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Research Title: Combating Counterfeits in Secondary Markets: Impacts of Manufacturer’s Blockchain Traceability and Platform’s AI-based Authentication

Combating Counterfeits in Secondary Markets: Impacts of Manufacturer's Blockchain Traceability and Platform's AI-based Authentication

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Abstract: Counterfeit products in secondary markets not only pose significant threats to branded manufacturers and C2C platforms but also alter the dynamics between primary and secondary product transactions, which raises concerns about the manufacturer's profit, consumer surplus, social welfare, and environmental sustainability. This paper examines the impacts of two anti-counterfeiting strategies on economic, social, and environmental sustainability: the manufacturer's blockchain-based traceability system and the C2C secondary platform's AI-based authentication service.

We develop a two-period analytical model in which a manufacturer sells new products to strategic consumers over two periods, while a C2C secondary platform facilitates the resale of used products. Consumers are heterogeneous in their valuations of product usage. Our findings reveal several key insights. First, the presence of counterfeits in secondary markets generates a value-shrinkage effect, which undermines the manufacturer's profit. Although the manufacturer's adoption of a blockchain traceability system can eliminate counterfeits through a quality-disclosure effect and expand the feasible range of used product transactions, it does not always guarantee positive returns for the manufacturer; its effectiveness depends critically on product durability, the extent of counterfeiting in the secondary market, and the unit implementation cost. Second, the AI-based authentication service offered by the C2C secondary platform induces both the quality-disclosure effect and a demand-reduction effect. It can also expand the secondary market and enhance the manufacturer's profit, but only under specific conditions, with product durability, the authentication fee, and the degree of counterfeiting invasion playing pivotal roles. Moreover, when extending our model to consider the impact of imperfect AI-based authentication, we find—counterintuitively—that an imperfect authentication service can, under certain conditions, yield higher profits for the manufacturer than a perfectly reliable service. Finally, we highlight the social and environmental implications of the two anti-counterfeiting strategies. While both can achieve win-win outcomes for consumers and the manufacturer, and improve social welfare under certain conditions, they may also exacerbate environmental burdens by encouraging additional production and consumption of new products. Our findings highlight the complex trade-offs involved in combating counterfeits in secondary markets and underscore the importance to balance economic outcomes, social welfare, and environmental sustainability.

Keywords: Anti-counterfeiting, secondary markets, blockchain traceability, artificial intelligence, environmental sustainability

Content

1. Introduction

Counterfeiting is a widespread global challenge. It is estimated that global trade in counterfeit goods in 2021 was approximately USD 467 billion (OECD/EUIPO, 2025). Within the EU, the clothing, cosmetics, and toy industries suffer annual losses of around EUR 16 billion due to counterfeiting, resulting in nearly 200,000 job losses (Rayon, 2024). Branded products are the main targets of counterfeiters. Historically, counterfeit products were primarily concentrated in luxury items, such as watches and branded clothing. Today, counterfeiting is increasingly prevalent across sectors including sportswear, medical equipment, automotive parts, consumer electronics, and cosmetics, medicines, and sportswear.

According to OECD/EUIPO (2021, 2025), C2C secondary markets are more vulnerable to counterfeit goods than primary markets for new products, and their effects on manufacturers and market dynamics are complex. Most secondary market transactions, whether involving high-value items such as diamonds and electronics (e.g., smartphones) or lower-value items like second-hand clothing, are susceptible to counterfeiting (Fontana et al., 2019; Ghose et al., 2005). Counterfeit products influence secondary markets in multiple ways. First, potential buyers, unable to accurately assess the authenticity of used products, are less willing to pay high prices when counterfeiting risk is present, which dampens the value-enhancement effect of the secondary market (Jiang & Tian, 2018). Conversely, lower prices for used goods can intensify the cannibalization effect and negatively affect manufacturers (Pang et al., 2024). Nevertheless, the presence of counterfeits may also encourage more consumers to purchase new products from manufacturers, thereby mitigating the demand-cannibalization effect of secondary markets on the primary market and increasing overall demand for new products (Oraiopoulos et al., 2012).

Counterfeit products not only disrupt C2C secondary market dynamics, but also reshape the primary market and threaten branded manufacturers. While it is intuitive that both manufacturers and C2C secondary platforms should proactively combat counterfeiting, practices are mixed. Some manufacturers of sportswear (e.g., Nike), automotive parts (e.g., GM and Renault), consumer electronics (e.g., Sony), cosmetics (e.g., L'Oréal), and platforms such as Dewu (poizon.com) and Xianyu (goofish.com) actively fight counterfeiting, whereas many others—including certain manufacturers and platforms like ebay.com—demonstrate little engagement. This variation motivates our investigation into the anti-counterfeiting strategies adopted by branded manufacturers and C2C secondary platforms, and their impacts on manufacturers, consumers, and social welfare.

In practice, branded manufacturers increasingly adopt blockchain traceability (BT) systems to combat counterfeiting. BT systems function as distributed, tamper-resistant ledgers that securely store and verify information within peer-to-peer networks (Olsen & Tomlin, 2020), and provide full transparency of their identities (Iyengar et al., 2022). For example, Nike adopts a BT system to authenticate sneakers and verify their provenance, in order to enhance consumer valuation in used products. BT systems enable firms to monitor the entire supply chain and provide buyers with reliable information about product authenticity. Therefore, they can enhance the value of used products in secondary markets and may mitigate the demand-cannibalization effect of secondary markets on the primary market. However, the substantial implementation costs (often exceeding USD 1 million) may deter the adoption of blockchain traceability (BT) and reduce manufacturers' profits. Moreover, the complex interaction between product durability, the degree of counterfeiting invasion, and other market factors complicates manufacturers' adoption decisions and may alter the dynamics between secondary and primary markets. This interplay motivates our first research question: *What are the impacts of a manufacturer's adoption of blockchain traceability systems?*

To address consumers' concerns about counterfeit products, many C2C secondary platforms (e.g., Dewu, Vestiaire Collective, ThredUP) provide artificial intelligence (AI) based authentication service. For instance, Dewu (poizon.com), one of China's largest C2C secondary platforms, leverages AI to verify the authenticity of used products, achieving a consistency rate with human authentication experts exceeding 99.9999%. Typically, C2C secondary platforms charge sellers a fee for AI-based authentication. If used products are identified as counterfeit, they cannot be sold on the platform. Consequently, AI-based authentication mitigates counterfeiting in secondary markets and increases buyers' willingness to pay for used products, which can further benefit the primary market. However, the authentication fees paid by sellers may raise resale prices and reduce demand for used goods, ultimately affecting the primary market. This complex interplay motivates our second research question: *Do AI-based authentication services provided by C2C secondary platforms benefit manufacturers?*

Beyond economic considerations, counterfeit products undermine the efforts of governments and manufacturers to promote sustainability and protect consumers. Secondary markets facilitate the circulation of used products, thereby extending their life cycles and serving as effective instruments for reducing environmental impact and achieving broader social objectives. For instance, in the furniture, sportswear, and apparel industries, firms such as IKEA (2024), Patagonia (2024), and Levi's (2024) have actively promoted used-goods transactions to support environmental sustainability. Governments worldwide are also committed to developing secondary markets and encouraging consumer participation in product circularity. Naturally, since both manufacturers' blockchain traceability (BT) systems and C2C platforms' AI-based authentication can alleviate consumers' concerns about product authenticity in secondary markets, while simultaneously imposing costs and altering the dynamics between primary and secondary markets, we are motivated to pose our third research question: *Do the two anti-counterfeiting strategies benefit consumer surplus, social welfare, and the environment?*

To address these questions, we develop an analytical model in which a manufacturer sells new products over two periods under a uniform pricing strategy. Consumers are forward-looking and strategically decide their purchases, recognizing that used products in the secondary market may be counterfeit. We examine two anti-counterfeiting strategies: the manufacturer's adoption of a blockchain traceability system to ensure product traceability and transparency, and the C2C platform's use of AI-based authentication to verify used goods. When either strategy is implemented, consumers are guaranteed access to genuine products in the secondary market. As an extension, we further examine the impact of imperfect AI-based authentication, which provides only partially reliable verification of used goods.

