cost [32]. (2) Smart contracts deployed on a distributed ledger can help automate some lease payments or ownership transfers, speeding up the processing of rental transactions [33]. (3) All historical events associated with the leased assets' operation and maintenance and the provenance-related financing activities are objectively recorded by multiple nodes on-chain, which could guarantee asset traceability and data credibility in the leasing business [34]. Hence, BCT is conducive for SMEs and LFs to effectively choose the suitable potential lessor/lessee to sign the LC.

2.4. Evolutionary Game Theory (EGT)

Evolutionary game theory (EGT) is derived to explore the behavior of the large population of boundedly rational agents who repeatedly engage in strategic interactions under incomplete information circumstances [35]. In contrast with classic game theory, EGT has the advantage of analyzing how the game player would dynamically change their own strategic decisions over time through learning and adapting to the other's strategic decisions [36]. There is a core concept in EGT named evolutionary stable strategy (ESS), which, if adopted by all players, means that the game cannot be invaded by alternative strategies [37]. Several researchers have applied EGT to leasing issues. For example, to study the safety supervision of town crane operation, Chen et al. [38] established a tripartite evolutionary game model, which reveals that when the penalty amount resulting from poor crane supervision is greater than the total safety investment cost, the stakeholders will apply strict supervision strategies to the asset.

In addition, some scholars have conducted similar works deciding whether to adopt BCT using evolutionary game theory. However, most of them focus on the supply chain (finance). For instance, Su et al. [39] constructed a tripartite game model to explore BCT in relation to the evolutionary stability strategies among CEs, SMEs, and FIs, discovering that relatively large default losses can help SMEs to repay receivables on time. Tang et al. [40] used an evolutionary game to demonstrate that BCT can effectively facilitate information sharing in supply chain collaborations. Sun et al. [41] established an evolutionary game model to reveal that BCT impacts credit risk, which plays a vital role in deciding whether financial institutions accept factoring applications in supply chain finance. Song et al. [42] analyzed a tripartite game model of an agricultural supply chain, discovering that blockchain operation costs significantly affect the behaviors of governments and agricultural enterprises.

Based on the above literature analysis, it can be found that most research mainly focuses on proposing a blockchain-based leasing scheme or using EGT to study the SME's BCT strategies in the supply chain. Nevertheless, our work not only provides a consortium blockchain-based leasing platform (CBLP) to streamline the information sharing between lessees and lessors, but also contributes to establishing a two-player evolutionary game model analyzing the lessee's leasing behaviors (i.e., complying with or defaulting on the LC) considering whether to adopt BCT for information sharing. This study will shed light on the long-term development of the leasing industry.

3. Description of Consortium Blockchain-Based Leasing Platform (CBLP)

Since the evolutionary model that this study will construct is of significant relevance to information storage (i.e., on- and off-chain) and consensus mechanisms (i.e., Raft with credit evaluation and transaction verification), in this section, it is necessary first to present the conceptual architecture of the proposed consortium blockchain-based leasing platform (CBLP), and then the transaction verification process will be concisely explained.

3.1. Conceptual Architecture of CBLP

This research first provides a consortium blockchain-based leasing platform integrated with RFID devices [43], which incorporates stakeholders such as OEM, SMEs, LFs, MCs, and regulators. The platform is built by using Hyperledger Fabric (HLF) [44], which is an enterprise-grade permissioned blockchain platform facilitating information sharing among multiple organizations [45,46]. In general, an authorized node is required to pay fees to access the consortium blockchain [47]. In the distributed ledger, only organizations with valid IDs can process transactions. More specifically, all authorized lessees and lessors have their PKI-CA certificate and unique Decentralized Identifiers (DIDs) registered on a blockchain with restricted access [48,49]. By scanning the RFID sensor tags encapsulated in the DID, the running condition of the leased asset is recorded as a transaction, which is then turned into a "block" and appended to the ledger. This means that the lessee cannot refute or alter the historical logs of equipment operation and maintenance. This data reliability is conducive to efficiently managing the whole life cycle of the physical leased asset [50], which can help to reduce the inspection costs during the leasing period. It is also critical for each participant involved to be certain about the asset traceability in case of fraud, damages, dispossession, or misdisposition.

On the other hand, due to the large data sets shared by many various stakeholders, there is a need to consider data storage and scalability challenges when assessing to what extent SMEs are willing to adopt BCT [51]. Our work leverages a hybrid on-chain and off-chain storage mechanism to store and access information (especially complexity data) on the CBLP [52,53]. Specifically, the encrypted raw data (e.g., file) are stored on an off-chain cloud storage provider (CSP) or distributed storage system (e.g., InterPlanetary File System, IPFS) [54]. The off-chain data are linked with the specific metadata via a hash pointer, which is stored as a transaction validated to the ledger and can be used to audit the off-chain data that were not modified [55]. The architecture of CBLP with on- and off-chain information storage mechanisms is shown in Figure 1.

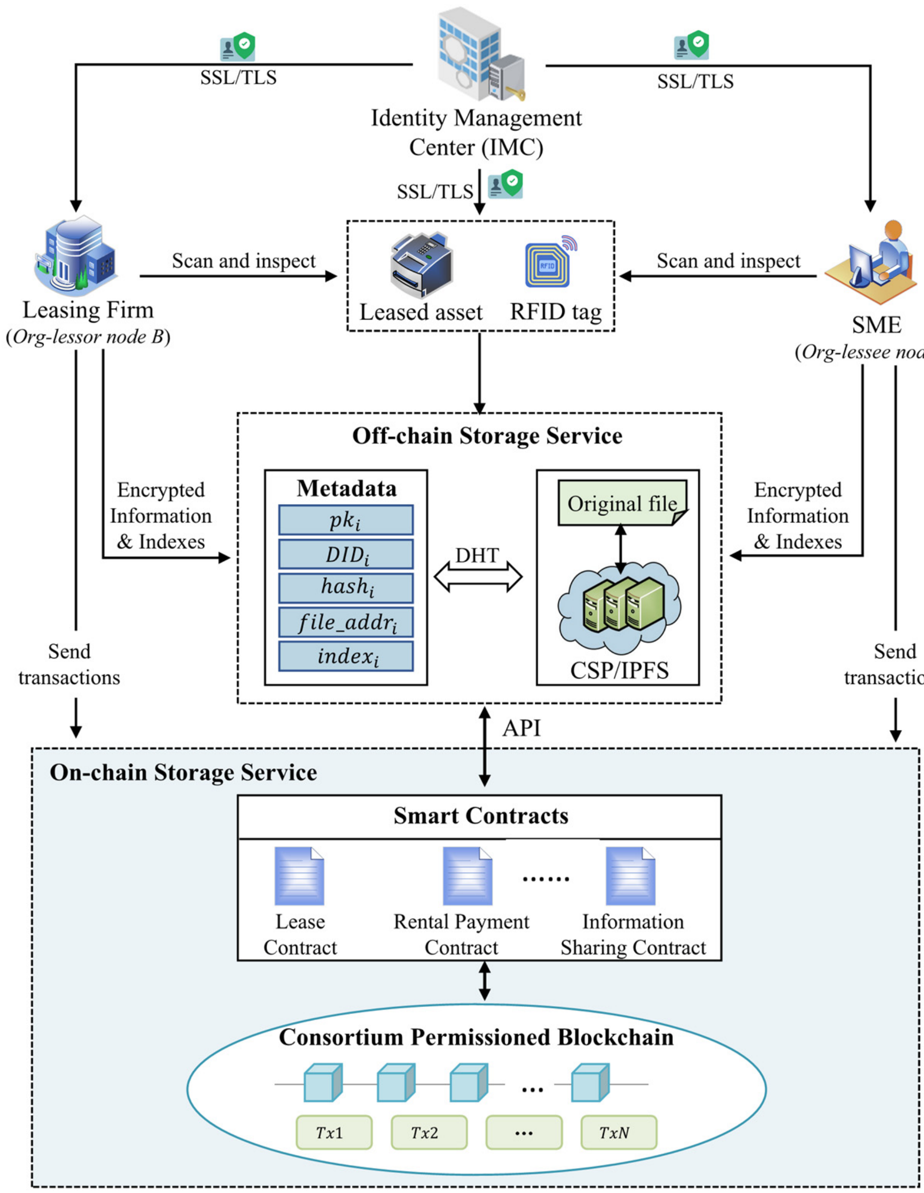


Figure 1. The architecture of CBLP with an on- and off-chain information storage mechanism.

3.2. Raft Consensus Based on Credit

Since various transactions are executed through triggering relevant smart contracts (e.g., lease contract, asset ownership transfer contract, lease payment contract, data sharing contract) using multiple organizational nodes, a consensus protocol is used by the CBLP. It plays a crucial role in ensuring that the transactions are recorded in an agreed order on-chain. Meanwhile, to avoid the untrusted consortium stakeholders uploading false information or changing the private data content on-chain to comply with the contract, we use a Raft consensus algorithm combined with "credit" incentives to maintain the blockchain. That is, an SME (*Org-lessee node A*) and an LF (*Org-lessor node B*) adopt the flow of "execute–order–validate" to record the transactions on-chain [45]. This is the most fundamental transaction process of Hyperledger Fabric at present and will not be elaborated on further due to the limitations of this paper's length, while it is depicted in Figure 2.

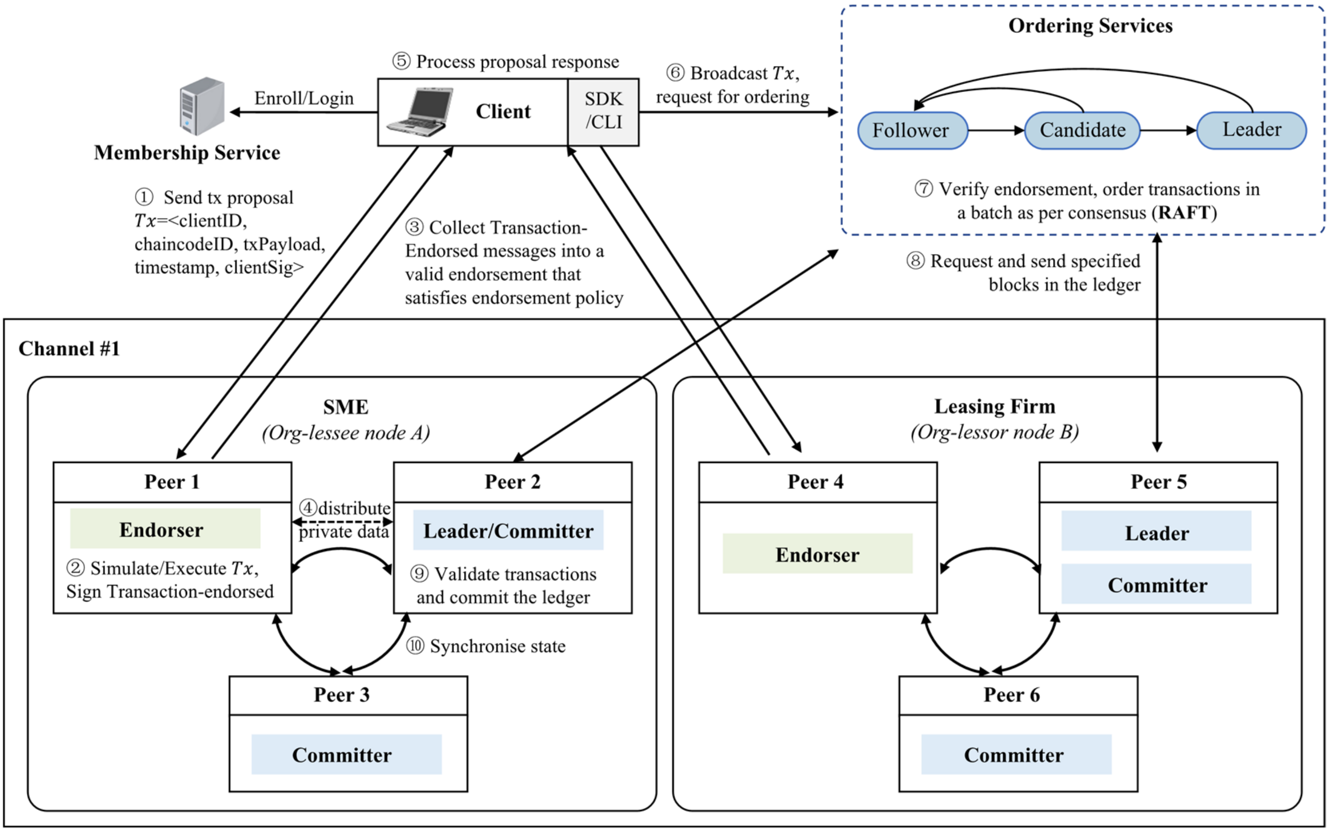


Figure 2. Transaction flow in Hyperledger Fabric with Raft consensus algorithm.

