Blockchain Adoption in Retail Operations: Stablecoins and Traceability[⋆]

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Abstract

Retailers are embracing cryptocurrency payments to gain a competitive edge. However, the fierce volatility of traditional cryptocurrencies like Bitcoin deters risk-averse consumers from using them regularly. This issue is particularly pronounced in retail markets with high product return rates, as consumers may bear the volatility risk by directly holding cryptocurrencies after claiming a refund. In real-world operations, collateralized stablecoins are proposed as a solution for transaction settlements, yet they still exhibit short-term volatility, as shown by empirical evidence. In this context, retailers can reduce the likelihood of returns by leveraging blockchain traceability to disclose information. This study analytically investigates how the retailer effectively utilizes the two blockchain functions to enhance firm profitability and increase consumer surplus. Our analysis shows that the retailer may offer a stingy or generous refund policy with blockchain adoption, depending on the degrees of information disclosure and price volatility. Next, we find that blockchain adoption always benefits consumers, though it may decrease social welfare. Interestingly, the benefit brought by blockchain to consumers declines if information is oversupplied. Further, we discover that blockchain adoption is likely to increase retailer profit when the information disclosure level is polarized (i.e., very high or low). Finally, the analysis reveals that higher stability of stablecoins benefits the retailer but hurts consumers. The reason for this seemingly counterintuitive result is that having stablecoins with high stability allows the retailer to charge a high price.

Keywords: Supply chain management, blockchain, stablecoins, retailing, product returns

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1. Introduction

The processing fees associated with credit card payments are often unignorable, prompting retailers to pass on the cost to consumers through surcharges or increased prices in practice.[1] Besides high processing fees, credit card payments have other drawbacks, such as limited card network coverage, slow processing speed, and data breach, which are particularly evident in online

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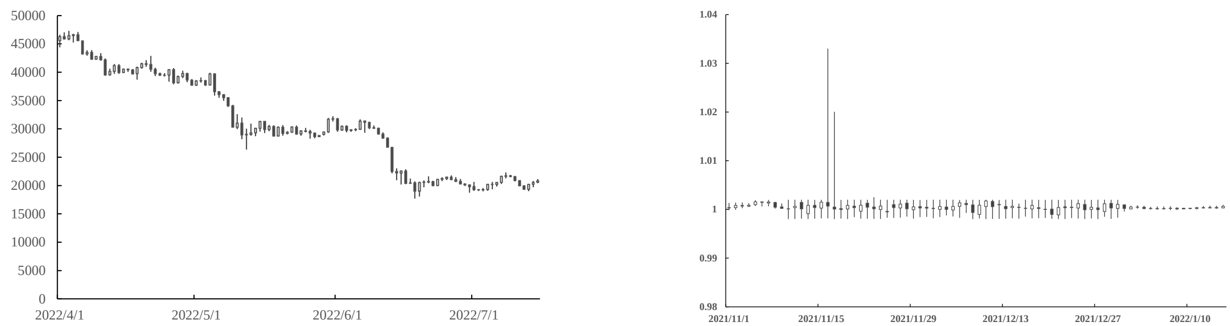
[1]See https://www.cnbc.com/2023/02/09/small-businesses-credit-card-swipe-fees.html.

retailing. By contrast, cryptocurrencies underpinned by blockchain have great potential to mitigate payment frictions. The decentralized and peer-to-peer nature of cryptocurrencies makes them low-cost, borderless, instant, and safe payment media (Tambe and Jain 2023). It is not rare for retailers to accept cryptocurrencies, such as the furniture closeout seller Overstock, the fashion luxury retail platform Farfetch, and the electronics retailer Newegg.

Figure 1: The open-high-low-close patterns of Bitcoin and Tether



(a) Bitcoin (b) Thether

Nonetheless, consumers are hesitant to make cryptocurrency payments. Such a dilemma is prevalent and understandable. Consumers are typically uninformed of the true product valuations in advance. Thus, after the true valuations are realized, consumers may claim a refund which is usually returned to the consumer in the form of the originally-paid cryptocurrency as in the current practice of many retailers (e.g., Overstock and Farfetch). However, it is well-known that many traditional cryptocurrencies (like Bitcoin) demonstrate drastic price volatility. For example, from 4 April to 4 July 2022, the price of Bitcoin fell by about 56% (see Figure 1(a)). Thus, by holding cryptocurrencies, consumers will be faced with high price volatility risks, which hinders their engagement in cryptocurrency payments.

Applying stablecoins (e.g., Tether and USD Coin) is a promising solution to increase consumers' interest in paying by cryptocurrencies (Maggio and Platias 2020, Baucherel 2020). The price stability of stablecoins is backed by real assets. For example, both Tether and USD Coin claim to be 100% backed by cash or cash equivalents.[2] Thus, the stable price of stablecoins can greatly enhance consumers' willingness to hold cryptocurrencies. However, it should be noted that even though the price of stablecoins is designed to be pegged to fiat currencies, we still observe that it is volatile in the short term, as shown in Figure 1(b). Furthermore, in moments of price instability (even if it appears to be temporary with hindsight), holders of specific stablecoins may overestimate the associated risk and rush for redemptions (Capoot 2023). This observation underscores consumers' lingering

[2]Algorithmic stablecoins, such as TerraUSD, are not stable because they are not backed by any real asset.

apprehensions regarding the price volatility of cryptocurrency payments, even when stablecoins are utilized. As a result, whether cryptocurrency payments can truly improve retailers' profitability is worth comprehensive examination.

On the other hand, the traceability offered by blockchain can also help mitigate consumers' concerns about cryptocurrency payments. The information provided by blockchain is considered trustworthy as the data is stored in a decentralized, transparent, and immutable way with the support of a well-designed consensus algorithm (Babich and Hilary 2020, Centobelli et al. 2021). Therefore, retailers can furnish rich information to blockchain, enabling consumers to ex-ante evaluate products and reduce the likelihood of returns (Wang et al. 2021). By doing so, consumers' concerns against the price volatility of cryptocurrencies can also be alleviated.

Recognizing the advantages of the two distinguished functions of blockchain mentioned above, some retailers have started to enjoy the integrated benefits of cryptocurrency (especially stablecoins) payments and blockchain traceability in enhancing online retail operations. One example is Caffè Barbera, a well-established coffee roastery founded in Italy that accepts leading stablecoins and allows consumers to access tamper-proof information (e.g., bean journey, production lot numbers, and quality certificates) provided by blockchain.[3] Besides, BitDial (a marketplace that trades luxury watches and jewelry) utilizes blockchain to track transactions and provide authenticity for customers. BitDial also allows customers to use multiple cryptocurrencies to pay for products.[4] In 2022, Gucci announced that it accepted five stablecoins in some U.S. stores and planned to roll out cryptocurrency acceptance to the whole of North America. Moreover, blockchain traceability is about to be provided for Gucci Eyewear through the project "V.I.R.T.U.S." with Kering Eyewear.[5] Some real-world blockchain application examples are shown in Table 1.

Table 1: Real-world blockchain practice

Firms	Cryptocurrency Payment	Blockchain Traceability
Overstock, Farfetch, Philipp Plein, Newegg, etc.	√	
Nestlé, Carrefour, Walmart, LVMH Group, De Beers, etc.		√
Caffè Barbera, Gucci, BitDial, Hublot, etc.	√	√

Despite the emerging real-world applications of blockchain in terms of cryptocurrency payments and traceability, how they affect retail operations where consumer returns are prevalent is still unknown. Intuitively, from the perspective of retailers, the benefits brought by cryptocurrency payments can be easily offset by the price volatility of cryptocurrency. As consumers' concern

[3]See `https://caffebarbera.com/en/notizie/caffe-barbera-partnership-algorand/` and `https://www.cafebarbera.com/the-innovation-process-of-caffe-barbera-continue-thanks-to-blockchain/`.

[4]See `https://jeangalea.com/bitdials-review/`.

[5]See`https://keringeyewear.com/newsroom/news/16065`.

against price volatility arises when product returns occur, retailers may adopt blockchain traceability to allow consumers to make informed purchases. However, blockchain traceability may cause low-valuation consumers to leave the market directly, so that the retailer cannot earn the profit by charging restocking fees on them. Taken together, it is unclear how blockchain adoption affects the retailer's pricing and return strategies as well as social welfare. Specifically, we are interested to explore the following questions:

(i) In the blockchain solution integrating cryptocurrency payments (especially stablecoins) and blockchain traceability simultaneously, what is the retailer's optimal pricing and refund strategy?

(ii) Under what conditions will the retailer adopt the blockchain solution? Does blockchain adoption possibly create a win-win result for the retailer and consumers?

(iii) Will it benefit consumers if cryptocurrencies are sufficiently stable? Will consumers always benefit from a higher level of information disclosure?

To answer the above questions, we develop an analytical model where a monopolistic retailer first determines whether to adopt blockchain and then decides the price and refund to maximize the expected profit. Product valuations are a prior unknown to consumers. When blockchain is absent, transactions are processed by traditional payment methods (e.g., credit cards), and consumers are aware of their true valuations only after the purchase is made. When blockchain is adopted, the retailer accepts stablecoins and enables traceability. Consumers who can utilize the technology to ex-ante examine their true valuations are referred to as searchers. The remaining consumers are nonsearchers who cannot or fail to discover desirable information (e.g., due to a lack of technology-savviness). Therefore, nonsearchers may claim a refund ex-post. Note that the refund will be discounted as consumers are risk-averse against the short-term volatility of stablecoins.

The contribution of this paper is highlighted by the following findings. First, the retailer provides a generous refund when the information disclosure level (the likelihood of consumers resolving valuation uncertainty with blockchain information) is high and the volatility discount is relatively low (implying a high degree of price volatility of stablecoins or a high degree of risk aversion of consumers). However, if the information disclosure level is low, the retailer provides a stingy refund. Interestingly, different from the findings in Su (2009) and Nageswaran et al. (2020), we find that the optimal refund can be lower than the salvage value of the product. Second, a higher volatility discount increases the retailer's profit but decreases the total consumer surplus. This result implies that a high degree of stability of stablecoins benefits the retailer but hurts consumers. Third, if the retailer has poor salvage capacities, it is necessary to increase the likelihood of consumers identifying their true valuations, e.g., by providing easier-to-use technology. Finally, although blockchain adoption improves consumer surplus, disclosing more information may undermine this benefit.

The rest of the paper proceeds as follows. After reviewing the related literature in Section 2, we formalize the main model in Section 3. Model comparisons are conducted in Section 4. In Section 5, we relax some key assumptions to demonstrate the robustness of main findings or provide further insights. Technical proofs are placed in Appendix and some details are relegated to the online supplementary materials.

2. Literature Review

2.1. Blockchain adoption in operations and supply chain management

Literature is increasingly investigating the strategic role of blockchain adoption in marketing and supply chain management fields such as supply chain financing (Chod et al. 2020, Wang et al. 2023), defective product tracking and recalls (Dong et al. 2023, Dai et al. 2021), counterfeits and copycats detection (Pun et al. 2021, Shen et al. 2022, Naoum-Sawaya et al. 2023), gray supply chain operations Zhang et al. (2023), virtual goods resale (Tan 2022), on-demand service platform operations (Choi et al. 2020, Sun et al. 2023), and sustainable operations (Xu et al. 2023, Biswas et al. 2023). The above studies deliver insightful results regarding blockchain application from the information flow perspective. Our study additionally gains insights from the financial flow by incorporating cryptocurrency payments.

Related literature has revealed several frictions of traditional cryptocurrencies (such as Bitcoin). Wei and Dukes (2021) show that price bubbles of cryptocurrencies, generated by speculative behaviors, increase adoption rates of cryptocurrencies. This network externality attracts more users who adopt cryptocurrencies purely as the medium of exchange, which in turn boosts investors' confidence in sustaining the bubble. However, the price bubble may unravel when the number of users in the market is rationally perceived to reduce in the future. Our study focuses on stablecoins such that speculative investments can be well deterred (Smith 2023). Malik et al. (2022) predict that Bitcoin payments cannot be economically scaled by increasing block capacity because large miners in the Bitcoin market collusively add partially filled blocks to combat block capacity increase. However, many stablecoins have been hosted on blockchains that rely on highly efficient consensus mechanisms (e.g., proof of stake).

