Blockchain Technology Application in an E-Commerce Supply Chain: Privacy Protection and Sales Mode Selection

Guangming Li, Zhi-Ping Fan, Qingli Zhao, and Minghe Sun

***Abstract*—This article investigates the impact of blockchain technology adoption for consumer privacy protection on an e-commerce supply chain and explores the sales mode selection when adopting blockchain technology. Stackelberg game models are set up to maximize the supply chain member profits, and backward induction is used to derive the equilibrium solutions. The results indicate that supply chain members and consumers can benefit from blockchain technology adoption if the operating cost is low or the consumer privacy concern cost is high. The supply chain members can achieve win–win outcomes in the resale mode if the operating cost is sufficiently low, or if the production cost is low, the commission rate is high and the operating cost is moderate. They can also achieve win–win outcomes in the market mode when the production cost is low, the commission rate is low, and the operating cost is moderate, or when the production cost is high and the operating cost is moderate. An important managerial implication is that the platform can interfere with the supplier sales mode selection by adjusting the commission rate, thereby achieving a win–win outcome if the production cost is low or the operating cost is moderate.**

***Index Terms*—Blockchain technology adoption, consumer privacy protection, e-commerce, pricing, sales mode selection.**

I. Introduction

In RECENT years, online shopping has become increasingly popular [1], [2], [3], [4], [5], [6]. According to eMarketer,[1] over 2.56×10^9 customers worldwide shopped online, and the total e-commerce retail sales exceeded \$5.00 $\times 10^{12}$ in 2022. The e-commerce retail sales are estimated to exceed \$6 $\times 10^{12}$ by 2024.[2] However, consumers often face the risk of privacy leakage when shopping online [7], [8], [9], [10]. There are two main ways to leak consumer personal information. One way is for e-commerce platform employees to steal the consumer personal information.[3] For example, several Amazon employees stole consumer personal information in 2020.[4] The second way is for cyber hackers to attack the information storage systems of e-commerce platforms [11], [12].[5] For example, a hacker stole approximately 1.2×10^9 pieces of user data from Taobao.com using crawler technology in 2020.[6] Once privacy leakage occurs, lawless individuals can use consumer personal information to engage in illegal and criminal activities, such as fraud, selling or disseminating personal information, and overdrafts using consumer credit information. Privacy leakage can cause significant losses to consumers and has negative impacts on profits and reputations of e-commerce platforms [12], [13]. According to the IBM Cost of a Data Breach Report 2023, the average global cost of a security breach was \$4.45 $\times 10^6$ in 2023.[7] Therefore, consumer privacy protection has become an important issue faced by enterprises.

According to Gartner, worldwide expenditure on traditional information security products and services was over \$133 $\times 10^9$ in 2020 and reached \$188.4 $\times 10^9$ in 2023.[8] However, the traditional privacy protection measures, such as secure sockets layer encryption mechanisms and firewalls, are inefficient [12], [14]. A main reason is that business firms have complete control over consumer personal information, which increases the risk of privacy leakage when consumer information is used for customized advertising. Therefore, consumers face challenges in detecting privacy leakage and protecting their rights. Moreover, the centralized information storage systems of e-commerce platforms also increase the risk of information leakage. Consequently, business firms, especially e-commerce supply chain members, urgently need a breakthrough information protection technology.

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The emergence of blockchain technology, characterized by decentralization, anonymity, and information traceability, has taken privacy protection to a new stage [12], [15], [16], [17], [18], [19], [20], [21], [22], [23]. Consumer personal information, such as registration and purchase history, can be stored in anonymous nodes when a blockchain system is applied to an e-commerce supply chain [21], [24], [25], [26]. After a consumer submits an order, the information is encrypted using the seller public key and transmitted to the seller node. The seller can only decrypt the information by using a private key.[9] Particularly, the information of employees processing orders is also recorded, and suspects can be identified once personal information is leaked from the blockchain system. The transparency and traceability of blockchain technology empower consumers, instead of the platforms, with the capability to control over their own information. Consumers can hold the platform accountable in the event of information leakage. In addition, compared with traditional privacy protection technologies, such as secure sockets layer encryption mechanisms and firewalls, blockchain systems also have the advantages of being less susceptible to hacking and information tampering [21], [27], [28], [29], [30]. Currently, blockchain technology is a favorable privacy protection mechanism. For example, Alibaba cloud, a blockchain technology platform, applies blockchain technology to ensure businesses operations environment security [12], OpenBazaar, a decentralized e-commerce platform, applies blockchain technology to enable peer-to-peer transactions,[10] and OpenBrix, an interactive prop-tech platform, applies blockchain technology to enable secure and private property transactions.[11] However, an e-commerce platform usually invests in expensive hardware and software and bears the operating cost of the system to adopt blockchain technology [31], [32], [33], which has a negative impact on supply chain profits. Moreover, the increase in costs may lead to an increase in prices, ultimately damaging consumer surplus. Controversy always exists over whether to use blockchain technology to protect consumer privacy. Some e-commerce platforms, such as Temu and TikTok, do not use blockchain technology. In fact, hundreds of blockchain technology startups have failed since 2018.[12] Therefore, it is necessary to explore the conditions for platforms to adopt blockchain technology and analyze the impacts of blockchain technology adoption on supply chain profits and consumer surplus to provide a reference basis for platform blockchain technology adoption decisions.

Practically, two, i.e., the resale and the market, sales modes are available for the supplier and the platform to choose from in an e-commence supply chain [34]. Under the resale mode, the platform sells products purchased from the upstream supplier to consumers [35]. Under the market mode, the supplier directly sells products to consumers through the platform and pays the platform a commission at a certain rate of the selling price for each transaction [36], [37]. The sales mode selection decision can be made by the platform or the supplier, depending on the supply chain power structure. Some platforms, such as Best Buy, and some suppliers, such as Coca-Cola and Pepsi, have the right to choose sales modes. Each sales mode has advantages and disadvantages to the platform and the supplier. The platform can compensate for the blockchain technology adoption cost by controlling the retail price and the supplier can gain a first-mover advantage under the resale mode. The market mode alleviates the double marginalization effect and allows the supplier to directly control the market price. Hence, it is necessary to explore supplier and platform sales mode selection for them to achieve win–win outcomes [37]. Previous articles showed that sales mode selection is affected by such factors as commission rate, logistics cost, and market scale [1], [38]. However, it is unclear whether the results of the previous articles on sales mode selection are still valid when blockchain technology is applied to protect consumer privacy due to the changes in cost structure and in consumer surplus. Therefore, studying sales mode selection is necessary to find the best sales mode that can benefit the platform, the supplier, and consumers when blockchain technology is used to protect consumer privacy.

As discussed above, data security management has become an important topic in engineering management. Blockchain technology application in e-commerce supply chains deserves further research to effectively protect consumer privacy. This article investigates the impacts of blockchain technology adoption for consumer privacy protection on e-commerce supply chains and examines the sales mode selection to benefit the supply chain members and consumers when adopting blockchain technology. Specifically, this article focuses on the following key issues: 1) Should the supplier and the platform adopt blockchain technology to protect consumer privacy and choose the resale mode or the market mode? 2) Is there a sales mode for supply chain members to achieve a win–win outcome? 3) What are the conditions required for the supplier and the platform to achieve a win–win outcome? 4) In either the resale or the market mode, how does blockchain technology adoption affect prices, demand, consumer surplus, and supply chain member profits?

To address the above key issues, this article considers an e-commerce supply chain consisting of a supplier and a platform. The supplier and the platform can choose either the resale mode or the market mode and may or may not adopt blockchain technology for consumer privacy protection, forming four scenarios. The scenarios without blockchain technology adoption are treated as the basic or reference scenarios. For each scenario, a Stackelberg game model maximizing the profit for each supply chain member is set up, and backward induction is used to obtain the equilibrium, i.e., the optimal solutions. The effects of blockchain technology adoption on the optimal solutions are examined by comparing the optimal results under the two scenarios for each sales mode. Furthermore, by comparing supplier and platform profits between the two scenarios with the blockchain technology adoption, the best sales mode is analyzed, and the conditions for the supplier and the platform to achieve a win–win outcome are explored. Finally, two extensions of the basic models are provided. One extension is the case in which blockchain technology adoption cannot completely eliminate consumer privacy concerns, and the other is the case in which the platform makes the decision first under the resale mode.

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This article makes the following major contributions. First, this article examines the impacts of blockchain technology adoption for consumer privacy protection on the e-commerce supply chain strategic decisions, exploring a new approach for e-commerce data security in engineering management. As far as known, this article is the first attempt on this topic, and consequently fills a research gap, because the existing studies on these topics have only focused on either privacy protection or on the sales mode selection [12], [39]. Second, this article investigates the impacts of blockchain technology adoption on the supply chain member operational decisions and consumer surplus, providing an important basis for the e-commerce supply chain strategic decisions. Third, some important findings obtained differ from those of previous articles [39], [40]. For example, the platform chooses the resale mode if the blockchain technology operating cost is either sufficiently low or sufficiently high, and chooses the market mode otherwise; and the supplier chooses the resale (market) mode if the blockchain technology operating cost is low (high). Particularly, the supply chain members can achieve a win–win outcome when the production cost, the blockchain technology operating cost, and the commission rate meet specific conditions, no matter which sales mode is chosen.

The rest of this article is organized as follows. Relevant literature is reviewed in Section II. Section III defines the notations and describes the research problem. Section IV sets up the models and obtains the optimal results through backward induction. Section V presents further analyses and discusses the major findings. Section VI presents two extensions. Section VII examines the main results of the study through numerical experiments and provides managerial implications. Finally, Section VIII concludes this article. The mathematical expressions of the critical thresholds and the proofs of the major results are presented in the Appendices.