Our main results are as follows. First, counterfeiting in the secondary market generates a value-shrinkage effect for used goods, which reduces the manufacturer's profit. This finding provides plausible explanation for manufacturers combating counterfeit products. When the manufacturer adopts a blockchain traceability (BT) system, counterfeit goods can be eliminated, creating a quality-disclosure effect that benefits the manufacturer under certain conditions, determined by product durability, the extent of counterfeiting in the secondary market, and the unit cost of implementing BT. Moreover, although the C2C platform's AI-based authentication service can also generate the quality-disclosure effect and enhance the manufacturer's profit under specific conditions, high authentication fees may result in a demand-reduction effect in the primary market and hurt the manufacturer's profitability. Compared with the absence of anti-counterfeiting measures, both BT and AI-based authentication broaden the conditions that sustain transactions in the secondary market.

Second, both the manufacturer's blockchain traceability system and the C2C secondary platform's AI-based authentication service can enhance consumer surplus and social welfare, creating win–win outcomes for both consumers and the manufacturer under certain conditions depending on product durability, the degree of counterfeiting invasion, the unit cost of adopting blockchain traceability system, and the AI-based authentication fee. However, these strategies may exacerbate environmental burdens by promoting additional production and consumption of new products.

Third, we extend the model to consider the reliability of AI-based authentication by assuming an imperfect authentication service. Our findings indicate that the manufacturer can achieve a higher profit when the C2C secondary platform provides an imperfect AI-based authentication service, particularly when product durability is low to medium and the authentication service cost is low. We thus caution platforms that there is no need to obsess over the absolute reliability of the AI-based authentication service; in some cases, a partially unreliable service can paradoxically help secure higher profits.

The remainder of the paper is organized as follows. Section 2 reviews the literature and highlights our contributions. Section 3 presents the model and benchmark equilibrium without anti-counterfeiting. In Section 4 and 5, we analyze outcomes under the manufacturer's blockchain traceability and the C2C platform's AI-based authentication strategies, respectively. Section 6 examines their social and environmental implications, and Section 7 specifically extends the model to examine the impact of imperfect AI-based authentication service. Section 8 concludes and discusses directions for future research.

2. Literature Review

This study relates to several streams of literature, including research on counterfeiting and anti-counterfeiting strategies, secondary markets, quality authentication, and the emerging literature on technologies in providing authentication.

Counterfeiting and Anti-Counterfeiting Strategies

The first stream is counterfeiting and anti-counterfeiting strategies adopted by governments and manufacturers. Grossman and Shapiro (1988a, b) classify the markets for counterfeit products into two types, which correspond to deceptive counterfeiting and non-deceptive counterfeiting. They explore the border inspection policy and enforcement policy designed to combat counterfeiting. By conducting a natural policy experiment with randomized lab experiments, Qian (2014) shows counterfeits have both advertising effects for a brand and substitution effects for authentic products. Cho et al. (2015) explore the effects of different strategies to combat counterfeiting on manufacturers, counterfeiters, and consumers. By analyzing anti-counterfeiting technologies that pharmaceutical companies employ to combat counterfeits, Gao (2018) finds that higher technology complexity in imitation may not achieve a lower scale of counterfeit drug purchasing. Yi et al. (2022) examine the motivation of anti-counteracting of different members of a supply chain in which a global manufacturer distributes products through a local retailer.

Different from existing studies, this study examines two anti-counterfeiting strategies targeting deceptive counterfeiting: the manufacturer's adoption of a blockchain traceability system and a C2C secondary platform's provision of an AI-based authentication service. Importantly, unlike prior literature that primarily focuses on counterfeiting in the primary market, our research extends the analysis to the secondary markets. We find that both the BT and AI-based authentication can generated a quality-disclosure effect, and expand the existence of transactions in the secondary market. But the manufacturer's proactively adoption of BT does not always guarantee benefits and may even result in profit loss under certain conditions. These outcomes are shaped not only by the implementation cost of BT, but also by product durability and the extend of counterfeiting in the secondary market. Moreover, the impacts of the C2C secondary platform's AI-base authentication service on the manufacturer are not monotonic. While it may benefit the manufacturer, it can also be detrimental under certain conditions. This finding enriches our understanding of anti-counterfeiting in secondary markets and differs from the conventional wisdom that anti-counterfeiting in the primary market always benefit manufacturers.

Secondary Markets

Secondary markets may arise for a variety of reasons, i.e., consumers may sell their used products due to product mismatch (Jiang et al., 2017; Lei, 2022), valuations changing over time (Johnson, 2011), pursuing upgraded products (Yin, 2010) and repeat purchase preferences (Alev, 2020; Pang et al., 2023). Our study investigates how the presence of counterfeit products influences consumers' purchase decisions on both new and used products. In secondary markets, the coexistence of new and used goods induces consumers to wait strategically, which raises the cannibalization effect that reduces new product sales and profits for manufacturers. Extant research has extensively analyzed how the cannibalization effect affects the pricing of new products and market structure (Abbey et al., 2015; Ghose et al., 2006;

Pang et al., 2024). On the other hand, secondary markets can add value to used products, known as the value-enhancement effect (Tian & Jiang, 2018).

In contrast to prior studies that primarily emphasize the mitigating effect of counterfeits on secondary market cannibalization, our findings show that counterfeits simultaneously erode the expected value of used products and ultimately reduce manufacturers' profits. Moreover, while prior research often highlights certification as unambiguously beneficial, we demonstrate that blockchain traceability (BT) and AI-based authentication yield more nuanced effects: both generate a quality-disclosure effect, but AI-based authentication also introduces a demand-reduction effect. These mechanisms jointly reshape the dynamics between primary and secondary markets.

Finally, our research also contributes to understanding the societal and environmental implications of secondary markets. Alev et al. (2020) demonstrate that the optimal design of recycling policies depends on product durability. Building on this insight, we show that the benefits manufacturers derive from anti-counterfeiting strategies likewise vary with product durability. Pang et al. (2024) find that secondary markets can harm the environment. Extending this line of research, we show that while anti-counterfeiting strategies can benefit consumers, manufacturers, and social welfare, these gains may come at the expense of environmental sustainability.

Quality Authentication

Our study also relates to the literature on quality authentication. Lizzeri (1999) and Albano and Lizzeri (2001) analyze the impact of certification intermediaries in resolving information asymmetries for buyers paying for authentication and sellers signaling high-quality, respectively. By examining the optimal commission and penalty fees, Li et al. (2023) point out that inspection services can generate additional revenue for the C2C secondary platform. To mitigate adverse selection issues in secondary markets, prior literature explore quality authentications. Huang et al. (2023) suggest that certified pre-owned programs can eliminate the information asymmetry between the firm and buyers under trade-in programs. Although literature has explored product quality differentiation in secondary markets and the role of authentication, it often assumes equal quantities of genuine and counterfeit products. In contrast, we highlight the degree of counterfeit invasion in secondary markets. When the extent of counterfeits in the secondary market is low, consumers cannot benefit from the adoption of either the manufacturer's blockchain-based traceability system or the C2C secondary platform's AI-based authentication services.

Emerging Technologies in Providing Authentication

Our analysis is also closely related to the literature on emerging technologies for product authentication. In particular, the adoption of blockchain technology offers a promising solution for controlling counterfeiting and enhancing supply chain transparency. (Cui et al., 2024; Babich and Hilary, 2020). Iyengar et al. (2024) examine two key factors driving manufacturers' adoption of blockchain technology: manufacturer risk aversion and consumer information asymmetry. Shen et al. (2022) explore whether manufacturers would sell their products through a permissioned blockchain technology platform as a strategy to combat counterfeiters in the supply chain. They unveil the interaction between the positive impact of quality disclosure and the negative effect of double marginalization. Pun et al. (2021) shows that blockchain adoption shifts the deceptive counterfeit to a non-deceptive counterfeit. Choi (2019) and Zhou et al. (2022) disclose the value of manufacturers selling through blockchain-based platforms under the setting of single-channel retail and dual-channel competition. Tan (2022) analyzes the role of the adoption of blockchain technology in regulating the trading of pre-owned virtual items, highlighting the potential benefits for both developers and consumers in conducting item transactions through the blockchain. Unlike previous studies, our paper shows that for used goods in secondary markets, the introduction of a blockchain traceability anti-counterfeiting strategy cannot guarantee a higher profit for manufacturers, consumer surplus and social welfare.