Notably, the Raft consensus protocol follows the "leader and follower" architecture [56,57] to implement the ordering service, where the leader nodes are dynamically elected from the *Consenter Set* and a node's credit value determines whether it can join the *Consenter Set* [58]. When the credit value exceeds a predetermined threshold, the node can join the *Consenter Set* as a consensus node. On the contrary, when the credit is lower than the minimum threshold, the node will face a penalty imposed by the CBLP. In addition, we propose that the credit value is increased or decreased according to the contract compliance or default behavior of the (SME) Org-lessee node in the leasing business; the more frequently it conforms to the lease contract, the higher its credit value and the greater the likelihood is that the node will be selected as the "Leader" in the *Consenter Set* to package transactions into a new block and finalize it. Credit assessed for the SME cannot be treated as an indicator of the lessee's reputation and contribution to the leasing business. Still, it can help the enterprise earn more recognition and achieve more lease financing opportunities from lessors, encouraging each lessee to share information on the CBLP [58].

In summary, based on the right balance of the above on- and off-chain storage costs and credit incentive mechanisms, the nodes will choose to actively comply with the LC and upload authentic information on-chain by joining the consortium blockchain for larger gains, resulting in the eventual emergence of a Nash equilibrium.

4. Problem Description

In this section, we will first describe the problem we studied. The basic lease scenario explored in this study is provided to better understand the game model. Afterward, the critical parameters are elucidated and presented in Table 1.

Table 1. Parameters. Explanation under the conventional/blockchain-based lease mode.

Mode	Party	Notation	Definition
Under the conventional lease mode	SME (*Org-lessee node A*)	R	Total rental payments to the LF under the terms of the lease
		r_1	Return rate of the SME on the lease
		r_3	Reinvestment rate of the SME after the contract's default
		f	Maintenance fee for the leased asset during the lease period
		p_1	Default penalty of the SME under the conventional lease
		σ	Incentives of the SME given by the LFs due to LC compliance
	LF (*Org-lessor node B*)	r_2	Return rate of the LF on the lease
		C_t	Marginal credit investigation costs of the LF
		C_0	Original acquisition cost of the leased asset
		C_1	Monitoring cost of asset's operation under the conventional lease
		v_s	Residual value of the leased asset at the end of the lease
		ε	Loss rate of the LF caused by the contract default
Under the blockchain-based lease mode	SME (*Org-lessee node A*)	C_b	Membership cost of the SME joining the consortium blockchain
		$\Delta\nu_c$	Increased credit value of the SME due to LC compliance on-chain
		I	Fixed reward when mining a block on-chain
		p_2	Default penalties of the SME on-chain
		$\mathcal{Z}_A$	Quantity of information shared by the SME on-chain
		u_A	Relative computing power provided by the SME on-chain
	LF (*Org-lessor node B*)	g	Synergy gain on the lease business empowered by the blockchain
		C_2	Monitoring cost of asset's operation under the blockchain-based lease
		$\mathcal{Z}_B$	Quantity of information shared by the LF on-chain
		u_B	Relative computing power provided by the LF on-chain
	SME and LF	φ	Coefficient of information transmission efficiency on-chain
		ω	Validation cost coefficient of confirming transaction on-chain
		λ	Storage cost coefficient of information stored off-chain CSP/IPFS
		η	Security risk coefficient of sharing information on-chain

4.1. Description of Problem

The game model involves two types of players in a lease: the lessee (i.e., an SME) and lessor (i.e., an LF). Under a conventional lease, the SME is responsible for paying fees for the right to use an asset leased from the LF, and generally, the SME as a lessee must maintain the asset to ensure that it remains in an operational condition [59]. The LF will pay the credit investigation cost to evaluate whether an SME can pay its rent on time. Meanwhile, it is difficult for the parties to immediately share information (including the historical default records) and for the LF to monitor the leased equipment/assets in real time. Applying BCT can solve the aforementioned issues [29]. If the LF requires the SME to join the consortium so as to upload information (such as historical asset operation documents or payment performance, etc.) on the CBLP, not only can a credit review be instantly conducted, but the ownership and provenance of the leased asset can also be tracked in real time through the asset's operation. Moreover, a smart contract can be automatically executed to make the lease payment as agreed in the lease contract (LC), which results in the synergetic gains of the leasing process and improves the efficiency of asset management empowered by the blockchain [60]. If stakeholders can share and process a greater quantity of information on-chain, thereby significantly improving the precision of the decisions made by each party, it is essential to take into consideration the corresponding data storage overheads, security exposure, and transaction verification costs when practically using BCT. Once the SME and LF adopt the CBLP, they need to be subject to harsher punishments resulting from defaulting behavior, which undermines the enterprise's reputation on the whole network. In addition, a blockchain-based credit evaluation mechanism can enhance the effective management of the leased asset, which is also conducive to mining reliable data blocks in the distributed ledger.

Therefore, this study intends to model the problem that considers the SME and LFs individual decision-makers concerning "complying with or defaulting on the LC" and "accessing or not accessing the CBLP" and to comprehensively analyze the dynamic influence of the four factors (i.e., information sharing, credit, incentive–penalty, and risk) on the choice of strategy by using evolutionary games.

4.2. Basic Lease Scenarios

The game model is constructed based on an operating lease with respect to heavy equipment (e.g., forklifts, trucks, and hoists) in the manufacturing supply chain. Generally, the equipment is relatively expensive to purchase, and leasing it is a better option for SMEs. The LF (the "lessor") first acquires an asset from an OEM and lends the asset to the SME (the "lessee") for a specific term in exchange for periodic rental payments. Once the LC is signed, the SME has the right to use the asset, whereas the ownership of the leased asset remains with the LF. Therefore, the SME must comply with the contract, not only paying the full rent on time but also reverting the asset to the LF at the maturity date of the lease; otherwise, the SME will pay the penalty for their default. In addition, the LC specifies that the lessee takes responsibility for the maintenance and outsources it to the OEM or MCs other than the lessor (LF in this case).

4.3. Model Parameters

Rental Payments (R): Rental payments refer to the monthly/quarterly rent that the SME (the "lessee") pays to the LF (the "lessor").

(1) Return rate (r_1, r_2): Return rate refers to the yield that can be earned when completing the investment activity on the lease.
(2) Reinvestment rate (r_3): Reinvestment rate refers to the yield that the lessee expects to earn when it does not pay or defers the full rental price, which can be put into other investments for extra gains.
(3) Maintenance fee (f): Maintenance fee refers to the cost of carrying out maintenance actions to ensure that the leased asset is in a proper operating condition. In this study, the LC states that the maintenance service must be provided by MCs and completed until the lease termination—the maintenance fee is not embedded in the rental payment.
(4) Loss rate (ε): Loss rate refers to the loss that could result from the lessee's defaulting behavior—for instance, if the lessee defaults by not returning the leased asset at the end of the lease, which cannot be re-leased to the next lessee upon termination of the previous LC.

The relevant parameters' notations and definitions are shown in Table 1.

5. Model Formulation

In this section, an evolutionary game model between the SME (the "lessee") and the LF (the "lessor") is developed. Before the mathematical payoff matrix is constructed, some assumptions are first provided.

5.1. Basic Assumptions

Assumption 1 (A1): *Rational Participants Assumption.*

All participants in the game are boundedly rational [61]. Nodes with constrained computing power may not be able to perfectly utilize all of the information on-chain owing to hardware faults or network congestion. Under asymmetric information, each node will constantly select the optimal strategy to maximize its interests while being affected by multiple factors and will eventually reach a state of equilibrium [62,63].

Assumption 2 (A2): *Strategy Selection Assumption.*

Assume that the SME (the "lessee") chooses to "comply with or default on the LC" with the respective probability of x or $1 - x,\ x \in [0,\ 1]$. The LF (the "lessor") chooses to "access or not access the CBLP", utilizing the information shared by stakeholders with the respective probability of y or $1 - y,\ y \in [0,\ 1]$.

Assumption 3 (A3): *Default Behavior Assumption.*

For the SME's unilateral default behavior, assume that it consists of two primary actions: one is not making the full rental payment by the due date, and the other is failing to return the leased asset to the lessor when the LC expires (for simplicity, this study considers that the two actions simultaneously occur when modeling).

Assumption 4 (A4): *Information Sharing Assumption.*

The quantity of information shared by the player is $\mathcal{Z}_i$, and the ability of each player to process and utilize the information on-chain [40] is u_j, which depends on the computing power. Hence, the amount of effective information on-chain that the SME or the LF obtains from each other is, respectively, $u_A \mathcal{Z}_B$ and $u_B \mathcal{Z}_A$.

Assumption 5 (A5): *Credit Assumption.*

Assume that each SME will be assigned a credit value Δv_c, which increases with the LC compliance performance. The higher the credit value owned by the SME, the greater the possibility of the enterprise becoming the "Leader" in the Raft Consensus Protocol (Section 3.2) to validate the lease transaction on each consensus round, so improving the lessee's reputation and recognition on-chain.

Assumption 6 (A6): *Incentive–Penalty Assumption.*

After the SME participates in information sharing, if the enterprise breaches the LC or tries to tamper with the existing LC to legalize the default behavior on-chain, this has a profoundly negative effect on the leasing business, hence making the SME's default penalty intensity larger under the CBLP—that is, $p_2 > p_1$. The penalty can be deducted from the lessee's token deposit by executing a smart contract of transferring transactions [64].

Assumption 7 (A7): *(Technology) Risk Assumption.*

BCT can improve the data transmission efficiency (φ) end-to-end, but meanwhile, each player has to bear the data validation on-chain (ω) and storage costs off-chain (λ) due to the blockchain's storage limitations. The player also may suffer security risks (η), such as data leakage risks and network attack risks [65]. This has practical implications, in that the benefits of sharing information outweigh the relevant costs after joining the blockchain network, $\varphi > \omega + \lambda + \eta$.

