Research Article

Blockchain-Driven Supply Chain’s Financing and Coordination Strategy under Nash Bargaining Scheme

Dan Tang

Asia-Australia Business College, Faculty of Economics, Liaoning University, Shenyang, Liaoning 110136, China

Correspondence should be addressed to Dan Tang: danoretang@163.com

Received 30 June 2022; Revised 22 December 2022; Accepted 27 January 2023; Published 22 February 2023

Academic Editor: Zhen Zhang

Copyright © 2023 Dan Tang. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Blockchain-driven supply chain finance (SCF) has become an emerging supply chain financing mode. Compared with the traditional SCF mode, blockchain-driven SCF can shorten the transaction process and provide real trade data that cannot be tampered with, thereby improving the efficiency of capital operation. This article explores the financing and coordination problems of a blockchain-driven supply chain. Based on the three most common supply chain contracts (revenue-sharing contract, profit-sharing contract, and two-part tariff contract), we construct a comparative model of bank credit financing (BCF) and blockchain-driven SCF, discuss the optimal decision-making strategy of the supply chain, and quantitatively analyze the performance of supply chain under each mode. The results show the following: (i) there is a threshold for the usage rate of the blockchain-driven SCF platform; (ii) only when the platform usage rate is lower than the threshold, the blockchain-driven SCF mode which benefits both manufacturer and retailer is a better choice; (iii) the above results always hold if supply chain contracts can coordinate the supply chain in terms of quantity decisions; (iv) the blockchain-driven SCF mode is more efficient for supply chains which are less capital-constrained. This article provides a decision basis for the selection of supply chain financing channels and provides an idea for future research on blockchain-driven SCF.

1. Introduction

Supply chain finance (SCF) is a series of technology-based business and financing procedures that connect multiple parties (suppliers, manufacturers, retailers, and financial institutions) to reduce financing costs and improve business efficiency. SCF provides short-term credit to supply chain members, which optimizes their working capital (https://www.investopedia.com/terms/s/supply-chain-finance.asp). Traditional SCF modes include bank credit finance (BCF) and trade credit finance (TCF) [1]. Under TCF, core enterprises provide short-term credit to capital-constrained small and medium-sized enterprises (SMEs) in the upstream and downstream of the supply chain [2]. Under BCF, it is difficult for SMEs to obtain loans due to their own credit or financial factors [3], so TCF is a more common financing choice for SMEs, and is also more conducive to supply chain coordination [4].

Blockchain technology is a peer-to-peer distributed database of assets that can be shared across multiple sites, geographic locations, or institutional networks [5]. In recent years, with the development of blockchain technology, the blockchain-driven SCF mode has become increasingly popular. The supply chain players can link to each other through the blockchain platform, optimize the overall credit environment, transfer the core corporate credit, simplify the financing transaction process, and effectively deal with the various drawbacks of traditional SCF [3]. Blockchain-driven supply chain platform has become a development trend and upsurge in the industry, which the industry refers to as “digital supply chain transformation” (https://www.forbes.com/sites/stevebanker/2019/09/18/20-things-to-know-about-digital-supply-chain-transformations/#7011e0b45b1). More and more companies and financial institutions are participating in this innovative mode of blockchain-driven SCF, such as ant financial’s “Shuangliantong” blockchain platform. Based on the real transaction background between supply chain players, the credit of core enterprises can be transferred and split on the
blockchain platform, which enables more SMEs in the supply chain to obtain equal and efficient inclusive financial services (https://www.lianmenhu.com/blockchain-15483-1). Another example is the accounts receivable chain platform of Zheshang bank. Till the end of June 2019, the platform has helped more than 8,000 companies to finance more than 170 billion yuan (https://www.lianmenhu.com/blockchain-15483-1).

The blockchain-driven SCF is an emerging financing mode that combines disruptive innovative technology and traditional SCF. It is the key to breaking through the existing barriers of traditional SCF and promoting the development of SCF to the next stage. Therefore, studies analyzing the characteristics and development issues of the emerging blockchain-driven SCF based on the traditional SCF theory and the realistic background of financial technology have sufficient practical operational significance to help the supply chain in reality and can help deepening the development of SCF theory.

This paper aims to solve the financing mode selection problem of a capital-constrained supply chain under the three most common supply chain contracts (including but not limited to revenue-sharing contract, profit-sharing contract, and two-part tariff contract) and explores it by comparing the traditional BCF with blockchain-driven SCF mode. Through comparing supply chain output decisions and supply chain performance under the above-given two modes, we analyze the impact of production costs, financing costs, and initial capital on the supply chain performance of the above-given modes, respectively. Our research results provide a decision-making basis for the selection of SCF modes and provide ideas for the research on blockchain-driven SCF.

The rest of this paper is organized as follows. Section 2 reviews the relevant literature. Section 3 first introduces the basic framework and assumptions of our model and then analyzes the supply chain coordination of the two financing modes (BCF and blockchain-driven SCF) under the three supply chain contracts. Section 4 compares the equilibrium between the two financing modes. Section 5 conducts numerical tests to examine and illustrate the influencing factors, values, and advantages of the blockchain-driven SCF mode. Section 6 summarizes our findings.

2. Literature Review

Our article is related to the following two streams of literature: traditional SCF modes considering supply chain contracts and blockchain-driven SCF solutions.

2.1. The Traditional SCF Modes and Supply Chain Contracts. Supply chain contracts are the basic form to promote supply chain coordination [6]. Academic studies on traditional SCF and supply chain contracts have achieved fruitful results. Most of the early studies mainly explored the effect of different supply chain contracts on supply chain coordination [7]. For example, Dada and Hu [8] considered the capital-constrained retailer and devised a mechanism for partial coordination of the supply chain with wholesale price contracts under the BCF mode. Caldentey and Haugh [9] designed supply chain contracts for a supply chain consisting of a manufacturer and a capital-constrained retailer. Kouvelis and Zhao [10] considered the bankruptcy risk and cost when borrowing from bank-insolvent suppliers and studied the contract design and supply chain coordination problems. Jing et al. [11] discussed the impact of production costs, initial capital, and changes in market demand on the financing efficiency of both the BCF and TCF modes. Chen [12] compared the supply chain equilibrium under BCF and TCF based on revenue-sharing contract and wholesale price contract.

As another important channel of supply chain financing, TCF has also attracted widespread attention. For example, Hwan Lee and Rhee [13] studied supply chain coordination mechanisms (including quantity discount contract, buyback contract, two-part tariff contract, and revenue-sharing contract) by considering active inventory financing costs, and found that all these contracts can be combined with TCF to coordinate the supply chain, but which is not working when combined with BCF. Under similar circumstances, Lee and Rhee [4] further discussed the coordination effect of price-cut subsidies and reached a similar conclusion that the supply chain cannot be fully coordinated in terms of BCF, but the supply chain can be coordinated under TCF. Zhang et al. [14] also explored supply chain coordination issues by considering trade credit and default risks. They proposed a modified quantity discount contract based on quantity and advance payment and found that when the retailer’s risk of default is higher and the supply chain is more likely to achieve coordination. Li et al. [15] compared partial credit guarantees and TCF and found that there was a region where TCF outperforms partial credit guarantees.