Emerging AI technologies generate value across various fields, including procurement (Cui et al., 2022), job evaluation (Tong et al., 2021), legal decision-making (Cohen et al., 2024), and medical services (Hou et al., 2024). Prior literature has examined adoption strategies of AI tools in different settings. For example, Gursoy et al. (2019) show that consumers' perceptions of AI performance greatly impact their adoption decisions over time. Many research also explore firms' or consumers' AI adoption behaviors (Wang et al., 2023; Kyung & Kwon, 2025). We contribute to this stream of literature by examining the adoption of AI-based authentication services and their operational implications. We find that a reliable AI-based authentication service can benefit the manufacturer. Counterintuitively, our results further reveal that an imperfect AI-based authentication service can generate higher profits for the manufacturer under certain conditions. This insight adds to the growing body of research on AI adoption across industries and fills a gap in the analytical study of AI-driven authentication for combating counterfeiting, thereby extending the literature on emerging technologies for product authentication.

3. The Baseline Model

3.1 Model Setup

3.1.1 Product

We develop a two-period model in which a monopolistic manufacturer sells branded products to consumers. Counterfeit products exist in the secondary market. Following Bulow (1982) and Desai et al (2004), life of the product is assumed to be two periods[1]. We define a product as new when it is sold by the manufacturer in the primary market, and as used when it has been previously owned by consumers and retains only a remaining period of useful life. We use subscripts n and u to denote new and used products respectively. In addition, used products are subject to a reduction in use value for the cause of the deterioration in the life cycle, which is captured by product durability factor $\delta \in$

[1] The assumption of a two-period lifespan for the product is equivalent to assuming its obsolescence after n periods. The crucial aspect lies in assuming a finite duration for the product's longevity (Bulow, 1982).

$(0,1)$. δ represents consumers' willingness to pay for used products compared with a new one (Esenduran et al., 2020; Alev et al., 2020). The difficulty of imitation and the popularity of different product categories are different, leading to different proportions of counterfeit products in secondary markets. Following Shen et al. (2022) and Zhou et al. (2022), we assume that consumers know the proportion of genuine used products, denoted by α, in the secondary market. Therefore, the probability that a used product purchased by a consumer in the secondary market as a counterfeit is $(1-\alpha)$.

3.1.2 Consumer

The consumer mass is assumed to be one unit. A consumer uses at most one unit of the product at any time. Consumers are heterogeneous in their per-period valuation of the new product, denoted by v, which follows a uniform distribution over $[0,1]$. Consumers are strategic, to maximize their total utilities across two periods, they decide whether to buy a new product from the manufacturer at the beginning of period 1. If they do (to become pre-owned consumers), they will choose whether to sell the used product on the C2C secondary platform or hold it at the beginning of period 2. Consumers who do not purchase the new product in period 1 (referred to as waiting consumers) will postpone their purchase decision until period 2, at which point they may either buy a used product or exit the market.

For counterfeits in the secondary market, consumers value them at a per-period value v_c. For simplicity, we assume consumers receive zero value from counterfeits, i.e., $v_c = 0$. Consumers ex-ante know the potential of receiving deceptive counterfeits when purchasing used products in the secondary market. Thus, they make used-product purchase decisions based on the expected utility, which is $\delta(\alpha v + (1-\alpha)v_c) = \delta\alpha v$.

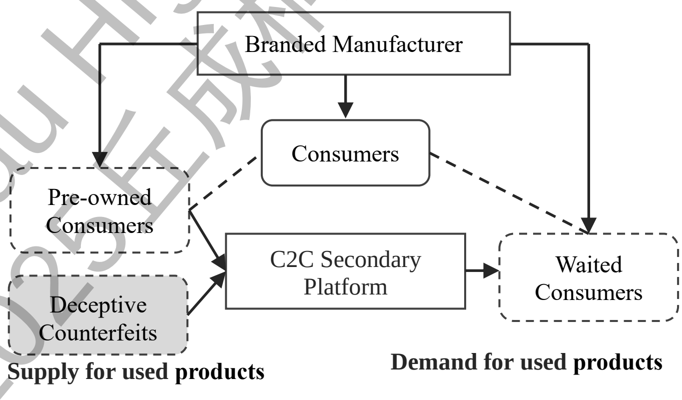

Figure 1 Market structure

3.1.3 Branded Manufacturer

Figure 1 depicts the market structure. Following Bitran & Caldentey (2003), Chen et al. (2019) and Liu & Zhang (2013), we assume the manufacturer adopts the uniform pricing strategy. Namely, it does not dynamically adjust the price of new products p_n due to the presence of the secondary market in period 2. In practice, most luxury goods and branded sneakers typically do not dynamically adjust their new product price due to the presence of secondary markets (Ang, 2016). Without loss of generality, we normalize the unit production cost to be zero.

The manufacturer's objective is to maximize the profit Π^j, where the superscript $j \in \{B, BT, AI, MAI\}$ represents different cases. Benchmark case B represents the case where counterfeit products exist in the secondary market, but no anti-counterfeiting strategy is adopted. Case BT represents the manufacturer's proactive anti-counterfeiting strategy that adopts a blockchain-based traceability system to offer transparent information to consumers. The adoption of blockchain traceability system imposes costs on the manufacturer, including expenditures on the infrastructure environment and implementation. We assume that the manufacturer incurs a per-unit cost c for implementing the blockchain traceability system. Case AI represents the C2C secondary platform offers a perfect AI-based authentication service to sellers of used products. In the extended model, we explore the Case MAI that the AI-based authentication is imperfect.

3.1.4 Frictionless C2C Secondary Platform

Second-hand transactions take place on a C2C secondary platform with price p_u. In equilibrium, a market-clearing price p_u^* coincides supply and demand in the secondary market (Jiang & Tian, 2018). Without loss of generality, we normalize the commission fee into zero to assume a frictionless secondary market[2] (Jiang et al., 2017). Under cases AI and MAI, the C2C secondary platform offers the AI-based authentication service at a price f, which is exogenous. We assume f represents the platform's service cost for authenticating used products. Sellers in the secondary market pay the authentication fee f to the platform (Stahl and Strausz, 2017).

3.1.5 Environmental Impact

Following Agrawal et al. (2012), we evaluate the total environmental impact across three life-cycle phases: production, use, and disposal. Let e_p represent the per-unit impact during the production phase, e_n and e_u the per-period per-unit impacts of new and used products during the use phase, and e_d the per-unit impact during the disposal phase. For each phase, the environmental impact is calculated as the product of the corresponding per-unit impact and the quantity of products involved.

TABLE 1 Notation list

Notations	Description
Indices	
t	Number of periods, $t = \{1, 2\}$
n, u	New product n; Used product u
j	Cases $j = B, BT, AI, MAI$
B	Benchmark
BT	The manufacturer's blockchain-based traceability service

[2] In practice, we can observe the existence of diverse frictionless platforms, including but not limited to Swappa, Craigslist, and autoTRADER. These platforms enable their customers to engage in trading activities without incurring transaction costs, while generating profits from alternative revenue streams such as advertisements and other sources.

AI	Platform's AI-based authentication service
MAI	Imperfect AI-based authentication service offered by the platform
NN, NH, WU, WL	Consumer choices in period 1 and 2 (N: New; U: Used; H: Hold; L: Leave)
Parameters	
v	Consumers' per-period value of a new product; $v \sim U[0,1]$
δ	Product durability
α	The proportion of genuine used products in the secondary market
c	The manufacturer's unit cost of implementing a BT system for each product
f_c	The platform's price of the AI-based authentication service
e_p, e_n, e_u, e_d	Per-unit impact of production-phase, use-phase impact of a new and a used product, disposal-phase, respectively
Decision variables	
p_n^j	The price of new products
Dependent variables	
p_u^j	The price of used products in the secondary market
D^j	Number of consumers
Π^j	The manufacturer's profit
CS^j	Consumer surplus
SW^j	Social welfare
E^j	Environmental impact

3.1.6 Time Sequence

The time sequence is shown in Figure 2. At the beginning of period 1, the manufacturer determines the price of new products and consumers decide to purchase or to wait. All consumers stay at the market at the end of period 1. At the beginning of period 2, consumers decide the purchase option that maximizes their utility.