Assumption 8 (A8): *Other Cost Assumption.*

A8.1: *The blockchain can record the SME's credit history as tamper-resistant and traceable data [66], and if the SME joins the blockchain network, the marginal credit investigation cost (C_t) will shrink and asymptotically approach zero.*

A8.2: *In leased asset management empowered by BCT, the LF can continuously monitor the condition of the leased asset at lower costs [67]—as such, $C_1 > C_2$.*

5.2. Payoff Matrix

In this model, there are four different strategies. Considering that the model is complicated to understand, based on the above lease scenario and assumptions, this subsection will thoroughly explain the players' payoff under each strategy.

(1) Strategy I: $S_1 = \{\text{Comply, Access}\}$

Since the SME (the "lessee") fully abides by the LC, and the LF accesses the CBLP, taking advantage of information sharing on-chain, this results in the SME obtaining the rewards of successfully mining the block I, effective information utilization $[(\varphi - \omega - \lambda - \eta)\mathcal{Z}_A + u_A \mathcal{Z}_B]$, the return on the lease Rr_1, the incentive σ given by the LF (the "lessor"), plus the credit value; however, the SME has to make the payments of rental R, maintenance fee f, and the consortium membership cost C_b.

On the other hand, the LF obtains rent R, the return on the lease Rr_2, effective information utilization $[(\varphi - \omega - \lambda - \eta)\mathcal{Z}_B + u_B \mathcal{Z}_A]$, synergy gain g on the lease empowered by BCT, plus the residual value of the leased asset v_s after receiving the leased asset returned from the SME, while bearing the cost of purchasing the asset from the OEM at price C_0, monitoring cost C_2, and the consortium membership cost C_b.

Therefore, in Strategy I, the payoffs of the SME and LF are formulated as in Equations (1) and (2), respectively.

$$P_A^{S_1} = I + [(\varphi - \omega - \lambda - \eta)\mathcal{Z}_A + u_A \mathcal{Z}_B] + R(r_1 - 1) + \sigma + \Delta v_c - f - C_b \quad (1)$$

$$P_B^{S_1} = R(r_2 + 1) + v_s + [(\varphi - \omega - \lambda - \eta)\mathcal{Z}_B + u_B \mathcal{Z}_A] + g - C_0 - C_2 - C_b \quad (2)$$

(2) Strategy II: $S_2 = \{\text{Default, Access}\}$

Due to default actions (Section 4.2.), the SME uses the rent to perform re-investment and dispose of the leased asset that has been exhaustively used for manufacturing at the end of the lease. Therefore, it gives the SME the chances to earn extra re-reinvestment return Rr_3 and sell the leased asset at the market value of the residual v_s. Adopting the BCT provides the SME with effective information utilization $[(\varphi - \omega - \lambda - \eta)\mathcal{Z}_A + u_A \mathcal{Z}_B]$. However, to continuously keep the leased asset effectively operating without impacting production, the SME still needs to pay the maintenance fee to the MC (instead of the LF) and will be punished in p_2 resulting from the default actions.

Meanwhile, although the LF can obtain the effective information utilization empowered by the BCT, the default behavior by the SME not only causes the LF to be unable to receive the rental payment R, but also leads to it losing the further earnings $R\varepsilon$ from re-leasing to other lessees due to the out-of-control of the leased asset when the rental period is complete. The asset acquiring cost C_0, monitoring cost C_2, and the consortium membership cost C_b occur.

Therefore, in Strategy II, the payoffs of the SME and LF are formulated as in Equations (3) and (4), respectively.

$$P_A^{S_2} = Rr_3 + v_s + [(\varphi - \omega - \lambda - \eta)\mathcal{Z}_A + u_A \mathcal{Z}_B] - f - p_2 - C_b \quad (3)$$

$$P_B^{S_2} = [(\varphi - \omega - \lambda - \eta)\mathcal{Z}_B + u_B \mathcal{Z}_A] - R\varepsilon - C_0 - C_2 - C_b \quad (4)$$

(3) Strategy III: $S_3 = \{\text{Comply, Not-access}\}$

When the SME actively keeps to the stipulations of the LC, the SME earns the investment return Rr_1 on the lease and is rewarded by the LF with the incentive σ. However, the SME needs to pay the maintenance fee f to ensure that the leased asset is in good condition.

For the lessor, the LF not only obtains benefit Rr_2 from the leasing activity, but it also retains the value of the leased asset v_s at the end of the LC. Nonetheless, the insufficient credit record integrity of the SME forces the LF to incur credit audit expenses C_t before making a decision on the lease. The costs $(C_0,\ C_1)$ of acquiring and monitoring the leased assets are ineluctable.

Therefore, in Strategy III, the payoffs of the SME and LF are formulated as in Equations (5) and (6), respectively.

$$P_A^{S_3} = R(r_1 - 1) + \sigma - f \tag{5}$$

$$P_B^{S_3} = R(r_2 + 1) + v_s - C_0 - C_t - C_1 \tag{6}$$

(4) Strategy IV: $S_4 = \{\text{Default, Not-access}\}$

Based on the above Strategies II and III, the SME will always earn the reinvestment return Rr_3 and residual value v_s, but it may also suffer from the default punishment p_1. In addition, although the SME will resell the leased asset by defaulting, the enterprise has to take responsibility for maintaining it f to ensure that the leased asset remains in an operational condition for manufacturing.

If the SME breaches the LC without joining the blockchain network, the LF does not get any returns, and may even be charged with the costs in credit auditing C_t, asset acquiring C_0, and monitoring C_1.

Therefore, in Strategy IV, the payoffs of the SME and LF are formulated as in Equations (7) and (8), respectively.

$$P_A^{S_4} = Rr_3 + v_s - f - p_1 \tag{7}$$

$$P_B^{S_4} = -R\varepsilon - C_0 - C_t - C_1 \tag{8}$$

Consequently, the profit matrix of the two-party game is shown in Table 2.

Table 2. Evolutionary game payoff matrix of the SME and LF.

Strategy		LF (Org-Lessor Node B)	
		Access	**Not-Access**
SME (Org-lessee node A)	Comply	$I + [(\varphi - \omega - \lambda - \eta)\mathcal{Z}_A + u_A\mathcal{Z}_B] + R(r_1 - 1) + \sigma + \Delta v_c - f - C_b$	$R(r_1 - 1) + \sigma - f$
		$R(r_2 + 1) + v_s + [(\varphi - \omega - \lambda - \eta)\mathcal{Z}_A + u_B\mathcal{Z}_A] + g - C_0 - C_2 - C_b$	$R(r_2 + 1) + v_s - C_0 - C_t - C_1$
	Default	$Rr_3 + v_s + [(\varphi - \omega - \lambda - \eta)\mathcal{Z}_A + u_A\mathcal{Z}_B] - f - p_2 - C_b$	$Rr_3 + v_s - f - p_1$
		$[(\varphi - \omega - \lambda - \eta)\mathcal{Z}_B + u_B\mathcal{Z}_A] - R\varepsilon - C_0 - C_2 - C_b$	$-R\varepsilon - C_0 - C_t - C_1$

6. Model Stability Analysis

This section will first construct the replicator dynamic equations between the SME and LF and then will discuss in depth how the two rational players reach an equilibrium state through iteratively changing strategies. A mathematical sensitivity analysis on each type of factor (i.e., information sharing, credit, incentive–penalty, risk) will ultimately be provided.

6.1. Replicator Dynamic System

Based on the above evolutionary game payoff matrix, we can calculate the expected returns of the SME (the "lessee") and LF (the "lessor") when they choose different strategies, and then construct the replicator dynamic equations for each subject.

6.1.1. Replication Dynamic Equation of the SME

Assuming the expected return of the SME's compliance with and, defaulting on the LC, the average returns are E_x, E_{1-x}, and $\overline{E_x}$, respectively. Then:

$$E_x = y[I + [(\varphi - \omega - \lambda - \eta)\mathcal{Z}_A + u_A \mathcal{Z}_B] + R(r_1 - 1) + \sigma + \Delta v_c - f - C_b] \\ +(1-y)[R(r_1 - 1) + \sigma - f] \quad (9)$$

$$E_{1-x} = y[Rr_3 + v_s + [(\varphi - \omega - \lambda - \eta)\mathcal{Z}_A + u_A \mathcal{Z}_B] - f - p_2 - C_b] \\ +(1-y)(Rr_3 + v_s - f - p_1) \quad (10)$$

$$\overline{E_x} = xE_x + (1-x)E_{1-x} \quad (11)$$

The replication dynamics equation (RDE) [68] of the SME is denoted as follows:

$$\begin{aligned} F(x) &= \tfrac{dx}{dt} \\ &= x\left(E_x - \overline{E_x}\right) \\ &= x(1-x)(E_x - E_{1-x}) \\ &= x(1-x)[y(I + \Delta v_c + p_2 - p_1) + (r_1 - r_3 - 1)\,R + \sigma + p_1 - v_s] \end{aligned} \quad (12)$$

Let $F(x) = 0$, and we obtain the stationary point of the differential equation as follows:

$$x_1^* = 0,\ x_2^* = 1 \quad (13)$$

$$y^* = \frac{(1 + r_3 - r_1)R + v_s - \sigma - p_1}{I + \Delta v_c + p_2 - p_1} \quad (14)$$

Based on Equation (14), we can discover that, as shown in Figure 3:

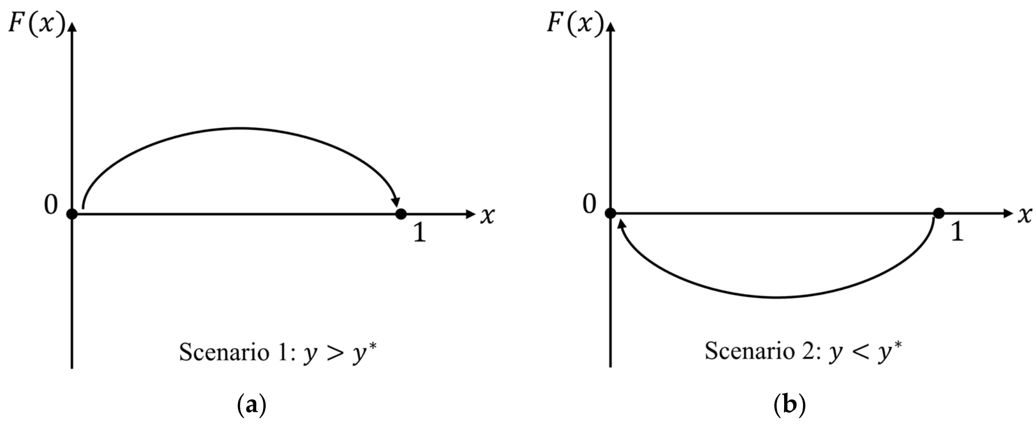


Figure 3. (**a**) The dynamic trend of the SME's strategy in the case of $y > y^*$; (**b**) The dynamic trend of the SME's strategy in the case of $y < y^*$.

When $y = y^*$, the LF can access the CBLP to use the information on-chain with a probability of y^*, and $\frac{\partial F(x)}{\partial x} = 0$ always holds. That is, the state is always stable, regardless of the value of x. Moreover, any change in other exogenous variables will not alter the stability of the state. x is the equilibrium point, and all states are stable.