II. Literature Review

This article is related to three streams of research, including consumer privacy concerns, privacy protection technology for supply chains, and supply chain sales mode selections. Relevant studies in these three research streams are reviewed in this section.

A. Consumer Privacy Concerns

The first stream of literature relevant to this article is about consumer privacy concerns. The works of Culnan and Armstrong [41], Dinev and Hart [42], and Tang et al. [43] collectively revealed the multifaceted implications of privacy concerns in online shopping. Tang et al. [43] extended this exploration, emphasizing the adverse effects of privacy concerns on the overall consumer experience in the digital marketplace. Lee et al. [44] provided further insights and explored the equilibrium consumer privacy protection strategies for two enterprises. Different from all the aforementioned studies, Chen et al. [45] studied the issue of information privacy regarding peer disclosure. Choi [9] approached the topic from a different angle, examining the prices and the promotion efforts of an e-tailer considering consumer privacy concerns, and found that the increase in consumer privacy concerns led to the reductions in the price and the promotion efforts. Different from the previous articles, this article focuses on using blockchain technology as a solution to alleviate or eliminate consumer privacy concerns, and analyzes the impacts of blockchain technology adoption for consumer privacy protection on the supply chain prices and profits and on the consumer surplus. This article facilitates the understanding of using blockchain technology to protect consumer privacy in engineering management that has never been explored before.

B. Privacy Protection Technology for Supply Chains

The second stream of research examined the privacy protection technology for supply chains. In earlier years, scholars focused on traditional privacy-preserving policies and technologies. Montes et al. [46] considered the consumer entrust in a third-party organization to delete the consumer web browsing data by bearing a privacy protection cost. Yang et al. [47] studied the security investment efforts of a cloud computing provider and the users. Kumar and Kumar [48] proposed a novel privacy protection algorithm based on fuzzy sets and reallocation, which can be used for social network data anonymization.

Entering the era of Industry 4.0, many enterprises are using advanced technologies to network their manufacturing systems, which brings new security challenges [49], [50]. Consequently, blockchain technology has become an effective approach to protect the enterprise and consumer privacy information [12], [15], [16]. For example, blockchain technology can be used to share comprehensive health data in real time among authorized entities, while ensuring a high level of health information protection [21]. Therefore, some scholars proposed new architectures based on blockchain technology to address privacy security issues. Yeh et al. [51] designed a new two-stage Bloom filter for efficient search with privacy preservation. Olivares-Rojas et al. [52] proposed a novel cybersecurity architecture for blockchain-based smart metering systems. Similarly, Casino and Patsakis [53] introduced a new architecture based on decentralized locally sensitive hash classification and a set of recommendation methods, and Sharma et al. [50] provided a secure distributed fog node architecture using SDN and blockchain technology.

However, only a few articles analyzed the values of blockchain technology for privacy protection from the perspective of engineering management. Luo and Choi [12] studied the impacts of blockchain technology on the cyber security level and the government cyber security penalty schemes, and found that an all-win situation could be created for enterprises and consumers. Unlike existing articles, this article investigates the supplier and platform sales mode selection when applying blockchain technology to protect consumer privacy, and found that blockchain technology adoption leads to increases in consumer surplus and in supplier and platform profits when consumers have high privacy concern costs.

C. Supply Chain Sales Mode Selections

The third stream of article studied supply chain sales mode selections. Although many relevant research results have been

TABLE I
COMPARISONS BETWEEN THIS ARTICLE AND THE RELATED LITERATURE

Literature	Blockchain technology	Privacy protection	Sales-mode selections	E-commerce platform
Luo and Choi [12]	✓	✓		✓
Liu et al. [39]	✓		✓	✓
Xu and Choi [40]	✓		✓	✓
Yeh et al. [51]	✓	✓		
Olivares-Rojas et al. [52]	✓	✓		
Casino and Patsakis [53]	✓	✓		
This article	✓	✓	✓	✓

published, only those closely related to this article are reviewed. Most of the articles identified the conditions under which supply chain members chose different sales modes. Hagiu and Wright [54] found that the resale mode benefited the intermediary if the marketing campaigns produced spillover effects. Some articles focused on the sales mode selections with blockchain technology adoption, but did not consider its privacy protection features. Liu et al. [39] investigated the sales mode selection of a fresh supply chain using blockchain technology to trace products. Xu and Choi [40] studied the sales mode selections of a manufacturer and an online platform with carbon emission information transparency through blockchain technology. A few articles tried to find sales modes that enable supply chain members to achieve win–win outcomes. Chen et al. [37] studied the retailer sales mode selections in a competitive environment and found that the two retailers could achieve an all-win outcome with the manufacturer if they chose different sales modes. Ha et al. [2] investigated the supply chain channel structure decisions, and analyzed the channel structure that could benefit both the platform and the manufacturer. This article differs from the aforementioned studies in two ways. The first is that this article examines the supplier and the platform sales mode selections when applying blockchain technology to protect consumer privacy, and analyzes the impacts of the operating cost on the sales mode selections. The second is that this article identifies the conditions under which the platform and the supplier can make optimal sales mode selection decisions, which deviates from the existing literature.

Table I presents comparisons of this article with the most relevant studies from the literature.

III. NOTATIONS AND PROBLEM DESCRIPTION

In this section, the notations used in this article are first defined, and then the problem studied is described.

A. Notations

The notations used in the models and results are shown in Table II. Scenarios RN and RB represent the resale made, and MN and MB represent the market mode, for without and with blockchain technology adoption, respectively. Accordingly, the superscript j for $j \in \{\mathrm{RN}, \mathrm{RB}, \mathrm{MN}, \mathrm{MB}\}$ is used in the notations to denote the corresponding scenario. Scenarios RN and MN are the basic or reference scenarios.

B. Problem Description

The e-commerce supply chain considered consists of a supplier and an e-commerce platform that consider blockchain technology adoption to protect consumer privacy. The supplier and the platform have two, i.e., the resale and the market, sales modes to choose from. A game theoretical approach is used to analyze the problem. Stackelberg game models with the supplier as the leader and the platform as the follower are set up to maximize the supplier and the platform profits, and backward induction is used to find the equilibrium solutions. The sequence of events in the game models is as follows. First, the platform or the supplier chooses the sales mode and then decides the prices. Specifically, the supplier first decides the wholesale price w^j, and the platform (supplier) then decides the retail price p^j under the resale (market) mode [55]. A different sequence of events is followed in the extension in Section VI when the platform, acting as the leader in the Stackelberg game, first decides the retail price under the resale mode.

Under each sales mode, the platform is assumed to provide logistics services and bears the unit logistics cost c_e. In reality, it is common for platforms to provide logistics services [56]. For example, Amazon and JD.com have established logistics systems to provide logistics services for their own stores and suppliers. In addition, the supplier unit production cost is c_p [57], [58].

Considering the risk of personal information leakage, consumers have privacy concerns that negatively affect their online purchase intention [7], [9]. For example, some consumers restrict their online activities because of privacy concerns, or hire privacy protection agencies to delete their online browsing data [13]. Hence, b, representing the consumer privacy concern cost, is used to describe the negative effect of consumer privacy concerns on consumer utility. Specifically, with the information digitization and the prevalence of online shopping, consumers become increasingly aware of the potential risks associated with the collection, use, and sharing of their personal data.

TABLE II
NOTATIONS

Notations	Descriptions
p^j	The product retail price under scenario j (decision variable), $p^j > 0$
w^j	The product wholesale price under scenario j (decision variable), $w^j > 0$
v	The consumer product valuation, $0 < v < 1$
u^j	The consumer utility under scenario j, $u^j > 0$
D^j	The demand under scenario j, $D^j > 0$
b	The consumer privacy concern cost, $b > 1$
μ	The commission rate, $0 < \mu < 1$
c_b	The blockchain technology operating cost, hereafter simply the operating cost, $c_b > 0$
c_e	The platform unit logistics cost, $c_e > 0$
c_p	The supplier unit production cost, $c_p > 0$
β	The reduction rate of consumer privacy concern cost after blockchain technology adoption, $0 < \beta < 1$
r	The platform markup, $r > 0$
CS^j	The consumer surplus under scenario j, $CS^j > 0$
$\prod_s^j$	The supplier profit under scenario j, $\prod_s^j > 0$
$\prod_p^j$	The platform profit under scenario j, $\prod_p^j > 0$

Consequently, the consumer's desire to purchase online decreases as the risk of privacy breach increases [43]. Blockchain technology adoption creates a secure shopping environment for consumers and ensures the security of transaction data, which helps reduce or eliminate consumer privacy concerns [12], [21]. The platform bears the operating cost c_b of blockchain technology adoption, which is a variable cost associated with each transaction [59], [60], [61], [62]. The operating cost c_b may include network maintenance cost, such as hardware and power consumption, data security cost, such as running encryption algorithms and conducting network security audits, and data storage cost. Therefore, the main parameter affecting the optimal results is the consumer privacy concern cost without, and is the operating cost with, blockchain technology adoption [63].

Without blockchain technology adoption, the consumer utility is $u^j = v - p^j - b$ when making a purchase, where v represents the consumer expected product valuation, which can be interpreted as the consumer taste. Consumers with higher valuations are more willing to pay for a given price. Since consumers may have different product valuations in reality, v is assumed to be uniformly distributed in the interval $[0, 1]$ [64], [65]. A consumer purchases the product only if his or her utility is nonnegative. The consumer utility becomes $u^j = v - p^j$ if blockchain technology is adopted to eliminate consumer privacy concerns. Although the increase in consumer utility implies an increase in product purchases, the platform may not necessarily benefit from it due to the accompanying operating cost. The uniqueness of the model is captured by characterizing the tradeoffs between the privacy concern cost b and the operating cost c_b.