2.2. Product information disclosure strategy

The traceability function of blockchain we studied is essentially a special product disclosure strategy. Therefore, we review the related literature on product information disclosure. Anderson and Renault (2009) show that a firm offering a low-quality product has a stronger incentive to disclose the match value of their rivals' product (if permissible) than a firm offering a high-quality product. Sun (2011) finds that a monopolist prefers nondisclosure of the horizontal attribute when the vertical attribute is known to be high. Interestingly, when the vertical attribute is unknown, the monopolist has opposite motivations for disclosing the vertical and horizontal attributes. Gu and Xie (2013) analyze fit revelation policies for competitive firms selling to consumers who have homogeneous preferences for the product value. They confirm that a firm selling a high-quality product is more likely to facilitate the disclosure compared to that selling a low-quality product. Subsequent studies explore the impact of the fit and/or quality disclosure strategy on participants under distribution channel settings (Zhao et al. 2018, Hao and Tan 2019, Sun and Tyagi 2020). In contrast to this body of work that is indifferent to any specific form of information disclosure, our work examines several unique characteristics of blockchain adoption. First, we distinguish between the different roles of blockchain traceability in disclosing uncertainty about product valuations and uncertainty about product matches. Second, blockchain traceability can improve retailers' salvage capabilities (helps retailers prevent return frauds through blockchain information traceability). In addition, the blockchain solution in our study considers the role of cryptocurrency payments. In this context, it is unclear how blockchain affects retailer profit and consumer surplus.

2.3. Consumer returns

Consumer returns are the key factor that inspires this study. Much of the literature on consumer returns treats the return rate to be exogenous or assumes a full refund strategy (e.g., Gu and Tayi 2017, Zhang et al. 2018, Mandal et al. 2021, Zhang and Choi 2021). Su (2009) considers a firm selling to consumers who face ex-ante valuation uncertainty and decide to keep or return the product after the valuation is realized. They find that a monopolistic retailer optimally sets a partial refund equal to the salvage value. The optimal return strategy generates maximum social welfare, whereas the seller maximally extracts consumer surplus. We benchmark our study against this work and make comparisons with a model that allows consumers to ex-ante evaluate products with blockchain information. More recently, Nageswaran et al. (2020) study the optimal return strategy under omnichannel settings where consumers can evaluate a product by either inspecting it in the store before purchase or an actual trial. The effect of inspecting the product in the store is somewhat similar to the effect of providing blockchain information, but has important differences. First, allowing consumers to inspect the product offline does not affect the utility of the online consumer base, whereas blockchain adoption in our study incurs price volatility risks for customers. Second, store inspections are practical in a local market, whereas blockchain solutions can be applied in cross-region and cross-border trade. Third, product uncertainty is perfectly resolved by an in-store inspection in Nageswaran et al. (2020); however, we note that uncertainty of some product attributes (e.g., product matches) is unlikely to be addressed by blockchain traceability.

Several papers incorporate other dimensions into retailers' return strategies, e.g., retailer competition (Shulman et al. 2011), return deadline (Xu et al. 2015), consumers' strategic behaviors (Altug and Aydinliyim 2016, Shang et al. 2017), recycling channel operations (Feng et al. 2017), and advanced selling operations (Wu et al. 2019). This paper complements consumer return studies by comprehensively examining cryptocurrency payments and traceability enabled by blockchain. Intuitively, cryptocurrency payments reinforce consumers' concerns about returns, while blockchain traceability reduces the likelihood of returns. This paper provides insights into how retailers can combine the two blockchain functions to improve firm profitability and consumer welfare.

3. The Model

We consider a market where a monopolist retailer (she) sells a product to a unit mass of consumers (he). The production cost of the good is c. The retailer makes two sequential decisions to maximize her expected profit.

In the first stage, the retailer decides whether to sell the product with blockchain adoption. Without blockchain adoption, consumers pay with credit cards. For a successful transaction (i.e., the product is purchased and kept by a consumer), the retailer incurs a processing fee f charged by credit card service providers (e.g., card issuers, card networks, and payment processors). If the product is returned, the retailer obtains a salvage value $s_1 > 0$ after disposing of the product.

Two functions of blockchain are comprehensively examined in this study to capture the uniqueness of blockchain technology. First, with blockchain adoption, transactions are settled by cryptocurrencies (e.g., BitDial marketplace). Note that in Section 5.1, we study a more flexible payment system provided by the retailer. Our study focuses on one promising category of cryptocurrencies known as stablecoins since other traditional cryptocurrencies, like Bitcoin, are not used for payments due to the extreme price volatility. Although stablecoins are considered stable in the long term, empirical evidence shows that stablecoins still face short-term volatility (Grobys et al. 2021, Hoang and Baur 2021). We assume that consumers are risk-averse to the short-term price volatility. Differently, the retailer is assumed to be insensitive to price volatility because retailers usually take a "hands-off" approach that avoids actually holding cryptocurrencies by cooperating with third-party service providers.[6] In Section 5.3, we investigate the "hands-on" approach and consider the retailer's risk aversion to price volatility. Second, blockchain traceability helps the retailer prevent potential return frauds in reverse logistics.[7] We thus assume that the salvage value of the product with blockchain adoption s_2 is higher than s_1 ($s_2 > s_1$) to capture the benefit. Notably, blockchain traceability makes consumers informed when making purchasing decisions. We assume that the cost of providing traceability is zero to isolate the effect of operational costs. The effect of operational costs of blockchain is well-studied in the related literature (Cho et al. 2021, Cai et al. 2021, Pun et al. 2021). In the second stage, the retailer decides the price $p \geq 0$ and refund $r \geq 0$ (the restocking fee is thus $p - r$). In Section 5.2, the full refund strategy is also investigated. Following many real-world practices (e.g., Overstock and Farfetch), the refund is sent back to the consumer through the original payment method (i.e., stablecoins).

Each consumer demands at most one unit of product, which is a common assumption in the

[6] See `https://www2.deloitte.com/us/en/pages/audit/articles/corporates-using-crypto.html`.
[7] See `https://nrf.com/media-center/press-releases/428-billion-merchandise-returned-2020`.

literature (Su 2009, Shang et al. 2017, Nageswaran et al. 2020, Mandal et al. 2021, Pun et al. 2021). The outside option has a utility of zero. Consumers ex-ante face uncertainties along two dimensions: product valuations and product matches. For example, the quality of coffee beans is determined by many factors, including freshness and storage environment. Traditionally, consumers can hardly obtain enough information and may form an expected valuation for the quality of coffee beans. By contrast, blockchain traceability allows consumers to access accurate information and thus form exact valuations. Regarding consumers' uncertainty about product matches (e.g., packaging and flavor), we note that it is unlikely to be addressed by blockchain traceability since it highly depends on individual preferences. Based on the above elaboration, we model consumer utility as follows. Consumer valuation for the matching good v follows a uniform distribution $U[0, 1]$. Without traceability, a consumer has to discover his valuation after purchasing (Su 2009, Shang et al. 2017, Nageswaran et al. 2020). Additionally, with probability $1 - m$, the consumer ex-post finds the product a mismatch and obtains a zero utility. In the main model, we focus on uncertainty about product valuations and hence assume $m = 1$. Section 5.5 establishes insights about product mismatches, i.e., $0 < m < 1$. In short, given price p and refund r, a consumer obtains a utility $v - p$ if he purchases and keeps the product. However, he obtains a utility $r - p$ if he buys and returns the product.[8] The consumer will purchase the product if his ex-ante expected utility, $U_{NB} = \mathbb{E}\max\{v, r\} - p = \frac{1+r^2}{2} - p$, is non-negative.

Blockchain adoption enables consumers to determine valuations by searching related information on blockchain. Our model accommodates consumer heterogeneity in search cost. The search cost manifests in factors such as individual patience in searching for desirable information, tolerance for installing traceability software, and proficiency in using blockchain. Therefore, a consumer may be less inclined to track blockchain information if his search cost is high.[9] This cost is private to the consumer and the distribution of the cost is publicly known. The main model assumes that consumers' search cost follows a two-point distribution and will be relaxed in Section 5.4. Specifically, there are two consumer segments, which we refer to as *searchers* and *nonsearchers*, with sizes α and $1 - \alpha$, respectively. Searchers incur no cost to search for blockchain information, while nonsearchers incur a prohibitively high cost so that they will not search. An alternative interpretation to parameter α is the overall information level disclosed by the retailer. If the retailer provides richer information and easier-to-use technology, consumers are more likely to successfully resolve their true valuations. Therefore, we define α as *information disclosure level*.

[8]Following the related literature, we assume that consumers cannot resale the product to a secondary market, which means the salvage value is zero for consumers.

[9]This assumption echoes a recent survey that reveals despite 80% of respondents expressing interest in information from a tracking system, there remains a contingent of 20% of consumers who are indifferent to any information. See "The Future of Traceability and Transparency in the Food System", available at `https://ag.purdue.edu/cfdas/wp-content/uploads/2023/06/Traceability_CFDASWhitePaper_FINAL.pdf`.

If a consumer decides to buy the product, the consumer first purchases stablecoins from a crypto wallet (e.g., Bitpay). The processing fee is very low and is normalized to zero (e.g., Bitpay is free to customers and charges less than half of credit card processing fees to merchants). Moreover, without loss of generality, we normalize the exchange rate by assuming that a unit of fiat currencies is equivalent to a unit of stablecoins at the very beginning of events. We then use a random variable ε to capture the exchange rate dynamics. Moreover, we assume that ε has a mean value of zero to capture the long-term stability and a variance of σ^2 to capture the short-term volatility.

As discussed earlier, stablecoins are returned if consumers claim the refund. Considering that most true stablecoins have no investment value, the consumer will convert reimbursed stablecoins into fiat currencies through cryptocurrency brokers before quitting the market. For simplicity, we adopt the mean-variance criterion to capture consumers' risk aversion to the price volatility of stablecoins (Chiu and Choi 2016). For r units of stablecoins, the consumer expects that it can be exchanged for $\tilde{r} = r(1-\varepsilon)$ units of fiat currencies.[10] Therefore, by the mean-variance risk criterion, the consumer perceives a discounted refund $\mathbb{E}[\tilde{r}] - \lambda\sqrt{Var[\tilde{r}]} = (1-\lambda\sigma)r$, where λ measures the extent of risk aversion of consumers to price volatility. We define $\beta = (1-\lambda\sigma)$, $\beta \in [0,1]$, as the *volatility discount*. A higher volatility discount means that consumers are less sensitive to price volatility risk (i.e., λ is small) or the stability of stablecoins is high (i.e., σ is small).

Based on the above analysis, a searcher ex-ante knows his product valuation and thus buys the product only if the valuation is higher than the price. Thus, the searcher does not face the price volatility risk since he does not return a matching product.[11] Therefore, a searcher gains a utility $U_{BC}^{\alpha} = \max\{v-p, 0\}$. For a nonsearcher, given the price p and the refund r, he obtains a utility $v-p$ if he buys and keeps the product; otherwise, he obtains a utility $\beta r - p$ if he buys and returns the product. For notational convenience, the discounted refund βr is denoted by t. Therefore, the expected utility of a nonsearcher is given by $U_{BC}^{1-\alpha} = \mathbb{E}\max\{v,t\} - p = \frac{1+t^2}{2} - p$.

Finally, we assume the following throughout our analysis. First, following the related literature (Su 2009, Akçay et al. 2013, Shang et al. 2017, Nageswaran et al. 2020), we assume $\frac{1}{2} \geq c > s_1$. The first inequality implies that the marginal production cost c is lower than consumers' expected valuation $\frac{1}{2}$. The second inequality means the salvage value of a returned product is smaller than the marginal production cost, which can help avoid the arbitrage case with infinite production. Next, we assume $f < \frac{1}{2}$, implying that the processing fee of credit card payment is not prohibitively large.

[10] It often takes 4-6 days to convert cryptocurrencies into fiat currencies through a third-party broker, so consumers cannot obtain the exact exchange rate when they make the return decision.

[11] A searcher may return a mismatching product, as analyzed in Section 5.5.

4. Model Analysis

In this section, we derive the optimal solutions for the models with and without blockchain adoption. Moreover, we elucidate the key forces that facilitate blockchain adoption and deliver welfare implications. All proofs are presented in Appendix.

4.1. Blockchain is absent

We first consider the benchmark model that blockchain is not adopted (denoted by strategy NB). Ex-post, a consumer will keep the product only if the realized valuation v is higher than the refund r. Therefore, the number of consumers who keep the product is $1 - r$ and the number of consumers who return the product is r. The retailer obtains a net profit $p-c-f$ if a product is kept and a net profit $p - r + s_1 - c$ if a product is returned. Therefore, the retailer's profit-maximizing problem is written as follows:

$$\begin{aligned} \max_{p,r} \quad & \Pi_{NB}(p,r) = (1-r)(p-c-f) + r(p-r+s_1-c) \\ \text{s.t.} \quad & U_{NB} \geq 0. \end{aligned} \tag{1}$$

The optimal solution in the model without blockchain adoption is characterized in Lemma 1.