When $y \neq y^*$, the system needs to satisfy two requirements to obtain evolutionary stability, i.e., $F(x^*) = 0$ and $F'(x^*) < 0$. Then:

- In the case of $y > y^*$, $F'(1) < 0$. $x = x_2^* = 1$ is an evolutionary stable strategy (ESS). When the probability of the LF accessing the CBLP is larger than y^*, the SME will converge with the equilibrium strategy of "comply with the LC". The number of SMEs who abide by the contract will gradually increase.
- In the case of $y < y^*$, $F'(0) < 0$. $x = x_1^* = 0$ is an evolutionary stable strategy (ESS). It implies that more SMEs will eventually evolve into a stable state of defaulting on the LC, since LFs struggle to distinguish the forgery of credit records without BCT [69].

According to Equation (14), we can find that the probability of the LF choosing to access the CBLP, requiring the SME to join the consortium, is small, and the SME tends to breach the LC. Moreover, the "comply with or default on the LC" decision of the SME has nothing to do with the information sharing ($\mathcal{Z}_i,\ u_j$), the asset maintenance fee (f), or the consortium membership fee (C_b). In contrast, the determinant of the decision is the size of the gap between the lease reinvestment earnings (i.e., $(1 + r_3 - r_1)R$) that the SME would gain for the default and the rewards (i.e., σ) it would receive for its compliance.

In addition, Equation (14) gives some further insights that the residual value of the leased asset (v_s) is positively correlated with the probability y that the LF chooses to access the CBLP. This is because if the LC provisions are that the lessors (i.e., LF) ensure that the residual value of the leased asset is immutably recorded on-chain, it mitigates the uncertainty of residual value risk, aiding the lessor to retain ownership of the asset at the end of the lease. Meanwhile, the default margin penalty ($\frac{p_2-p_1}{p_1}$) imposed on the SME is negatively correlated with y. When $\frac{p_2-p_1}{p_1}$ decreases, the probability of the LF choosing to access the CBLP increases, the main reason for which is that the relatively small penalty (p_2) set up on-chain can effectively reduce the default risk of the SME, which makes the LF is more willing to access the CBLP. In addition, owing to the compliance behavior, the higher credit (Δv_c) achieved by the SME will stimulate the LF to stick with the conventional leasing mode.

6.1.2. Replication Dynamic Equation of the LF

Assuming the expected return of the LF accessing and not accessing the CBLP to utilize the information shared on-chain, the average returns are $E_y,\ E_{1-y}$, and $\overline{E_y}$, respectively. Then:

$$\begin{aligned} E_y &= x[R(r_2+1) + v_s + [(\varphi - \omega - \lambda - \eta)\mathcal{Z}_B + u_B\mathcal{Z}_A] + g - C_0 - C_2 - C_b] \\ &\quad +(1-x)[[(\varphi - \omega - \lambda - \eta)\mathcal{Z}_B + u_B\mathcal{Z}_A] - R\varepsilon - C_0 - C_2 - C_b] \end{aligned} \tag{15}$$

$$E_{1-y} = x[R(r_2+1) + v_s - C_0 - C_t - C_1] + (1-x)[-R\varepsilon - C_0 - C_t - C_1] \tag{16}$$

$$\overline{E_y} = yE_y + (1-y)E_{1-y} \tag{17}$$

The replication dynamics equation (RDE) [68] of the LF is denoted as follows:

$$\begin{aligned} &F(y) = \frac{dy}{dt} \\ &= y\left(E_y - \overline{E_y}\right) \\ &= y(1-y)\left(E_y - E_{1-y}\right) \\ &= y(1-y)[gx + ((\varphi - \omega - \lambda - \eta)\mathcal{Z}_B + u_B\mathcal{Z}_A + C_t + C_1 - C_2 - C_b)] \end{aligned} \tag{18}$$

Let $F(y) = 0$, and we obtain the stationary point of the differential equation as follows:

$$y_1^* = 0,\ y_2^* = 1, \tag{19}$$

$$x^* = \frac{C_b + C_2 - (\varphi - \omega - \lambda - \eta)\mathcal{Z}_B - u_B\mathcal{Z}_A - C_t - C_1}{g} \tag{20}$$

Based on Equation (20), we can discover that, as shown in Figure 4:

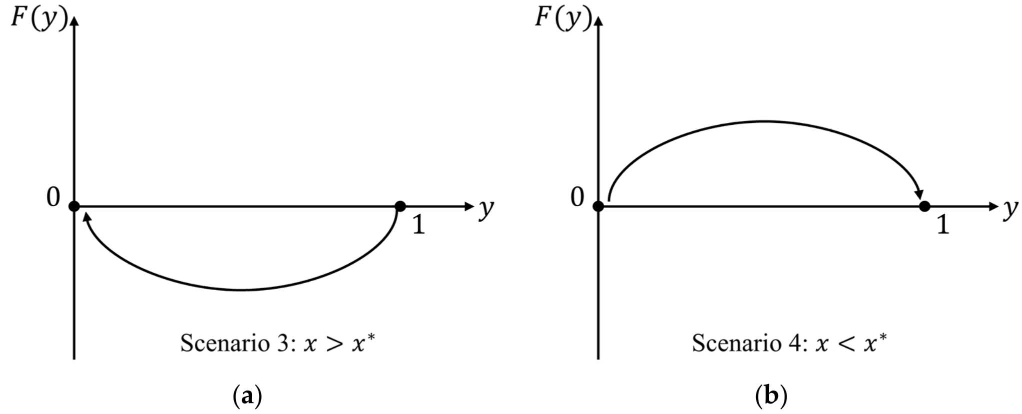


Figure 4. (**a**) The dynamic trend of the LF's strategy in the case of $x > x^*$; (**b**) The dynamic trend of the LF's strategy in the case of $x < x^*$.

When $x = x^*$, the SME complies with the LC with a probability of x^*, and $\frac{\partial F(y)}{\partial y} = 0$ is always established. The state is always stable no matter how the value of y changes. In this case, y is the equilibrium point, and all states are stable.

When $x \neq x^*$, the system needs to satisfy two requirements to obtain evolutionary stability, i.e., $F(y^*) = 0$ and $F'(y^*) < 0$. Then:

- In the case of $x > x^*$, $F'(0) < 0$. $y = y_1^* = 0$ is an evolutionary stable strategy (ESS). When the probability of SME compliance is larger than x^*, the LF converges to the equilibrium strategy of "not accessing the CBLP ", and thereby the SME does not need to join the consortium blockchain to share information.
- In the case of $x < x^*$, $F'(1) < 0$. $y = y_2^* = 1$ is an evolutionary stable strategy (ESS). When the probability of SME compliance is less than x^*, the LF will converge with the equilibrium strategy of "access the CBLP " to participate in information sharing on-chain to complete the lease.

According to Equation (20), we can find that considering the long-term cooperation, when the SME is more likely to abide by the LC, the LF will decide not to access the CBLP due to the limited synergy and information utilization benefits obtained.

In addition, Equation (20) gives some further insights that the asset maintenance cost (f) will not affect the SME's decision to comply or default, since once an outsourced maintenance action begins, it will not be interrupted until the lease expires. Both the consortium membership fee (C_b) and asset monitoring cost on-chain (C_2) are positively correlated with the x. When the CBLP sets up higher costs for stakeholders to join the consortium, to improve the lease willingness of the LF, the SME is more inclined to comply with the LC and provide genuine lease information. When the leased asset is fully inspected under the CBLP, the SME will not easily default by deferring the lease payment or not returning the leased asset after signing the LC on-chain. Notably, the LF has a higher ability to absorb more high-quality information that the SME shares on-chain, which can expedite the SME's default behavior. It seems to be a paradox that is contrary to the LF's decision-making in terms of accessing or not accessing the CBLP. This is because when BCT empowers more information synergy for the LF, the LF is more willing to access the CBLP, which compels the SME to bear the consortium membership cost, data storage, and verification overhead. To compensate for the potential losses that may be suffered, the SME will take risks, opting for default, decreasing the likelihood of compliance. The whole process will finally be formed as an unstable circle.

6.2. Analysis of Equilibrium Stability and ESS

Based on the above analysis, the game system has five local equilibrium points: (0, 0), (1, 0), (0, 1), (1, 1), and (x^*, y^*).

To find the evolutionary stability strategy (ESS), the local stability analysis of the Jacobian matrix is employed [70,71], and thereby we take the first-order derivatives of Equations (12) and (18), respectively, achieving the following Jacobian matrix $\boldsymbol{J}$.

$$\boldsymbol{J} = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} \end{bmatrix} \tag{21}$$

where:

$$\frac{\partial F(x)}{\partial x} = (1-2x)[y(I+\Delta v_c + p_2 - p_1) + (r_1 - r_3 - 1)\ R + \sigma + p_1 - v_s] \tag{22}$$

$$\frac{\partial F(x)}{\partial y} = x(1-x)(I+\Delta v_c + p_2 - p_1) \tag{23}$$

$$\frac{\partial F(y)}{\partial x} = y(1-y)g \tag{24}$$

$$\frac{\partial F(y)}{\partial y} = (1-2y)[gx + ((\varphi - \omega - \lambda - \eta)\mathcal{Z}_B + u_B\mathcal{Z}_A + C_t + C_1 - C_2 - C_b)] \tag{25}$$

Next, we can calculate the trace value $tr\boldsymbol{J}$ and determinant value $det\boldsymbol{J}$ of the Jacobian matrix $\boldsymbol{J}$.

$$tr\boldsymbol{J} = \frac{\delta F(x)}{\delta x} + \frac{\delta F(y)}{\delta y} \tag{26}$$

$$det\boldsymbol{J} = \left[\frac{\delta F(x)}{\delta x}\right]\left[\frac{\delta F(y)}{\delta y}\right] - \left[\frac{\delta F(x)}{\delta y}\right]\left[\frac{\delta F(y)}{\delta x}\right] \tag{27}$$

Thus, the $tr\boldsymbol{J}$ and $det\boldsymbol{J}$ to the equilibrium point are shown in Table 3.

Table 3. The analysis table for judging the stability of equilibrium points.