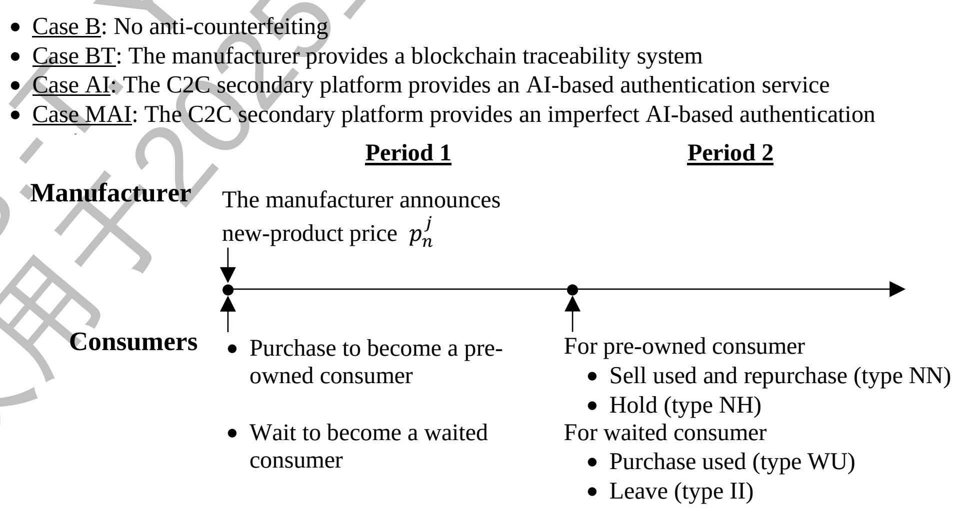

Figure 2 Time sequence

3.2 Benchmark

We start with the benchmark case (B), in which neither the manufacturer nor the C2C platform adopts any anti-counterfeiting technology, allowing counterfeit products to circulate in the secondary market. The benchmark serves as a baseline for evaluating the effects of anti-counterfeiting strategies. Consumers have four options:

(a) NN: buy a new product in both periods and sell used products in period 2, which yields a utility: $V_{NN} = 2v - 2p_n^B + p_u^B$;

(b) NH: buy a new product in period 1, and hold it in period 2, which yields a utility: $V_{NH} = (1+\delta)v - p_n^B$;

(c) WU: wait in period 1 and buy a used product in period 2, which yields a utility: $V_{WU} = \delta\alpha v - p_u^B$;

(d) WL: wait in period 1 and leave in period 2 to get zero utility: $V_{WL} = 0$.

We assume that each pre-owned consumer will hold at least one unit of the product at hand. By this assumption, there will no consumers buy new products in either period 1, resell used ones and leave the market. Additionally, consumers will not choose to wait in period 1 and buy a new product in period 2 with utility $v - p_n^B$ since this option is dominated by choice NH.

The existence of transactions in the secondary market is conditional on the level of product durability δ. Specifically, when δ is high, transactions in the secondary market fail to emerge, i.e., neither type NN nor type WU is present in the market. The reason is two-fold. First, high durability raises the price of new products, discouraging consumers from reselling used items and repurchasing new ones. Second, consumers with durable products prefer to retain them, reducing the supply of used goods. Consequently, the secondary market collapses. In contrast, when δ is low, supply and demand are better aligned, sustaining secondary market transactions. The market-clearing price (p_u^*) of used products is determined by equating the supply (from NN-type consumers) with the demand (from WU-type consumers) for used products.

The number of consumers corresponding to the options is D_{NN}^B, D_{NH}^B, D_{WU}^B and D_{WL}^B, respectively. The total demand for the new product under case B is $2D_{NN}^B + D_{NH}^B$ since NN-type consumers buy new products in both periods. The manufacturer's profit function is:

$$\Pi^B = p_n^B(2D_{NN}^B + D_{NH}^B) \quad (1)$$

Using backward induction, we derive Lemma 1 that shows that the optimal price decision and the corresponding profit of the manufacturer, which are influenced by product durability (δ) and the proportion of genuine products in the secondary market α, as shown in Figure 3. All proofs and thresholds are relegated to Appendix.

Lemma 1. *In the benchmark, the manufacturer's optimal prices and profits are as follows:*[3]

[3] In this paper, we use parameters δ_g^j and α_g^j, where $j \in \{B, BT, AI, MAI\}$ and $g \in \{1,2,3 \ldots\}$. These two parameters are

$$p_n^{B*}=\begin{cases}\dfrac{-1+\alpha\delta+\delta^2-\alpha\delta^2}{-1-\alpha-\delta+2\alpha\delta} & 0<\delta<\dfrac{1}{3}\ and\ 0<\alpha<\alpha_1^B;\ \dfrac{1}{3}<\delta<\delta_1^B\ and\ \alpha_2^B<\alpha<\alpha_1^B\\ \dfrac{-2+\alpha\delta^2}{-4+2\alpha\delta} & 0<\delta<\delta_2^B\ and\ \max\left\{\alpha_1^B,\alpha_3^B\right\}\le\alpha<1\\ \dfrac{1+\delta}{2} & \dfrac{1}{3}<\delta<\delta_1^B\ and\ 0<\alpha\le\alpha_2^B;\ \delta_1^B<\delta<1\ and\ 0<\alpha<\max\left\{\alpha_3^B,1\right\}\end{cases},$$

$$\Pi^{B*}=\begin{cases}\dfrac{(1-\delta)(-1-\delta+\alpha\delta)\left(-2\delta+\alpha(-2+3\delta)\right)}{(1+\alpha+\delta-2\alpha\delta)^2} & 0<\delta<\dfrac{1}{3}\ and\ 0<\alpha<\alpha_1^B;\\ & 0<\delta<\delta_1^B\ and\ \alpha_2^B<\alpha<\alpha_1^B\\ \dfrac{\left(-2+\alpha\delta^2\right)^2}{4(-2+\alpha\delta)\left(-1-\delta+\alpha\delta^2\right)} & 0<\delta<\delta_2^B\ and\ \max\left\{\alpha_1^B,\alpha_3^B\right\}\le\alpha<1.\\ \dfrac{1+\delta}{4} & \dfrac{1}{3}<\delta<\delta_1^B\ and\ 0<\alpha\le\alpha_2^B;\\ & \delta_1^B<\delta<1\ and\ 0<\alpha<\max\left\{\alpha_3^B,1\right\}\end{cases}$$

Lemma 1 provides the optimal pricing decisions and the manufacturer's profit, which depend on the level of counterfeit product invasion (e.g., $1-\alpha$) and product durability (e.g., δ). In Region 1, the low-value and low-authenticity of used products induces the manufacturer to set a low price to attract more consumers to buy new products in the first period. In Region 2, when product durability is low and the proportion of genuine products in the secondary market is high, the manufacturer sets a moderate price because a low degree of counterfeiting intrusion enhances consumers' valuation of used products, which in turn supports a higher price for new products. However, when product durability is relatively high (Region 3), the manufacturer sets a high price to pursue greater profit margins. However, at such a price, no consumer resells used products—not only because they must pay a high price for new ones, but also because they assign low valuations to used products due to potential counterfeiting risk. Consequently, no transactions take place in the secondary market.

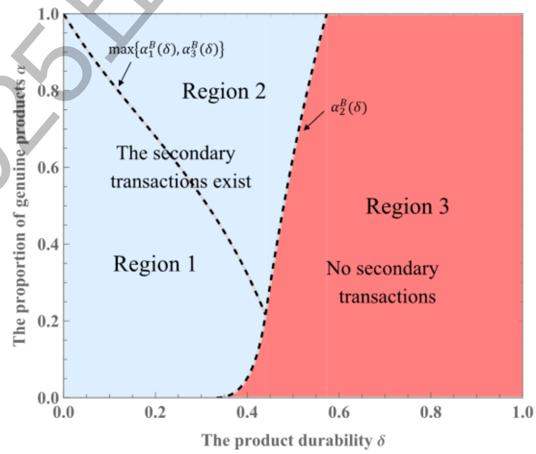

Figure 3 Equilibrium outcomes under Benchmark

used to distinguish between different thresholds of δ and α in equilibrium outcomes under each case. Specifically, superscript j is used to distinguish thresholds under different cases and subscript g is used to distinguish different thresholds under the same case.