Lemma 1. *Without blockchain adoption, the optimal price and refund are* $p^*_{NB} = \frac{1+(s_1+f)^2}{2}$ *and* $r^*_{NB} = s_1 + f$*, respectively, and the retailer's optimal profit is* $\pi^*_{NB} = \frac{1+(s_1+f)^2}{2} - f - c$*.*

From Lemma 1, we can find that the retailer optimally provides a partial refund $f + s_1$ for a returned product. With the optimal refund, the retailer obtains the same margin from a sold product and a returned product. Comparing with the no return case (i.e., $r = 0$), allowing product returns brings a higher profit for the retailer since it increases consumers' ex-ante willingness to pay for the product (i.e., $\mathbb{E}\max\{v, r\}$). Moreover, the retailer's optimal profit decreases in the processing fee of credit card payments f.

We are also interested in welfare implications. The total consumer surplus $CS_{NB}(p,r)$ and social welfare $SW_{NB}(p,r)$ are defined as follows:

$$CS_{NB}(p,r) = \int_0^1 (\max\{v,r\} - p)\,dv, \tag{2}$$

$$SW_{NB}(p,r) = CS_{NB}(p,r) + \Pi_{NB}(p,r). \tag{3}$$

Substituting p^*_{NB} and r^*_{NB} into Eq. (2) and Eq. (3), the total consumer surplus and social welfare under the optimal strategy is evaluated as CS^*_{NB} and SW^*_{NB}, respectively.

Proposition 1. *Without blockchain adoption, the optimal price* p^*_{NB} *and refund* r^*_{NB} (i) *extract all consumer surplus (i.e.,* $CS^*_{NB} = 0$*); and* (ii) *constitute a welfare-maximizing strategy (i.e.,*

$(p^*_{NB}, r^*_{NB}) \in \arg\max_{p,r} SW_{NB}(p,r))$.

Part (i) of Proposition 1 shows that the retailer will extract the maximum consumer surplus without blockchain adoption. This result suggests the advantage of the partial refund strategy relative to the full refund strategy. With the price p^*_{NB} and refund r^*_{NB}, the retailer attracts all consumers to make a purchase. Then, the retailer can profit from low-valuation consumers who claim a refund ex-post by charging a restocking fee. However, Part (ii) of Proposition 1 suggests that the optimal price-refund pair (p^*_{NB}, r^*_{NB}) maximizes social welfare. These benchmark results under the uniformly distributed valuation assumption are consistent with Su (2009) wherein the general distribution and quantity decisions are discussed to show the benefit of the partial refund strategy.

4.2. Using blockchain

We now investigate the blockchain adoption case (denoted by strategy BC). Note that nonsearchers will buy the product only if $U^{1-\alpha}_{BC} \geq 0$. Ex-post, a consumer will keep the product only if the realized valuation v is higher than the discounted refund t. Therefore, the number of nonsearchers who keep the product is $1-t$ and the number of nonsearchers who return the product is t. Next, searchers ex-ante know product valuations. Therefore, the number of searchers who purchase the product is $1-p$. The retailer obtains a net profit $p-c$ if a product is kept and a net profit $p-r+s_2-c$ if a product is returned. Hence, the retailer's profit-maximizing problem is formulated as follows:[12]

$$\begin{aligned} \max_{p,t} \quad & \Pi_{BC}(p,t) = (1-\alpha)[(1-t)(p-c) + t(p - \frac{t}{\beta} + s_2 - c)] + \alpha(1-p)(p-c) \\ \text{s.t.} \quad & U^{1-\alpha}_{BC} \geq 0. \end{aligned} \tag{4}$$

The optimal solution in the model with blockchain adoption is characterized in Lemma 2.

Lemma 2. *With blockchain adoption, the optimal price and refund are $p^*_{BC} = \frac{1+t^2_{BC}}{2}$ and $r^*_{BC} = \frac{t_{BC}}{\beta}$, respectively, where t_{BC} is the unique non-negative real root of the cubic function $f(t) = -\alpha t^3 + [\alpha c + (1-\alpha)(1-\frac{2}{\beta})]t + (1-\alpha)s_2$. The optimal profit π^*_{BC} is given by $\Pi_{BC}(p^*_{BC}, \beta r^*_{BC})$.*

To gain insights behind Lemma 2, we discuss two special cases: no disclosure case (i.e., α approaches to 0) and full disclosure case (i.e., α approaches to 1). It is worth noting that the optimal price in the full disclosure case is charged as $p^*_{BC} = \frac{1+c}{2}$, which is higher than the optimal price $\frac{1}{2}(1 + (\frac{\beta}{2-\beta}s_2)^2)$ in the no disclosure case (see the proofs in the Appendix). This is because if the information is totally disclosed, all consumers ex-ante know their valuations, which helps

[12]In the main model, we focus on the case that the retailer serves the two consumer segments, i.e., $U^{1-\alpha}_{BC} \geq 0$. The searcher-only strategy is discussed in Online Appendix A.5.

the retailer to exploit high-valuation consumers. However, if there is no information disclosure, consumers are highly homogeneous in their (ex-ante) valuations, and correspondingly, the demand is highly elastic. Therefore, the retailer will undercut to attract more consumers.

The result regarding the optimal refund is interesting. According to Su (2009) and Nageswaran et al. (2020), the optimal refund is at least as large as the salvage value. However, we find that the optimal refund can be lower than the salvage value of the product. For example, in the no disclosure case, the optimal refund equals $\frac{1}{2-\beta}s_2$, which is strictly lower than s_2 unless consumers are risk-neutral. This is because, with risk-aversion attitudes, the refund becomes less attractive to nonsearchers. Thus, the retailer applies a lower refund strategy to yield a higher margin from a returned product, as consumers become more risk averse.

We next analyze the retailer's optimal price and refund with blockchain adoption.

Corollary 1. *With blockchain adoption:*

(i) *The optimal price* p^*_{BC} *is* (a) *increasing in* α *and* (b) *increasing in* β*.*

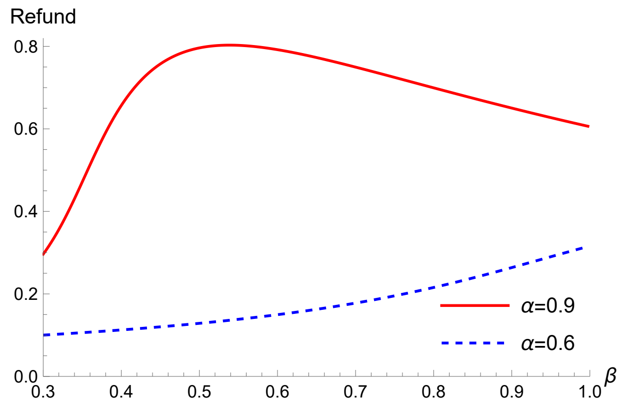
(ii) *The optimal refund* r^*_{BC} *is* (a) *increasing in* α *and* (b) *first increasing and then (can be) decreasing in* β*.*

(iii) *The optimal restocking fee* $p^*_{BC} - r^*_{BC}$ *is* (a) *decreasing in* α *and* (b) *non-monotone in* β*.*

Part i(a) of Corollary 1 shows that the optimal price increases in α. As explained earlier, a higher level of information disclosure enables the retailer to extract more surplus from high-valuation consumers. The optimal refund r^*_{BC} is bounded by $p = \frac{1}{2}(1 + (\beta r)^2)$, forcing the optimal refund r^*_{BC} to increase in α as well (i.e., Part ii(a)). For Part i(b), a higher β will increase nonsearchers' ex-ante willingness to pay (i.e., $\mathbb{E}\max\{v, \beta r\}$), so the retailer can reap more surplus by raising the selling price.

To see the intuition behind Part ii(b), we define the *volatility elasticity of discounted refund* as $\frac{dt_{BC}/t_{BC}}{d\beta/\beta}$. This indicator measures how sensitive the discounted refund is to the change of volatility discount. When the volatility elasticity of discounted refund is low (i.e., $\frac{dt_{BC}/t_{BC}}{d\beta/\beta} < 1$), a unit increase in β does not cause a significant increase in t_{BC}. Thus, the selling price is not greatly affected by β (recall that $p = \frac{1+t^2}{2}$). So the retailer is willing to charge a lower refund since she obtains a higher profit margin from a returned product. On the contrary, if the volatility elasticity of discounted refund is greater than 1, a unit increase in volatility discount β will significantly increase t_{BC}, which further greatly raises the selling price. Therefore, to make the product still attractive to nonsearchers, the retailer has to increase the refund amount. In addition, we find that if the information disclosure level becomes lower, the optimal refund always increases in volatility discount β. Note that the overall elasticity becomes higher when there is a larger nonsearcher base, so the retailer always sets a higher refund to encourage nonsearchers to purchase the product when volatility discount β becomes higher. Figure 2 illustrates the result in Part ii(b).

Figure 2: The optimal refund in the blockchain model ($s_2 = 0.2$, $c = 0.35$)



Part iii(a) shows that a unit increase in information disclosure level α has a greater impact on r^*_{BC} than p^*_{BC}, resulting in a lower restocking fee. This result implies that the retailer earns a lower profit margin from a returned product as the proportion of searchers increases. However, the restocking fee is non-monotone in volatility discount β.

Surprisingly, we find that the retailer may offer a refund (in stablecoins) higher than the selling price (in stablecoins).[13] Note that the impact of a high refund is twofold. On one hand, it leads to a high selling price that allows the retailer to exploit high-valuation consumers. On the other hand, the retailer obtains a negative margin from a returned product when the refund exceeds the price. When information disclosure level α is sufficiently high and volatility discount β is relatively low, the benefit of the high refund is prominent so that the retailer is willing to provide consumers with a generous refund.[14] This result implies that the retailer may undertake price volatility risk by refunding in the form of fiat currencies (note that fiat currencies are more valuable than stablecoins to risk-averse agents). For example, German luxury fashion brand Philipp Plein provides a full refund in fiat currencies for consumers paying via cryptocurrencies.[15] Philipp Plein charges a high price and mainly targets consumers who are informed of their products. In this case, Philipp Plein can also provide a generous return strategy to attract uninformed consumers.

The next proposition characterizes the impact of information disclosure level α and volatility discount β on the retailer's profit.

Proposition 2. *With blockchain adoption, the retailer's optimal profit π^*_{BC} is* (i) *first decreasing and then (can be) increasing in α and* (ii) *increasing in β.*

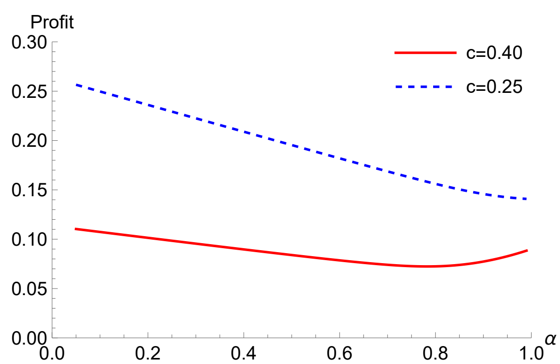
[13] Note that the arbitrage problem of consumers obtaining a positive utility by buying a product and returning it will not emerge if consumers are risk-averse to price volatility. If a nonsearcher buys a product and returns it, he obtains a utility $\mathbb{E}\max\{v, \beta r^*_{BC}\} - p^*_{BC} = 0$ according to Lemma 2. If a searcher buys a product and returns it, he obtains a utility $\beta r^*_{BC} - p^*_{BC} \leq \mathbb{E}\max\{v, \beta r^*_{BC}\} - p^*_{BC} = 0$.

[14] One may consider that the retailer should prevent nonsearchers from purchasing. However, we can show that this strategy is suboptimal (see Online Appendix A.2).

[15] See `https://www.plein.com/hk/en/search/?cgid=crypto`.

The case with $c = 0.4$ in Figure 3 shows that when the information disclosure level α is currently at a low level, a unit increase in α decreases the retailer's profit. By contrast, when the information disclosure level is high, a unit increase in α increases the retailer's profit. To explain this result, we note that $\frac{d\pi^*_{BC}}{d\alpha} = \frac{\partial}{\partial\alpha}(\alpha\pi^s_{BC} + (1-\alpha)\pi^n_{BC}) = \pi^s_{BC} - \pi^n_{BC}$, where π^n_{BC} is the profit from nonsearchers and π^s_{BC} is the profit from searchers. Therefore, the profit change resulting from an additional unit α can be measured by the benefit obtained from replacing nonsearchers with searchers. As the information disclosure level α increases from 0 to 1, the retailer first mainly focuses on serving nonsearchers and then serving searchers. Recall that the retailer obtains a lower restocking fee as α increases (see Part iii(a) in Corollary 1). Therefore, the retailer still obtains a relatively high margin from a returned product when α is small. In this case, disclosing more information undermines the retailer since more low-valuation nonsearchers leave the market directly. However, when α is large, we find that the retailer obtains a negative margin from a returned product, and therefore a higher level of information disclosure helps the retailer deter product returns. Together, the retailer's profit is U-shaped in information disclosure level α. Figure 3 further shows that the retailer's profit can decrease in α if production cost c is small (i.e., $c = 0.25$). This is because, with better salvage capacities, the retailer is willing to serve more nonsearchers since she can always profit from a returned product.