2.2. The Blockchain-Driven SCF. The current research on blockchain-driven SCF is still in its infancy [16, 17]. Most available studies have discussed the impact of blockchain on supply chain management [18–22]. Current literature has made it clear that the blockchain can increase the overall performance of the supply chain by simplifying business processes and reducing management costs from the perspective of supply chain management [13–26], especially the reduction of the transaction and verification costs [27, 28] and the networking costs [29]. Besides, blockchain technology also can improve the current supply chain drawbacks (e.g., information asymmetry, data quality, low efficiency, and supply chain incoordination), enhance the traceability of product information management [24, 30], and reform the modern management of supply chains [31, 32].

Some studies also highlight the role of blockchain technology to improve SCF. The current literature has primarily focused on comparing the blockchain-driven SCF with traditional SCF to explore the value of blockchain technology to SCF, which is also mostly related to our research. For example, Wang et al. [32] set up a theoretical blockchain-driven platform to analyze financing solutions
for SMEs. Yan and Zhang [2] built a three-level SCF decision model based on the Stackelberg game based on the technical characteristics of trustless blockchain technology and discussed how the role of blockchain technology can improve the supply chain performance under different decision-making models. Deng and Li [33] built a supply chain factoring financing decision model based on game theory and analyzed the influence of blockchain technology on traditional supply chain coordination. Choi [3] compared traditional BCF with blockchain-driven SCF and used Nash bargaining methods to compare and analyze the decision-making and game process of the supply chain under the revenue-sharing contract. Choi also analyzed the risks of this model and gave relevant management suggestions. De Giovanni [34] compared a traditional supply chain online platform and a blockchain platform, highlighting the smart contracts which make blockchain applications more appealing from the point of supply chain management. There are also a few studies that explored the innovative application of the blockchain-driven supply chain model. Tang and Zhuang [1] considered the credit transfer mechanism of the blockchain, applied the traditional newsvendor model to study the decision-making problem of a multiperiod supply chain, and verified the improvement impact of the blockchain-driven SCF platform on the supply chain financing performance. Choi and Ouyang [35] compared the SCF performance with and without digital currency as an incentive mechanism and found that a supply chain that adopts both blockchain technology and digital currency can achieve a win-win situation. Natanelov et al. [36] identified examples of how financial risks can be mitigated or reduced with blockchain and smart contracts, where the credit financing itself could be fundamentally transformed.

An overview of the most related studies to ours in Table 1 reveals that most of the available literature still focuses on the role of blockchain technology in supply chain management, and few studies have considered this emerging SCF model from the perspective of both supply chain contracts and financing efficiency. Therefore, on the basis of Choi [3], we further consider the situation that the supply chain is capital-constrained, compare the blockchain-driven SCF and traditional BCF, analyzes the similarities and differences of these two financing modes in supply chain output decisions and supply chain performance, and discusses the ordering strategies as well as the performance of the supply chain in different modes under the most common supply chain contracts.

2.3. Contribution Statement. Blockchain-driven SCF is an important topic. With the rapid development of blockchain-driven SCF in practical applications, the decision-making of supply chain and screening of financing channels is an urgent problem that enterprises and academia are concerned. At the same time, a supply chain contract is an important way to increase supply chain cash flow efficiency and promote supply chain coordination. Therefore, this paper considers the most commonly used supply chain contracts (revenue-sharing contract, profit-sharing contract, and two-part tariff contract), and based on which compares and analyzes the blockchain-driven SCF and traditional BCF modes, which can provide valuable guidance to supply chain on the selection of financing channel.

3. Model Description and Assumptions

This study considers a supply chain consisting of a capital-constrained manufacturer \( M \) with limited initial capital \( m \) and a newsvendor-like retailer \( R \). The manufacturer \( M \) provides the retailer \( R \) with a production cost of \( c \) and a quantity of \( Q \) products at a wholesale price \( w \). Retailer \( R \) sells the product at a unit retail price \( p \). The salvage value of the product is \( s \). The market demand is \( D \), which follows a probability density function \( f(x) \) and cumulative distribution function \( F(x) \).

Assume that the supply chain can choose from traditional BCF mode (B) and blockchain-driven SCF mode (BCT). The supply chain considers the expected profit \[ \Pi_i^j (i = R, M; j = B, BCT) \], the optimal output \( Q_{SC}^j (j = B, BCT) \) the operation fee \( \theta \) of the blockchain-driven supply chain platform, and the supply chain financing cost \( r_B \) to determine its financing model (notation details are provided in Table 2). To analytically show how supply chain contracts coordinate both types of the supply chain, and how do they influence the supply chain’s selection of financing channels, we compare the optimal performances between the two models.

To further analyze the influence of supply chain power structure on the above-given decisions, suppose that the manufacturer and the retailer possess bargaining powers. The retailer’s bargaining power is \( \alpha \), and the manufacturer’s bargaining power is \( 1 - \alpha \). We consider the Nash bargaining solution, which is often used when two players decide how to share the surplus [37, 38]. Many studies [39–41] apply the Nash bargaining solution to analyze the game and decision-making between upstream and downstream enterprises in the supply chain.

In this study, the manufacturer and the retailer first negotiate the main indicators under supply chain contracts (revenue-sharing contract, profit-sharing contract, and two-part tariff contract). Then, the retailer determines its optimal order quantity. To satisfy the order quantity, the capital-constrained manufacturer needs to determine the financing method and loan amount based on the order quantity and its initial capital.

3.1. Revenue-Sharing Contract. Under the revenue-sharing contract, the retailer shares a certain percentage \( \eta, 0 < \eta < 1 \) of sales revenue to the manufacturer to obtain lower wholesale prices and improve the performance of supply chain operations.