Referring to Chiang et al. [64] and Ru et al. [65], the population size is scaled to 1. The market demand is $D^j = \int_{p^j+b}^{1} dv = 1 - p^j - b$ without, or is $D^j = \int_{p^j}^{1} dv = 1 - p^j$ with, blockchain technology adoption, where $p^j + b$ or p^j is the minimum and 1 is the maximum consumer product valuations, respectively. Accordingly, as in Shao et al. [66] and Huang et al. [67], the consumer surplus is $\mathrm{CS}^j = \int_{p^j+b}^{1} (v - p^j - b)dv$ without, or is $\mathrm{CS}^j = \int_{p^j}^{1} (v - p^j)dv$ with, blockchain technology adoption. The restrictions $b < 1 - c_p - c_e$ and $c_b < 1 - c_p - c_e$ under the resale mode, and $\mu < 1 - \frac{c_p}{1-b}$ and $b < 1 - \frac{c_p}{1-\mu}$ under the market mode, are imposed to ensure positive profits.

IV. Model Setup and the Optimal Results

In this section, the models are set up and the optimal results are obtained for all scenarios. The effects of some main parameters on the optimal results are also analyzed for each scenario.

A. Resale Mode

Under Scenario RN, the supplier and the platform profit maximization models can be expressed as follows:

$$\max_{1-p^{\mathrm{RN}}-b>0} \prod\nolimits_s^{\mathrm{RN}}(p^{\mathrm{RN}}, w^{\mathrm{RN}}) = (w^{\mathrm{RN}} - c_p) \int_{p^{\mathrm{RN}}+b}^{1} dv \tag{1}$$

$$\max_{1-p^{\mathrm{RN}}-b>0} \prod\nolimits_p^{\mathrm{RN}}(p^{\mathrm{RN}}, w^{\mathrm{RN}}) = (p^{\mathrm{RN}} - w^{\mathrm{RN}} - c_e) \int_{p^{\mathrm{RN}}+b}^{1} dv \tag{2}$$

where $1 - p^{\mathrm{RN}} - b$ is the demand under Scenario RN.

Backward induction is used to obtain the equilibrium results [12], [35], [68]. The second partial derivative of $\prod_p^{\mathrm{RN}}$ with respect to p^{RN}, i.e., $\frac{\partial^2 \prod_p^{\mathrm{RN}}}{\partial (p^{\mathrm{RN}})^2} = -2$, is obtained first. Since $\frac{\partial^2 \prod_p^{\mathrm{RN}}}{\partial (p^{\mathrm{RN}})^2} < 0$, $\prod_p^{\mathrm{RN}}$ is concave in p^{RN}, indicating that a unique optimal value for p^{RN} always exists. Then, $p^{\mathrm{RN}}(w^{\mathrm{RN}}) = \frac{-b+w^{\mathrm{RN}}+c_e+1}{2}$ is derived from the first-order condition of (2). Substituting

$p^{\mathrm{RN}}(w^{\mathrm{RN}})$ into (1), $\frac{\partial^2 \prod_s^{\mathrm{RN}}}{\partial (w^{\mathrm{RN}})^2} = -1$ is obtained. Hence, a unique optimal value for w^{RN} always exists. The optimal results are presented in Lemma 1.

Lemma 1: The optimal wholesale price is $w^{\mathrm{RN}*} = \frac{c_p - c_e - b + 1}{2}$ and the optimal retail price is $p^{\mathrm{RN}*} = \frac{c_e - 3b + c_p + 3}{4}$ under Scenario RN.

The optimal demand $D^{\mathrm{RN}*} = \frac{1 - c_p - c_e - b}{4}$, consumer surplus $CS^{\mathrm{RN}*} = \frac{(1 - c_p - c_e - b)^2}{32}$, supplier profit $\prod_s^{\mathrm{RN}*} = \frac{(1 - c_p - c_e - b)^2}{8}$, and platform profit $\prod_p^{\mathrm{RN}*} = \frac{(1 - c_p - c_e - b)^2}{16}$ are derived from the results in Lemma 1. To ensure the satisfaction of $1 - p^{\mathrm{RN}} - b > 0$, $w^{\mathrm{RN}} > 0$, and $p^{\mathrm{RN}} > 0$, the feasible region of the models in (1) and (2) is defined by $b < 1 - c_p - c_e$ for Scenario RN. The effects of the consumer privacy concern cost b on the optimal results are presented in Corollary 1.

Corollary 1: The effects of the consumer privacy concern cost on the optimal results are given by $\frac{\partial p^{\mathrm{RN}*}}{\partial b} < 0$, $\frac{\partial w^{\mathrm{RN}*}}{\partial b} < 0$, $\frac{\partial D^{\mathrm{RN}*}}{\partial b} < 0$, $\frac{\partial \mathrm{CS}^{\mathrm{RN}*}}{\partial b} < 0$, $\frac{\partial \prod_s^{\mathrm{RN}*}}{\partial b} < 0$, and $\frac{\partial \prod_p^{\mathrm{RN}*}}{\partial b} < 0$ under Scenario RN.

Corollary 1 shows that the consumer privacy concern cost negatively affects prices, demand, consumer surplus, and platform and supplier profits when blockchain technology is not adopted. The reason is that consumer willingness to pay decreases as the privacy concern cost increases, leading to the decreases in the demand, consumer surplus, and platform and supplier profits. To maintain demand, supply chain members can reduce prices to attract consumer purchase.

Under Scenario RB, the supplier and the platform profit maximization models can be stated as follows:

$$\max_{1 - p^{\mathrm{RB}} > 0} \prod_s^{\mathrm{RB}} (p^{\mathrm{RB}}, w^{\mathrm{RB}}) = (w^{\mathrm{RB}} - c_p) \int_{p^{\mathrm{RB}}}^{1} dv \tag{3}$$

$$\max_{1 - p^{\mathrm{RB}} > 0} \prod_p^{\mathrm{RB}} (p^{\mathrm{RB}}, w^{\mathrm{RB}}) = (p^{\mathrm{RB}} - w^{\mathrm{RB}} - c_e - c_b) \int_{p^{\mathrm{RB}}}^{1} dv \tag{4}$$

where $1 - p^{\mathrm{RB}}$ is the demand under Scenario RB.

Backward induction is used to obtain the equilibrium results [12], [35], [68]. The second partial derivative of $\prod_p^{\mathrm{RB}}$ with respect to p^{RB}, i.e., $\frac{\partial^2 \prod_p^{\mathrm{RB}}}{\partial (p^{\mathrm{RB}})^2} = -2$, is obtained first. Since $\frac{\partial^2 \prod_p^{\mathrm{RB}}}{\partial (p^{\mathrm{RB}})^2} < 0$, $\prod_p^{\mathrm{RB}}$ is concave in p^{RB}, indicating that a unique optimal value for p^{RB} always exists. Similarly, $\prod_s^{\mathrm{RB}}$ is concave in w^{RB} from (4). The optimal results are presented in Lemma 2.

Lemma 2: The optimal wholesale price is $w^{\mathrm{RB}*} = \frac{c_p - c_e - c_b + 1}{2}$ and the optimal retail price is $p^{\mathrm{RB}*} = \frac{c_e + c_b + c_p + 3}{4}$ under Scenario RB.

The optimal demand $D^{\mathrm{RB}*} = \frac{1 - c_p - c_e - c_b}{4}$, consumer surplus $CS^{\mathrm{RB}*} = \frac{(1 - c_p - c_e - c_b)^2}{32}$, supplier profit $\prod_s^{\mathrm{RB}*} = \frac{(1 - c_p - c_e - c_b)^2}{8}$, and platform profit $\prod_p^{\mathrm{RB}*} = \frac{(1 - c_p - c_e - c_b)^2}{16}$ are derived from the results in Lemma 2. To ensure the satisfaction of $1 - p^{\mathrm{RB}} > 0$, $w^{\mathrm{RB}} > 0$, and $p^{\mathrm{RB}} > 0$, the feasible region of the models in (3) and (4) is defined by $c_b < 1 - c_p - c_e$ for Scenario RB.

The effects of the operating cost c_b on the optimal results are presented in Corollary 2.

Corollary 2: The effects of the operating cost c_b on the optimal results are given by $\frac{\partial p^{\mathrm{RB}*}}{\partial c_b} > 0$, $\frac{\partial w^{\mathrm{RB}*}}{\partial c_b} < 0$, $\frac{\partial D^{\mathrm{RB}*}}{\partial c_b} < 0$, $\frac{\partial CS^{\mathrm{RB}*}}{\partial c_b} < 0$, $\frac{\partial \prod_s^{\mathrm{RB}*}}{\partial c_b} < 0$, and $\frac{\partial \prod_p^{\mathrm{RB}*}}{\partial c_b} < 0$ under Scenario RB.

Corollary 2 indicates that the retail price increases, and the wholesale price, demand, consumer surplus, and platform and supplier profits monotonously decrease with the increase in the operating cost. If the operating cost is high, the platform has to extract consumer surplus by increasing the retail price, leading to a more serious double marginalization effect. Therefore, the demand and the platform profit decrease with the increase in the operating cost. Furthermore, to avoid reduction in demand, the supplier alleviates the double marginalization effect by reducing the wholesale price, thereby hurting its profit.

B. Market Mode

Under Scenario MN, the supplier profit maximization model can be stated as follows:

$$\max_{1 - p^{\mathrm{MN}} - b > 0} \prod_s^{\mathrm{MN}} (p^{\mathrm{MN}}) = ((1 - \mu) p^{\mathrm{MN}} - c_p) \int_{p^{\mathrm{MN}} + b}^{1} dv \tag{5}$$

where $1 - p^{\mathrm{MN}} - b$ is the demand under Scenario MN.