Figure 3: The retailer's profit in the blockchain model ($s_2 = 0.2$, $\beta = 0.8$)



Part (ii) of Proposition 2 implies that a higher value for volatility discount β benefits the retailer. The intuition is that, as β increases, the retailer can charge a higher price to reap more surplus from high-valuation searchers. Recall that a higher value for volatility discount is led by a lower degree of consumers' risk aversion or a higher stability of stablecoins. It means that it is beneficial for the retailer if consumers are less risk-averse or stablecoins are more stable.

Furthermore, we examine welfare implications under blockchain adoption. The full details of the total consumer surplus $CS_{BC}(p, r)$ and social welfare $SW_{BC}(p, r)$ are given in Appendix.

Proposition 3. *With blockchain adoption, the optimal price-refund pair (p^*_{BC}, r^*_{BC}) extracts all the surplus from nonsearchers while leaves some surplus for searchers; the total consumer surplus* *of all consumers is $CS^*_{BC} = \frac{1}{8}\alpha(1-t^2_{BC})^2$, which is decreasing in β.*

Proposition 3 shows that the surplus of nonsearchers is totally extracted by the retailer (i.e., $CS^{1-\alpha}_{BC}(p^*_{BC}, r^*_{BC}) = 0$). However, a searcher can obtain a positive utility, leading to a positive total consumer surplus. We further uncover that the total surplus is decreasing in β. This result has two implications. First, although searchers are not directly exposed to the price volatility risk, they are indirectly affected by volatility discount β through the price. Specifically, when consumers behave highly risk-averse to price volatility (i.e., a high λ), the retailer has to offer a low price that improves the total consumer surplus. Second, the high stability of stablecoins has no impact on the surplus of nonsearchers, but reduces the surplus of searchers. Therefore, offering highly stable stablecoins actually harms consumers. Combining Proposition 2 and Proposition 3, the insights regarding the stability of stablecoins are highlighted in Theorem 1.

Theorem 1. *A higher stability of stablecoins benefits the retailer but hurts consumers.*

The following result shows the impact of information disclosure level α on consumer surplus.

Proposition 4. *With blockchain adoption, there exists a threshold $\bar{\alpha}_1 \in (0,1)$ such that the total consumer surplus CS^*_{BC} is increasing in α when $\alpha < \bar{\alpha}_1$, and decreasing in α when $\alpha \geq \bar{\alpha}_1$.*

Interestingly, the total consumer surplus is inverted U-shaped in α. This result implies that it may backfire if consumers demand more information. The reason is that when the information is sufficiently supplied, a marginal increase in α does not bring a significant improvement in the overall information disclosure level, but the increased selling price hurts high-valuation searchers.

Furthermore, Part (ii) of Proposition 1 shows that the partial refund strategy maximizes social welfare when blockchain is absent. However, this is not the case if blockchain is adopted.

Corollary 2. *With blockchain adoption, the optimal price p^*_{BC} and refund r^*_{BC} are not a welfare-maximizing strategy.*

The proof of Corollary 2 shows that the welfare-maximizing strategy suggests a constant selling price $p^{**}_{BC} = c$ and a constant refund $r^{**}_{BC} = \frac{1}{2-\beta}s_2$, regardless of the value of the information disclosure level α. Accoring to Corollary 1, we have $p^*_{BC} > p^{**}_{BC}$ and $r^*_{BC} > r^{**}_{BC}$. Therefore, p^*_{BC} and r^*_{BC} cannot constitute a social-welfare maximizing strategy. Welfare losses emerge because searchers obtain ex-ante heterogeneity for product valuations with blockchain information. As a remark, although social welfare is not maximized, both the retailer and searchers can benefit from blockchain adoption, as demonstrated in the following subsection.

4.3. Impact of blockchain adoption

In this section, we discuss the impact of blockchain adoption on the retailer and consumers by comparing the solutions in Section 4.1 and Section 4.2. We first discuss how blockchain adoption affects the retailer's optimal profit.

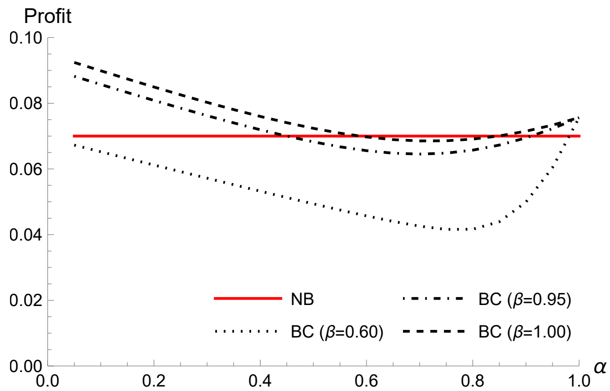
Proposition 5. *Comparing the retailer's profit with and without blockchain adoption, we know that* (i) *there exists a threshold* $\hat{\beta} \in (0, 1)$ *such that* $\pi^*_{BC} > \pi^*_{NB}$ *if* $\beta > \hat{\beta}$, *and* $\pi^*_{BC} \leq \pi^*_{NB}$ *otherwise;* (ii) $\pi^*_{BC} > \pi^*_{NB}$ *if* α *is sufficiently low or sufficiently high.*

Part (i) of Proposition 5 states that the retailer's profit with blockchain adoption can be higher than that without blockchain adoption. Specifically, when the processing fee of credit card payments f is sufficiently high, blockchain adoption always benefits the retailer. As f becomes low, blockchain is still preferred by the retailer, unless consumers are highly risk-averse to price volatility of stablecoins, since traceability offered by blockchain can significantly improve the retailer's salvage capacities (i.e., c and s_2 are large, and s_1 is small). However, if consumers are highly risk-averse, the retailer will not adopt blockchain because a very low volatility discount β degenerates the partial return strategy into the no refund strategy. Additionally, the retailer may never adopt blockchain even though consumers are risk-neutral to price volatility (mathematically, we have $\hat{\beta} > 1$). This result is likely to occur when the retailer has relatively good salvage capabilities and the processing fee of credit card payments is low. The rationale of the result is discovered by examining the effect of blockchain traceability shown in Part (ii) of Proposition 5.

It is easy to see that the payment efficiency provided by blockchain can promote its adoption. Hence, we remove this trivial effect by setting $f = 0$.[16] As shown in Figure 4, blockchain adoption increases the retailer profit when the information disclosure level is either sufficiently high or sufficiently low. However, if the information disclosure level is intermediate, the retailer should not adopt blockchain. Note that strategy NB is driven by demand expansion because the retailer will undercut to attract sufficient ex-ante demand and alleviate the negative impact of product returns by charging restocking fees. By contrast, strategy BC is underpinned by profit margins since the retailer can extract enough surplus from high-valuation consumers with a high price and from low-valuation nonsearchers with better salvage capabilities. When the information disclosure level α is sufficiently low, the information disclosure effect is not significant, and hence the retailer obtains a higher profit due to the improved salvage value of returned products. With the increase of α, the information disclosure effect becomes more prominent. However, the effect first decreases the retailer's profit since it causes massive low-valuation consumers to leave the market directly while the price cannot extract enough surplus from high-valuation consumers. By contrast, under strategy NB, the retailer can still induce these consumers to purchase the product and obtain a positive margin from these low-valuation consumers who claim a refund. When α becomes sufficiently high, the effect in turn benefits the retailer through the sufficiently high price. Thus, the retailer may prefer strategy BC over strategy NB when the retailer's salvage capability is significantly improved by blockchain technology.

[16] The insights on payment facilitation are well studied in Section 5.1.

Figure 4: Profit comparisons between NB and BC strategies ($c = 0.45$, $s_2 = 0.3$, $s_1 = 0.2$, $f = 0$)



Finally, welfare implications of blockchain adoption are shown in Corollary 3.

Corollary 3. (i) *Blockchain adoption improves the total consumer surplus;* (ii) *blockchain adoption improves social welfare when the retailer's profit is not significantly reduced.*

Recall that Proposition 1 has shown that consumer surplus is entirely extracted if blockchain is absent. By contrast, Corollary 3 shows that blockchain adoption improves the total consumer surplus. Additionally, the retailer can benefit from blockchain adoption (see Proposition 5). Therefore, blockchain adoption achieves a win-win situation for the retailer and consumers. In other words, blockchain adoption improves social welfare. In addition, we find that blockchain adoption could significantly decrease the retailer's profit under some circumstances. In this case, we suggest that the policymaker with social welfare concerns may consider subsidizing retailers to implement blockchain, as blockchain adoption can still benefit consumers.

5. Model Extensions

In this section, some key assumptions in the main model are relaxed to confirm the robustness of main findings and provide further insights.[17]

5.1. Self-selection payment policy

In the main model, transactions are assumed to be settled by stablecoins when blockchain is adopted. However, in reality, retailers may allow consumers to self-select their preferred payment methods. To investigate this self-selection payment policy, we allow consumer heterogeneity in payment costs by assuming that the cost of paying with credit cards, δ_c, is uniformly distributed in $[0, \frac{1}{2}]$ and the cost of paying with stablecoins is $\delta_s \in [0, \frac{1}{2}]$. For model tractability, we assume that consumers either have a high valuation (i.e., $v = 1$) or a low valuation (i.e., $v = 0$) for the product with the same probability. As we aim to derive insights into payment costs, the marginal

[17]We thank the insightful comments raised by the review team.

Table 2: The optimal solution when blockchain is adopted

Case	Parameter Value	(p^*_{BC}, r^*_{BC})
A	$0 \leq \delta_s \leq d^o_3 \cap 0 \leq f \leq h^o_1$	$(\frac{1-2\delta_s}{2-\beta}, \frac{1-2\delta_s}{2-\beta})$
B	$\Big\{0 \leq \delta_s \leq d^o_3 \cap \max\{h^o_1, 0\} \leq f \leq \min\{f^o_2, k^o_3\}\Big\}$ $\cup \Big\{d^o_3 \leq \delta_s \leq d^o_2 \cap 0 \leq f \leq k^o_2\Big\}$ $\cup \Big\{\delta_s > d^o_2 \cap 0 \leq f \leq k^o_1\Big\}$	$(\frac{1}{2} - \delta_s, 0)$
C	$\delta_s > d^o_2 \cap k^o_1 \leq f \leq g^o_2$	$(\frac{1+f-\alpha f}{2-2\alpha}, \frac{1+f-\alpha f}{2-2\alpha})$
D	$\Big\{d^o_3 \leq \delta_s \leq d^o_2 \cap k^o_2 \leq f \leq f^o_1\Big\}$ $\cup \Big\{\delta_s > d^o_2 \cap g^o_2 \leq f \leq f^o_1\Big\}$	$(1-\delta_s, 1-\delta_s)$
E	$\Big\{0 \leq \delta_s \leq d^o_3 \cap f > \min\{f^o_2, k^o_3\Big\}$ $\cup \Big\{d^o_3 \leq \delta_s \leq d^o_2 \cap f \geq f^o_1\Big\}$ $\cup \Big\{\delta_s > d^o_2 \cap f^o_1 \leq f \leq f^o_2\Big\}$	$(1-\delta_s, \frac{3-f-4\delta_s}{2})$
F	$\delta_s > d^o_2 \cap f > f^o_2$	$(\frac{1+f}{2}, \frac{1+f}{2})$

production cost c is removed to isolate the impact of return costs. Moreover, we consider that $p \geq r$ is satisfied to avoid the arbitrage behavior of consumers (i.e., paying with credit cards and then returning the product). Finally, we assume the following.

Assumption 1. *We have* $\delta_s < d^o_1 = \frac{4-4\beta-\alpha(8-(8-\beta)\beta)}{8(1-\alpha)(1-\beta)}$.

Here, Assumption 1 implies that the cost of paying with stablecoins is not prohibitively high; otherwise, the retailer may always prevent nonsearchers paying with stablecoins. The technical proofs and expressions of thresholds in this subsection are shown in Online Appendix B.