3.1.1. The Bank Credit Finance (Model B). Under this model, the capital-constrained manufacturer \( M \) applies for financing from the bank to satisfy the order quantity from the newsvendor-like retailer \( R \). The loan interest rate is \( r_B \). Both
<table>
<thead>
<tr>
<th>Literature</th>
<th>Research angel</th>
<th>Financing channel</th>
<th>Model setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zhan et al. [13]</td>
<td>Centralised supply chain decision</td>
<td>Accounts’ receivable financing pledge;</td>
<td>Traditional SCF</td>
</tr>
<tr>
<td></td>
<td></td>
<td>trade credit finance</td>
<td></td>
</tr>
<tr>
<td>Chen [11]</td>
<td>Supply chain coordination</td>
<td>Bank credit finance;</td>
<td>Traditional SCF</td>
</tr>
<tr>
<td>Hofmann and Zumsteg (2015)</td>
<td>Supply chain efficiency and risk</td>
<td>Accounts’ receivable platform</td>
<td>Traditional SCF</td>
</tr>
<tr>
<td>Wang et al. [31]</td>
<td>Information asymmetry</td>
<td>Blockchain-driven credit financing;</td>
<td>Blockchain-driven SCF</td>
</tr>
<tr>
<td>Deng and Li [32]</td>
<td>Supply chain coordination</td>
<td>Factoring</td>
<td>Blockchain-driven SCF</td>
</tr>
<tr>
<td>Choi [3]</td>
<td>Nash bargaining; supply chain contracts</td>
<td>Bank credit finance;</td>
<td>Blockchain-driven SCF</td>
</tr>
<tr>
<td>Pietro de Giovanni [33]</td>
<td>Supply chain management; smart contracts</td>
<td>blockchain supply chain financing</td>
<td>Blockchain-driven SCF</td>
</tr>
<tr>
<td>Tang and Zhuang [1]</td>
<td>Multiperiod supply chain; Newsboy model</td>
<td>Traditional supply chain financing</td>
<td>Traditional SCF</td>
</tr>
<tr>
<td>This paper</td>
<td>Supply chain coordination; supply chain contracts; Nash bargaining</td>
<td>Bank credit finance; blockchain-driven supply chain financing</td>
<td>Traditional SCF</td>
</tr>
</tbody>
</table>
manufacturer $M$ and retailer $R$ seek to maximize their profits. Therefore, the retailer $R$'s profit function is

$$\pi_R = [(1 - \eta)p - w]Q - [(1 - \eta)p - s] \max(Q - x, 0). \tag{1}$$

From equation (1), the retailer $R$'s expected profit is written as follows:

$$\mathbb{E}_R = [(1 - \eta)p - w]Q - [(1 - \eta)p - s] \int_0^Q (Q - x)f(x)dx.$$ \tag{2}

Since

$$\frac{d}{dQ} \mathbb{E}_R(Q) = [(1 - \eta)p - w]Q - [(1 - \eta)p - s]F(Q),$$ \tag{3}

$$\frac{d^2}{dQ^2} \mathbb{E}_R(Q) = -[(1 - \eta)p - s]f(Q) < 0,$$

it is easy to find the optimal ordering quantity of retailer $R$ as follows:

$$Q_R^* = F^{-1} \left[ \frac{(1 - \eta)p - w}{(1 - \eta)p - s} \right]. \tag{4}$$

Similarly, the profit and expected profit functions of manufacturer $M$ are derived as follows:

$$\pi_M = wQ - (cQ - m)(1 + r_B) - m + \eta p \max(Q - x, 0),$$

$$\mathbb{E}_M = wQ - (cQ - m)(1 + r_B) - m + \eta p \int_0^Q (Q - x)f(x)dx.$$ \tag{5}

The respective profit and expected profit functions of the supply chain are
\[ \pi_{B}^{SC} = pQ - (cQ - m)(1 + r_{B}) - m - (p - s)\max (Q - x, 0), \]

\[ \prod_{B}^{SC} = pQ - (cQ - m)(1 + r_{B}) - m - (p - s) \int_{0}^{Q} (Q - x) f(x)dx. \]

It is also easy to derive the optimal product quantity of the supply chain by solving the first-order condition of equation (7):

\[ Q_{B}^{SC*} = F^{-1}\left[ \frac{p - c(1 + r_{B})}{p - s} \right]. \]

Lemma 1. \( Q_{B}^{SC*} \) decreases in \( c \) and \( r_{B} \).

Lemma 1 indicates that, under model \( B \), both the production cost and the manufacturer \( M \)’s financing cost have a great impact on the optimal output of the supply chain.

Following the Nash bargaining framework [3, 6], the supply chain needs to solve the following problem (B):

\[ \max \Theta_{B} = \left[ \prod_{B}^{R} \prod_{B}^{M} \right]^{1 - \alpha}, \text{Subject to } \prod_{B}^{R} + \prod_{B}^{M} \leq 1. \]

(9)

To coordinate the supply chain, the optimal ordering quantity of the retailer \( R \) should be equalled to the optimal output quantity of the supply chain, which means

\[ F^{-1}\left[ \frac{(1 - \eta)p - w}{(1 - \eta)p - s} \right] = F^{-1}\left[ \frac{p - c(1 + r_{B})}{p - s} \right]. \]

(10)

For problem (B), the optimal whole price of manufacturer \( M \) and the optimal revenue sharing rate can both be derived.

\[ \pi_{R}^{BCT} = [(1 - \eta)p - \theta] \min (x, Q) - wQ - (s - \theta) \max (Q - x, 0), \]

\[ \prod_{BCT}^{R} = [(1 - \eta)p - \theta - w]Q - [(1 - \eta)p - s] \int_{0}^{Q} (Q - x) f(x)dx, \]

(13)

Obviously, \( d\prod_{BCT}^{R}(Q)/dQ = [(1 - \eta)p - \theta - w] - [(1 - \eta)p - s] F(Q) < 0 \) and \( d^{2}\prod_{BCT}^{R}(Q)/dQ^{2} = -[(1 - \eta)p - s] f(Q) < 0 \).

Therefore, solving the first-order equation of (13), we can derive the optimal order quantity of retailer \( R \) as follows:

\[ Q_{BCT}^{R*} = F^{-1}\left[ \frac{(1 - \eta)p - \theta - w}{(1 - \eta)p - s} \right]. \]

(14)

Proposition 1. With the Nash bargaining scheme, the supply chain under the bank credit finance model can be coordinated by setting the parameters as follows (see Appendix):

\[ \eta_{B}^{*} = \frac{(p - s)(1 - \alpha)\prod_{B}^{SC} - mr_{B}}{p(\prod_{B}^{SC} - mr_{B})}, \]

\[ w_{B}^{*} = \frac{ac(1 + r_{B})\prod_{B}^{SC} + s(1 - \alpha)\prod_{B}^{SC} - mr_{B}}{\prod_{B}^{SC} - mr_{B}}. \]

Proposition 1 shows that, under the bank credit financing model, supply chain coordination can be achieved through a revenue-sharing contract, and under the Nash bargaining strategy, the parameters of this supply chain contract are unique and optimal.