From the second partial derivative of $\prod_s^{\mathrm{MN}}$ with respect to p^{MN}, i.e., $\frac{\partial^2 \prod_s^{\mathrm{MN}}}{\partial (p^{\mathrm{MN}})^2} = -2(1 - \mu)$, $\prod_s^{\mathrm{MN}}$ is concave in p^{MN}, indicating that a unique optimal value for p^{MN} always exists. The optimal retail price is obtained according to the first-order condition of (5) and is presented in Lemma 3.

Lemma 3: The optimal retail price is $p^{\mathrm{MN}*} = \frac{c_p + (1 - b)(1 - \mu)}{2(1 - \mu)}$ under Scenario MN.

The optimal demand $D^{\mathrm{MN}*} = \frac{1 + \mu b - c_p - \mu - b}{2(1 - \mu)}$, consumer surplus $CS^{\mathrm{MN}*} = \frac{(1 + \mu b - c_p - \mu - b)^2}{8(1 - \mu)^2}$, and supplier profit $\prod_s^{\mathrm{MN}*} = \frac{(1 - b - c_p - \mu + \mu b)^2}{4(1 - \mu)}$ are derived from the results in Lemma 3. The platform profit can be expressed as $\prod_p^{\mathrm{MN}} = (\mu p^{\mathrm{MN}} - c_e) \int_{p^{\mathrm{MN}} + b}^{1} dv$ under Scenario MN. Substituting $p^{\mathrm{MN}*}$ into the expression of $\prod_p^{\mathrm{MN}}$, the optimal platform profit $\prod_p^{\mathrm{MN}*} = \frac{(-2\mu c_e + 2c_e - \mu c_p - \mu + \mu^2 + b\mu - b\mu^2)(c_p - 1 + \mu + b - b\mu)}{4(1 - \mu)^2}$ is derived from the results in Lemma 3. To ensure the satisfaction of $1 - p^{\mathrm{MN}} - b > 0$ and $p^{\mathrm{MN}} > 0$, the feasible region of the model in (5) is defined by $b < 1 - \frac{c_p}{1 - \mu}$ for Scenario MN.

The effects of the consumer privacy concern cost b on the optimal results are presented in Corollary 3.

Corollary 3: The effects of the consumer privacy concern cost b on the optimal results are given by $\frac{\partial p^{\mathrm{MN}*}}{\partial b} < 0$, $\frac{\partial D^{\mathrm{MN}*}}{\partial b} < 0$, $\frac{\partial CS^{\mathrm{MN}*}}{\partial b} < 0$, $\frac{\partial \prod_s^{\mathrm{MN}*}}{\partial b} < 0$, and $\frac{\partial \prod_p^{\mathrm{MN}*}}{\partial b} < 0$ under Scenario MN.

From Corollary 3, all the values of the optimal results decrease with the increase in the privacy concern cost under Scenario MN. From Corollaries 1 and 3, consumer privacy concerns hurt the supplier and the platform profits and the consumer surplus regardless of the sales modes.

Under Scenario MB, the supplier profit maximization model can be stated as follows:

$$\max_{1-p^{\mathrm{MB}}>0} \prod\nolimits_s^{\mathrm{MB}} = ((1-\mu)p^{\mathrm{MB}} - c_p)\int_{p^{\mathrm{MB}}}^{1} dv \tag{6}$$

where $1-p^{\mathrm{MB}}$ is the demand under Scenario MB.

From the second partial derivative of $\prod_s^{\mathrm{MB}}$ with respect to p^{MB}, i.e., $\frac{\partial^2 \prod_s^{\mathrm{MB}}}{\partial (p^{\mathrm{MB}})^2} = -2(1-\mu)$, $\prod_s^{\mathrm{MB}}$ is concave in p^{MB}, indicating that a unique optimal value for p^{MB} always exists. The optimal retail price is obtained according to the first-order condition of (6), and is presented in Lemma 4.

Lemma 4: The optimal retail price is $p^{\mathrm{MB}*} = \frac{1+c_p-\mu}{2(1-\mu)}$ under Scenario MB.

The optimal demand $D^{\mathrm{MB}*} = \frac{1-c_p-\mu}{2(1-\mu)}$, consumer surplus $CS^{\mathrm{MB}*} = \frac{(1-c_p-\mu)^2}{8(1-\mu)^2}$, and supplier profit $\prod_s^{\mathrm{MB}*} = \frac{(1-c_p-\mu)^2}{4(1-\mu)}$ are derived from the results in Lemma 4. The platform profit can be expressed as $\prod_p^{\mathrm{MB}} = (\mu p^{\mathrm{MB}} - c_e - c_b)\int_{p^{\mathrm{MB}}}^{1} dv$ under Scenario MB. Substituting $p^{\mathrm{MB}*}$ into the expression of $\prod_p^{\mathrm{MB}}$, the optimal platform profit $\prod_p^{\mathrm{MB}*} = \frac{(1-c_p-\mu)(c_p\mu-\mu^2+\mu+2c_b\mu+2c_e\mu-2c_b-2c_e)}{4(1-\mu)^2}$ is derived from the results in Lemma 4. To ensure the satisfaction of $1-p^{\mathrm{MB}} > 0$ and $p^{\mathrm{MB}} > 0$, the feasible region of the model in (6) is defined by $\mu < 1 - c_p$ for Scenario MB.

The effects of the operating cost c_b on the optimal results are presented in Corollary 4.

Corollary 4: The effects of the operating cost c_b on the optimal results are given by $\frac{\partial p^{\mathrm{MB}*}}{\partial c_b} = 0$, $\frac{\partial D^{\mathrm{MB}*}}{\partial c_b} = 0$, $\frac{\partial CS^{\mathrm{MB}*}}{\partial c_b} = 0$, $\frac{\partial \prod_s^{\mathrm{MB}*}}{\partial c_b} = 0$, and $\frac{\partial \prod_p^{\mathrm{MB}*}}{\partial c_b} < 0$ under Scenario MB.

Corollary 4 reveals that the platform profit decreases with the increase in the operating cost under Scenario MB. Under the market mode, the operating cost is undertaken by the platform and consequently does not affect the supplier decisions.

V. Analyses and Discussions

In this section, the effects of blockchain technology adoption on the optimal results are first analyzed. The platform and the supplier sales mode selections are then examined. The conditions for the platform and the supplier to achieve win–win outcomes are finally explored.

A. *Effects of Blockchain Technology Adoption on the Prices, Demand, and Consumer Surplus*

The effects of blockchain technology adoption on prices are obtained by comparing the retail and wholesale prices between Scenarios RN and RB, and the retail prices between Scenarios MN and MB, respectively. The results are presented in Proposition 1.

Proposition 1: The effects of blockchain technology adoption on the prices are 1) $p^{\mathrm{RB}*} > p^{\mathrm{RN}*}$ and $p^{\mathrm{MB}*} > p^{\mathrm{MN}*}$; and 2) $w^{\mathrm{RB}*} \le w^{\mathrm{RN}*}$ if $0 < b \le c_b$, and $w^{\mathrm{RB}*} > w^{\mathrm{RN}*}$ otherwise.

Proposition 1 implies that blockchain technology adoption results in higher retail prices under both sales modes, meaning that consumers need to pay for privacy protection, because either the supplier or the platform needs to raise the retail price to compensate for the loss caused by the operating cost. Montes et al. [46] also showed that it is necessary for consumers to pay for privacy protection. The wholesale price may be higher under Scenario RN than under Scenario RB. Blockchain technology adoption for privacy protection may not effectively affect consumers who are indifferent to privacy concerns. Consequently, the supplier may reduce the wholesale price to alleviate the double marginalization effect, and to incentivize the platform to adopt blockchain technology under the resale mode.

The effects of blockchain technology adoption on demand and consumer surplus are stated in Proposition 2.

Proposition 2: The effects of blockchain technology adoption on the consumer surplus and demand are 1) $D^{\mathrm{RB}*} \le D^{\mathrm{RN}*}$ and $CS^{\mathrm{RB}*} \le CS^{\mathrm{RN}*}$ if $b \le c_b$, and $D^{\mathrm{RB}*} > D^{\mathrm{RN}*}$ and $CS^{RB*} > CS^{RN*}$ otherwise, under the resale mode; and 2) $D^{\mathrm{MB}*} > D^{\mathrm{MN}*}$ and $CS^{\mathrm{MB}*} > CS^{\mathrm{MN}*}$ under the market mode.

Proposition 2 reveals that blockchain technology adoption can lead to higher demand and consumer surplus only when the privacy concern cost is high or the operating cost is low under the resale mode. Demand and consumer surplus are mainly influenced by the retail price and the privacy concern cost. Blockchain technology adoption enables supply chain members to raise the retail price, which increases with the increase in operating cost. However, the high retail price can reduce demand and consumer surplus. In addition, blockchain technology adoption can eliminate consumer privacy concerns, thereby increasing the demand and consumer surplus. Moreover, consumers can benefit more from blockchain technology adoption when they have higher privacy concerns. Because the impacts of the retail price on demand and consumer surplus are dominant, blockchain technology adoption leads to the reduction in demand and consumer surplus if the privacy concern cost is low or the operating cost is high. Blockchain technology adoption can benefit consumers, although the retail price increases, because the benefits brought to consumers by privacy protection are sufficient to compensate for the losses due to the higher retail price when the privacy concern cost is high or the operating cost is low. Interestingly, blockchain technology adoption always enhances both consumer surplus and demand under the market mode, possibly because of the elimination of the double marginalization effect by mitigating the adverse effects of the retail price. The above results are different from those in Lee et al. [44], which showed privacy protection always led to a lower consumer surplus.