If blockchain is absent, the retailer will offer a full refund and the optimal price is $p^*_{NB} = \frac{1+f}{2}$. This result basically hinges on the exogenous return probability due to the two-point distribution assumption on consumers' valuations in this extended model. The following analysis, however, shows that the partial refund strategy may be optimal for the retailer if blockchain is adopted.

Table 2 summarizes the retailer's optimal pricing and return strategies along two dimensions: the consumer cost associated with stablecoin payments δ_s and the processing fee of credit card payments f. When both δ_s and f are low (i.e., Case A), the retailer offers a full refund, and searchers and nonsearchers will pay with stablecoins if the consumer cost associated with credit card payment is high. However, as δ_s or f increases, the seller minimizes the refund to incentivize consumers to pay with stablecoins. Simultaneously, the retailer will undercut to attract consumers with high credit card payment costs, as shown in Case B. As f increases further, the retailer has to increase the price (and refund) to cover the cost, even though doing so will discourage nonsearchers from paying with stablecoins (i.e., Cases C, D, and E). In Case F, when δ_s is prohibitively high, the retailer prefers compensating the high processing fee by increasing the price, instead of motivating stablecoin payments, which makes stablecoin payments inapplicable to all consumers.

Proposition 6. *Comparing the optimal solutions with and without blockchain adoption leads to the following: (i) Blockchain adoption benefits the retailer; (ii) blockchain adoption increases consumer surplus in the following regions: (a) $\delta_s < d_3^o$ and $f > \max\{h_1^o, l_1^o\}$; (b) $d_3^o \le \delta_s < d_2^o$ and $f \le \min\{k_2^o, l_2^o\} \cup f > l_2^o$; (c) $\delta_s \ge d_2^o$ and $f < k_1^o \cup f > \max\{f_1^o, l_2^o\}$. In other regions, blockchain adoption reduces consumer surplus.*

Note that blockchain adoption facilitates payments. Moreover, the downside of information disclosure (captured by the main model) is absent in this extended model because the retailer charges no restocking fee without blockchain adoption. Hence, as shown in Part (i) of Proposition 6, blockchain adoption always benefits the retailer. Next, blockchain adoption benefits consumers when the processing fee f is sufficiently high. This is because the retailer will set a high price to cover the processing fee if blockchain is not adopted. By contrast, adopting blockchain motivates the retailer to charge relatively low prices to steer consumers to pay with stablecoins. In addition, when δ_s and f are high (i.e., Case F), blockchain adoption does not affect the retailer's optimal pricing and return strategies, and consumers will solely benefit from the information disclosure function of blockchain. Blockchain adoption can also benefit consumers when f is sufficiently low unless δ_s is very low. The reason is that the retailer will promote the use of stablecoins by lowering the refund, as well as lowering prices to compensate consumers (e.g., Case B). Strikingly, blockchain adoption with the flexible payment policy may hurt consumers, which happens when δ_s and f are low, or f is intermediate, because the retailer charges a high price with blockchain adoption.

Corollary 4. *When the retailer provides the self-selection payment policy, a higher degree of stability of stablecoins still increases retailer profit and decreases consumer surplus.*

Corollary 4 shows that higher stability of stablecoins still increases retailer profit and decreases consumer surplus under the flexible payment policy, which verifies the robustness of Theorem 1.

Proposition 7. *Under Assumption 1, if blockchain is adopted, the retailer obtains a higher profit by allowing consumers to pay with credit cards only when the following two conditions are satisfied:* (i) $\delta_s \ge \max\{d_2^o, d_4^o\}$ *and* $\alpha \le \frac{2-2\beta}{2-\beta}$; (ii) f *is low.*

Finally, Proposition 7 shows that the retailer may accept credit card payments when the fraction of searchers is small and the consumer cost of paying with stablecoins is high, or the processing fee of credit card payments is low. This is intuitive because stablecoin payments do not significantly facilitate payments in these parameter regions.

5.2. Mandatory full refund policy

In the main model, we find that the retailer entirely extracts the surplus of nonsearchers. Conventional wisdom might suggest mandating a full refund to protect these consumers. A practical example is that the U.K. government requires online sellers to leave a cooling-off period of at least 14 days, during which consumers can claim a full refund without any reason.[18] In this section, we investigate the impact of the full refund strategy for blockchain-powered retail businesses.

When blockchain is absent, a consumer's ex-ante utility is derived to be $\mathbb{E}\max\{v,p\}-p=\frac{(1-p)^2}{2}$. The retailer's profit-maximizing problem is $\Pi^F_{NB}(p)=(1-p)(p-c-f)+p(s_1-c)$. Solving the profit-maximizing problem, we obtain the optimal price $p^{F*}_{NB}=\frac{1+s_1+f}{2}$ and the profit $\pi^{F*}_{NB}=\frac{(1+s_1+f)^2}{4}-c-f$. Moreover, the consumer surplus is evaluated as $CS^{F*}_{NB}=\frac{(1-s_1-f)^2}{8}$, and the social welfare is $SW^{F*}_{NB}=\frac{1}{8}(2(1+s_1+f)^2+(1-s_1-f)^2)-c-f$.

Together with Lemma 1, we know that the mandatory full refund policy will increase consumer surplus but reduce social welfare when blockchain is absent. According to Su (2009), the full refund strategy is a free information mechanism to help consumers determine their valuations, and the strategy undermines the retailer because she loses a useful operational instrument (mathematically, the partial refund strategy introduces a free decision variable r and removes the constraint $r=p$). However, the information mechanism is not free when blockchain is adopted because of the price volatility risk. In what follows, we explore the welfare implications of the mandatory full refund policy in blockchain-enabled retail markets.

Table 3: The optimal solution for blockchain adoption in the full refund case

Case	p^{F*}_{BC}	π^{F*}_{BC}
A	$\frac{1+\alpha c+(1-\alpha)\beta s_2}{2(\alpha+(1-\alpha)\beta)}$	$\frac{\alpha^2c^2-2c(\alpha+2\beta+\alpha^2\beta s_2-\alpha\beta(s_2+2))+((\alpha-1)\beta s_2-1)^2}{4\alpha(1-\beta)+4\beta}$
B	$(\frac{1}{1+\sqrt{1-\beta^2}})^-$	$\frac{(1-cX_0)(X_0-\alpha)-(1-\alpha)\beta(1-s_2X_0)}{X_0^2}$
C	$\frac{1+c}{2}$	$\frac{1}{4}\alpha(1-c)^2$
D	$(\frac{1}{1+\sqrt{1-\beta^2}})^+$	$\alpha(1-\frac{1}{X_0})(\frac{1}{X_0}-c)$

Let $X_0=1+\sqrt{1-\beta^2}$, $(x_0)^-=\lim_{x\to x_0^-}x$, and $(x_0)^+=\lim_{x\to x_0^+}x$. The retailer's optimal price p^{F*}_{BC} and profit π^{F*}_{BC} when blockchain is adopted are shown in Table 3. In Case A, the retailer serves both searchers and nonsearchers with a price that leaves a positive surplus for nonsearchers. In Case B, although the retailer still serves searchers and nonsearchers, she charges a price that entirely extracts the surplus of nonsearchers. In both Case C and Case D, the retailer will not serve nonsearchers. The difference is that the retailer charges the "first-best" price for serving searchers in the former case, while in the latter case the retailer has to set a high price to prevent nonsearchers' purchasing. The parameter values for each case and the comparative statics analysis are given in Online Appendix C.

Our further analysis shows that a higher volatility discount β may reduce the retailer's profit when a full refund is offered. As shown in Corollary 5 and Figure 5, a sufficient condition for this

[18]See https://www.gov.uk/online-and-distance-selling-for-businesses.

result is that the production cost is low. More interestingly, even though a higher value for β may hurt the retailer, it is not necessarily beneficial for consumers. For example, in Case B, the retailer extracts all surplus of nonsearchers with the price $(\frac{1}{1+\sqrt{1-\beta^2}})^-$. In this case, a higher β implies a higher price, thereby reducing the total consumer surplus.

Corollary 5. *Define* $c_m = \frac{1-\alpha(\sqrt{1-\beta^2}+(\beta-2)\beta+1)+\beta(-\sqrt{1-\beta^2}+\beta-1)+\sqrt{1-\beta^2}+(\alpha-1)(-\beta^2+2\sqrt{1-\beta^2}+2)s_2}{\alpha\beta(\sqrt{1-\beta^2}+1)}$. *When* $c \le c_m$, π^{F*}_{BC} *is (weakly) decreasing in* β *in Cases A-D.*

Figure 5: The optimal profit under the full refund policy ($s_2 = 0.2$, $\alpha = 0.8$)

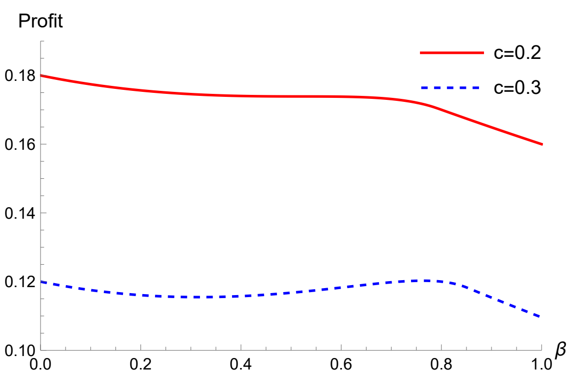
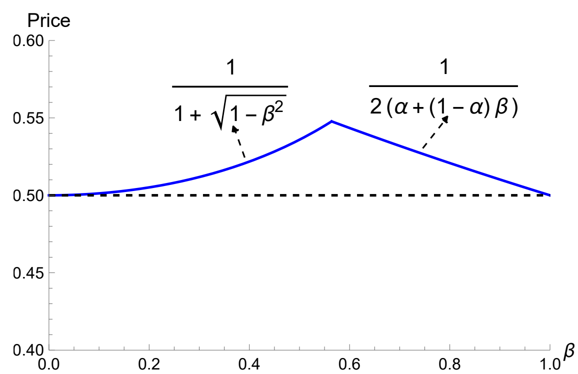


Figure 6: The optimal price under the full refund policy ($c = 0$, $s_2 = 0$, $\alpha = 0.8$)



It is intuitive that the mandatory full refund policy hurts the retailer because it imposes a constraint $p = r$ on the retailer's decision-making process. We next show that it may also hurt consumers by discussing two special cases. The first case is that the retailer optimally serves only searchers, which occurs when c is large and s_2 is small. In this case, if a partial refund is applied, the retailer sets the price as $\frac{1+c}{2}$ and the refund $r < \frac{\sqrt{c}}{\beta}$ to deter nonsearchers' purchasing (see Online Appendix A.5). However, if a full refund is applied, she charges the price $(\frac{1}{1+\sqrt{1-\beta^2}})^+$ to deter nonsearchers' purchasing. As a result, mandating a full refund increases the price.

For the more general case that the retailer profitably serves nonsearchers, the lose-lose outcome still emerges. Motivated by Proposition 3, when $c = 0$, serving nonsearchers is the retailer's optimal strategy. The optimal price is charged as $p^{F*}_{BC} = \min\{\frac{1}{2(\alpha+(1-\alpha)\beta)}, (\frac{1}{1+\sqrt{1-\beta^2}})^-\}$ in which the former price in the minimum operator leaves some surplus for nonsearchers while the latter entirely extracts the surplus of nonsearchers. Because p^{F*}_{BC} is larger than $\frac{1}{2}$ which is the optimal price under the partial refund strategy (see the proof of Lemma 2), mandating the full refund strategy may reduce the total consumer surplus. This is because the retailer can set a low refund (e.g., $r = 0$ when $c = 0$) to deter consumer returns with the partial-refund strategy. Meanwhile, the retailer has to set a low price to attract nonsearchers, which also benefits searchers. However, with the full refund strategy, the retailer sets a high price to extract enough surplus from high-valuation nonsearchers. This motivation is strong when β is mild (see Figure 6).