3.1.2. The Blockchain-Driven Supply Chain Financing (Model BCT). Under this model, the supply chain-related transaction information is automatically recorded on the blockchain-driven SCF platform, and every transaction on the platform will incur a certain operating fee \( \theta [3] \), which means both the retailer and the manufacturer will pay the operating fee. Since there is no loan involved and the manufacturer \( M \) does not need to pay financing interest, the retailer \( R \)’s profit and expected profit functions are
can use the account receivable corresponding to the order to purchase raw materials on the platform. Therefore, under the BCT model, the manufacturer $M$ does not need to raise funds or pay financing interest, only a certain platform usage fee (fee rate $\theta$) is required. Similar to model $B$, we can derive the profit and expected profit functions of the manufacturer $M$ and the supply chain as follows:

$$
\pi^M_{BCT} = (w - c)Q + \eta \rho [Q - \max (Q - x, 0)] - \theta Q,
$$

$$
\pi^M_{BCT} = (w - c - \theta)Q + \eta \rho \left[ Q - \int_0^Q (Q - x) f(x) dx \right],
$$

(15)

$$
\pi^{SC}_{BCT} = (p - c - 2\theta)Q - (p - s)\max (Q - x, 0),
$$

(16)

$$
\sum_{BCT} = (p - c - 2\theta)Q - (p - s)\int_0^Q (Q - x) f(x) dx.
$$

(17)

Based on equations (15)-(17), the optimal product quantity of the supply chain can be derived as follows:

$$
Q^{SC*}_{BCT} = F^{-1}\left[ \frac{p - c - 2\theta}{p - s} \right].
$$

(18)

**Lemma 2.** $Q^{SC*}_{BCT}$ decreases in $c$ and $\theta$.

Similarly, following the Nash bargaining framework, the supply chain needs to solve the following problem (BCT):

$$
\text{Max} \Theta_{BCT} = \left[ \prod_{BCT} R \right]^{\alpha} \left[ \prod_{BCT} M \right]^{1 - \alpha},
$$

$$
\text{Subject to:} \quad \prod_{BCT} R + \prod_{BCT} M \leq \prod_{BCT} SC.
$$

(19)

To coordinate the supply chain, the optimal ordering quantity of the retailer $R$ should be equaled to the optimal product quantity of the supply chain, which means

$$
F^{-1}\left[ \frac{p - c - 2\theta}{p - s} \right] = F^{-1}\left[ \frac{(1 - \eta)p - \theta - w}{(1 - \eta)p - s} \right].
$$

(20)

For problem (BCT), the optimal whole price of manufacturer $M$ and the optimal revenue-sharing rate can both be derived in the following.

**Proposition 2.** With the Nash bargaining scheme, the supply chain under the blockchain-driven SCF model can be coordinated by setting the parameters as follows (see Appendix):

$$
\eta^*_{BCT} = \frac{(1 - \alpha)(p - s)}{p},
$$

$$
\mu^*_{BCT} = \alpha(c + \theta) + (1 - \alpha)(s - \theta).
$$

Proposition 2 shows that, under the blockchain-driven SCF model, the supply chain coordination is also achievable by using the revenue-sharing contract, and under the Nash bargaining scheme, the optimal contract parameters are also unique.

3.2. Profit-Sharing Contract. Under a profit-sharing contract, the retailer shares a certain percentage ($\lambda, 0 < \lambda < 1$) of the profit from the sale of the product to the manufacturer to obtain a lower wholesale price.

3.2.1. The Bank Credit Finance (Model B). Under this model, the capital-constrained manufacturer $M$ still needs to apply for financing from the bank to satisfy the order quantity from the newsvendor-like retailer $R$. Keeping other conditions unchanged, the retailer $R$’s profit function (we denote a “−” to represent the profit-sharing contract) is

$$
\pi^R = (1 - \lambda)[(p - w)Q - (p - s)\max (Q - x, 0)].
$$

(22)

From equation (24), the retailer $R$’s expected profit is written as follows:

$$
\pi^R = (1 - \lambda)\left[ (p - w)Q - (p - s)\int_0^Q (Q - x) f(x) dx \right].
$$

(23)

Since

$$
\frac{d^2 \pi^R}{dQ^2} = -(p - s)f(Q) < 0,
$$

(24)

$$
Q^R = F^{-1}\left[ \frac{p - w}{p - s} \right],
$$

(25)

it is easy to find the optimal ordering quantity of retailer $R$ as follows:
Similarly, the profit and expected profit functions of manufacturer $M$ are derived as follows:

\[
\pi^M_B = \left[ w - c (1 + r_B) \right] Q + mr_B + \lambda \left[ (p - w)Q - (p - s) \max (Q - x, 0) \right],
\]
\[
\prod^M_B = \left[ w - c (1 + r_B) \right] Q + mr_B + \lambda \left[ (p - w)Q - (p - s) \int_0^Q (Q - x)f(x)dx \right].
\]  

(26)

Keeping other settings of the model unchanged, the expected profit function of the supply chain and the optimal order quantity are the same as in Section 3.1.1 (see equations (6) and (7)).

Following the Nash bargaining framework, the supply chain needs to solve the following problem ($B$):

\[
\text{Max } \mathbb{E}_B = \prod^R_B \left[ \prod^M_B \right]^{1-a},
\]
Subject to \( \prod^R_B + \prod^M_B \leq \prod^SC_B \).

(27)

Similarly, to coordinate the supply chain, we equalize the optimal order quantities of the retailer and the supply chain:

\[
F^{-1} \left[ \frac{p - w}{p - s} \right] = F^{-1} \left[ \frac{p - C(1 + r_B)}{p - s} \right].
\]

(28)

By solving problem ($B$), we can derive the optimal wholesale price and the optimal profit share rate for manufacturer $M$.

**Proposition 3.** With the Nash bargaining scheme, the supply chain under the BCF model can be coordinated by setting the parameters as follows (see Appendix):

\[
\pi^R = (1 - \lambda)\left[ (p - \theta)\min (x, Q) - wQ - (s - \theta)\max (Q - x, 0) \right],
\]
\[
\prod^R = (1 - \lambda)\left[ (p - \theta - w)Q - (p - s) \int_0^Q (Q - x)f(x)dx \right].
\]

(30)

Obviously, \( d\prod^R / dQ |_{Q^*} = (1 - \lambda)(p - \theta - w) - (1 - \lambda)(p - s)F(Q) \) and \( d^2\prod^R / dQ^2 |_{Q^*} = -(1 - \lambda)(p - s)f(Q) < 0. \)

Therefore, solving the first-order equation of (31), we can derive the optimal order quantity of retailer $R$ as follows:

\[
\prod^R_{BCT} = F^{-1} \left[ \frac{p - \theta - w}{p - s} \right].
\]

(32)

Similar to Section 3.1.2, we can obtain the profit and expected profit functions of the manufacturer $M$ as follows:

\[
\pi^M_{BCT} = \lambda [(p - w)Q - (p - s)\max (Q - x, 0)] + (w - c - \theta)Q,
\]
\[
\prod^M_{BCT} = \lambda \left[ (p - w)Q - (p - s) \int_0^Q (Q - x)f(x)dx \right] + (w - c - \theta)Q.
\]

(33)

Therefore, the optimal product quantity of the supply chain can be derived as follows:

\[
Q^*_{BCT} = F^{-1} \left[ \frac{p - c - 2\theta}{p - s} \right].
\]

(34)
Similarly, under the Nash bargaining scheme, the supply chain needs to solve the following problem (BCT):

$$\text{Max } \bar{\lambda}_{\text{BCT}} = \left[ \prod_{BCT}^{R} \right]^{1-a} \prod_{BCT}^{M} ;$$  

Subject to: \( \prod_{BCT}^{R} + \prod_{BCT}^{M} \leq \prod_{SC}^{BCT} \). \hspace{1cm} (35)

By equaling equations (34) with (32), and solving problem (BCT), we can derive the optimal whole price of manufacturer \( M \) and the optimal profit-sharing rate in the following.