B. *Effects of Blockchain Technology Adoption on the Profits*

The effects of blockchain technology adoption on the supply chain member profits under the resale mode are presented in Proposition 3.

Proposition 3: The effects of blockchain technology adoption on the optimal profits under the resale mode are $\prod_p^{\mathrm{RB}*} \le \prod_p^{\mathrm{RN}*}$ and $\prod_s^{\mathrm{RB}*} \le \prod_s^{\mathrm{RN}*}$ if $b \le c_b$, and $\prod_p^{\mathrm{RB}*} > \prod_p^{\mathrm{RN}*}$ and $\prod_s^{\mathrm{RB}*} > \prod_s^{\mathrm{RN}*}$ otherwise.

Proposition 3 shows that blockchain technology adoption is profitable for the platform and the supplier under the resale mode when the privacy concern cost is high or the operating cost is low because blockchain technology adoption can lead to increased retail price and demand under these conditions. Thus, the platform obtains sufficient revenue after adopting blockchain technology to cover the operating cost. The supplier profit increases as demand increases even if the wholesale price decreases. Hence, the supplier should set a thin margin when the platform adopts blockchain technology. Therefore, blockchain technology adoption can simultaneously benefit the supplier, the platform, and the consumers when consumer privacy concern cost is high.

The impacts of blockchain technology adoption on the platform and the supplier profits under the market mode are presented in Proposition 4.

Proposition 4: The effects of blockchain technology adoption on the optimal profits under the market mode are 1) $\prod_s^{\mathrm{MB}*} > \prod_s^{\mathrm{MN}*}$; and 2) $\prod_p^{\mathrm{MB}*} > \prod_p^{\mathrm{MN}*}$ if $c_b < c_{b_1}$, and $\prod_p^{\mathrm{MB}*} \leq \prod_p^{\mathrm{MN}*}$ otherwise.

Proposition 4 implies that blockchain technology adoption always benefits the supplier because the supplier directly sets a retail price under the market mode. The supplier can benefit from the higher profit margin and demand with than without blockchain technology adoption. However, the platform profit may not always increase with blockchain technology adoption because it needs to bear the operating cost. As a result, the platform may abandon the blockchain technology adoption to reduce financial burden when the barriers to blockchain technology adoption are high. Significantly, blockchain technology adoption can achieve an all-win outcome for the platform, the supplier, and consumers under the market mode, as shown in Propositions 2 and 4.

C. Sales Mode Selection

Either the platform or the supplier can decide the sales mode, depending on the e-commerce supply chain power structure.

1) The Platform Sales Mode Selection: In this subsection, the platform is assumed to determine the sales mode. The motivation for the platform to choose different sales modes is given by comparing the retail prices between Scenarios RB and MB, and the results are provided in Proposition 5.

Proposition 5: The retail prices have the relationship $p^{\mathrm{MB}*} \geq p^{\mathrm{RB}*}$ if $c_b \leq c_{b_2}$, and $p^{\mathrm{MB}*} < p^{\mathrm{RB}*}$ otherwise.

Proposition 5 indicates that the retail price is higher under Scenario MB than under Scenario RB if the operating cost is low, a result contrary to the double marginalization effect. The reasons are as follows. The platform adopting blockchain technology has a relatively low financial burden and can attract more consumers by setting a lower retail price if the operating cost is low under the resale mode. However, the platform needs to set a higher retail price to increase the marginal profit if the operating cost is high, resulting in a higher retail price under Scenario RB than under Scenario MB.

The platform sales mode selection results are presented in Proposition 6.

Proposition 6: The platform sales mode selection can be determined by comparing its profits between Scenarios RB and MB, i.e., $\prod_p^{\mathrm{RB}*} \geq \prod_p^{\mathrm{MB}*}$ if $0 < c_b \leq \max\{0, c_{b_3}\}$ or $\max\{0, c_{b_4}\} \leq c_b < 1 - c_p - c_e$, and $\prod_p^{\mathrm{RB}*} < \prod_p^{\mathrm{MB}*}$ otherwise, with blockchain technology adoption.

Proposition 6 reveals that the platform chooses the resale mode if the operating cost is sufficiently low or sufficiently high, and chooses the market mode otherwise. The platform can obtain the channel power to set the retail price by choosing the resale mode, and can eliminate the double marginalization effect by choosing the market mode. The platform financial burden is low when the operating cost is sufficiently low, i.e., $c_b \leq \max\{0, c_{b_3}\}$, so the platform can set a lower retail price under Scenario RB than under Scenario MB, meaning that the double marginalization effect under the resale mode is not severe. Thus, the platform prefers to gain channel power rather than to eliminate the double marginalization effect. With the increase in the operating cost, the double marginalization effect under the resale mode becomes more severe, leading the platform to choose the market mode when the operating cost becomes moderate, i.e., $\max\{0, c_{b_3}\} < c_b \leq \max\{0, c_{b_4}\}$. The platform chooses the resale mode if the operating cost is sufficiently high, i.e., $c_b > \max\{0, c_{b_4}\}$, because the platform prefers the use of the channel power to make up for the loss caused by the high operating cost despite the severe double marginalization effect.

2) The Supplier Sales Mode Selection: In this subsection, the supplier is assumed to determine the sales mode. The results of the supplier sales mode selection are presented in Proposition 7.

Proposition 7: The supplier sales mode selection can be determined by comparing its profits between Scenarios RB and MB, i.e., $\prod_s^{\mathrm{RB}*} \geq \prod_s^{\mathrm{MB}*}$ if $0 < c_b \leq \max\{0, c_{b_5}\}$, and $\prod_s^{\mathrm{RB}*} < \prod_s^{\mathrm{MB}*}$ otherwise, with blockchain technology adoption.

Proposition 7 indicates that the supplier chooses the resale mode only if the operating cost is low. The supplier can seize the first-mover advantage with the resale mode and benefit from the elimination of the double marginalization effect under the market mode. If the operating cost is not high, the double marginalization effect is low under the resale mode from Proposition 5 and, thus, the supplier chooses the resale mode to obtain the first-mover advantage. The retail price increases with the increase in the operating cost under the resale mode, leading to a severe double marginalization effect. Consequently, the supplier has to give up the first-mover advantage and choose the market mode to eliminate the double marginalization effect. Hence, the supplier can use the operating cost as an indicator to measure the double marginalization effect, and choose an appropriate sales mode according to the value of this indicator.

D. Conditions for the Supply Chain Members to Achieve Win–Win Outcomes

This subsection explores the conditions for the supply chain members to achieve win–win outcomes. From Propositions 6 and 7, the results in Proposition 8 can be obtained.

Proposition 8: The conditions for the supply chain members to achieve win–win outcomes can be determined by comparing their profits between different sales modes as follows.

1) $\prod_p^{\mathrm{RB}*} \geq \prod_p^{\mathrm{MB}*}$ and $\prod_s^{\mathrm{RB}*} > \prod_s^{\mathrm{MB}*}$ when $0 < c_b \leq \max\{0, c_{b_3}\}$.

2) $\prod_p^{\mathrm{RB}*} \leq \prod_p^{\mathrm{MB}*}$ and $\prod_s^{\mathrm{RB}*} \leq \prod_s^{\mathrm{MB}*}$ if $0 < \mu \leq \frac{7}{9}$ and $\max\{0, c_{b_5}\} \leq c_b \leq \max\{0, c_{b_4}\}$; and $\prod_p^{\mathrm{RB}*} \geq \prod_p^{\mathrm{MB}*}$ and $\prod_s^{\mathrm{RB}*} \geq \prod_s^{\mathrm{MB}*}$ if $\frac{7}{9} < \mu < 1 - c_p$ and $\max\{0, c_{b_4}\} \leq c_b \leq \max\{0, c_{b_5}\}$, when $c_p < \frac{2}{9}$.
3) $\prod_p^{\mathrm{RB}*} \leq \prod_p^{\mathrm{MB}*}$ and $\prod_s^{\mathrm{RB}*} \leq \prod_s^{\mathrm{MB}*}$ if $\max\{0, c_{b_5}\} \leq c_b \leq \max\{0, c_{b_4}\}$ when $c_p \geq \frac{2}{9}$.

Proposition 8 (1) indicates that the supply chain members can achieve a win–win outcome by choosing the resale mode when the operating cost is sufficiently low, i.e., $0 < c_b \leq \max\{0, c_{b_3}\}$, for any commission rate and any production cost. Under this condition, the retail price is lower under the resale mode than under the market mode, which benefits the platform and the supplier through the low double marginalization effect. Proposition 8 (2) indicates that, with the increase in the operating cost, the production cost and the commission rate become dominant factors affecting the sales mode selection. Specifically, the supply chain members can achieve a win–win outcome by choosing the market mode if the commission rate is not high, i.e., $0 < \mu \leq \frac{7}{9}$, and the operating cost is moderate, i.e., $\max\{0, c_{b_5}\} \leq c_b \leq \max\{0, c_{b_4}\}$. Moreover, they can achieve a win–win outcome by choosing the resale mode if the commission rate is high, i.e., $\frac{7}{9} < \mu < 1 - c_p$, and the operating cost is moderate, i.e., $\max\{0, c_{b_4}\} \leq c_b \leq \max\{0, c_{b_5}\}$, when the production cost is not high, i.e., $c_p < \frac{2}{9}$. Given a low commission rate, the supplier can improve the marginal profit, and the platform can mitigate the double marginalization effect, by choosing the market mode. With a high commission rate, the supplier tends to choose the resale mode, and the platform can compensate for the loss due to the high operating cost through the channel power under the resale mode. In addition, from Corollary 2, the retail price increases and the wholesale price decreases with the increase in the operating cost under the resale mode. Therefore, the double marginalization effect is not serious under the resale mode when the operating cost is not high, which is another advantage of choosing the resale mode. Proposition 8 (3) indicates that the supply chain members achieve a win–win outcome by choosing the market mode with a moderate operating cost, i.e., $\max\{0, c_{b_5}\} \leq c_b \leq \max\{0, c_{b_4}\}$, when the production cost is high, i.e., $c_p \geq \frac{2}{9}$. The supplier has a heavier financial burden with a higher production cost and is more inclined to exert the pricing power through the market mode, and the platform benefits from the mitigated double marginalization effect and the commission paid by the supplier under the market mode. Hence, when the supplier chooses the sales mode, the platform can obtain more profits or interfere with the supplier sales mode selection to achieve a win–win outcome by adjusting the commission rate if the production cost is low and the operating cost is moderate. For example, the platform should set a relatively high commission rate within a relatively low commission rate range, i.e., $0 < \mu \leq \frac{7}{9}$. Accordingly, the supplier chooses the market mode to achieve a win–win outcome, and the platform can gain a larger share of the supply chain profit. Furthermore, the platform can also set a sufficiently high commission rate, i.e., $\frac{7}{9} < \mu < 1 - c_p$, to push the supplier to choose the resale mode.