Proposition 1. *In the presence of the secondary market, counterfeit products reduce the manufacturer's profit.*

By comparing the manufacturer's profit under the benchmark with that in a market without counterfeiting ($\alpha = 1$), we find that $\Pi^{B*}_{\alpha=1} > \Pi^{B*}_{0<\alpha<1}$ in the presence of counterfeiting in the secondary market, which reveals the negative impact of counterfeit products. When there are no secondary transactions ($\delta > \delta_1^N = \delta_2^B$), we can obtain that the manufacturer's profits are equal to that in the case without counterfeiting. The presence of counterfeits reduces the expected value of used products, leading to lower demand in the secondary market. Consequently, the value-enhancement effect of the secondary market on the primary market is weakened, resulting in lower manufacturer profits—an outcome we refer to as the *value-shrinkage effect* ($\text{i.e.}, \frac{\partial \Pi^{B*}}{\partial \alpha} > 0$). Proposition 1 proves that the manufacturer has an incentive to combat counterfeits in the secondary market. In Section 4, we analyze two scenarios: the manufacturer adopting the blockchain-based traceability system and the C2C secondary platform adopting the AI-based authentication service, respectively.

4. Manufacturer's Blockchain Traceability System

Many branded manufacturers offer blockchain traceability systems to combat counterfeit products. For each product, the unit cost for implementing blockchain traceability system is c. With the blockchain traceability system, consumers can access transparent product information across the manufacturer's supply chain. As a result, counterfeits in the secondary market are exposed and forced to be eliminated (i.e., $\alpha = 1$). In this situation, the expected utility of purchasing used products in the secondary market changes to δv for WU-type consumers, who derive a utility $V_{WU} = \delta v - p_u^{BT}$. The manufacturer's profit is:

$$\Pi^{BT} = (p_n^{BT} - c)(2D_{NN}^{BT} + D_{NH}^{BT}) \tag{2}$$

Using backward induction, Lemma 2 derives the optimal price decisions and profits of the manufacturer, which are influenced by product durability δ and the service cost c, as shown in Figure 4.

Lemma 2. *When providing the blockchain traceability, the manufacturer's optimal prices and profit are as follows:*

$$p_n^{BT*} = \begin{cases} \dfrac{c}{2} + \dfrac{-2+\delta^2}{2(-2+\delta)} & 0 < \delta < \delta_1^{BT} \text{ and } 0 < c \le 1 - \delta^2 - \sqrt{\dfrac{-\delta^2 - 2\delta^3 + \delta^5}{-2+\delta}} \\ \dfrac{1}{2}(1 + c + \delta) & 0 < \delta < 1 \text{ and } \max\left\{1 - \delta^2 - \sqrt{\dfrac{-\delta^2 - 2\delta^3 + \delta^5}{-2+\delta}}, 0\right\} < c < 1 \end{cases},$$

$$
\Pi^{BT*}=\begin{cases}\dfrac{\left(2+c\left(-2+\delta\right)-\delta^2\right)^2}{4\left(2+\delta-3\delta^2+\delta^3\right)} & 0<\delta<\delta_1^{BT} \text{ and } 0<c\le 1-\delta^2-\sqrt{\dfrac{-\delta^2-2\delta^3+\delta^5}{-2+\delta}} \\ \dfrac{\left(1-c+\delta\right)^2}{4\left(1+\delta\right)} & 0<\delta<1 \text{ and } \max\left\{1-\delta^2-\sqrt{\dfrac{-\delta^2-2\delta^3+\delta^5}{-2+\delta}},0\right\}<c<1\end{cases}
$$

We illustrate Lemma 1 in Figure 4. When product durability and the unit cost of adopting blockchain traceability are both low (Region 1), the manufacturer sets a low price to compete with the secondary market. As either product durability or the unit cost of implementing blockchain traceability system increases, the manufacturer will opt for setting a higher new product price to offset the cost, which makes no consumer resells used products in the secondary market (Region 2).

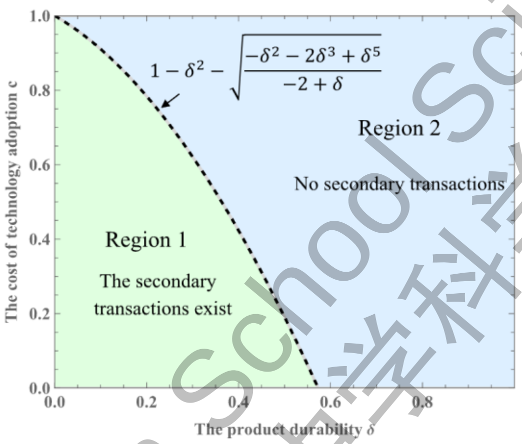

Figure 4 Equilibrium outcomes under case BT

Comparing the conditions for the existence of transactions in the secondary market between case B and case BT, we identify that the adoption of the blockchain traceability system enlarges the feasible region for sustaining secondhand transactions.

Proposition 2. *When the manufacturer implements a blockchain traceability (BT) system, the range of conditions supporting secondary-market transactions expands. Specifically, compared with the benchmark case, secondary transactions also occur for medium product durability (δ) and low unit cost (c) (Region 3[a] in Figure 5), i.e., given* α *if* $\frac{1}{3}<\delta<\delta_2^B$ *and* $0\le c<1-\delta^2-\sqrt{\frac{-\delta^2-2\delta^3+\delta^5}{-2+\delta}}$.

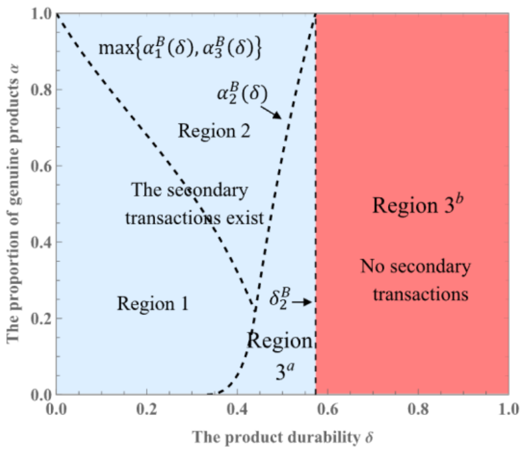

Figure 5 Feasible regions for the secondary transactions

The adoption of blockchain traceability system rules out the counterfeit goods in the secondary market, which increase the expected value of used products by authenticating their genuineness. We referred to it as the *quality-disclosure effect* (i.e., $\delta\alpha v \rightarrow \delta v$). Recall that in Region 3[a] (in Figure 3) of the benchmark case, no secondary-market transactions take place due to counterfeiting risk. In contrast, when the manufacturer implements the blockchain traceability system at a low unit cost (i.e., $0 \leq c < 1-\delta^2-\sqrt{\frac{-\delta^2-2\delta^3+\delta^5}{-2+\delta}}$), pre-owned consumers in Region 3[a] (in Figure 5) can sell their used products at a relatively high price, driven by the quality-disclosure effect of BT. As a result, secondary-market transactions emerge in this region when BT is implemented.

By comparing the manufacturer's profits between case B and case BT, Proposition 3 identifies the conditions under which the manufacturer can achieve a higher profit from combating counterfeits.