**Proposition 4.** With the Nash bargaining scheme, the supply chain using profit sharing contract under the blockchain-driven SCF model can be coordinated by setting the parameters as follows (see Appendix):

$$\bar{\lambda}_{\text{BCT}} = 1 - \alpha.$$ \hspace{1cm} \( \bar{\omega}_{\text{BCT}} = c + \theta. \)

(36)

Proposition 4 shows that under the blockchain-driven SCF model, profit-sharing contracts can also coordinate the supply chain by setting unique parameters. Different from Proposition 2, the supply chain profit-sharing ratio is only affected by the bargaining power.

### 3.3. The Two-Part Tariff Contract

Under the two-part tariff contract, the retailer pays the manufacturer a fixed transfer fee \( L \) while ordering products from the manufacturer at the wholesale price \( w \) (we denote a "∼" to represent the two-part tariff contract).

#### 3.3.1. The Bank Credit Finance (Model \( \bar{B} \)).

Similar to Sections 3.1.1 and 3.2.1, we can obtain the retailer \( R \)'s profit function as follows:

$$\bar{\pi}_{B} = (p-w)Q - (p-s)\max(Q-x,0) - L. \hspace{1cm} (37)$$

From equation (37), the retailer \( R \)'s expected profit is written as follows:

$$\prod_{B}^{R} = (p-w)Q - (p-s)\int_{0}^{Q} (Q-x)f(x)dx - L. \hspace{1cm} (38)$$

Since

$$\frac{d\prod_{B}^{R}(Q)}{dQ} = (p-w) - (p-s)F(Q),$$

(39)

$$\frac{d^{2}\prod_{B}^{R}(Q)}{dQ^{2}} = -(p-s)f(Q) < 0,$$

it is easy to find the optimal ordering quantity of retailer \( R \) as follows:

$$\bar{Q}_{B} = F^{-1}\left[ \frac{p-w}{p-s} \right]. \hspace{1cm} (40)$$

Similarly, the profit and expected profit functions of manufacturer \( M \) are derived as follows:

$$\bar{\pi}_{M} = \left[ w - c(1 + r_{B}) \right]Q + mr_{B} - \max(Q-x,0) + L,$$

$$\prod_{M}^{B} = \left[ w - c(1 + r_{B}) \right]Q + mr_{B} + \int_{0}^{Q} (Q-x)f(x)dx + L. \hspace{1cm} (41)$$

The respective profit and expected profit functions as well as the optimal product quantity of the supply chain are the same in Section 3.1.1.

Following the Nash bargaining framework, the supply chain needs to solve problem (\( \bar{B} \)):

$$\text{Max } \bar{\lambda}_{B} = \left[ \prod_{B}^{R} \right]^{1-a} \prod_{B}^{M} ;$$  

Subject to: \( \prod_{B}^{R} + \prod_{B}^{M} \leq \prod_{SC}^{B}. \)

(42)

We equalize the optimal ordering quantity of the retailer \( R \) to the optimal product quantity of the supply chain:

$$F^{-1}\left[ \frac{p-w}{p-s} \right] = F^{-1}\left[ \frac{p-c(1+r_{B})}{p-s} \right]. \hspace{1cm} (43)$$

With Problem (\( \bar{B} \)), the optimal whole price of manufacturer \( M \) and the optimal transfer fee can both be derived.

**Proposition 5.** With the Nash bargaining scheme, the supply chain under the BCF model can be coordinated by setting the parameters as follows (see Appendix):

$$L_{B} = (1-\alpha)\prod_{BCT}^{SC} - mr_{B},$$

$$\bar{\omega}_{B} = c(1 + r_{B}). \hspace{1cm} (44)$$

Proposition 5 shows the following: (1) in the BCF model, the two-part tariff contract can also promote supply chain coordination; (2) the Nash negotiation framework ensures the uniqueness of the contract parameter settings, and the transfer fee \( L_{B} \) depends on \( \prod_{SC}^{BCT} \) the profit of the entire supply chain and the bargaining power of the supply chain members.

#### 3.3.2. The Blockchain-Driven Supply Chain Financing (Model BCT).

Similarly, the retailer \( R \)'s profit and expected profit functions are

$$\bar{\pi}_{BCT} = (p-\theta)\min(x,Q) - wQ - (s-\theta)\max(Q-x,0) - L, \hspace{1cm} (45)$$

(46)

Obviously, \( d\prod_{BCT}^{R}(Q)/dQ = (p-\theta-w) - (p-s)F(Q) \), and \( d^{2}\prod_{BCT}^{R}(Q)/dQ^{2} = -(p-s)f(Q) < 0. \)

Therefore, solving the first-order equation of equation (46), we can derive the optimal order quantity of retailer \( R \) as follows:

$$\bar{Q}_{BCT} = F^{-1}\left[ \frac{p-w}{p-s} \right]. \hspace{1cm} (40)$$
\[ \bar{Q}^{R*}_{BCT} = F^{-1} \left[ \frac{p - \theta - \omega}{p - s} \right]. \] (47)

Similar to Sections 3.1.2 and 3.2.2, we can easily obtain the profit and expected profit functions of the manufacturer \( M \) as follows:

\[
\begin{align*}
\pi^M_{BCT} &= (w - c)Q + p \left[ (Q - x) - \theta Q + L \right] \\
\bar{Q}^{M*}_{BCT} &= (w - c - \theta)Q + p \left[ Q - \int_0^Q (Q - x) f(x) dx \right] + L.
\end{align*} \] (48)

As the other conditions remain the same, the respective profit and expected profit functions as well as the optimal output quantity of the supply chain are unchanged (refer to equations (16) and (17)).

\[
\bar{Q}^{SC*}_{BCT} = F^{-1} \left[ \frac{p - c - 2\theta}{p - s} \right]. \] (49)

Similarly, following the Nash bargaining framework, the supply chain needs to solve the following problem (BCT):

\[
\begin{align*}
\max \overline{\Theta}_{BCT} &= \left[ \bar{Q}^M_{BCT} \right]^{\alpha} \left[ \bar{Q}^R_{BCT} \right]^{1-\alpha} \\
\text{subject to:} & \quad \bar{Q}^R_{BCT} + \bar{Q}^M_{BCT} \leq \bar{Q}^{SC}_{BCT}.
\end{align*} \] (50)

Seemingly,

\[
F^{-1} \left[ \frac{p - c - 2\theta}{p - s} \right] = F^{-1} \left[ \frac{p - \theta - \omega}{p - s} \right]. \] (51)

With problem (BCT), the optimal whole price of manufacturer \( M \) and the optimal transfer fee can both be derived in the following.