VI. Extensions

In this section, some assumptions in the basic models are relaxed and two extensions are provided. The first extension considers the case where blockchain technology adoption cannot completely eliminate consumer privacy concerns. The second extension considers the case where the platform first makes the retail price decision under the resale mode.

A. *Inability of Blockchain Technology Adoption to Eliminate Consumer Privacy Concerns*

In this subsection, the assumption that the consumer privacy concern cost $b = 0$ after blockchain technology adoption is relaxed to test the robustness of the above results. The scenarios under the resale and the market modes are denoted by NRB and NMB, respectively, with blockchain adoption. The superscript j for $j \in \{\mathrm{NRB}, \mathrm{NMB}\}$ is used in the notations to represent the corresponding scenarios. The consumer utility is $u^j = v - p^j - \beta b$, where β with $0 < \beta < 1$ represents the reduction rate of consumer privacy concern cost after blockchain technology adoption. Specifically, privacy protection using blockchain technology can enhance consumer trust and, therefore, the consumer privacy concern cost is reduced from b to βb after blockchain technology adoption. Consequently, the market demand is $D^i = \int_{p^i+\beta b}^1 dv$. The restrictions $c_b < 1 - c_p - c_e - \beta b$ and $\mu < 1 - c_p - \beta b + \mu\beta b$ are imposed to ensure positive profits.

Under Scenario NPB, the supply chain member profit maximization models can be stated as follows:

$$\max_{1-p^{\mathrm{NRB}}-\beta b} \prod\nolimits_s^{\mathrm{NRB}} = (w^{\mathrm{NRB}} - c_p) \int_{p^{\mathrm{NRB}}+\beta b}^1 dv \tag{7}$$

$$\max_{1-p^{\mathrm{NRB}}-\beta b} \prod\nolimits_p^{\mathrm{NRB}} = (p^{\mathrm{NRB}} - w^{\mathrm{NRB}} - c_e - c_b) \int_{p^{\mathrm{NRB}}+\beta b}^1 dv. \tag{8}$$

The optimal results of (7) and (8) are obtained using backward induction, as presented in Lemma 5.

Lemma 5: The optimal wholesale price is $w^{\mathrm{NRB}^*} = \frac{1+c_p-c_e-c_b-\beta b}{2}$ and the optimal retail price is $p^{\mathrm{NRB}^*} = \frac{3+c_e+c_b+c_p-3\beta b}{4}$ under Scenario NRB.

The optimal demand $D^{\mathrm{NRB}^*} = \frac{1-c_e-c_b-c_p-\beta b}{4}$, supplier profit $\prod_s^{\mathrm{NRB}^*} = \frac{(1-c_e-c_b-c_p-\beta b)^2}{8}$, and platform profit $\prod_p^{\mathrm{NRB}^*} = \frac{(1-c_e-c_b-c_p-\beta b)^2}{16}$ are derived from the results in Lemma 5.

Under Scenario NMB, the supplier profit maximization model can be stated as follows:

$$\max_{1-p^{\mathrm{NMB}}-\beta b} \prod\nolimits_s^{\mathrm{NMB}} = ((1-\mu)p^{\mathrm{NMB}} - c_p) \int_{p^{\mathrm{NMB}}+\beta b}^1 dv. \tag{9}$$

The optimal retail price of (9) is obtained and is presented in Lemma 6.

Lemma 6: The optimal retail price is $p^{\mathrm{NMB}^*} = \frac{(1-\mu)(1-\beta b)+c_p}{2(1-\mu)}$ under Scenario NMB.

From the result in Lemma 6, the optimal demand $D^{\mathrm{NMB}^*} = \frac{(1-\mu-c_p-\beta b+\mu\beta b)}{2(1-\mu)}$ and supplier profit $\prod_s^{\mathrm{NMB}^*} =$

$\frac{((1-\mu)(1-\beta b)-c_p)^2}{4(1-\mu)}$ are derived. The platform profit can be expressed as $\prod_p^{\text{NMB}} = (\mu p^{\text{NMB}} - c_e - c_b)\int_{p^{\text{NMB}}}^{1} dv$ under Scenario NMB. Substituting $p^{\text{NMB}*}$ into the expression of $\prod_p^{\text{NMB}}$, the optimal platform profit $\prod_p^{\text{NMB}^*} = \frac{((1-\mu)(1-\beta b)-c_p)(c_p\mu+\mu(1-\mu)(1-\beta b)+2c_b\mu+2c_e\mu-2c_b-2c_e)}{4(1-\mu)^2}$ is derived.

Proposition 9: The platform and the supplier sales mode selections with blockchain technology adoption when it cannot completely eliminate consumer privacy concerns are as follows.

1) $\prod_p^{\text{NRB}^*} \leq \prod_p^{\text{NMB}*}$ if $\max\{0, c_{b_6}\} \leq c_b \leq \max\{0, c_{b_7}\}$, and $\prod_p^{\text{NRB}*} > \prod_p^{\text{NMB}*}$ otherwise.
2) $\prod_s^{\text{NRB}*} \geq \prod_s^{\text{NMB}*}$ if $0 < c_b \leq \max\{0, c_{b_8}\}$, and $\prod_s^{\text{NRB}*} < \prod_s^{\text{NMB}*}$ otherwise.

Proposition 9 (1) shows that the platform can benefit from the market mode only when the operating cost is moderate. This result is consistent with that in Proposition 6. The reason behind this result is the tradeoff between the channel power and the double marginalization effect. Proposition 9 (2) indicates that the supplier optimal sales mode selection shifts from the resale mode to the market mode as the operating cost increases. This result verifies the robustness of the results in Proposition 7.

From Proposition 9, the conditions for the supply chain members to achieve win–win outcomes are determined, as presented in Proposition 10.

Proposition 10: The conditions for the supply chain members to achieve win–win outcomes when blockchain technology adoption cannot completely eliminate consumer privacy concerns are given as follows.

1) $\prod_p^{\text{NRB}*} \geq \prod_p^{\text{NMB}*}$ and $\prod_s^{\text{NRB}*} > \prod_s^{\text{NMB}*}$ when $0 < c_b \leq \max\{0, c_{b_6}\}$.
2) $\prod_p^{\text{NRB}*} \leq \prod_p^{\text{NMB}*}$ and $\prod_s^{\text{NRB}*} \leq \prod_s^{\text{NMB}*}$ if $0 < \mu \leq \frac{7}{9}$ and $\max\{0, c_{b_8}\} \leq c_b \leq \max\{0, c_{b_7}\}$; and $\prod_p^{\text{NRB}*} \geq \prod_p^{\text{NMB}*}$ and $\prod_s^{\text{NRB}*} \geq \prod_s^{\text{NMB}*}$ if $\frac{7}{9} < \mu < 1 - c_p - \beta b + \mu\beta b$ and $\max\{0, c_{b_7}\} \leq c_b \leq \max\{0, c_{b_8}\}$ when $c_p < \frac{2}{9} - \beta b + \mu\beta b$.
3) $\prod_p^{\text{NRB}*} \leq \prod_p^{\text{NMB}*}$ and $\prod_s^{\text{NRB}*} \leq \prod_s^{\text{NMB}*}$ if $\max\{0, c_{b_8}\} \leq c_b \leq \max\{0, c_{b_7}\}$ when $c_p \geq \frac{2}{9} - \beta b + \mu\beta b$.

Proposition 10 clarifies that the supply chain members achieve a win–win outcome by choosing the resale mode when the operating cost is sufficiently low, independent of the production cost and the commission rate. The supply chain members can benefit from the market (resale) mode when the production cost is low, the commission rate is low (high), and the operating cost is moderate, or can benefit from the market mode when the production cost is not low and the operating cost is moderate. These results verify the robustness of the results in Proposition 8.

B. The Platform First-Mover Retail Price Decision Under the Resale Mode

This subsection examines an extension where the platform first makes the retail price decision under the resale mode. Some large e-commerce platforms, such as Walmart, have dominant positions in the e-commerce supply chains and have priority in determining the retail price [69]. The scenario where the platform makes the retail price decision first under the resale mode is denoted by FRB to distinguish it from Scenario RB. As in Tao et al. [69] and Giri et al. [70], the platform markup for each product is assumed to be r with $r = p^{\text{FRB}} - w^{\text{FRB}}$, where p^{FRB} and w^{FRB} are the retail and the wholesale prices, respectively, under this scenario. To ensure positive profits and to avoid trivial results, the restriction $c_b < 1 - c_p - c_e$ is imposed.