5.3. Risk-averse retailer

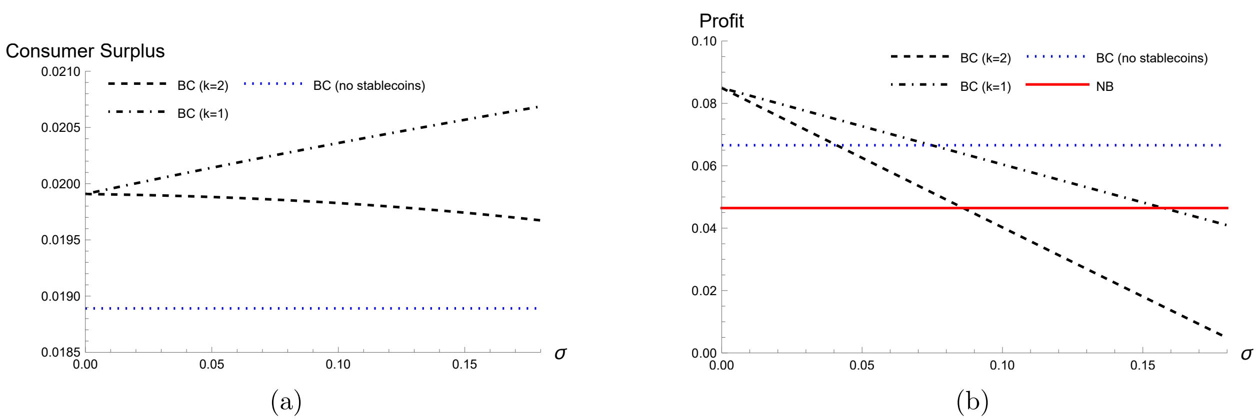
In this subsection, we investigate the retailer's risk aversion to the price volatility of stablecoins. Similar to the main model, the expected number of nonsearchers who keep the product is $1 - \beta r$ and the expected number of nonsearchers who return the product is βr. The number of searchers who make the purchase is $1 - p$. The retailer's profit-maximizing problem is modified as follows.

$$\begin{aligned} \max_{p,t} \quad & \tilde{\Pi}_{BC}(p,t) = (1-\alpha)[(1-\beta r)(\tilde{p}-c) + \beta r(\tilde{p} - \tilde{r} + s_2 - c)] + \alpha(1-p)(\tilde{p}-c) \\ \text{s.t.} \quad & U_{BC}^{1-\alpha} \geq 0. \end{aligned} \tag{5}$$

Let η measure the retailer's extent of risk aversion to the price volatility of stablecoins. We define $\tau = 1 - \eta\sigma$, $\tau \in [0,1]$, as the *retailer volatility discount*. Moreover, we define $k = \frac{\eta}{\lambda}$ as the ratio of the degree of risk aversion of the retailer relative to consumers (hereafter, *risk aversion ratio*). When $k = 1$, the retailer has the same degree of risk aversion as consumers. When $k = 0$, the retailer is risk-neutral. By the mean-variance criterion, the retailer's expected profit is written as $\Pi_{BC}(p,t) = (1-\alpha)[(1-t)(\tau p - c) + t(\tau(p - \frac{t}{\beta}) + s_2 - c)] + \alpha(1-p)(\tau p - c)$. We then obtain Proposition 8, with proofs shown in Online Appendix D.

Proposition 8. *Let $\hat{c} = \frac{c}{\tau}$ and $\hat{s}_2 = \frac{s_2}{\tau}$. If the retailer is risk-averse and sells the product with blockchain, the optimal price and refund are $p_{BC}^* = \frac{1+(\min\{t_{BC},1\})^2}{2}$ and $r_{BC}^* = \frac{\min\{t_{BC},1\}}{\beta}$, respectively, where t_{BC} is the unique non-negative real root of the cubic function $f(t) = -\alpha t^3 + [\alpha\hat{c} + (1-\alpha)(1-\frac{2}{\beta})]t + (1-\alpha)\hat{s}_2$. Moreover, $\frac{dp_{BC}^*}{d\tau} < 0$ and $\frac{dp_{BC}^*}{d\beta} > 0$.*

Figure 7: The impact of price volatility ($\lambda = 0.5$, $\eta = 1$, $c = 0.45$, $s_2 = 0.3$, $s_1 = 0.2$, $f = 0.03$, and $\alpha = 0.2$)



Proposition 8 shows that the retailer still extracts all surplus of nonsearchers and leaves the positive surplus for searchers. Besides, since $\tau = 1 - \eta\sigma$ and $\beta = 1 - \lambda\sigma$, we know that the railer raises the price if she is highly risk-averse (i.e., η is large) and reduces the price if consumers are highly risk-averse (i.e., λ is large). However, as σ (the price volatility of stablecoins) increases, the retailer may increase or decrease the price. This result implies that the total consumer surplus can increase or decrease in σ. According to Figure 7(a), a higher value for σ decreases the total consumer surplus when the risk aversion ratio k is large as the retailer exhibits great sensitivity to price volatility risks. Finally, Figure 7(b) suggests that lower values for k and σ increase the likelihood of the retailer accepting cryptocurrency payments when blockchain is adopted.

5.4. Endogenous information disclosure level

In the main model, we assume that consumers' search cost follows a two-point distribution for analytical tractability. This assumption implies the fraction of searchers is an exogenous parameter and is not affected by the retailer's decisions. In this section, we endogenize consumers' search choices to examine the robustness of our main findings.

If a consumer decides to evaluate his valuation by searching for blockchain information, we assume that he will incur a search cost s, which is uniformly distributed in [0,1]. After a search, the consumer obtains the expected utility $U_s = \mathbb{E}\max\{v-p,0\} - s$. Alternatively, if the consumer chooses to buy the product directly without a search, the expected utility is $U_n = \mathbb{E}\max\{v,t\} - p$. Comparing U_s and U_n, a consumer prefers searching for information if his search cost $s < \frac{p^2-t^2}{2} = \frac{p^2-(\beta r)^2}{2} \equiv s_0$. Intuitively, when the selling price is higher or the refund is lower, more consumers will search for the information; when volatility discount β is higher (due to a low λ or a low σ), fewer consumers will search for the information. The proofs are given in Online Appendix E.

Lemma 3. *When the information disclosure level is endogenized, the optimal price and refund of the blockchain model are $p^*_{BC} = \frac{1+t^2_{BC}}{2}$ and $r^*_{BC} = \frac{t_{BC}}{\beta}$, respectively, where t_{BC} is the unique non-negative real root of the function $f(t) = \frac{1}{32\beta}(-8\beta t^7 + 12(\beta c+2)t^5 - 20\beta s_2 t^4 - 8(\beta(c-1)+4)t^3 + 24\beta s_2 t^2 - 4(\beta(c-8)+14)t + 28\beta s_2)$.*

Lemma 3 characterizes the retailer's optimal price p^*_{BC} and refund r^*_{BC}. Plugging p^*_{BC} and r^*_{BC} into s_0 determines the number of consumers who can successfully find valuations with the blockchain traceability function (or the optimal information disclosure level). We next study the impact of blockchain adoption when the information disclosure level is endogenized.

Proposition 9. *When the information disclosure level is endogenized:* (i) *The retailer's profit increases in β. Moreover, blockchain adoption can still benefit the retailer, which tends to emerge when β, c, s_2, and f are high, and s_1 is low.* (ii) *The retailer extracts all surplus of high-cost consumers who do not search for information while leaving some surplus for low-cost consumers who search for information. The total consumer surplus, $CS^*_{BC} = \frac{1}{128}(1-t^2_{BC})^4$, decreases in β.*

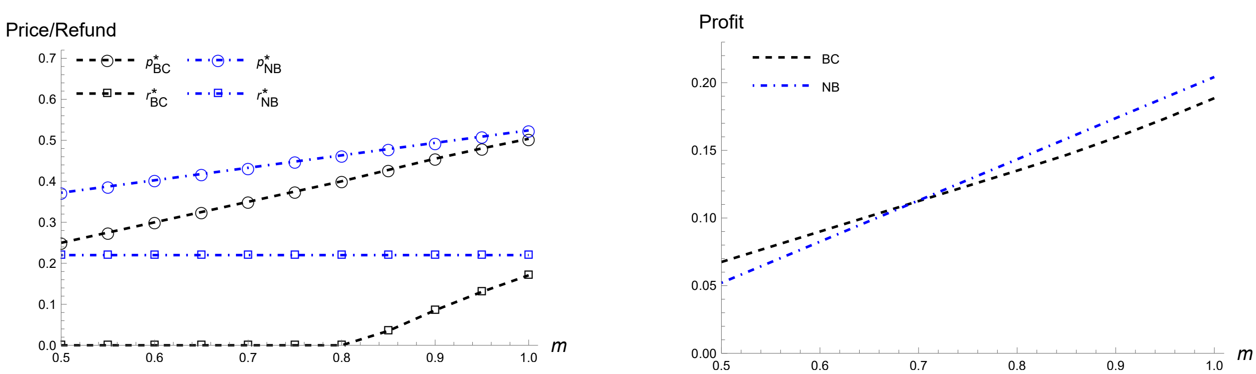
Part (i) of Proposition 9 confirms the robustness of the result that blockchain can benefit the retailer when consumers' search costs are continuously distributed. Moreover, similar to the main model, the retailer profit increases in volatility discount β. Part (ii) of Proposition 9 verifies the robustness of welfare implications. With blockchain adoption, low-cost consumers can use blockchain information to resolve their valuation uncertainty before making a purchase. So the retailer cannot extract all surplus from these searchers. However, high-cost consumers have to resolve their valuations after making a purchase. Accordingly, the retailer can set the restocking fee to extract the maximum surplus from nonsearchers. In addition, a higher value for β does not affect the surplus of nonsearchers, but it indirectly reduces the surplus of searchers, which validates the robustness of Theorem 1. Finally, the result that blockchain adoption creates a win-win situation for the retailer and consumers qualitatively holds even though consumers' information search behavior is endogenously affected by the retailer's decisions.

5.5. Uncertainty about product matches

The uncertainty about product matches is another reason that leads to consumer returns, while blockchain traceability is less likely to tackle this problem compared to the uncertainty about product valuations. In this extension, we investigate the impact of product mismatches on blockchain adoption of the retailer. First, following Proposition 10, we find that blockchain still strictly increases the total consumer surplus. The proofs are given in Online Appendix F.

Proposition 10. *Without blockchain adoption, the retailer entirely extracts consumer surplus. By contrast, with blockchain adoption, the retailer entirely extracts the surplus of nonsearchers and leaves a positive surplus for searchers.*

Figure 8: The impact of the probability of a match ($\beta = 0.5$, $c = 0.3$, $s_2 = 0.25$, $s_1 = 0.2$, $\alpha = 0.2$, and $f = 0.02$)



(a) (b)

Since it is difficult to analytically compare the optimal solutions with and without blockchain adoption, we conduct numerical studies to gain insights into product mismatches. In Figure 8(a), as the possibility of product mismatches becomes higher (i.e., m is lower), the gap of prices with and without blockchain adoption becomes larger. Notice that, without blockchain, the retailer provides a partial refund to profit from consumers who decide to return. By contrast, with blockchain adoption, the retailer is motivated to provide no refund when m is low because the price volatility causes the refund to be less attractive to consumers than that without blockchain adoption. At the same time, the retailer compensates with a significantly low price to attract nonsearchers. This result implies that blockchain is more beneficial for consumers when m is lower. In addition, Figure 8(b) shows that the retailer benefits from blockchain adoption when m is lower. To summarize, our numerical studies show that blockchain adoption is more valuable for both the retailer and consumers when product mismatches are more prevalent.

6. Conclusion

Nowadays, retailers endeavor to boost sales by utilizing the blockchain technology. This paper examines the unique impact of blockchain adoption on retail businesses from the perspective of the flow of information and finance. On one hand, cryptocurrency payments (esp., stablecoins) underpinned by blockchain offer advantages over traditional payment tools like credit cards. However, it creates disutility associated with cryptocurrency price volatility for consumers who may decide to return the product ex-post due to the uncertain product valuations. On the other hand, blockchain-enabled traceability discloses product evaluation, thereby reducing consumer returns. This paper has shed light on the impact of the combined utilization of these two blockchain functions.

Table 4: Implications of blockchain adoption

	Information disclosure level		
	Low	Medium	High
Low price volatility case			
Retailer profit	↑	↓	↑
Consumer surplus		↑	
Social welfare	↑	↑ or ↓	↑
High price volatility case			
Retailer profit		↓	
Consumer surplus		↑	
Social welfare		↑ or ↓	

Note: "↑" implies an increase and "↓" implies a decrease.

Table 4 summarizes the welfare implications after blockchain is introduced. The bright side of blockchain adoption we derived is that it can achieve a win-win outcome for the retailer and consumers. In broad strokes, blockchain adoption brings payment facilitation and salvageability improvement to retailers. It also gives consumers the ability to obtain information in advance. We further concretize the role of blockchain adoption from perspectives of information disclosure level and price volatility of stablecoins. We find that blockchain adoption benefits the retailer when the information disclosure level is polarized. Otherwise, it may undermine the retailer because massive low-valuation consumers leave the market directly and the surplus of high-valuation consumers is not well exploited. Moreover, our result suggests that demanding a higher level of information disclosure is not necessarily beneficial for consumers because the marginal benefit can be offset by the higher price. In terms of the price volatility of stablecoins, we first find that a higher value for the volatility discount (i.e., either a lower degree of consumers' risk aversion or a higher degree of stability of stablecoins) increases the retailer's profit. By contrast, it reduces the total consumer surplus. This result is contrary to the conventional wisdom that the stability of cryptocurrencies protects consumer welfare.