Equilibrium Point	tr***J***	det***J***
$E_1(0,0)$	$[(r_1 - r_3 - 1)\ R + \sigma + p_1 - v_s] + [(\varphi - \omega - \lambda - \eta)\mathcal{Z}_B + u_B\mathcal{Z}_A + C_t + C_1 - C_2 - C_b]$	$[(r_1 - r_3 - 1)\ R + \sigma + p_1 - v_s] * [(\varphi - \omega - \lambda - \eta)\mathcal{Z}_B + u_B\mathcal{Z}_A + C_t + C_1 - C_2 - C_b]$
$E_2(0,1)$	$[(r_1 - r_3 - 1)\ R + (I + \Delta v_c + p_2 + \sigma - v_s)] + [C_b + C_2 - (\varphi - \omega - \lambda - \eta)\mathcal{Z}_B - u_B\mathcal{Z}_A - C_t - C_1]$	$[(r_1 - r_3 - 1)\ R + (I + \Delta v_c + p_2 + \sigma - v_s)] * [C_b + C_2 - (\varphi - \omega - \lambda - \eta)\mathcal{Z}_B - u_B\mathcal{Z}_A - C_t - C_1]$
$E_3(1,0)$	$[(1 + r_3 - r_1)R + (v_s - \sigma - p_1)] + [g + (\varphi - \omega - \lambda - \eta)\mathcal{Z}_B + u_B\mathcal{Z}_A + C_t + C_1 - C_2 - C_b]$	$[(1 + r_3 - r_1)R + (v_s - \sigma - p_1)] * [g + (\varphi - \omega - \lambda - \eta)\mathcal{Z}_B + u_B\mathcal{Z}_A + C_t + C_1 - C_2 - C_b]$
$E_4(1,1)$	$[-(I + \Delta v_c + p_2 + \sigma - v_s + (r_1 - r_3 - 1)R)] + [-(g + (\varphi - \omega - \lambda - \eta)\mathcal{Z}_B + u_B\mathcal{Z}_A + C_t + C_1 - C_2 - C_b)]$	$[-(I + \Delta v_c + p_2 + \sigma - v_s + (r_1 - r_3 - 1)R)] * [-(g + (\varphi - \omega - \lambda - \eta)\mathcal{Z}_B + u_B\mathcal{Z}_A + C_t + C_1 - C_2 - C_b)]$
$E_5(x^*, y^*)$	0	H [1]

[1] $H = -x^*(1-x^*)(I + v_c + p_2 - p_1) * y^*(1-y^*)$

The local stability analysis of the five equilibria was performed to investigate the relationship between positive and negative tr***J*** and det***J*** and evolutionary stability at the five equilibrium points. When a local equilibrium point satisfies the conditions that trace tr***J*** < 0 and the determinant det***J*** > 0 of the Jacobian matrix ***J***, it is an evolutionary stable strategy (ESS) [72]. If the tr***J*** > 0 and det***J*** > 0, the equilibrium point is unstable or a saddle point.

Nonetheless, it is obvious that the stationary point (x^*, y^*) should meet $0 \leq x^* \leq 1, 0 \leq y^* \leq 1$, which is meaningful. Considering $g > 0$ and

$0 \leq \frac{C_b + C_2 - (\varphi - \omega - \lambda - \eta)\mathcal{Z}_B - u_B \mathcal{Z}_A - C_t - C_1}{g} \leq 1$, demonstrating that:

$$\text{Condition 1}: \begin{cases} C_b + C_2 - (\varphi - \omega - \lambda - \eta)\mathcal{Z}_B - u_B \mathcal{Z}_A - C_t - C_1 > 0 \\ g > 0 \\ (\varphi - \omega - \lambda - \eta)\mathcal{Z}_B + u_B \mathcal{Z}_A + C_t + C_1 + g - C_2 - C_b > 0 \end{cases} \quad (28)$$

Similarly, according to Assumption 3, we know that $p_2 > p_1$, which indicates the denominator of y^*, $I + \Delta v_c + p_2 - p_1 > 0$, then: $0 \leq \frac{(1+r_3-r_1)R + v_s - \sigma - p_1}{I + \Delta v_c + p_2 - p_1} \leq 1$, demonstrating that:

$$\text{Condition 2}: \begin{cases} (1 + r_3 - r_1)R + v_s - \sigma - p_1 > 0 \\ I + \Delta v_c + p_2 - p_1 > 0 \\ I + \Delta v_c + p_2 + \sigma - v_s - (1 + r_3 - r_1)R > 0 \end{cases} \quad (29)$$

Based on Condition 1 and Condition 2, we can use the signs of tr$J$ and det$J$ to judge the stability of the equilibrium point of the evolutionary game. The results are shown in Table 4.

Table 4. The analysis of the evolutionary stability of the system equilibrium point.

Equilibrium Point E_i	Symbol of tr$J$	Symbol of det$J$	Judgment
$E_1(0,0)$	<0	>0	ESS
$E_2(0,1)$	>0	>0	Unstable point
$E_3(1,0)$	>0	>0	Unstable point
$E_4(1,1)$	<0	>0	ESS
$E_5(x^*,y^*)$	0	+/-	Saddle point

According to Table 4, we can find that $E_2(0,1)$ and $E_3(1,0)$ are unstable points. $E_5(x^*,y^*)$ is a saddle point revealing that evolutionary stability is affected by the values of x^* and y^*. The game system has two ESS equilibrium points: $E_1(0,0)$ and $E_4(1,1)$. This indicates that the game's ultimate evolutionary strategies are "Strategy I: $S_1 = \{$Comply, Access$\}$" and "Strategy IV: $S_4 = \{$Default, Not-access$\}$", meaning that both SMEs and LFs converge at the locations E_1 and E_4 in Figure 5.

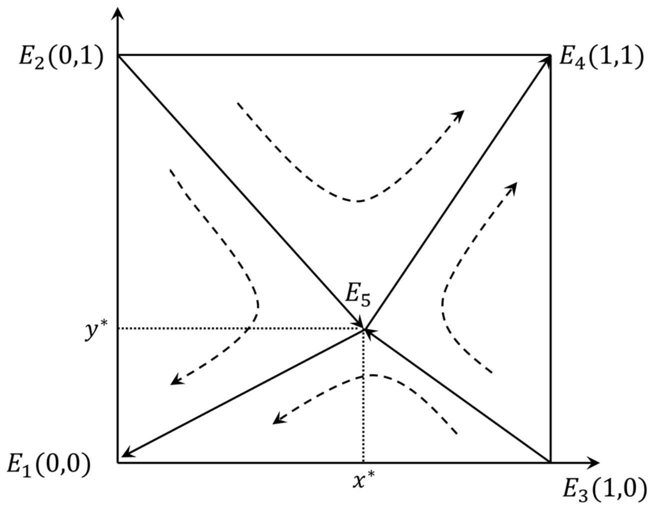


Figure 5. Dynamics evolution schematic diagram of the SME and the LF.

That is, when both parties' decisions are in the region $E_1E_2E_5E_3$, the game evolves to point $E_1(0,0)$, i.e., the SME breaches the LC, and the LF does not access the CBLP, requiring the SME to access the consortium blockchain. When both parties' decisions are located in region $E_2E_4E_3E_5$, the game evolves into the ideal stable state $E_4(1,1)$, i.e., the SME abides by the LC and the LF requires the SME to access the consortium blockchain. The probability of the evolutionary outcome between the game subjects can be represented in terms of the area of the regions $E_1E_2E_5E_3$ and $E_2E_4E_3E_5$ [73], the size of which depends on the coordinates of the point E_5 (the saddle point (x^*, y^*)), where: $S_{E_1E_2E_5E_3} = \frac{1}{2}(x^* + y^*)$, $S_{E_2E_4E_3E_5} = \frac{1}{2}[(1 - x^*) + (1 - y^*)]$. The possibility that the SME will conform to the contract and be required to access the CBLP increases as the region $E_2E_4E_3E_5$ expands.

6.3. Sensitivity Analysis in the Evolutionary Game

The choices made by the game subjects are influenced by the exogenous variables in the model. By taking derivatives of $S_{E_2E_4E_3E_5}$ (abbreviated hereafter as 'S') while holding the other parameters constant, it is possible to determine how each parameter affects the game's evolutionary results (i.e., $S_{E_2E_4E_3E_5}$).

$$x^* = \frac{C_b + C_2 - (\varphi - \omega - \lambda - \eta)\mathcal{Z}_B - u_B\mathcal{Z}_A - C_t - C_1}{g} \tag{30}$$

$$y^* = \frac{(1 + r_3 - r_1)R + v_s - \sigma - p_1}{I + \Delta v_c + p_2 - p_1} \tag{31}$$

$$S_{E_2E_4E_3E_5} = S = \frac{1}{2}\left[\left(1 - \frac{C_b + C_2 - (\varphi - \omega - \lambda - \eta)\mathcal{Z}_B - u_B\mathcal{Z}_A - C_t - C_1}{g}\right) + \left(1 - \frac{(1 + r_3 - r_1)R + v_s - \sigma - p_1}{I + \Delta v_c + p_2 - p_1}\right)\right] \tag{32}$$

The evolutionary game results are primarily related to the four main determinants: information sharing, credit, incentive–penalty, and risk. The sensitivity analysis of the influence of the four factors on $S_{E_2E_4E_3E_5}$ is described below.

6.3.1. Impact of Information Sharing on S

Taking the derivatives of Equation (32) corresponding to $\mathcal{Z}_A$, $\mathcal{Z}_B$, and u_B,

$$\frac{\partial S}{\partial \mathcal{Z}_A} = \frac{u_B}{2g} > 0 \tag{33}$$

$$\frac{\partial S}{\partial \mathcal{Z}_B} = \frac{\varphi - \omega - \lambda - \eta}{2g} > 0 \tag{34}$$

$$\frac{\partial S}{\partial u_B} = \frac{\mathcal{Z}_A}{2g} > 0 \tag{35}$$

S is an increasing function of $\mathcal{Z}_A$ and $\mathcal{Z}_B$, since Equation (34) is true under Assumption 7 (A7). That is, as the amount of information shared on-chain ($\mathcal{Z}_i$) increases, S will gradually increase, indicating the possibility of evolution to the stable state $E_4(1,\ 1)$ as the quantity of information shared on-chain increases. It further means that this parameter has a favorable impact on the probability of SMEs' decisions to comply with the contract and being required to join the consortium. The more accurate the information that is shared on the blockchain network, the easier it will be to create a transparent and reliable environment for leasing, and the more SMEs will actively disclose high-quality information to ensure that leasing transactions are executed smoothly.

S is an increasing function of u_B. The more the LF can use the effective data on-chain, the more the LF is likely to access the CBLP to clearly monitor the SME's compliance with the LC, thus increasing the likelihood of rental payment on time.

6.3.2. Impact of Credit on S

Taking the derivatives of Equation (32) corresponding to Δv_c,

$$\frac{\partial S}{\partial \Delta v_c} = \frac{(1 + r_3 - r_1)R + v_s - \sigma - p_1}{2(I + \Delta v_c + p_2 - p_1)^2} > 0 \tag{36}$$

S is an increasing function of Δv_c. Therefore, as Δv_c increases, the SME has a higher probability of conforming to the LC. Then, a higher credit value is assigned to the SME, resulting in the SME's nodes having a higher probability of being selected as a leader node when performing the Raft consensus protocol. Conversely, a node will be removed from the *Consenter Set* if its total credit value falls below the minimum threshold because of multiple defaults, escalating the penalty and helping to establish a high-credit leasing environment.

6.3.3. Impact of Incentive–Penalty on S

Taking the derivative of Equation (32) corresponding to σ, I, g and p_2,

$$\frac{\partial S}{\partial \sigma} = \frac{1}{2(I + \Delta v_c + p_2 - p_1)} > 0 \tag{37}$$

$$\frac{\partial S}{\partial I} = \frac{(1 + r_3 - r_1)R + v_s - \sigma - p_1}{2(I + \Delta v_c + p_2 - p_1)^2} > 0 \tag{38}$$

$$\frac{\partial S}{\partial g} = \frac{C_b + C_2 - (\varphi - \omega - \lambda - \eta)\mathcal{Z}_B - u_B \mathcal{Z}_A - C_t - C_1}{2g^2} > 0 \tag{39}$$

$$\frac{\partial S}{\partial p_2} = \frac{(1 + r_3 - r_1)R + v_s - \sigma - p_1}{2(I + \Delta v_c + p_2 - p_1)^2} > 0 \tag{40}$$

S is an increasing function of σ, I, g, and p_2. The likelihood that previously defaulting SMEs will start to keep their contracts and that the SME is motivated to access the blockchain increases with the incentives the LF provides to them. To encourage a node to choose the on-chain strategy and to encourage more SMEs to become consortium nodes, the LF can appropriately boost the compliance reward of the SMEs when creating the incentive strategy. No matter whether the SME defers the rental payment or refuses to return the leased asset, both default behaviors will lead to the lessee being charged a penalty, which irrevocably damages the SME's reputation on-chain. Hence, once the SME joins the consortium, the likelihood of compliance rises as the default penalties rise. The LF will also keep using the on-chain strategy to observe how the SMEs choose their payment strategies. Therefore, the penalties for SMEs should be suitably enhanced to guarantee a prompt rental payment.