**Proposition 6.** With the Nash bargaining scheme, the supply chain under the blockchain-driven supply chain financing model can be coordinated by setting the parameters as follows (see Appendix):

\[
\begin{align*}
L^*_{BCT} &= (1 - \alpha) \bar{Q}^{SC}_{BCT}, \\
\bar{w}^*_{BCT} &= c + \theta.
\end{align*} \] (52)

Proposition 6 shows that, under the blockchain-driven SCF model, the two-part tariff contract can also help supply chain coordination, and the Nash bargaining scheme also ensures the uniqueness of contract parameters.

Comparing Sections 3.1, 3.2, and 3.3, we find that the difference between the optimal solutions of the two models under the three supply chain contracts lies in the financing cost of each model. In other words, the different financing costs between the two models have a large impact on the financing and pricing decisions of the supply chain (discussed in Section 4), this finding provides a theoretical basis of decision-making for manufacturer \( M \) when faced with two different financing channels.

### 4. Impact of Blockchain on SCF

Through the above-given analysis, we have obtained the optimal ordering and pricing decisions under different models and supply chain contracts, as well as the maximum profit of each player in the supply chain. Next, we will compare the above three settings to explore the optimal financing options for the manufacturer and the whole supply chain.

#### 4.1. Optimal Output

**Proposition 7.** The relationship between the outputs of the supply chain under the two financing models is (i) if \( \theta < cr_B/2, Q^{SC}_{BCT} > Q^{SC}_{BCT} \); (ii) if \( \theta \geq cr_B/2, Q^{SC}_{BCT} \geq Q^{SC}_{BCT} \).

To explore the advantage of blockchain-driven SCF, we compare the optimal outputs of the two financing models and find that the financing costs will affect the optimal output of the supply chain. There is one threshold for the blockchain platform usage fee rate, and when the blockchain platform fee rate is higher than the threshold, the blockchain-driven SCF mode no longer has an advantage in terms of output; and when the platform fee rate is lower than the threshold, the blockchain-driven SCF mode is the more conducive financing model to increasing production in the supply chain (See Appendix for proof of Proposition 7).

#### 4.2. Profit

**Proposition 8.** The relationship between the expected profits of the supply chain under the two financing models is (i) \( \theta < cr_B/2, \pi^{SC}_{BCT} > \pi^{SC}_{BCT} \); (ii) if \( \theta \geq cr_B/2, \pi^{SC}_{BCT} \geq \pi^{SC}_{BCT} \).

Proposition 8 is similar to Proposition 7. It shows that the profits of the supply chain change positively with the outputs. The larger the output, the greater the supply chain profits. Like the optimal outputs of the supply chain, the expected profits of the supply chain are also affected by the financing cost. The higher the financing cost is, the lower the optimal output and the expected profits, and vice versa (See Appendix for proof of Proposition 8).

#### 4.3. Benefits of Blockchain on SCF

To be specific, the optimal settings of the above three supply chain contracts are summarized in Table 3.

**Proposition 9.** If Proposition 8 holds, then

(i) \( \eta_B^{*} < \eta_{BCT}^{*}, \lambda_B^{*} < \lambda_{BCT}^{*}, L_B^{*} < L_{BCT}^{*} \)

(ii) \( \omega_B^{*} > \omega_{BCT}^{*}, \omega_B^{*} > \omega_{BCT}^{*}, \omega_B^{*} > \omega_{BCT}^{*} \)

Proposition 9 clearly states the relationship between optimal wholesale prices and supply chain contract parameters. Clearly, retailers under the BCT model share a higher contract ratio or amount in the supply chain, showing this model can improve the working capital efficiency of a retailer.

**Proposition 10.** The supply chain power structure has no effect on the above-given equilibrium results.

Proposition 10 is also straightforward because both the optimal order quantities \( (Q^{SC}_{BCT}, Q^{SC}_{BCT}) \) and the expected...
<table>
<thead>
<tr>
<th>Contract Type</th>
<th>Traditional SCF</th>
<th>Blockchain-driven SCF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue-sharing contract</td>
<td>[ \eta_B^* = (p - s)(1 - \alpha) \prod_{b}^{SC} - mr_B ]/(p(\prod_{b}^{SC} - mr_B)) w_B^* = ac(1 + r_B)\prod_{b}^{SC} + s[(1 - \alpha) \prod_{b}^{SC} - mr_B] ]</td>
<td>[ \eta_{RCT}^* = (1 - \alpha)(p - s)/p ]</td>
</tr>
<tr>
<td></td>
<td>[ w_B^* = c(1 + r_B) ]</td>
<td>[ w_{BCT}^* = \alpha(c + \theta) + (1 - \alpha)(s - \theta) ]</td>
</tr>
<tr>
<td>Profit-sharing contract</td>
<td>[ \lambda_B^* = (1 - \alpha) \prod_{b}^{SC} - mr_B]/\prod_{b}^{SC} - mr_B ]</td>
<td>[ \lambda_{RCT}^* = 1 - \alpha ]</td>
</tr>
<tr>
<td></td>
<td>[ \overline{w}_B^* = c(1 + r_B) ]</td>
<td>[ \overline{w}_{BCT}^* = c + \theta ]</td>
</tr>
<tr>
<td>Two-part tariff contract</td>
<td>[ L_B^* = (1 - \alpha) \prod_{b}^{SC} - mr_B ]</td>
<td>[ L_{RCT}^* = (1 - \alpha) \prod_{b}^{SC} ]</td>
</tr>
<tr>
<td></td>
<td>[ \overline{w}_B^* = c(1 + r_B) ]</td>
<td>[ \overline{w}_{BCT}^* = c + \theta ]</td>
</tr>
</tbody>
</table>
Proposition 10 shows that the power structure of the supply chain only affects the profit distribution of the internal members of the supply chain (manufacturer and retailer) and does not affect the expected profit of the entire supply chain.

5. Numerical Studies

To obtain more insights about the supply chain’s financing strategy preference, we present some concrete numerical studies in this section to illustrate and verify the above-given conclusions. In light of the parameters set by Buzacott and Zhang (2004), the exponential distribution (0.01) is used to isolate the effect of the market demand volatility. The base values of the other parameters are $p = 10, s = 2, c = 4, r_B = 0.12, m = 50, \theta = 0.1$, and $\alpha = 0.2$.