Several extended models are studied to establish more insights. First, we study the case that the retailer provides a flexible payment policy for consumers when blockchain is adopted. We interestingly find that blockchain adoption may reduce consumer surplus under the proposed flexible payment policy. Second, we discuss the impact of the mandatory full refund policy on blockchain-facilitated retail businesses. We find that the mandatory full refund policy may result in a lose-lose situation for consumers and the retailer. Third, we find that a higher degree of stability of stablecoins benefits consumers when the retailer is highly risk-averse relative to consumers. Fourth, we confirm the robustness of our key findings when the information disclosure level (or equivalently, the fraction of searchers) is endogenized. Finally, we incorporate consumers' uncertainty about product mismatches. The result shows that blockchain is more valuable for the retailer and consumers in the market where product mismatches are more prevalent.

We acknowledge that several assumptions have been made for analytical tractability or to prevent distractions from the focal points. First, we do not capture the case that cryptocurrencies are extremely volatile. Risk-seeking behavior is more relevant in this case. Second, relaxing the assumption on deterministic demand will likely yield new insights (see Teunter et al. (2018) for a good example). Thirdly, it would be desirable to study retailers' blockchain adoption strategies under a competitive environment (Jiang et al. 2022, Zhang et al. 2022). Finally, We expect future research to extend this study in the presence of secondary markets (Li et al. 2019, Lei et al. 2022).

Appendix. Technical Proofs for Main Results

Proof of Lemma 1. The retailer should charge $p = \mathbb{E}\max\{v, r\} = \frac{1+r^2}{2}$. So, the retailer's profit is maximized when $r = s_1 + f$. Therefore, we have $r^*_{NB} = s_1 + f$, $p^*_{NB} = \frac{1+(s_1+f)^2}{2}$, and $\pi^*_{NB} = \frac{1+(s_1+f)^2}{2} - f - c$. □

Proof of Proposition 1. (i) By Eq. (2), we have $CS_{NB}(p, r) = \int_0^1 (\max\{v, r\} - p)\, dv = \frac{1+r^2}{2} - p$. Lemma 1 shows that the optimal selling price and refund satisfy $p^*_{NB} = \frac{1+r^{*2}_{NB}}{2}$. Plugging p^*_{NB} and r^*_{NB} into $CS_{NB}(p, r)$, we obtain $CS^*_{NB} = 0$. (ii) By Eq. (1) and $CS_{NB}(p, r)$, the total social welfare $SW_{NB}(p, r)$ is given by $SW_{NB}(p, r) = CS_{NB}(p, r) + \Pi_{NB}(p, r) = -\frac{1}{2}r^2 + rs_1 + \frac{1}{2} - (1 - r)f - c$. We know that $SW_{NB}(p, r)$ is maximized when $r = s_1 + f$. Therefore, p^*_{NB} and r^*_{NB} maximize social welfare. □

Proof of Lemma 2. First, following the similar procedures in Nageswaran et al. (2020) (see Lemma OA-1 in Online Appendix A.1), we can show that the retailer's profit is maximized at a boundary solution. Next, denoting $F(t) = \Pi_{BC}(\frac{1+t^2}{2}, t)$, the first-order derivative of $F(t)$ w.r.t. t is given by $f(t) = \frac{\partial F(t)}{\partial t} =$

$-\alpha t^3 + [\alpha c + (1-\alpha)(1-\frac{2}{\beta})]t + (1-\alpha)s_2$, and the second-order derivative of $F(t)$ w.r.t. t is given by $f'(t) = \frac{\partial^2 F(t)}{\partial t^2} = -3\alpha t^2 + \alpha c + (1-\alpha)(1-\frac{2}{\beta})$. Now we discuss the maximizer of $F(t)$ as follows: (1) When $\alpha \neq 0$, $\alpha \neq 1$ and $s_2 \neq 0$, $f(t)$ has exactly one positive root based on Descartes' Rule of Signs. Note that $f(0) = (1-\alpha)s_2 > 0$ and $f(1) = -\frac{2(1-\alpha)}{\beta} - 2\alpha + \alpha c + (1-\alpha)s_2 + 1 < s_2 + \alpha c - \alpha s_2 - 1 < 0$. Therefore $f(t)$ is maximized at $t_{BC} \in (0,1)$ which is the unique non-negative real root of $f(t)$. (2) When α approaches to 0, $f(t) = s_2 - \frac{2-\beta}{\beta}t$. FOC gives $t_{BC} = \frac{\beta}{2-\beta}s_2$, which is the maximizer as $f'(t) = -\frac{2-\beta}{\beta} < 0$. (3) When $\alpha = 1$, $f(t) = -t^3 + ct$. FOC gives $t = 0$ and $t = \sqrt{c}$, with $f'(0) = c$ and $f'(\sqrt{c}) = -2c$, respectively. Therefore the maximizer is $t_{BC} = \sqrt{c}$. (4) When $s_2 = 0$, $f(t) = -\alpha t^3 + [\alpha c + (1-\alpha)(1-\frac{2}{\beta})]t$. FOC gives $t = 0$ and $t = \sqrt{\frac{\alpha\beta c + (1-\alpha)(\beta-2)}{\alpha\beta}}$ with $f'(0) = \frac{1}{\beta}(\alpha\beta c + (1-\alpha)(\beta-2))$ and $f'(\sqrt{\frac{\alpha\beta c+(1-\alpha)(\beta-2)}{\alpha\beta}}) = -\frac{2}{\beta}(\alpha\beta c + (1-\alpha)(\beta-2))$. Therefore, when $\alpha\beta c + (1-\alpha)(\beta-2) > 0$, $t_{BC} = \sqrt{\frac{\alpha\beta c+(1-\alpha)(\beta-2)}{\alpha\beta}}$ is the maximizer; when $\alpha\beta c + (1-\alpha)(\beta-2) < 0$, $t_{BC} = 0$ is maximizer. When $\alpha\beta c + (1-\alpha)(\beta-2) = 0$, $f(t) = -\alpha t^3$, and thus $t_{BC} = 0$ achieves the maximum value. □

Proof of Corollary 1. From Lemma 2, the first-order condition of $F(t)$ gives $f(t_{BC};\kappa) = 0$, and $\kappa \in \{\alpha, \beta, s_2, c\}$. Based on Implicit Function Theorem, we have $\frac{dt_{BC}}{d\kappa} = -\frac{\frac{\partial f(t_{BC};\kappa)}{\partial\kappa}}{f'(t_{BC})}$. Due to the necessity of the second-order condition, we know that $\frac{dt_{BC}}{d\kappa}$ has the same sign as $\frac{\partial f(t_{BC};\kappa)}{\partial\kappa}$. Then we have the following results: (1) $\frac{\partial f(t_{BC};\beta)}{\partial\beta} = \frac{2t_{BC}}{\beta^2}(1-\alpha)$; (2) $\frac{\partial f(t_{BC};s_2)}{\partial s_2} = 1-\alpha$; (3) $\frac{\partial f(t_{BC};c)}{\partial c} = \alpha t_{BC}$; (4) $\frac{\partial f(t_{BC};\alpha)}{\partial\alpha} = -t_{BC}^3 + t_{BC}(\frac{2}{\beta} + c - 1) - s_2$. It is easy to verify the monotonicity of t_{BC} w.r.t. β, s_2, c, and we next show $\frac{\partial f(t_{BC};\alpha)}{\partial\alpha} > 0$. First, we note that $f(\frac{\beta}{2-\beta}s_2) = \frac{s_2\alpha\beta(c(2-\beta)^2 - s_2^2\beta^2)}{(2-\beta)^3} > 0$ since we have the condition $\frac{1}{2} > c > s_2 > 0$. Therefore we have $t_{BC} > \frac{\beta}{2-\beta}s_2$. Let $g_1(t) \equiv -t^3 + t(\frac{2}{\beta} + c - 1) - s_2$, which is concave in t. According to Descartes' Rule of Signs, $g_1(t)$ has no or two positive roots since there are two sign changes. We also note that $g_1(0) = -s_2$ and $g_1(1) = \frac{2}{\beta} - 2 + c - s_2 > 0$, implying $g_1(t)$ has a smaller positive root $\hat{t}_s \in (0,1)$ and a larger positive root $\hat{t}_l > 1$. In addition, we have $g_1(\frac{\beta}{2-\beta}s_2) = \frac{s_2\beta(c(2-\beta)^2 - s_2^2\beta^2)}{(2-\beta)^3} > 0$. Therefore, $g_1(t) > 0$ when $t \in (\frac{\beta}{2-\beta}s_2, 1]$. Note that $t_{BC} \in (\frac{\beta}{2-\beta}s_2, 1]$, implying $\frac{\partial f(t_{BC};\alpha)}{\partial\alpha} > 0$. Now we show the comparative statics w.r.t. selling price p_{BC}^* and refund r_{BC}^*.

(i) Since $p_{BC}^* = \frac{1+t_{BC}^2}{2}$, we have $\frac{dp_{BC}^*}{d\kappa} = t_{BC} \cdot \frac{dt_{BC}}{d\kappa}$, which suggests that p_{BC}^* has the same monotonicity as t_{BC} w.r.t. $k \in \{\alpha, \beta, c, s_2\}$. (ii) According to $r_{BC}^* = \frac{t_{BC}}{\beta}$, we know that r_{BC}^* has the same monotonicity as t_{BC} w.r.t. κ when $\kappa \neq \beta$. When $\kappa = \beta$, we have $\frac{dr_{BC}^*}{d\beta} = \frac{1}{\beta^2}(\frac{dt_{BC}}{d\beta}\beta - t_{BC})$. Therefore, we have $\frac{dr_{BC}^*}{d\beta} \geq 0$ when $\frac{dt_{BC}/t_{BC}}{d\beta/\beta} \geq 1$, and $\frac{dr_{BC}^*}{d\beta} < 0$ when $\frac{dt_{BC}/t_{BC}}{d\beta/\beta} < 1$. To show r_{BC}^* first increases and then can decrease in β, we note that $f(r_{BC}^*) = f(t_{BC})|_{t_{BC}=\beta r_{BC}^*} = r_{BC}^*(\beta + \alpha(\beta(c-1)+2) - 2) - \alpha\beta^3(r_{BC}^*)^3 - \alpha s_2 + s_2 = 0$. By Implicit Function Theorem, we know that $\frac{dr_{BC}^*}{d\beta}$ have the same sign as $\frac{\partial f(r_{BC}^*)}{\partial\beta}$. The result is obtained because $\lim_{\beta\to 0^+} \frac{\partial f(r_{BC}^*)}{\partial\beta} = r_{BC}^*(1 - \alpha(1-c)) \geq 0$, and $\lim_{\alpha\to 1^-}\left(\lim_{\beta\to 1^-} \frac{\partial f(r_{BC}^*)}{\partial\beta}\right) = -c\sqrt{c} \leq 0$. (iii) Let $\mathcal{R}_{BC} = p_{BC}^* - r_{BC}^* = \frac{1}{2} + \frac{t_{BC}^2}{2} - \frac{1}{\beta}t_{BC}$. We have $\frac{d\mathcal{R}_{BC}}{dk} = (1 - \frac{1}{\beta})\frac{dt_{BC}}{dk}$ when $k \neq \beta$. Therefore, $\mathcal{R}_{BC}$ is decreasing in α. Let $g_2(t_{BC}) = \frac{d\mathcal{R}_{BC}}{d\beta} = t_{BC}\frac{dt_{BC}}{d\beta} + \frac{1}{\beta^2}t_{BC} - \frac{1}{\beta}\frac{dt_{BC}}{d\beta}$. Plugging $\frac{dt_{BC}}{d\beta} = -\frac{\frac{\partial f(t_{BC})}{\partial\beta}}{f'(t_{BC})}$ into $g_2(t_{BC})$, we find that $\lim_{\alpha\to 0} g_2(t_{BC}) = -\frac{(2-\beta-2\beta s_2)s_2}{(2-\beta)^3} < 0$ and $\lim_{\alpha\to 1} g_2(t_{BC}) = \frac{\sqrt{c}}{\beta^2} > 0$. □