6.3.4. Impact of Risk on S

Taking the derivatives of Equation (32) corresponding to φ, ω, λ, and η,

$$\frac{\partial S}{\partial \varphi} = \frac{\mathcal{Z}_B}{2g} > 0 \tag{41}$$

$$\frac{\partial S}{\partial \omega} = \frac{-\mathcal{Z}_B}{2g} < 0 \tag{42}$$

$$\frac{\partial S}{\partial \lambda} = \frac{-\mathcal{Z}_B}{2g} < 0 \tag{43}$$

$$\frac{\partial S}{\partial \eta} = \frac{-\mathcal{Z}_B}{2g} < 0 \tag{44}$$

S is an increasing function of φ. When more high-quality data are effectively distributed and shared by each subject on-chain, more subjects will join the consortium to complete the leasing transactions as more return is generated.

In addition, S is a decreasing function of ω, λ, and η. If the participants bear more consensus verification and storage costs, and take on greater security risks, they will be more reluctant to join the consortium and the probability of default will increase.

To sum up, different types of factors will have different effects on decision-making.

7. Numerical Experiments and Implications

This section will present some simulation results. We first use VENSIM PLE to build a system dynamics (SD) model to analyze the causal relationships among the variables and strategies. Then, MATLAB_R2021b is employed to examine the efficacy of the evolutionary stable strategies (ESSs) and to demonstrate the previous mathematical sensitivity analysis of each factor. Lastly, some implications of the results are given.

The game system has intermediate variables (including E_x, E_{1-x}, E_y, E_{1-y}) and a range of exogenous variables (as presented in Table 1). We set initial values for the exogenous variables involved in the model, as shown in Table 5. In this study, it is assumed that all exogenous variables are positive, and the return of each strategy of each game subject is guaranteed to be positive.

Table 5. Initial value of simulation parameters.

R	r_1	r_2	r_3	f	v_s	p_1	p_2	C_b	C_t	C_1	C_2	Δv_c
8	0.2	0.25	0.3	0.05	0.8	3	6	4	0.08	0.6	0.4	1
I	$\mathcal{Z}_A$	$\mathcal{Z}_B$	u_A	u_B	ε	σ	g	φ	ω	λ	η	/
1.2	5	3	0.5	0.5	0.15	5	1.5	0.6	0.2	0.2	0.2	/

7.1. System Dynamics Model Experiment

We establish the SD model of the two-party evolutionary game system as depicted in Figure 6. The arrow tails in Table 5 are connected to the independent variables in the associated equation, and the arrowheads are connected to the dependent variables. We set the simulation parameters of INITIAL TIME = 0, FINAL TIME = 10, and TIME STEP = 0.0078125.

It can be seen from Figure 7a,b that when the initial states of both sides are pure strategies (i.e., $(0,\ 0)$, $(0,\ 1)$, $(1,\ 0)$, and $(1,\ 1)$), no party in the system is willing to change the current state to break the equilibrium. For instance, the initial state of $(x = 0,\ y = 0)$ or $(x = 1,\ y = 1)$ will be unchanged if there is no interruption during the evolution. However, this does not mean that these equilibrium states are stable, and once one or both parties take the initiative to make a small change, the equilibrium state will be broken. Although the SME's compliance probability x and the LF's CBLP access probability y (for 0.0001) evolve with small mutations, they quickly shift to a new strategy once they find that doing this will yield a higher expected return, thus adjusting the strategy through a mutation of parties to bring the system into a new equilibrium. In addition, through simulating the model, we also discover that the ultimate equilibrium state is $(1,\ 1)$ when the initial state is $x = 0.5$, $y = 0.5$, as shown in Figure 7c.

In fact, when $x = 0$, no matter how y ranges from 0 to 1, the system will reach an equilibrium state $(0,\ 0)$. When $x = 1$, no matter how y ranges from 0 to 1, the system will reach an equilibrium state $(1,\ 1)$. Similarly, when $y = 0$, no matter how x ranges from 0 to 1, the system will reach an equilibrium state $(0,\ 0)$, and when $y = 1$, no matter how x ranges from 0 to 1, the system will reach an equilibrium state $(1,\ 1)$.

7.2. Effect of Parameter Changes on Evolutionary Stable Strategies

We initiate the probabilities of x and y with values ranging from 0 to 1 in steps of 0.1. It can be seen from Figure 8 that almost all curves converge at $(0,\ 0)$ and $(1,\ 1)$, which is consistent with the preceding discussion in Section 6.2.

The following subsection further discusses the impacts of the four factors on evolution. Here, we assume the initial strategy probability for each participant is 0.5.

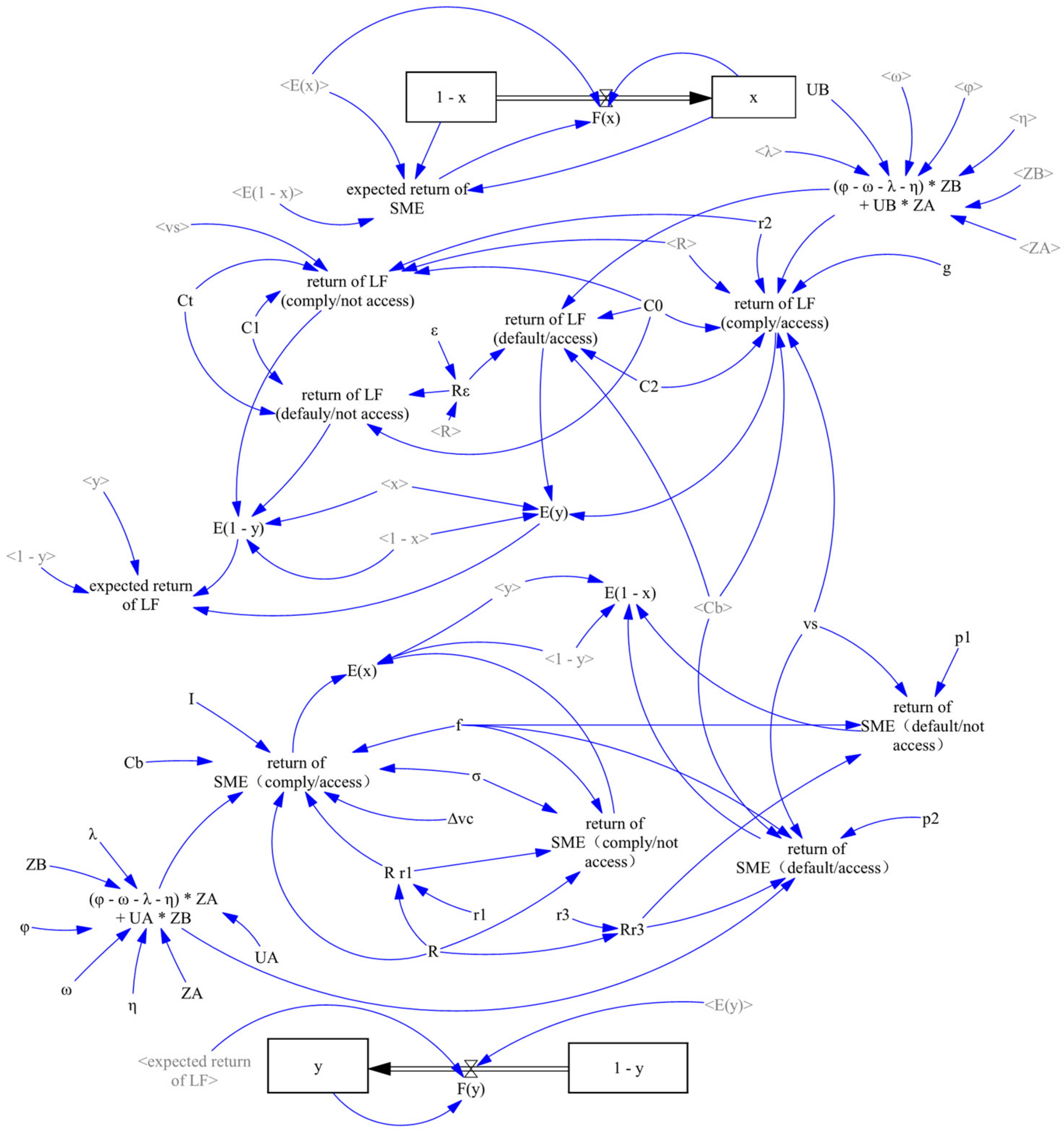
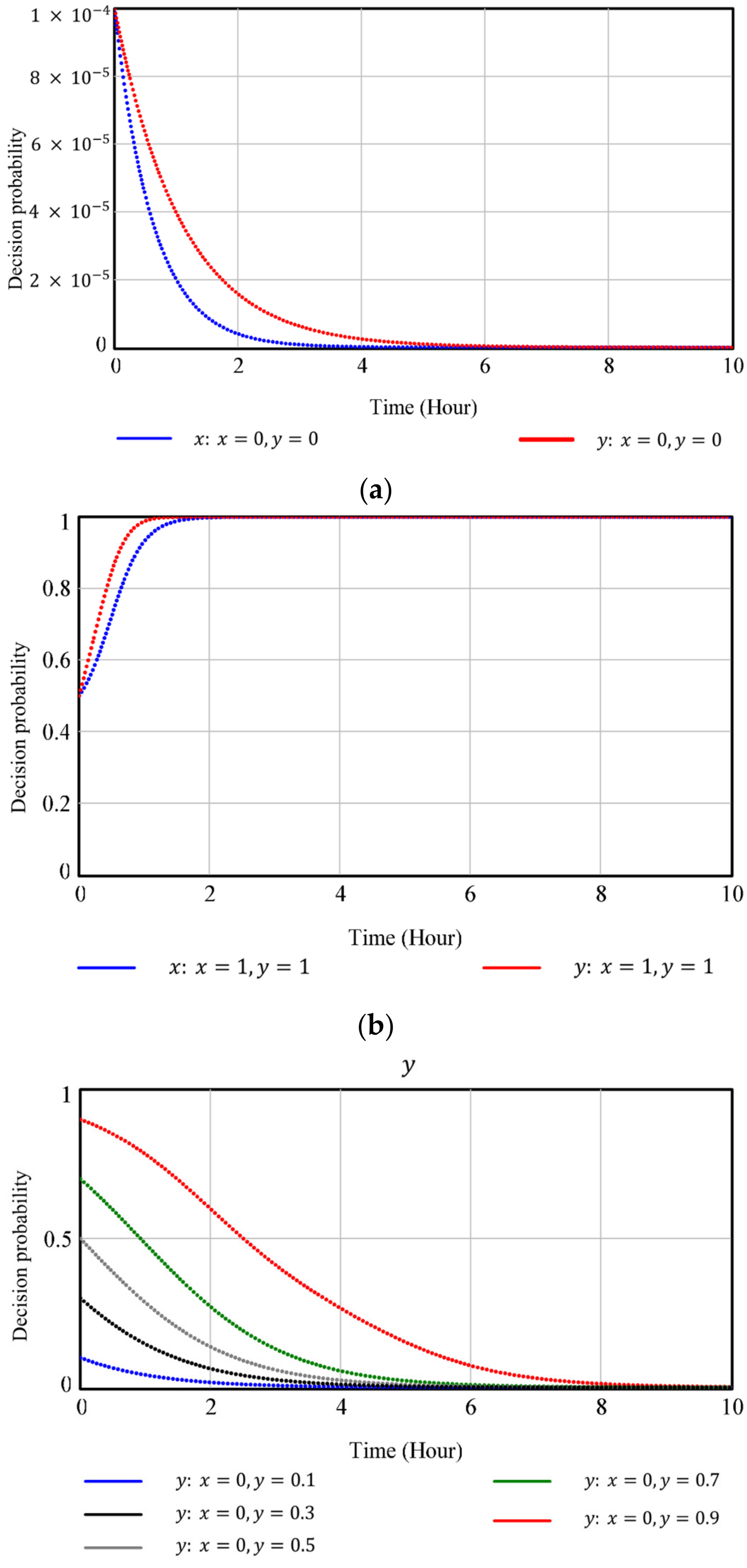


Figure 6. System dynamics model for the consortium blockchain-based leasing strategies.