5.1. Impact of Production Cost on the Comparison. To examine the impact of production cost (which is an exogenous factor) on the efficiencies of different financing models, we keep other parameters at the basic value and vary the

---

**Figure 1:** The impact of production cost on the efficiency of different financing models.

![Figure 1](image-url)
production cost $c$. The corresponding optimal production quantity, the profit of the supply chain, and the profits of the retailer and manufacturer are compared as follows.

Figure 1 shows that the BCT financing model is better than the other financing models on the above three aspects. This is reasonable because the BCT financing model benefits from the technical characteristics of blockchain technology such as trustless and decentralization, which can eliminate the cumbersome loan review process in the traditional SCF mode, save time and reduce the cost of loan review, which in turn improves financing efficiency and supply chain production efficiency.

Figures 1(a) and 1(b) are examples of Propositions 7 and 8. When we keep the other parameters the basic value, which means $\alpha = 0.2, r_B = 0.12, \theta = 0.1$, it is easy to find that if the production cost $c > 2\theta/r_B = 1.67$, then $Q_{BCT}^{SC} > Q_B^{SC}$ and $\Pi_{BCT}^{SC} > \Pi_B^{SC}$. This finding suggests that if the production costs and the financing costs of the two models meet certain conditions, then model BCT is more efficient than model B; otherwise, model B is better. Model B is less efficient when the production cost increases. This is because under model B, the capital cost of the manufacturer $r_B$ as the interest rate set by the bank is usually high due to the complicated loan process and high handling fees,
especially for the SMEs (such as the manufacturer M discussed in this paper).

Besides, Figure 1(c) illustrates the changes in the expected revenue of retailers and manufacturer with production costs. It is obvious that as production costs increase, the blockchain-driven SCF mode is also a better choice for the supply chain.

5.2. Impact of Financing Costs on the Comparison. To investigate the impact of the financing cost of each model on the efficiencies of model BCT and B, we vary the financing cost of each model and keep the other parameters at the basic value. For the BCT model, we see the platform usage fee rate θ as the financing cost; For model B, the capital cost rB is the corresponding financing cost. In light of Zhen et al., [6], We define \( \Delta \pi^{SC}_{BCT-B} = \pi^{SC}_{BCT} - \pi^{SC}_{B} \). If \( \Delta \pi^{SC}_{BCT-B} > 0 \), then model BCT is more efficient than model B; Otherwise, model BCT is less efficient than model B.

Figure 2(a) is an extension experiment of Figure 1, we find that when we keep other parameters unchanged as the basic value, only if the production cost \( c > 1.67 \), the BCT model is more efficient than model B, which means \( \Delta \pi^{SC}_{BCT-B} > 0 \); otherwise, B model is better.

In Figure 2(b), we investigate how the financing cost of model B rB influence the efficiencies of the two financing models. When we vary rB and set the other parameters as the basic value \( (c = 4, \alpha = 0.2, \theta = 0.1) \), it is easy to find that \( \theta < crB/2 \) and BCT model is always the more efficient financing model however the capital cost of the manufacturer varies (Proposition 7 and 8).

In Figure 2(c), we keep the other parameters unchanged and vary the blockchain-driven SCF platform usage fee rate θ, to investigate the impact of which on the preference of the BCT model. As shown in Figure 2(c), there is one threshold values \( crB/2 \) for the blockchain-driven SCF platform usage fee rate θ. When the platform rate is higher than the threshold \( crB/2 = 0.24 \), the profit of the supply chain under the BCT model is lower than the traditional BCF model, which means the BCT model no longer has the advantage; otherwise, the BCT model is the more efficient financing model for the supply chain, that is, the supply chain performance is the higher under this model. Figure 2(c) further verifies Propositions 7 and 8. In reality, the blockchain-driven SCF mode is still in its infancy, to attract customers, its financing cost (platform usage fee rate) is usually low, which further shows that this emerging supply chain financing solution has advantages in improving supply chain performance.

5.3. Impact of Initial Capital on the Comparison. This set of numerical studies illustrates how the degree of capital constraints of the manufacturer affects the performance of model BCT and model B. We define the initial capital of the manufacturer \( m = 0 \) as the highly constrained situation, \( m = 50 \) as the moderate-constrained situation, and \( m = 100 \) as the less-constrained situation. In this section, we introduce a ROC (Receiver Operating Characteristic) curve analysis to compare the performance of the above-given two financing models. ROC curve is an important and common statistical analysis method which sorts the samples according to the prediction results of the learner and predicts the samples one
by one as positive examples in this order. Each time two important values (TPR, FPR) are calculated, and they are plotted as the horizontal and vertical coordinates. The AUC value (which is between 0.1 and 1) is the area under the ROC curve. As a value, you can intuitively evaluate the quality of the classifier. The larger the value, the better (see [42, 43], for more information).

In this article, we compared the performance of model B and BCT. We first divided the capital cost of the retailer \( r_B \) (0.06 ≤ \( r_B \) ≤ 0.2) into 29 sample groups, then kept the other parameters as the basic value, calculated the corresponding profits of the supply chain under the two financing models, and at last repeated the experiment as the platform usage fee rate \( \theta \) (0 ≤ \( \theta \) ≤ 0.2), and the degree of the capital constraint of the manufacturer changes. Similarly, when the total expected profit of the supply chain under the BCT model is greater than that of the B model, it is recorded as a positive sample (TP); otherwise, it is a negative sample (NP). The results of the data processing are shown in Table 4.

According to Table 4, we have obtained the ROC curve comparing model BCT and B under three different degrees of capital constraints situations as shown in Figure 3. From Figure 3, the blockchain-driven SCF (model BCT) is always more effective than the bank credit finance (model B), as the platform usage fee rate \( \theta \) varies, and the less \( \theta \) is, the more effective model BCT is. Therefore, the degree of capital constraints of the manufacturer has no impact on the performance of the two financing models.

6. Conclusion

6.1. Results. Blockchain-driven SCF is a new technological innovation supply chain financing mode in recent years. Because of the characteristics of blockchain technology, this mode effectively addresses the disadvantages of traditional SCF such as high cost and cumbersome review procedures. At present, this “digital supply chain transformation” has become a development trend. Therefore, it is very urgent and practical to study the similarities and differences between the blockchain-driven SCF mode and the traditional SCF mode from different perspectives. This study thoroughly explored the performance of the blockchain-driven SCF and the traditional BCF mode under the most common supply chain contracts in terms of supply chain financing, pricing and production decision-making, and supply chain performance and analyzed the relationship between the financing costs of the above-given three models and the changes in the supply chain performance of each financing model under different financing costs. The results are as follows:

1. The financing costs of different financing models have a great impact on the optimal output and the expected profit of the supply chain.
2. There is one threshold for the blockchain-driven SCF platform fee rate. When the blockchain-driven SCF platform fee rate is higher than the threshold, the BCT model no longer has an advantage in terms of supply chain performance; when the platform rate is lower than the threshold, the BCT model is the more conducive financing model to increasing production in the supply chain.
3. If the supply chain contracts can coordinate the supply chain in terms of the optimal order quantity decision, the above-given results hold.
4. Whatever the degree of capital constraint is, the blockchain-driven SCF mode is always better than the BCF mode.