Proof of Proposition 2. By Envelope Theorem, we have $\frac{d\pi_{BC}^*}{d\beta} = \frac{\partial F(t)}{\partial\beta}|_{t=t_{BC}} = \frac{(1-\alpha)t_{BC}^2}{\beta^2} > 0$. Therefore π_{BC}^* is increasing in β. For information level α, we have $\frac{d\pi_{BC}^*}{d\alpha} = \frac{\partial F(t)}{\partial\alpha}|_{t=t_{BC}} = \frac{g_3(t_{BC})}{4\beta}$, where $g_3(t_{BC}) = -\beta t_{BC}^4 + 2t_{BC}^2(\beta(c-1)+2) - 4\beta s_2 t_{BC} - \beta(1-2c)$. According to Corollary 1, the discounted refund t_{BC} is increasing in α, and thus we can verify the sign of $g_3(t_{BC})$ as follows: (1) We first prove that $g_3(t_{BC})$ is strictly increasing in α. Note that $\frac{dg_3(t_{BC})}{d\alpha} = \frac{dt_{BC}}{d\alpha}(4t_{BC}(\beta(c-1)+2) - 4\beta s_2 - 4\beta t_{BC}^3)$. Since $t_{BC} > \frac{\beta}{2-\beta}s_2$, $\frac{dt_{BC}}{d\alpha} > 0$, and $\frac{1}{2} > c > s_2 > 0$, we verify that $\frac{dg_3(t_{BC})}{d\alpha} > 0$. (2) Next, we show $g_3(t_{BC})$

can be either negative or positive. From Lemma 2, we have $\lim_{\alpha\to 0} t_{BC} = \frac{\beta}{2-\beta}s_2$. Then $\lim_{\alpha\to 0} g_3(t_{BC}) = \beta(c(\frac{2\beta^2 s_2^2}{(\beta-2)^2}+2) - \frac{\beta^4 s_2^4}{(\beta-2)^4} + \frac{2\beta s_2^2}{\beta-2} - 1)$, which is verified to be negative. By continuity, $\frac{d\pi^*_{BC}}{d\alpha} < 0$ when α is small. Further, we have $\lim_{\alpha\to 1} t_{BC} = \sqrt{c}$, and thus $\lim_{\alpha\to 1} g_3(t_{BC}) = 4c - (1 - c^2 + 4\sqrt{c}s_2)\beta$. We know that $\lim_{\alpha\to 1} \frac{d\pi^*_{BC}}{d\alpha}$ is positive when $\beta < \min\{\beta_1^b, 1\}$, where $\beta_1^b = \frac{4c}{1-c^2+4\sqrt{c}s_2}$. Therefore, $\frac{d\pi^*_{BC}}{d\alpha}$ can be positive when α is large. In addition, we have $\frac{d\beta_1^b}{dc} = \frac{4(c^2+2\sqrt{c}s_2+1)}{(c^2-4\sqrt{c}s_2-1)^2} > 0$ and $\frac{d\beta_1^b}{ds_2} = -\frac{16c^{3/2}}{(c^2-4\sqrt{c}s_2-1)^2} < 0$, so β_1^b is increasing in $c - s_2$. Summarizing (1) and (2), there is a threshold such that π^*_{BC} decreases in α before it and increases after. $\square$

Proof of Proposition 3. The total consumer surplus and social welfare are defined as $CS_{BC}(p,r) = (1-\alpha)CS^{1-\alpha}_{BC}(p,r) + \alpha CS^{\alpha}_{BC}(p,r)$ and $SW_{BC}(p,r) = CS_{BC}(p,r) + \Pi_{BC}(p,r)$, respectively. Under the optimal solutions, the surplus of nonsearchers is given by $CS^{1-\alpha}_{BC}(p^*_{BC}, r^*_{BC}) = \int_0^{\beta r^*_{BC}} \beta r^*_{BC} - p^*_{BC}\, dv + \int_{\beta r^*_{BC}}^1 v - p^*_{BC}\, dv = \frac{1}{2}((\beta r^*_{BC})^2 + 1) - p^*_{BC}$. Recall that $p^*_{BC} = \frac{1+(\beta r^*_{BC})^2}{2}$. We obtain $CS^{1-\alpha}_{BC}(p^*_{BC}, r^*_{BC}) = 0$. The surplus of searchers is given by $CS^{\alpha}_{BC}(p^*_{BC}, r^*_{BC}) = \int_{p^*_{BC}}^1 v - p^*_{BC}\, dv = \frac{1}{2}(1-p^*_{BC})^2 = \frac{1}{8}(1-t^2_{BC})^2$. So the we have $CS^*_{BC} = \frac{1}{8}\alpha(1-t^2_{BC})^2$. Further, $\frac{dCS^*_{BC}}{d\beta} = -\frac{1}{2}\alpha t_{BC}(1-t^2_{BC}) \cdot \frac{dt_{BC}}{d\beta} < 0$ since $\frac{dt_{BC}}{d\beta} > 0$. $\square$

Proof of Proposition 4. Note that $\frac{dCS^*_{BC}}{d\alpha} = \frac{1}{8}(1-t^2_{BC})(1-t^2_{BC}-4\alpha t_{BC}\frac{dt_{BC}}{d\alpha})$ and $\frac{d^2CS^*_{BC}}{d\alpha^2} = \frac{1}{8}(-2t_{BC}\frac{dt_{BC}}{d\alpha})(1-t^2_{BC} - 4\alpha t_{BC}\frac{dt_{BC}}{d\alpha}) + \frac{1}{8}(1-t^2_{BC})(-2t_{BC}\frac{dt_{BC}}{d\alpha} - 4t_{BC}\frac{dt_{BC}}{d\alpha} - 4\alpha((\frac{dt_{BC}}{d\alpha})^2 + \frac{d^2t_{BC}}{d\alpha^2}))$. By Implicit Function Theorem, we can drive $\frac{dt_{BC}}{d\alpha}$ and $\frac{d^2t_{BC}}{d\alpha^2}$. And we then obtain $\frac{d^2CS^*_{BC}}{d\alpha^2} = \frac{M_1}{M_2}$. The detailed expressions are shown in Online Appendix A.3. Using the condition $f(t_{BC}) = t_{BC}((1-\alpha)(1-\frac{2}{\beta}) + \alpha c) + (1-\alpha)s_2 - \alpha t^3_{BC} = 0$, we can show that $M_1 < 0$ and $M_2 > 0$. Therefore, CS^*_{BC} is cancave in α. In addition, we have $\lim_{\alpha\to 0+} \frac{dCS^*_{BC}}{d\alpha} = \frac{1}{8}(1-\frac{\beta^2 s_2^2}{(2-\beta)^2})^2 > 0$, and $\lim_{\alpha\to 1-} \frac{dCS^*_{BC}}{d\alpha} = \frac{(c-1)(\beta c^{3/2}+(4-3\beta)\sqrt{c}-2\beta s_2)}{8\beta\sqrt{c}} < 0$. Therefore, there must be a threshold $\bar{\alpha}_1$ such that CS^*_{BC} is increasing in α when $\alpha < \bar{\alpha}_1$ and decreasing otherwise. $\square$

Proof of Corollary 2. The welfare-maximizing problem under strategy BC is given by $\max_{p,t} SW_{BC}(p,t) = \Pi_{BC}(p,t) + CS_{BC}(p,t)$, s.t. $\mathbb{E}\max(v,t) \geq p$. (1) When $\alpha \neq 0$ and $\alpha \neq 1$, FOCs for the unconstrained problem $\frac{\partial SW_{BC}(p,t)}{\partial p} = 0$ and $\frac{\partial SW_{BC}(p,t)}{\partial t} = 0$ give $p^{**}_{BC} = c$ and $t^{**}_{BC} = \frac{\beta}{2-\beta}s_2$. It is easy to verify that the interior solutions always satisfy the non-convex constraint with the condition $s_2 < c \leq \frac{1}{2}$. Moreover, it can be verified that the second-order conditions of the unconstrained problem are satisfied. (2) When $\alpha = 0$, we have $SW_{BC}(p,t) = -c + s_2 t + \frac{\beta+(\beta-2)t^2}{2\beta}$. FOC gives $t^{**}_{BC} = \frac{\beta}{2-\beta}s_2$. (3) When $\alpha = 1$, we have $SW_{BC}(p,t) = \frac{1}{2}(p-1)(2c-p-1)$. FOC gives $p^{**}_{BC} = c$. $\square$

Proof of Proposition 5. By Proposition 2, π^*_{BC} is increasing in β. The following situations are considered: (1) Consider $\beta = 1$. Let $\mathcal{B}_1(t) = \Pi_{BC}(\frac{1+t^2}{2}, t)|_{\beta=1} - \pi^*_{NB}$. $\mathcal{B}_1(t)$ is also maximized at t_{BC} with maximum value $\mathcal{B}_1^*$. Due to $\frac{d\mathcal{B}_1^*}{dc} = \frac{\partial \mathcal{B}_1(t)}{\partial c}|_{t=t_{BC}} = \frac{1}{2}\alpha(1+t^2_{BC}) > 0$, $\frac{d\mathcal{B}_1^*}{ds_2} = \frac{\partial \mathcal{B}_1(t)}{\partial s_2}|_{t=t_{BC}} = (1-\alpha)t_{BC} > 0$, $\frac{d\mathcal{B}_1^*}{ds_1} = -s_1 - f < 0$, and $\frac{d\mathcal{B}_1^*}{df} = 1 - f - s_1 > 0$, we know that $\mathcal{B}_1(t)$ is increasing in c, s_2 and f, and is decreasing in s_1. We first prove that $\pi^*_{BC}|_{\beta=1} > \pi^*_{NB}$ is possible. When $c = s_2 = \frac{1}{2}$ and $s_1 = 0$, $\mathcal{B}_1^* = \frac{1}{4}(1-t_{BC})t_{BC}(\alpha(t^2_{BC} + t_{BC} - 2) + 2) + f - \frac{1}{2}f^2 > 0$ as $t_{BC} \in (0,1)$. By the continuity arguments, $\mathcal{B}_1^*$ is positive when c and s_2 are sufficiently large and s_1 is sufficiently small. Then we prove that $\pi^*_{BC}|_{\beta=1}$ can be lower than π^*_{NB}. When $c = s_2 = s_1 = \frac{1}{2}$ and $f = 0$, we have $\mathcal{B}_1(t) = \frac{1}{8}(-2\alpha t^4 + (6\alpha - 4)t^2 - 4(\alpha-1)t - 1)$. Note that $\mathcal{B}_1(t)$ is maximized at the unique non-negative value t_{BC} that solves $\frac{\partial \mathcal{B}_1(t)}{\partial t} = 0$. In addition, we have $\frac{d\mathcal{B}_1^*}{d\alpha} = -2(t_{BC}-1)^2 t_{BC}(t_{BC}+2) < 0$, implying $\mathcal{B}_1^* < \lim_{\alpha\to 0} \mathcal{B}_1^* = -(1-2t_{BC})^2 \leq 0$. Next, when $c = s_2 = s_1 = \frac{1}{2}$ and $f = \frac{1}{2}$, we have $\mathcal{B}_1(t) = \frac{1}{4}(1-t_{BC})t_{BC}(\alpha(t^2+t-2)+2) > 0$. Therefore, $\mathcal{B}_1^*$ is negative when s_1 is sufficiently large and f is sufficiently low. (2) Consider $\beta = 0$. In this case a nonsearcher obtains ex-ante utility $U^{1-\alpha}_{BC} = \frac{1}{2} - p$ if he buys the product, and the retailer's optimization problem is given by $\max_p\ (1-\alpha)(p-c)+\alpha(1-p)(p-c)\quad \text{s.t. } p \le \frac{1}{2}$. The retailer obtains the maximum profit $\pi^*_{BC}|_{\beta=0} = \frac{1}{4}(2-\alpha)(1-2c)$ when $p=\frac{1}{2}$. Denote $\mathcal{B}^*_2 = \pi^*_{BC}|_{\beta=0} - \pi^*_{NB}$. And $\mathcal{B}^*_2$ increases in c and f but decreases in s_1. When $c=\frac{1}{2}$ and $s_1=0$, $\mathcal{B}^*_2 = \frac{1}{2}(2-f)f \ge 0$. In addition, $\mathcal{B}^*_2|_{f=\frac{1}{2}} > 0$ and $\mathcal{B}^*_2|_{f=0} < 0$.

(i) Summarizing (1) and (2), it is possible to find a threshold $\hat{\beta} \in (0,1)$ such that $\pi^*_{BC} < \pi^*_{NB}$ before it and $\pi^*_{BC} > \pi^*_{NB}$ after. (ii) For the impact of α: By Proposition 2, we know that π^*_{BC} can be U-shaped in α, while π^*_{NB} is independent of α. The further analysis in Online Appendix A.4 shows that $\mathcal{B}^*_1(\alpha) = \pi^*_{BC}|_{\beta=1} - \pi^*_{NB}$ can have two positive roots w.r.t. α. $\square$

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