Proposition 3. *Compared with the benchmark, the manufacturer's profit increases from offering the blockchain traceability system when:*

(a) the unit cost for blockchain traceability is low, i.e., $0 \leq c < c_1$*, if both product durability and the proportion of genuine used products are low (Region 1);*

(b) the unit cost for blockchain traceability is low, i.e., $0 \leq c < c_2$*, if product durability is low and the proportion of genuine used products is high (Region 2);*

(c) the unit cost for blockchain traceability is low, i.e., $0 \leq c < c_3$*, if product durability is medium (Region 3*[a]*).*

where $c_1 = \frac{\delta^2-2}{\delta-2} - 2\sqrt{\frac{3\alpha^2\delta^5-8\alpha^2\delta^4+4\alpha^2\delta^3+3\alpha^2\delta^2-2\alpha^2\delta-5\alpha\delta^5+9\alpha\delta^4+4\alpha\delta^3-9\alpha\delta^2-\alpha\delta+2\alpha+2\delta^5-2\delta^4-4\delta^3+2\delta^2+2\delta}{(\delta-2)(2\alpha\delta-\alpha-\delta-1)^2}}$, $c_2 = \frac{-2+\delta^2}{-2+\delta} - \sqrt{\frac{-4-4\delta+4\delta^2+4\alpha\delta^2+4\alpha\delta^3-4\alpha\delta^4-\alpha^2\delta^4-\alpha^2\delta^5+\alpha^2\delta^6}{(-2+\delta)(2+2\delta-\alpha\delta-3\alpha\delta^2+\alpha^2\delta^3)}}$, *and* $c_3 = \frac{-2+\delta^2}{-2+\delta} - \sqrt{\frac{-1-2\delta+\delta^3}{-2+\delta}}$.

Otherwise, adopting the blockchain traceability system hurts the manufacturer.

On one hand, the quality-disclosure effect not only enhances consumers' willingness to pay for used products, strengthening the secondary market's value-enhancement effect, and enabling the manufacturer to charge a higher price for new products. On the other hand, the higher price of used products mitigates the secondary market's demand-cannibalization effect, thereby increasing demand for new products. Consequently, compared with the benchmark case, when the cost of implementing blockchain traceability system is low, the manufacturer can achieve a higher profit in Region 1 and Region 2 (Figure 5). Moreover, when product durability is relatively high (Region 3[a]), the sustained transactions of used products in the secondary market allow pre-owned consumers to resell used products at relatively high prices without fearing counterfeiting risk. This encourages them to purchase new products in period 2 at higher prices, ultimately benefiting the manufacturer. However, when product durability is sufficiently high (Region 3[b]), no pre-owned consumers resell used products under either case B or case BT. Consequently, adopting a blockchain traceability system, which entails additional costs, can become a burden for the manufacturer and may lead to profit loss.

Proposition 3 indicates that combating counterfeiting through a blockchain traceability system can benefit the manufacturer under certain conditions. In addition to the unit cost of implementing the system, we identify two other critical factors: product durability and the extent of counterfeiting in the secondary market. For highly durable products, consumers are less likely to resell in the secondary market, thereby reducing the relevance of counterfeiting concerns and diminishing the necessity for manufacturers to adopt BT systems. The findings echo the practice of manufacturers adopting blockchain traceability systemin different industries. In the beauty and cosmetics industries (Region 1), where product durability is low and counterfeiting is widespread in secondary markets, Estée Lauder[4] has partnered with blockchain technology companies to enable product traceability (Cui et al., 2023; Dong et al., 2023; Iyengar et al., 2022). In the consumer electronics industry (Region 2), although product durability varies, most products traded in secondary markets are genuine. Companies such as Sony and Apple have adopted blockchain technology for supply chain traceability and warranty verification, ensuring the authenticity of parts and refurbished units. Moreover, in the sneaker and automobile parts industries (Region 3^a), as product durability is medium, Nike and General Motor have embraced blockchain technology to support counterfeit-fighting efforts[5].

5. C2C Platform's AI-Based Authentication Service

To verify the authenticity of used goods listed by sellers, C2C secondary platforms provide AI-based authentication services. For example, Dewu (poizon.com), the largest C2C secondary platform in China, implements an AI-based authentication system, which is trained by billions of authentication records and a vast product database accumulated over many years, offers an accuracy rate as high as 99.9999%. Similarly, GOAT, as one of the leading C2C platform for secondary sneakers, uses machine learning and graphic recognition to enhance its AI-based authentication.

Following the practice of Dewu, we assume that counterfeits are eliminated on the C2C secondary platform empowered by the AI-based authentication service (i.e., $\alpha = 1$). This assumption is also based on the understanding that platforms typically strive to reach the highest level of reliability to maintain brand image. We relax this assumption to explore the imperfect AI-based authentication in Section 7. we assume that pre-owners selling used products pay an authentication fee f to the platform. Therefore, the NN-type consumers derive the utility $V_{NN} = 2v - 2p_n^{AI} + p_u^{AI} - f$, and the WU-type consumers derive the utility $V_{WU} = \delta v - p_u^{AI}$. In the subsequent analysis, a technical assumption $0 < f < \frac{\delta - \delta^2}{1+\delta}$ is added to exclude trivial cases. To isolate the effect of the AI-based authentication service, we assume that the platform already possesses this capability and can effectively control its associated costs. The

[4] https://theorganicmagazine.com/body-care/skin-care/how-estee-lauder-companies-is-using-blockchain-to-trace-its-madagascan-vanilla-supply-chain/, access on June 10, 2025.
[5] https://ipbusinessacademy.org/nike-blockchain-patent-strategy-cryptokicks-against-counterfeiting, Access on June 10, 2025.

manufacturer's profit function is:

$$\Pi^{AI} = p_n^{AI}\left(2D_{NN}^{AI} + D_{NH}^{AI}\right) \tag{3}$$

Lemma 3 presents the manufacturer's optimal pricing decisions and profit, which are jointly determined by product durability (δ) and the authentication service fee (f), as illustrated in Figure 6.

Lemma 3. *When the C2C secondary platform provides an AI-based authentication service, the manufacturer's optimal prices and profits are as follows:*

$$p_n^{AI*} = \begin{cases} \dfrac{-\delta+\delta^2-f+\delta^2 f}{-2\delta+\delta^2} & 0<\delta<\dfrac{1}{3} \ and \ f_1^{AI}<f<\dfrac{\delta-\delta^2}{1+\delta}; \\ & \dfrac{1}{3}<\delta<\delta_1^{AI} \ and \ f_1^{AI}<f<f_2^{AI} \\ \dfrac{-2+\delta^2+f}{2(-2+\delta)} & 0<\delta<\delta_2^{AI} \ and \ 0<f\le \min\left\{f_1^{AI}, f_3^{AI}\right\} \\ \dfrac{1+\delta}{2} & \dfrac{1}{3}<\delta<\delta_1^{AI} \ and \ f_1^{AI}\le f<\dfrac{\delta-\delta^2}{1+\delta}; \\ & \delta_1^{AI}<\delta<1 \ and \ \max\left\{f_3^{AI},0\right\}<f<\dfrac{\delta-\delta^2}{1+\delta} \end{cases},$$

$$\Pi^{AI*} = \begin{cases} \dfrac{(1-\delta)(\delta-f)(\delta+f+\delta f)}{(2-\delta)\delta^2} & 0<\delta<\dfrac{1}{3} \ and \ f_1^{AI}<f<\dfrac{\delta-\delta^2}{1+\delta}; \\ & \dfrac{1}{3}<\delta<\delta_1^{AI} \ and \ f_1^{AI}<f<f_2^{AI} \\ \dfrac{\left(-2+\delta^2+f\right)^2}{4\left(2+\delta-3\delta^2+\delta^3\right)} & 0<\delta<\delta_2^{AI} \ and \ 0<f\le \min\left\{f_1^{AI}, f_3^{AI}\right\} \\ \dfrac{1+\delta}{4} & \dfrac{1}{3}<\delta<\delta_1^{AI} \ and \ f_2^{AI}\le f<\dfrac{\delta-\delta^2}{1+\delta}; \\ & \delta_1^{AI}<\delta<1 \ and \ \max\left\{f_3^{AI},0\right\}<f<\dfrac{\delta-\delta^2}{1+\delta} \end{cases}.$$

The manufacturer's pricing strategy varies across product durability and the authentication service fee (see Figure 6). In Region 1, for products with low ($0<\delta<\frac{1}{3}$) to moderate durability ($\frac{1}{3}<\delta<\delta_1^{AI}$) and high authentication service fees (i.e., $f_1^{AI}<f<\dfrac{\delta-\delta^2}{1+\delta}$ or $f_1^{AI}<f<f_2^{AI}$, respectively), the manufacturer sets a relatively low price to stimulate new product purchases. In Region 2, for products with low to moderately high durability ($0<\delta<\delta_2^{AI}$) and a low authentication service fee ($0<f\le\min\left\{f_1^{AI}, f_3^{AI}\right\}$), the manufacturer raises the price moderately, ensuring consumers retain an incentive to resell used products; this demand-driven strategy leverages the secondary market to stimulate demand for new products in period 2. Finally, in Region 3, for highly durable products, used items retain significant value, consumers are more inclined to hold onto them. The manufacturer adopts a high-margin strategy by setting a higher price. However, excessively high prices can dissuade consumers from reselling, resulting in no secondary market transactions.