6.2. Future Research. This research considers a financing channel selection problem for a capital-constrained manufacturer under supply chain contracts. The results of the study provide a decision-making basis for the selection of the manufacturer’s financing channel, that is, the blockchain-driven SCF. What needs to be further explored is whether the blockchain-driven SCF mode still has advantages when all supply chain players are subject to capital constraints. In addition, under other types of supply chain contracts, such as quantity discounts and wholesale prices, the performance of the blockchain-driven SCF mode is also an issue that can be further studied.

Appendix

For notation table, see Table 2.

Proof of Proposition 1. First, we need to solve Problem (B) as follow to obtain the optimal “Nash bargaining solution.”

\[
\text{Max } \Theta_B = \left( \prod_{B} R \right)^{\alpha} \left( \prod_{B} M \right)^{1-\alpha},
\]

Subject to \( \prod_{B} R + \prod_{B} M \leq \prod_{B} SC \).

Following the standard solution for Nash bargaining in the available research [3, 7], first, to maximize \( \Theta_B \), both the retailer and manufacturer have to maximize its corresponding expected profit. Under the revenue-sharing contract, the restriction \( \prod_{B} R + \prod_{B} M \leq \prod_{B} SC \) can be written as \( \prod_{B} R + \prod_{B} M = \prod_{B} SC \); therefore, \( \prod_{B} = \prod_{B} SC - \prod_{B} \).
\[ \frac{\partial \Omega_B}{\partial \Pi_B^M} = \frac{\partial}{\partial \Pi_B^M} \left[ \left( \Pi_B^S - \Pi_B^M \right)^{1-a} \right] \]

\[ = -\left( \Pi_B^M \right)^{1-a} \left[ -\alpha \Pi_B^S + \left( \Pi_B^M \right)^{1-a} \right] + (1-a) \left( \Pi_B^S - \Pi_B^M \right)^{1-a} \]

\[ = \left( \Pi_B^S - \Pi_B^M \right)^{1-a} \left( \Pi_B^M \right)^{1-a} \left[ -\alpha \Pi_B^S + (1-a) \left( \Pi_B^S - \Pi_B^M \right) \right] \]

\[ = \left( \Pi_B^S - \Pi_B^M \right)^{1-a} \left( \Pi_B^M \right)^{1-a} \left[ (1-a) \Pi_B^S - \Pi_B^M \right] \] (A.2)

From \( \partial \Omega_B / \partial \Pi_B^M = 0 \), it is easy to obtain the following equation:

\[ \Pi_B^M = (1-a) \Pi_B^S \]. (A.3)

Similarly, through solving \( \partial \Omega_B / \partial \Pi_B^B = 0 \), we can obtain the following equation:

\[ \Pi_B^B = \alpha \Pi_B^S \]. (A.4)

From equation (10), it is easy to obtain the following equation:

\[ \eta_B = \frac{amr_B (p-s) + [\alpha p + (1-a)] s \left[ pQ - cQ (1+r_B) - (p-s) \int_0^{Q_B^S} F(Q_B^S) \right] \left( Q_B^S - x \right) dx}{p \left[ pQ - cQ (1+r_B) - (p-s) \int_0^{Q_B^S} F(Q_B^S) \right] dx} \]. (A.7)

Rearranging equation (A.7), we have the following equation:

\[ \eta_B = \frac{(p-s) \left[ (1-a) \Pi_B^S - mr_B \right]}{p \left( \Pi_B^S - mr_B \right)} \]. (A.8)

Putting equations (A.8) into (A.5) yields

\[ w_B = \frac{\frac{\alpha c (1+r_B) \Pi_B^S}{\Pi_B^S - mr_B} + s \left[ (1-a) \Pi_B^S - mr_B \right]}{\Pi_B^S - mr_B} \]. (A.9)

**Proof of Proposition 2.** Similar to the proof of Proposition 1, we need to find the optimal “Nash bargaining solution” for the following problem (BCT):

\[ (\eta p - \theta - w) Q_{BCT}^{SC^*} - (\eta p - s) \int_0^{Q_{BCT}^{SC^*}} \left( Q_{BCT}^{SC^*} - x \right) f(x) dx = \alpha \Pi_{BCT}^{S} \]. (A.13)
From equations (10), it is easy to obtain the following equation:

$$w_{BCT} = \frac{s(p-c-2\theta) - \eta p(s-c-2\theta) - (p-s)\theta}{p-s}. \quad (A.14)$$

Putting equations (A.14) and (13) into (A.13), we have the following equation:

$$\eta_{BCT}^* = \frac{(1-\alpha)(p-s)}{p}. \quad (A.15)$$

Putting equations (A.15) into (A.12) yields the following equation:

$$w_{BCT}^* = \alpha(c+\theta) + (1-\alpha)(s-\theta) \quad (A.16)$$

Proof of Proposition 3. To avoid duplication, we refer to the proof of Proposition 1.

Proof of Proposition 4. To avoid duplication, we refer to the proof of Proposition 2.

Proof of Proposition 5. To avoid duplication, we refer to the proof of Proposition 1.

Proof of Proposition 6. To avoid duplication, we refer to the proof of Proposition 2.

Proof of Proposition 7

(i) Comparing equations (34) and (49), it is easy to obtain that when \( \theta < cr_B/2 \), \( p-c-2\theta/p-s > p-c(1+r_B)/p-s \); therefore, \( Q_{BCT}^{SCC} > Q_{BCT}^{SCC} \). When \( \theta \geq cr_B/2 \), it is easy to obtain that \( p-c(1+r_B)/p-s \geq p-c-2\theta/p-s \); therefore, \( Q_{BCT}^{SCC} \geq Q_{BCT}^{SCC} \).

(ii) From Proposition 7, when \( \theta \geq cr_B/2 \), \( Q_{BCT}^{SCC} \geq Q_{BCT}^{SCC} \). Similarly, it is easy to find that \( \prod_{BCT}^{R} > \prod_{BCT}^{R} \).

Data Availability

This study used numerical analysis to validate the model and does not use actual data.

Conflicts of Interest

The author declares that there are no conflicts of interest.

Acknowledgments

This paper was supported by grants from the Natural Science Foundation of Shandong Province (Grant No. ZR2022QG019), Postdoctoral Innovation Project of Shandong Province (Grant No. SDCX-RS-202202004), Key R&D program of Shandong Province (Grant No. 2022RKY03011), and Key R&D program of Finance Application in Shandong Province (Grant No. 2022-JRZZ-02).

References