Under Scenario FRB, the supplier and the platform profit maximization models can be expressed as follows:

$$\max_{1-w^{\text{FRB}}-r} \prod\nolimits_s^{\text{FRB}}(w^{\text{FRB}}) = (w^{\text{FRB}} - c_p)\int_{w^{\text{FRB}}+r}^{1} dv \quad (10)$$

$$\max_{1-w^{\text{FRB}}-r} \prod\nolimits_p^{\text{FRB}}(r) = (r - c_e - c_b)\int_{w^{\text{FRB}}+r}^{1} dv. \quad (11)$$

The optimal results for (10) and (11) are obtained using backward induction, as presented in Lemma 7.

Lemma 7: The optimal markup of the platform is $r^* = \frac{c_e+c_b-c_p+1}{2}$ and the optimal wholesale price is $w^{\text{FRB}*} = \frac{3c_p-c_e-c_b+1}{4}$ under Scenario FRB.

From the results in Lemma 7, the optimal retail price $p^{\text{FRB}*} = \frac{c_p+c_e+c_b+3}{4}$, demand $D^{\text{FRB}*} = \frac{1-c_p-c_e-c_b}{4}$, consumer surplus $CS^{\text{FRB}*} = \frac{(1-c_p-c_e-c_b)^2}{32}$, supplier profit $\prod_s^{\text{FRB}*} = \frac{(1-c_p-c_e-c_b)^2}{16}$, and platform profit $\prod_p^{\text{FRB}*} = \frac{(1-c_p-c_e-c_b)^2}{8}$ are obtained. The platform and supplier sales mode selections are examined, with results presented in Proposition 11.

Proposition 11: The platform and supplier sales mode selections with blockchain technology adoption when the platform first decides the retail price are as follows.

1) $\prod_p^{\text{FRB}*} \leq \prod_p^{\text{MB}*}$ if $\max\{0, c_{b_9}\} \leq c_b \leq \max\{0, c_{b_{10}}\}$, and $\prod_p^{\text{FRB}*} > \prod_p^{\text{MB}*}$ otherwise.
2) $\prod_s^{\text{FRB}*} \geq \prod_s^{\text{MB}*}$ if $0 < c_b \leq \max\{0, c_{b_{11}}\}$, and $\prod_s^{\text{FRB}*} < \prod_s^{\text{MB}*}$ otherwise.

Proposition 11 (1) shows that the platform chooses the market mode if the operating cost is moderate, and chooses the resale mode otherwise, when it decides the retail price first. Therefore, the robustness of Proposition 6 is verified. Proposition 11 (2) indicates that the supplier chooses the resale mode if the operating cost is low and chooses the market mode otherwise if the platform decides the retail price first.

The impacts of the platform first-mover retail price decision on the platform and the supplier sales mode selections can be obtained by comparing the threshold values between $c_{b_4} - c_{b_3}$ and $c_{b_{10}} - c_{b_9}$, and the threshold values between $c_{b_{11}}$ and c_{b_5}. The comparison results are presented in Corollary 5.

Corollary 5: The platform and the supplier preferences in the sales mode selection are $c_{b_4} - c_{b_3} > c_{b_{10}} - c_{b_9}$ and $c_{b_5} > c_{b_{11}}$.

Corollary 5 implies that the platform prefers the resale mode when it decides the retail price first, which is intuitive because the platform has the pricing power and the first-mover advantage. Therefore, the platform can benefit more by choosing the resale than the market mode. Corollary 5 also shows that the supplier

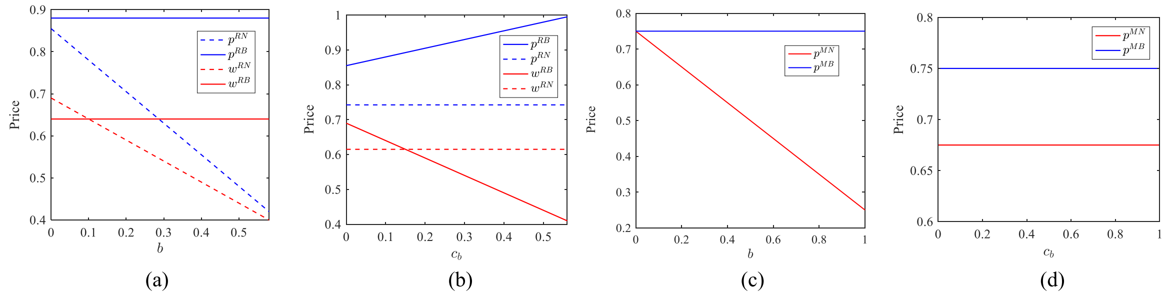

Fig. 1. Comparisons of the prices, (a) when b changes under the resale mode, (b) when c_b changes under the resale mode, (c) when b changes under the market mode, and (d) when c_b changes under the market mode.

prefers the market mode when the platform decides the retail price first because the supplier loses the first-mover advantage under the resale mode.

Proposition 12: The conditions for the supply chain members to achieve win–win outcomes when the platform decides the retail price first under the resale mode are given as follows.

1) $\prod_p^{\mathrm{FRB}*} \geq \prod_p^{\mathrm{MB}*}$ and $\prod_s^{\mathrm{FRB}*} > \prod_s^{\mathrm{MB}*}$ if $0 < c_b \leq \max\{0, c_{b_9}\}$.
2) $\prod_p^{\mathrm{FRB}*} \leq \prod_p^{\mathrm{MB}*}$ and $\prod_s^{\mathrm{FRB}*} \leq \prod_s^{\mathrm{MB}*}$ if $0 < \mu \leq \frac{8}{9}$ and $\max\{0, c_{b_{11}}\} \leq c_b \leq \max\{0, c_{b_{10}}\}$; and $\prod_p^{\mathrm{FRB}*} \geq \prod_p^{\mathrm{MB}*}$ and $\prod_s^{\mathrm{FRB}*} \geq \prod_s^{\mathrm{MB}*}$ if $\frac{8}{9} < \mu < 1 - c_p$ and $\max\{0, c_{b_{10}}\} \leq c_b \leq \max\{0, c_{b_{11}}\}$, when $c_p < \frac{1}{9}$.
3) $\prod_p^{\mathrm{FRB}*} \leq \prod_p^{\mathrm{MB}*}$ and $\prod_s^{\mathrm{FRB}*} \leq \prod_s^{\mathrm{MB}*}$ if $\max\{0, c_{b_{11}}\} \leq c_b \leq \max\{0, c_{b_{10}}\}$ when $c_p \geq \frac{1}{9}$.

The supply chain members achieve a win–win outcome when the operating cost is sufficiently low, i.e., $0 < c_b \leq \max\{0, c_{b_9}\}$, for any commission rate and production cost. The supply chain members achieve a win–win outcome by choosing the market mode if the commission rate is low, i.e., $0 < \mu \leq \frac{8}{9}$, and the operating cost is moderate, i.e., $\max\{0, c_{b_{11}}\} \leq c_b \leq \max\{0, c_{b_{10}}\}$, and by choosing the resale mode if the commission rate is high, i.e., $\frac{8}{9} < \mu < 1 - c_p$, and the operating cost is moderate, i.e., $\max\{0, c_{b_{10}}\} \leq c_b \leq \max\{0, c_{b_{11}}\}$, when the production cost is not high, i.e., $c_p < \frac{1}{9}$. The supply chain members achieve a win–win outcome by choosing the market mode if the operating cost is moderate, i.e., $\max\{0, c_{b_{11}}\} \leq c_b \leq \max\{0, c_{b_{10}}\}$, and the production cost is high, i.e., $c_p \geq \frac{1}{9}$. Apparently, the results in Proposition 12 verify the robustness of Proposition 8.

VII. Numerical Experiments and Managerial Implications

In this section, the theoretical results are verified through numerical experiments and managerial implications are provided for e-commerce supply chain members. The values of the main parameters are set to $c_p = 0.4$, $c_b = 0.1$, $c_e = 0.02$, $b = 0.15$, and $\mu = 0.2$ for the numerical experiments. These values satisfy the assumptions and constraints given in Sections III, IV, and V.

The prices, consumer surpluses, and supply chain member profits are compared between without and with blockchain technology adoption as the consumer privacy concern cost b and the operating cost c_b change. The results for the resale mode and the market mode are depicted in Figs. 1, 2, and 3, respectively. Results in Figs. 1, 2, and 3 illustrate that blockchain technology adoption may harm the consumer surplus and the supply chain member profits, although it protects consumer privacy. These results are similar to those of some previous articles [19], [20], [33], although these previous articles did not focus on privacy protection using blockchain technology. For example, Choi and Ouyang [61] found that both the supply chain member profits and consumer surplus decrease if the operating cost is high. Hence, a managerial implication is that the platform should consider the consumer privacy concern cost as a key factor when making the consumer privacy protection decisions. Previous articles also elucidated the impacts of consumer privacy protection on operational decisions [7], [9], [12]. The platform can measure the consumer privacy concern cost by investigating the risk of privacy leakage and the consumer understanding about privacy protection. Another managerial implication is that the platform should adopt blockchain technology and set a higher retail price with than without blockchain technology adoption if the consumer privacy concern cost is not high. Moreover, the platform should adjust the retail price according to the operating cost, and the supplier should reduce the wholesale price under the resale mode to indirectly share the operating cost.

The platform and supplier sales mode section results are depicted in Fig. 4 as the operating cost c_b and the commission rate μ change. Results in Fig. 4 show that the platform and the supplier should fully evaluate the operating cost and then choose the appropriate sales mode, regardless of who makes the sales mode selection decision. This finding enriches the literature for sales mode selection because previous articles did not consider the impact of the operating cost on sales mode selection [39], [40]. A managerial implication is that a supply chain member sales mode selection, when having an absolute dominant position, may harm the profit of the other member, which hinders the e-commerce supply chain long-term development.