(**c**)

Figure 7. (**a**) The dynamic diagram to strategy (0,0); (**b**) the dynamic diagram to strategy (1,1); (**c**) the dynamic diagram to strategy of $x = 0,\ y = \{0.1, 0.3, 0.5, 0.7, 0.9\}$. * Considering that dx/dt and dy/dt have to be explanatory, when performing the simulation, we take the initial state (x = 0.0001, y = 0.0001), which is close to 0. Similarly, the initial state (x = 0.9999, y = 0.9999) is set as 1.

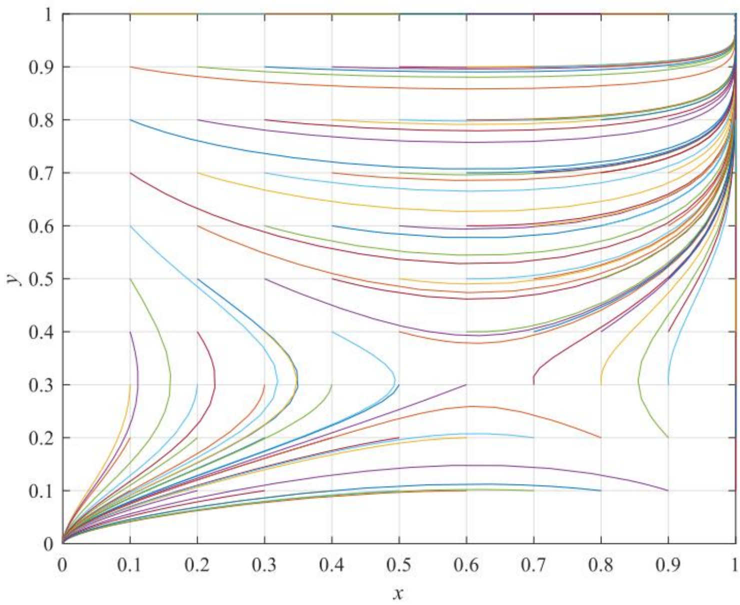
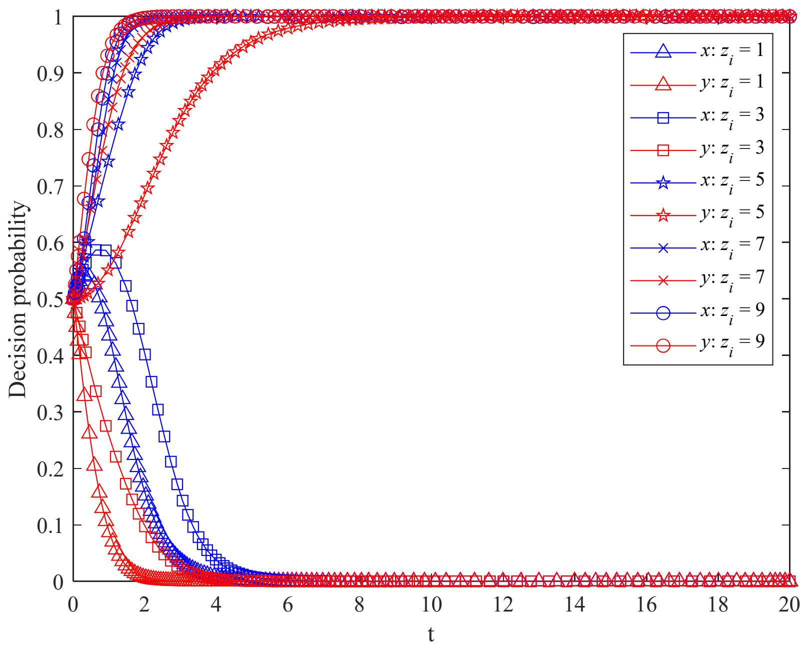


Figure 8. The dynamic diagram of SMEs and LFs.

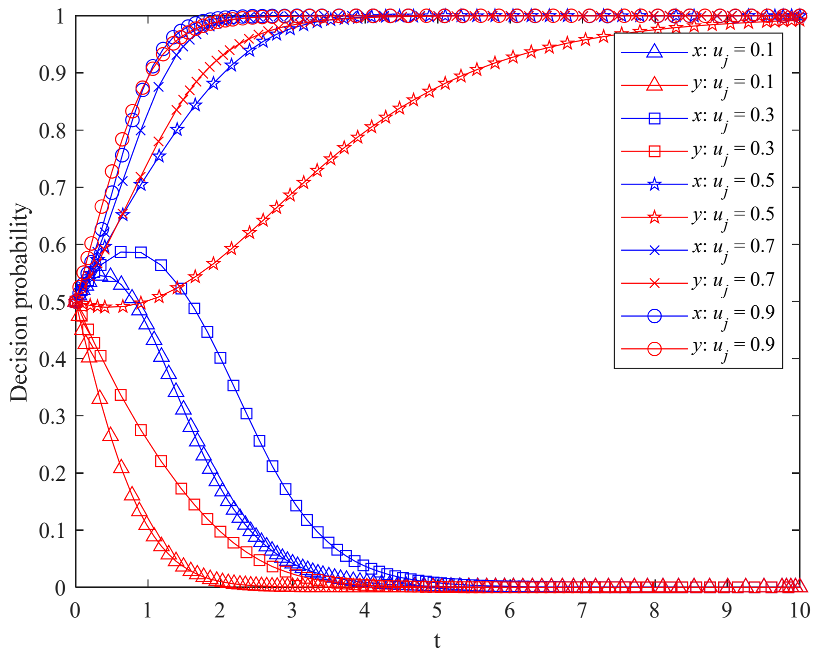
7.2.1. Evolution Impacted by Information Sharing

The initial quantity of information sharing ($\mathcal{Z}_i$) for each participant was set to 1, 3, 5, 7, and 9. As shown in Figure 9a. there are two critical values. When $\mathcal{Z}_i$ is greater than 5 and less than 3, the probability is that all parties will converge at 1 and 0, respectively. The system evolves to the states (1, 1) and (0, 0), accordingly. When the computing power u_j of each organization is less than 0.3, x and y both converge at 0, and the system evolves to the state $(0,\ 0)$ (see Figure 9b). When u_j is greater than 0.5, it results in an evolutionary state $(1,\ 1)$, indicating that the parties with higher computation are more willing to be incentivized to join the consortium blockchain to share information.



(**a**)

Figure 9. *Cont.*



(**b**)

Figure 9. System evolution of $\mathcal{Z}_i$ and u_j: (**a**) system evolution of $\mathcal{Z}_i = \{1, 3, 5, 7, 9\}$; (**b**) system evolution of $u_j = \{0.1, 0.3, 0.5, 0.7, 0.9\}$.

7.2.2. Evolution Impacted by Credit

In order to further study how different levels of credit affect the decision-making of SMEs and LFs, we simulate the factor "credit value" in the range from 1 to 10, with a step size of 2, while keeping the other parameters at their initial values. Figure 10 indicates that all curves gradually converged to $x = 1,\ y = 1$, indicating that higher credit helps to motivate the SME to fulfill the contract and join the blockchain to share their information. However, it also can be found that the SME's strategy of choosing to keep the contract is more influenced and motivated by "credit" than the strategy of joining the blockchain.

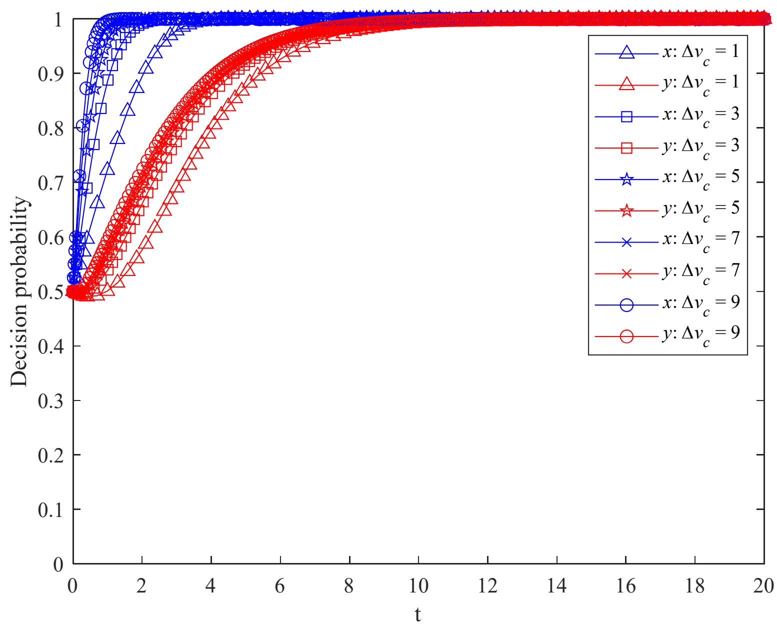
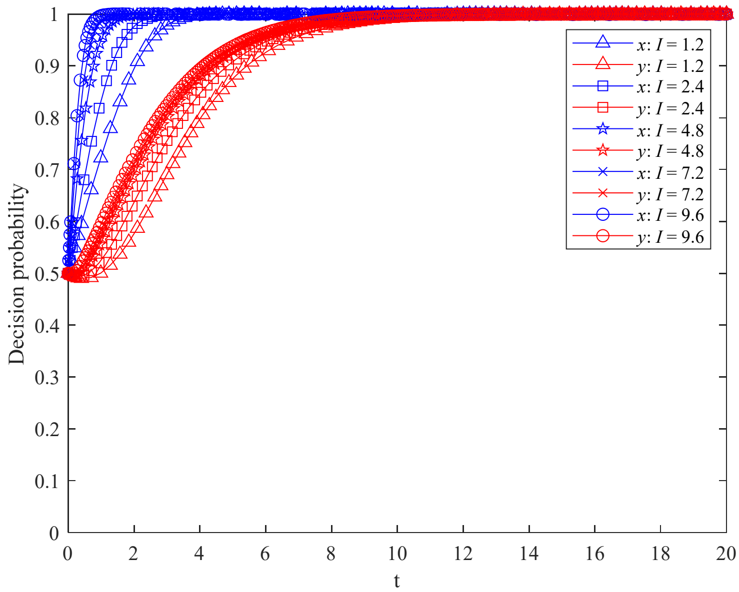