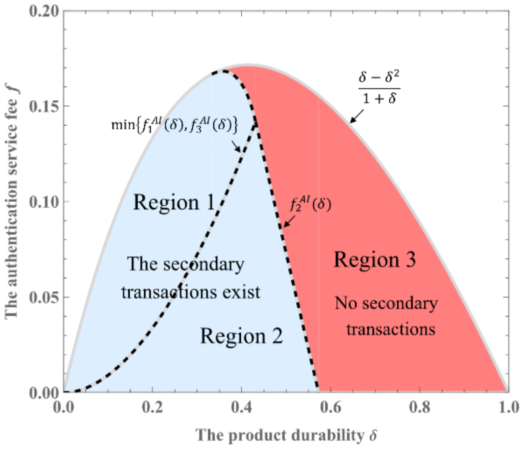

Figure 6 Equilibrium outcomes under case AI

By comparing the equilibrium outcomes between case B and case AI, Proposition 4 reveals the impact of the platform's AI-based authentication service, which is illustrated in Figure 7.

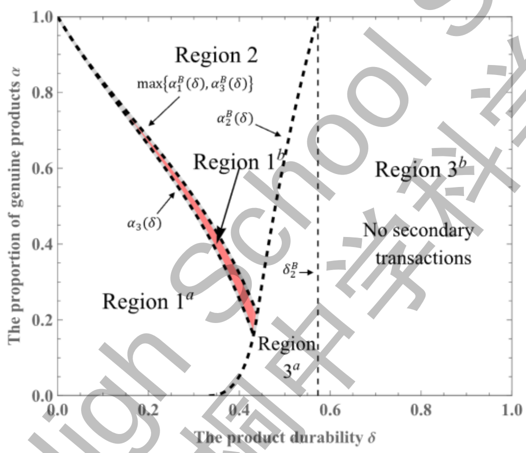

Figure 7 Profitable regions for the manufacturer under case AI

Proposition 4. *Compared with the benchmark, the manufacturer benefits from the C2C platform's AI-based authentication service if one of the following conditions holds:*

(a) In Region 1[a] where $0 < \delta < \frac{1}{3}$ *and* $0 < \alpha < \alpha_3$*, or* $\frac{1}{3} \le \delta < \delta_4$ *and* $\alpha_2^B < \alpha < \alpha_3$*, and* $0 < f < f_1$ *; and in Region 1[b] where* $0 < \delta < \delta_1^B$, $\max\{\alpha_3, \alpha_2^B\} \le \alpha < \alpha_1^B$*, and the corresponding authentication service fee satisfies* $0 < f \le f_2$ *and* $f_1 > f_2$[6]*;*

(b) In Region 2 where product durability is low to moderately high and the proportion of genuine products in the secondary market is high, i.e., $0 < \delta < \delta_2^B$ and $\max\{\alpha_1^B, \alpha_3^B\} \le \alpha < 1$*, and the corresponding authentication service fee satisfies* $0 < f < f_3$*;*

(c) in Region 3[a] when product durability is relatively high ($\frac{1}{3} < \delta < \delta_1^{AI}$ *or* $\delta_1^{AI} \le \delta < \delta_2^{AI}$*), and the corresponding authentication service fee and the proportion of genuine products in the secondary*

[6] $\alpha_3 = \frac{2-3\delta-4\delta^2+3\delta^3}{2+\delta-8\delta^2+4\delta^3}$; $f_1 = \frac{-\delta+\alpha\delta+\delta^2-\alpha\delta^2}{-1-\alpha-\delta+2\alpha\delta}$; $f_2 = 2-\delta^2-2\sqrt{-\frac{3\alpha^2\delta^6-14\alpha^2\delta^5+20\alpha^2\delta^4-5\alpha^2\delta^3-8\alpha^2\delta^2+4\alpha^2\delta-5\alpha\delta^6+19\alpha\delta^5-14\alpha\delta^4-17\alpha\delta^3+17\alpha\delta^2+4\alpha\delta-4\alpha+2\delta^6-6\delta^5+10\delta^3-2\delta^2-4\delta}{(2\alpha\delta-\alpha-\delta-1)^2}}$.

market satisfy $\alpha < \alpha_2^B$ *and* $0 < f < f_2^{AI}$ *; or* $\delta_1^{AI} \leq \delta < \delta_2^{AI}$ $\alpha < \alpha_3^B$ *and* $0 < f < f_3^{AI}$ *, respectively.*

Otherwise, the platform's AI-based authentication service reduces the manufacturer's profit.

Proposition 4 shows that given the C2C secondary platform provides the AI-based authentication service to combat counterfeits, the manufacturer's profit is jointly shaped by product durability, the proportion of genuine products in the secondary market, and the authentication service fee. When the platform's authentication service fee is too high, the manufacturer may incur revenue loss due to increased costs being passed on to consumers. Similar to Case BT, the provision of an AI-based authentication service effectively combats counterfeits in the secondary market and also generates the quality-disclosure effect (i.e., $\delta\alpha v \rightarrow \delta v$). As a result, compared with the benchmark, secondary transactions emerge in Region 3[a].

The quality-disclosure effect raises the price of used products, enhancing the value-enhancement effect and mitigating the cannibalization effect of the secondary market, ultimately benefiting the manufacturer. However, the price of used products is strongly influenced by the authentication service fee charged to sellers: higher authentication fees prompt sellers to set higher resale prices, which reduces buyer willingness to purchase and decreases transaction volume in the secondary market. As consumers become less likely to resell their used products, their demand for new products also declines. With an increase in the authentication fee, the demand for new products falls (i.e., $\frac{\partial D_{NN}^*}{\partial f} < 0$), a mechanism referred to as the *demand-reduction effect*. Consequently, as the authentication fee increases, the loss induced by the demand-reduction effect gradually outweighs the benefit derived from the quality-disclosure effect, leading to a decline in the manufacturer's profit. Therefore, the manufacturer can benefit from the platform's AI-based authentication service only when the service fee remains below a certain threshold.

Proposition 4(a) indicates that the manufacturer is more likely to benefit from the platform's authentication service when product durability, the proportion of genuine products in the secondary market, and the authentication fee are low (i.e., α and δ are in Region 1[a]). More specifically, compared with Region 1[b], the constraint on the authentication service fee is more relaxed ($f_1 \geq f_2$). The rationale is as follows: when the degree of counterfeiting in the secondary market is more serious, the provision of authentication service can more effectively combat counterfeiting, i.e., the quality-disclosure effect is high. The benefit derived from the quality-disclosure effect is more likely to outweigh the loss caused by the demand-shrinkage effect, giving the platform greater flexibility to charge higher authentication service fees. Consequently, the manufacturer is more likely to benefit as well. The rationale of Proposition 4(b) is similar to Proposition 4(a). When the probability of genuine products in the market is relatively high, consumers are more likely to get a genuine product, which can enhance the demand for new products and benefits the manufacturer. Accordingly, the platform charges a relatively low fee for the authentication service since consumers have a higher probability of buying a genuine product in the secondary market. Proposition 4(c) does not put forward more stringent restrictive requirements on the authentication fee. The reason is that, under this condition, the medium durability of used products attracts more consumers to purchase them. This shifts the market structure from a scenario with no secondary-market transactions under case B to one in which used-product transactions emerge in Region 3^a under case AI. The expanded range of secondary-market transactions ultimately benefits the manufacturer.