The conditions are depicted in Fig. 5 for the platform and the supplier win–win outcomes when c_b and μ change for a high and a low supplier unit production cost at $c_p = 0.4$ and $c_p = 0.1$, respectively. The labels $\mathrm{RB} - \mathrm{MB}$, $\mathrm{MB} - \mathrm{RB}$, $\mathrm{RB} - \mathrm{RB}$, and $\mathrm{MB} - \mathrm{MB}$ in Fig. 5 represent the scenario preferences, from which the platform and the supplier can benefit when adopting blockchain technology. For example, $\mathrm{RB} - \mathrm{MB}$ indicates that the platform benefits from the resale mode and the supplier benefits from the market mode with blockchain

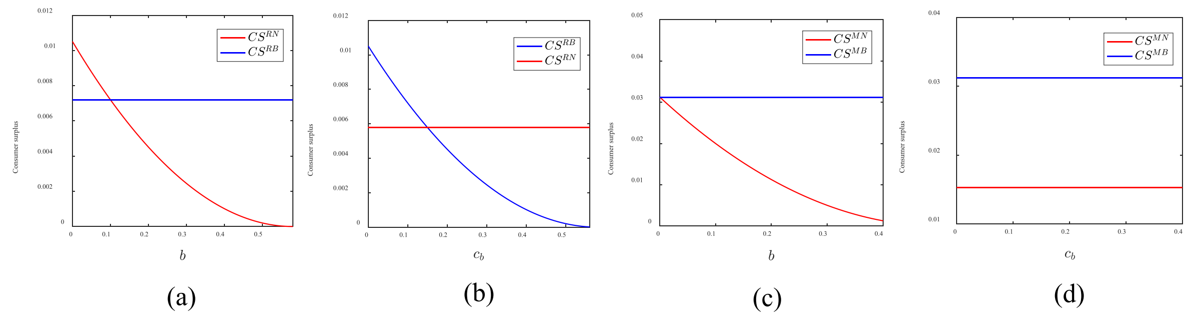

Fig. 2. Comparisons of the consumer surpluses, (a) when b changes under the resale mode, (b) when c_b changes under the resale mode, (c) when b changes under the market mode, and (d) when c_b changes under the market mode.

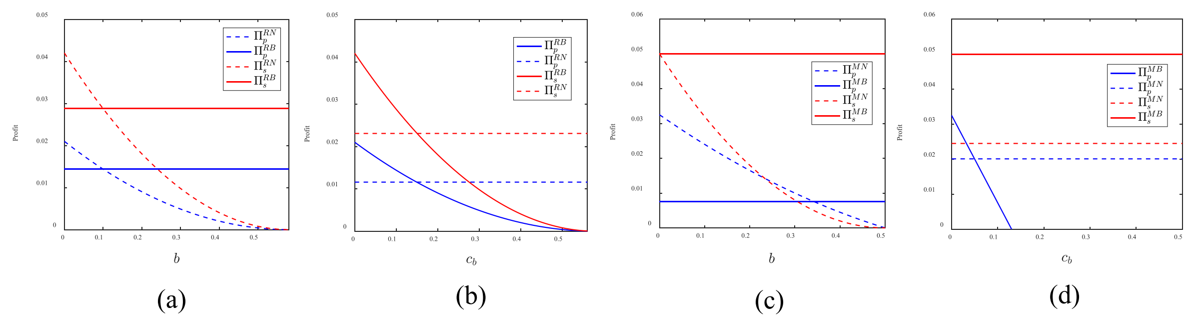

Fig. 3. Comparison of the profits, (a) when b changes under the resale mode, (b) when c_b changes under the resale mode, (c) when b changes under the market mode, and (d) when c_b changes under the market mode.

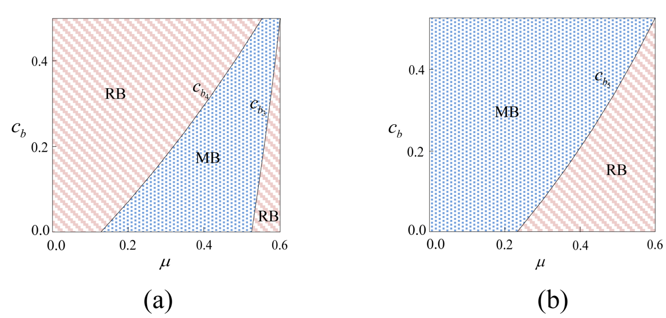

Fig. 4. Platform and the supplier sales mode selections (a) the platform and (b) the supplier.

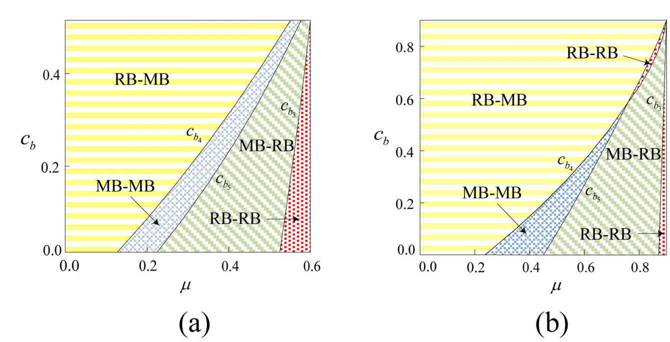

Fig. 5. Win–win sales modes for the platform and the supplier, (a) High c_p level ($c_p = 0.4$) and (b) Low c_p level ($c_p = 0.1$).

technology adoption. The supplier and the platform can keep long-term cooperation by selecting the appropriate sales mode, thus achieving a win–win outcome, as shown in Fig. 5. Previous articles, such as Ha et al. [2] and Chen et al. [37], did not focus on consumer privacy protection using blockchain technology although they explored the win–win sales modes. Operating cost is a key factor that supply chain members should consider when using blockchain technology to protect consumer privacy. A managerial implication is that, when the production cost is low and the operating cost is moderate, the platform can gain more profits or can interfere with the supplier sales mode selection by adjusting the commission rate, thereby achieving a win–win outcome. When the platform chooses a sales mode, the supplier should disclose the production cost information to the platform, which helps the platform choose an appropriate sales mode to achieve a win–win outcome.

VIII. Conclusion

This article examines the sales mode selection of an e-commerce supply chain consisting of a platform and a supplier when blockchain technology is applied to protect consumer privacy. Two sales, i.e., the resale and the market, modes usually used in practice are examined. Under each sales mode, two scenarios, i.e., without (basic scenario) and with blockchain technology adoption, are considered. Under each scenario, Stackelberg game models are set up for the supply chain members, and backward induction is used to obtain the equilibrium solutions. The effects of blockchain technology adoption on the optimal results are examined and the optimal sales mode selection is analyzed. Moreover, the conditions for the supply chain members to achieve win–win outcomes are determined. Two extensions are studied, where blockchain technology adoption cannot completely eliminate consumer privacy concerns in one extension, and the platform decides the retail price first under the resale mode in the other.

A. Conclusion

The main findings are summarized as follows.

1) The operating cost strongly affects the supplier and the platform sales mode selection decisions. The platform should choose the resale mode if the operating cost is sufficiently low or sufficiently high, and should choose the market mode if the operating cost is moderate, when it makes sales mode selection decisions. The supplier should choose the resale mode if the operating cost is low, and should choose the market mode otherwise, when it makes the sales mode selection decisions.
2) The supply chain members achieve win–win outcomes by choosing the resale mode when the operating cost is sufficiently low, or when the production cost is low, the commission rate is high and the operating cost is moderate; and by choosing the market mode when the production cost and the commission rate are low and the operating cost is moderate, or when the production cost is high and the operating cost is moderate.
3) Under each sales mode, the platform should raise the retail price if blockchain technology is applied to protect consumer privacy in the e-commerce supply chain. Particularly, under the resale mode, blockchain technology adoption leads to an increase in the wholesale price only if the consumer privacy concern cost is not low or the operating cost is low. However, the supplier reduces the wholesale price as the operating cost increases. Moreover, blockchain technology adoption may harm the consumer surplus and damage the platform profit. Furthermore, the platform, the supplier, and the consumers can achieve all-win outcomes with blockchain technology adoption only if consumer privacy concern cost is high or the operating cost is low. In addition, the consumer privacy concern cost negatively affects prices, demand, consumer surplus, and supplier and platform profits. The operating cost positively affects the retail price and negatively affects the wholesale price, demand, consumer surplus, and supplier and platform profits.
4) The sales mode selections in the e-commerce supply chain are still related to the operating cost when the blockchain technology adoption cannot completely eliminate but can reduce consumer privacy concerns, or when the platform first decides the retail price under the resale mode. In addition, the supplier and the platform can still reach an agreement on the sales mode selections with the relaxation of some assumptions, which validates the robustness of the basic models.

B. Future Research

Future article can continue from this article. First, it is common for a supplier to cooperate with multiple competing platforms, or for multiple suppliers to sell the same type of products with the same platform. Therefore, it could be of interest to examine the sales mode selections of e-commerce supply chains adopting blockchain technology in a competitive environment. Second, suppliers in reality may have both online and offline sale channels. Therefore, it is interesting to consider blockchain technology adoption in a dual-channel environment. Third, future article should focus on the blockchain technology adoption to improve the supply chain sustainability. For example, blockchain technology can be used to track or verify the origin of carbon-neutral and renewable energy sources, ensuring the transparency and nontamperability of enterprise sustainability measures. Fourth, it is interesting to explore the blockchain-enabled digital smart contracts in supply chains. Specifically, smart contracts can be used to ensure the supply chain digital transformation compliance, which requires verification of the compliance feasibility and effectiveness.

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