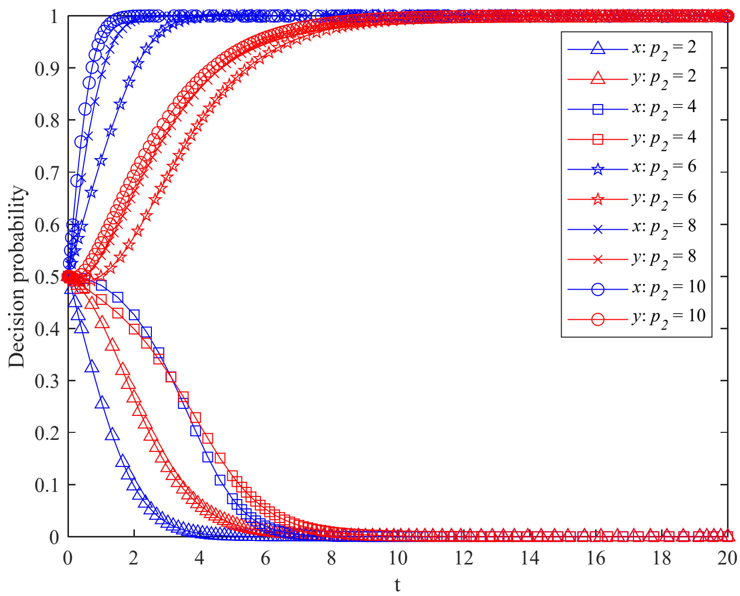
Figure 10. System evolution of $\Delta v_c = \{1, 3, 5, 7, 9\}$.

7.2.3. Evolution Impacted by Incentive-Penalty

We award an incentive I (e.g., a kind of "gas" fee with blockchain) to the SMEs who publish a valid block during the financing transaction confirmation process. When we dynamically adjust the incentive value I from 1.2 to 9.6, we are surprised to find that the system always evolves to the equilibrium point $(1, 1)$ in Figure 11a. This means that no matter how many block rewards are paid to the SME for being a block verifier/miner, the SME resolutely adheres to conforming to the contract and enters the blockchain, whereas with a higher I, the SME is more proactive in participating in information sharing on-chain.



(**a**)



(**b**)

Figure 11. (**a**) System evolution of $I = \{1.2, 2.4, 4.8, 7.2, 9.6\}$; (**b**) system evolution of $p_2 = \{2, 4, 6, 8, 10\}$.

We set the penalty on-chain (p_2) to 2, 4, 6, 8, and 10, revealing the evolution curves of $x(t)$ and $y(t)$ following the change in p_2, as shown in Figure 11b. The figure shows that when the punishment intensity is relatively small, for instance $p_2 = 2$, the SME tends to breach the contract, and when the punishment intensity increases to $p_2 = 8$, the SME tends to actively comply with the contract. In other words, the penalty has a threshold that affects the SME's strategy selection of SMEs joining the blockchain, which is outside of the initial expectations—for example, a high penalty erodes the incentive to participate in information sharing.

7.2.4. Evolution Impacted by Risk

We set the risk cost of the consensus on-chain (ω) and storage off-chain (μ) to 0.2, 0.4, 0.6, 0.8, and 1.0, and the corresponding impacts on the two parties' strategies were analyzed. As shown in Figure 12, the critical value of the initial risk cost is between 0.2 and 0.4. When the risk is less than 0.2, the SME's and LF's probabilities x and y both converged at 1. Vice versa, when the risk level is greater than 0.4, the system evolves to point $(1, 1)$. Similar results can be inferred from the influencing security risk (η).

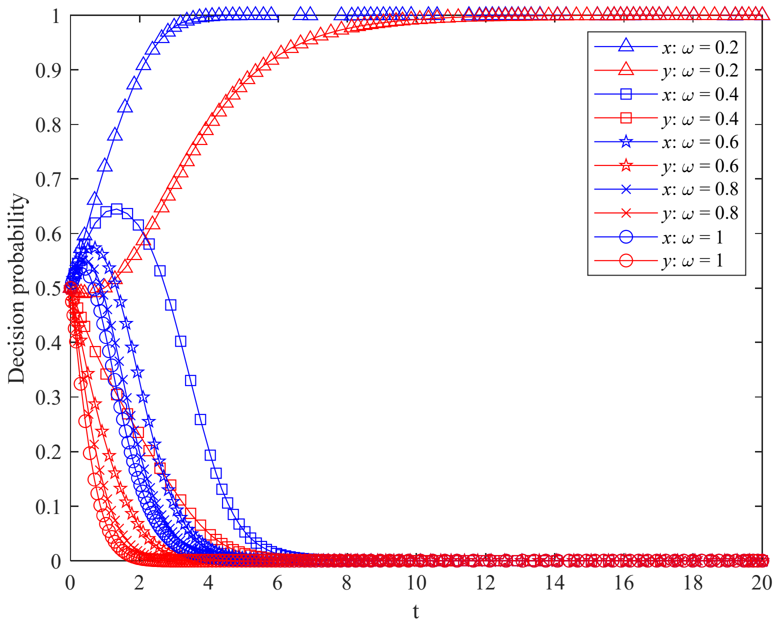


Figure 12. System evolution of $\omega = \{0.2, 0.4, 0.6, 0.8, 1\}$.

7.3. Implications of the Results

Based on the above replicator dynamic analysis and simulation results, this study provides some implications:

(1) The results reveal that the residual value of the leased asset is a decisive factor supporting the lessor's access strategy. Before signing the LC, it is necessary to estimate the asset residual value; if the value is relatively large at the termination of the lease, LFs (lessors) have a high probability of actively adopting BCT to efficiently prove their ownership of the leased asset on-chain. Thus, from the perspective of reducing risks of leased asset default, a blockchain-based leasing service provided by the lessor is more beneficial for an operating lease than a capital lease.

(2) Most leasing businesses tend to treat maintenance as a non-core activity and commonly outsource it to a third-party MC [10], as assumed in this study (Section 4). The results indicate that when the maintenance fee is not embedded in the rental payment, the maintenance charge is not a determinant impacting the lessee's decisions regarding compliance with/defaulting on the LC. Hence, before the lessor decides whether to adopt BCT, it is necessary to take into consideration the in-house or outsourced maintenance problem.

(3) To encourage lessees and lessors to evolve to the ideal equilibrium state, an incentive mechanism should be designed to motivate all parties to cooperatively construct a

sustainable and more trustworthy leasing environment. More high-quality information should be shared on-chain, and stakeholders should also improve the capability to effectively utilize the data on- and off-chain [74]. In contrast to the fixed rewards resulting from block mining, the incentive associated with incremental or deductible credit value for consensus action tends to inspire lessees' willingness to comply with the contract under the BCT-based leasing business. An appropriate default penalty should be set up on-chain that can deter the lessee from defaulting and encourage it to make rental payments on time and return the leased asset as agreed in the LC. When making strategic decisions to join the consortium to share information, participants (particularly lessees) are more sensitive to the technology risk factor to which they are subject. To reduce the cost of building and maintaining the blockchain system to support the leasing business (e.g., on-chain and off-chain storage costs, verification costs, etc.), it is advised and helpful to embed blockchain-as-a-service (BaaS) in our CBLP in the future [75], which will also enhance SMEs' willingness to share more valuable information on-chain, achieving a win–win outcome in the leasing business.

8. Conclusions and Future Works

8.1. Conclusions

BCT provides a new idea for leasing to address the challenges of the information asymmetry and traceability of leased assets to some degree. Hence, there exists great significance in designing an incentive mechanism to encourage lessees and lessors to join the consortium blockchain and actively share information on-chain. This study first proposes a conceptual architecture of the consortium blockchain-based leasing platform (CBLP), then constructs a dynamical evolutionary game model between the SME (the "lessee") and LF (the "lessor"). Our primary findings are as follows:

(1) With long-term cooperation, the two parties (lessee and lessor) eventually evolve to adopt strategies in which the lessee is more inclined to conform to the LC and the lessor becomes more proactive in accessing the CBLP as a consortium node to share information on-chain.

(2) According to previous basic lease scenarios that we assumed, two default actions are explored: (i) overdue rental payment; (ii) asset disposal against the LC. For the former default action, we found that the larger proceeds gained resulting from reinvesting the rental payment will cause the lessee to default, and at this time, the lessor will tend to adopt BCT to mitigate the overdue-payment default risk. In addition, the residual value of the leased asset has a positive impact on the exposure at default, and the lessee will be more likely to default by not returning the leased asset to the lessor due to the temptation of the high profit achieved from asset disposal at the end of the lease. Meanwhile, the lessee's default on asset disposals will result in the lessor being more inclined to adopt BCT to ensure a timely claim of repossession of the leased asset.

(3) Although blockchain can guarantee data reliability (e.g., maintenance events) [76], maintenance cost is not a determinant of the equilibrium state once the maintenance service is outsourced. On the contrary, in-house maintenance provided by the lessor may affect the two parties' strategic decisions.

(4) When the lessee and lessor have incentives to participate in sharing or utilizing more information on-chain, the lessee will eventually evolve to conform to the LC, which will benefit the lessor and leasing industry. Setting up a changeable credit associated with the lessee's LC performance to compete for a block accounting right via a consensus mechanism [77] is an effective way to incentivize the lessee to comply with the LC, while this method does not work much to incentive the lessor to adopt BCT. In addition, only when the default penalty on-chain exceeds a critical value can it work to incentivize lessees to correctly fulfill their obligations in the LC [78], once the penalty is lower than a critical value, which will in return increase the default risk. The technology risks and relevant costs concerning CBLP deployment play a vital role

in encouraging the consortium to participate in information sharing on-chain, which is consistent with what we expected in reality.

In summary, this study enables lessees and lessors to build a trustworthy cooperative relationship on the consortium blockchain-based leasing platform, while also assisting lessors or regulators in taking effective measures to incentivize lessees to comply with the lease contract and share more information on-chain to enhance the management of default risks in the leasing industry.

8.2. Limitations and Future Directions

Considering that the practical application of BCT in the leasing industry is rare, it is difficult to obtain real data. Thus, this study focuses on mathematical modeling and numerical simulation. The conclusions of this study can be further demonstrated and enriched via empirical analysis of specific cases. Meanwhile, there are still some avenues to be explored in the future. For example, it is meaningful to explore "tripartite–win" strategies among lessees, lessors, and OEMs (or third-party MCs). Additionally, blockchain smart contracts play an essential role in financing transactions [79]. Further research can offer new insights into the cost reduction and value transfer of using smart contracts [80] to motivate the related parties to share information.

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Abbreviations

OEM	Original Equipment Manufacturer
SMEs	Small and Medium-Sized Enterprises
LFs	Leasing Firms
MCs	Maintenance Centers
LC	Lease Contract
CPL	Capital Lease
OPL	Operating Lease
EGT	Evolutionary Game Theory
ESS	Evolutionary Stable Strategy
BCT	Blockchain Technology
RDE	Replication Dynamics Equation
CBLP	Consortium Blockchain-Based Leasing Platform
HLF	Hyperledger Fabric
BaaS	Blockchain as a Service
CSP	Cloud Storage Provider
IPFS	InterPlanetary File System

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