In summary, the C2C secondary platform's AI-based authentication service fee leads to higher prices of used products in secondary markets, but sellers in secondary markets do not receive higher revenue as a result. The platform captures part of the revenue through the authentication service fee. Therefore, although the AI-based authentication service achieves the purpose of solving the problem of counterfeiting, it also hinders the realization of the second-hand transaction to a certain extent, which in turn affects the decision of consumers to buy new products again. This result underscores the pivotal role of the AI-based authentication service fee in sustaining secondary market operations. Ongoing advances in AI technology are expected to further reduce authentication costs, thereby promoting the growth of secondary markets and enhancing manufacturers' profitability.

6. Social and Environmental Implications

This section examines the social and environmental implications of the manufacturer's and platform's anti-counterfeiting technologies, focusing on their effects on consumer surplus, social welfare, and environmental outcomes.

6.1 Consumer Surplus and Social Welfare

We define social welfare as the sum of consumer surplus, the manufacturer's profit, and the C2C platform's revenue from the AI-based authentication service. When comparing changes in social welfare, we exclude the profit of counterfeiters in the secondary market. We then compare consumer surplus and social welfare across the Benchmark, BT, and AI cases, and derive the following results.

Proposition 5. Consumer Surplus and Social Welfare of BT

The manufacturer's adoption of the blockchain traceability system can improve consumer surplus and social welfare, and can achieve a win-win outcome for the manufacturer and consumers.

(a) Specifically, $CS^{BT} > CS^{B}$ *when: (i) product durability (δ) and the proportion of counterfeits in the secondary market (α) are in Region* 1^d *(Figure 8), if* $0 < \delta < \frac{1}{3}$, $0 < \alpha < \alpha_3$ *and* $0 < c < c_8$, *or* $\frac{1}{3} \le \delta < \delta_4$, $\alpha_2^B < \alpha < \alpha_3$ *and* $0 < c < c_8$[7]*;or (ii)* δ *and* α *are in Region* 3^a*(Figure 9),* $0 <$

[7] $\alpha_3 = \frac{28\delta^6-67\delta^5-7\delta^4+82\delta^3-10\delta^2-24\delta+4}{40\delta^6-124\delta^5+67\delta^4+96\delta^3-80\delta^2-8\delta+12} + 2\sqrt{\frac{6\delta^{12}-49\delta^{11}+146\delta^{10}-158\delta^9-71\delta^8+249\delta^7-14\delta^6-226\delta^5+45\delta^4+144\delta^3-56\delta^2-32\delta+16}{(40\delta^6-124\delta^5+67\delta^4+96\delta^3-80\delta^2-8\delta+12)^2}}$ and $c_8 = \frac{\delta^2-2}{\delta-2} -$

$c < min\left\{1-\delta^2-\sqrt{\frac{-\delta^2-2\delta^3+\delta^5}{-2+\delta}}, c_9\right\}$, *where* $c_9 = \frac{-2+\delta^2}{-2+\delta} - \sqrt{\frac{2+3\delta-6\delta^2-6\delta^3+5\delta^4}{(-2+\delta)^2}}$.

Otherwise, $CS^{BT} \leq CS^B$;

(b) Specifically, $SW^{BT} > SW^B$ *when: (i)* δ *and* α *are in Region 1 (Figure 8),* $0 < c < c_{10}$[8]*; or (ii)* δ *and* α *are in Region 2 (Figure 9),* $0 < c < c_{11}$[9]*;or (iii)* δ *and* α *are in Region* 3^a *(Figure 9),* $0 < c < min\left\{\frac{-2+\delta^2}{-2+\delta} - \sqrt{\frac{6+9\delta-10\delta^2-10\delta^3+7\delta^4}{3(-2+\delta)^2}}, 1-\delta^2-\sqrt{\frac{-\delta^2-2\delta^3+\delta^5}{-2+\delta}}\right\}$.

Otherwise, $SW^{BT} \leq SW^B$.

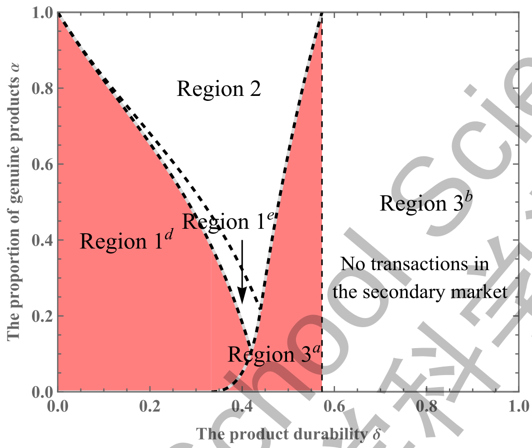

Figure 8 Consumer surplus and social welfare under Case BT

Proposition 5(a) shows that when the level of counterfeiting in the secondary market is relatively high and product durability is not high (i.e., in Region 1^d and Region 3^a), consumers' willingness to pay is relatively low. In this case, only when the unit cost of implementing the blockchain traceability (BT) system is low can the BT strategy substantially enhance consumers' utility from purchasing authenticated used products in the secondary market, thereby increasing consumer surplus ($CS^{BT} > CS^B$). In contrast, when the level of counterfeiting products in the secondary market is low (in Region 1^e and Region 2), compared with the benchmark, the manufacturer can capture more consumer surplus by adopting blockchain traceability system (e.g., $CS^{BT} < CS^B$). Consumers are willing to pay a higher price for a used product, allowing the manufacturer to increase revenue by raising the price of new products.

Proposition 5(b) indicates that the adoption of anti-counterfeiting technology can enhance social welfare. By ensuring product traceability, the manufacturer's adoption of the blockchain traceability system can increase the manufacturer's profit and, under certain conditions, improves consumer surplus.

$$2\sqrt{\frac{11\alpha^2\delta^6-32\alpha^2\delta^5+13\alpha^2\delta^4+28\alpha^2\delta^3-17\alpha^2\delta^2-6\alpha^2\delta+4\alpha^2-15\alpha\delta^6+33\alpha\delta^5+8\alpha\delta^4-39\alpha\delta^3-\alpha\delta^2+10\alpha\delta+5\delta^6-7\delta^5-10\delta^4+9\delta^3+7\delta^2}{(\delta-2)^2(2\alpha\delta-\alpha-\delta-1)^2}}$$

[8] $c_{10} = \frac{\delta^2-2}{\delta-2} - 2\sqrt{\frac{5\alpha^2\delta^6-4\alpha^2\delta^5-27\alpha^2\delta^4+38\alpha^2\delta^3-\alpha^2\delta^2-14\alpha^2\delta+4\alpha^2-5\alpha\delta^6-5\alpha\delta^5+36\alpha\delta^4-5\alpha\delta^3-35\alpha\delta^2+2\alpha\delta+8\alpha+\delta^6+5\delta^5-10\delta^4-11\delta^3+11\delta^2+8\delta}{3(\delta-2)^2(2\alpha\delta-\alpha-\delta-1)^2}}$.

[9] c_{11} is shown in the Appendix B.6.

Although the manufacturer can capture more consumer surplus when the level of counterfeiting products in the secondary market is low, the increase in the manufacturer's profit exceeds the reduction in consumer surplus when the unit cost of BT adoption is low. Thus, when the unit cost of adopting BT is below a certain threshold, the manufacturer's adoption of the blockchain traceability system enhances social welfare ($SW^{BT} > SW^{B}$).

In summary, when the level of counterfeiting is high, both manufacturers and consumers can achieve win-win outcomes, provided the unit cost of implementing blockchain traceability systems remains low. High costs of BT implementation can result in higher prices for new products, thereby reducing consumer surplus.

Proposition 6. Consumer Surplus and Social Welfare of AI-based Authentication

The C2C secondary platform's adoption of AI-based authentication can improve consumer surplus and social welfare, and can reach a win-win for consumers and the manufacturer.

(a) Specifically, $CS^{AI} > CS^{B}$ *when: (i) in Region 1^f that product durability* (δ) *are low, and the platform's AI-based authentication service fee* (f) *are low; or (ii) in Region 2^a, when the proportion of genuine products in the secondary market is high, and both product durability* (δ) *and the platform's AI-based authentication service fee* (f) *are intermediate (i.e.,* $f_4 < f < f_5$*; or (iii) in Region 3^a, when product durability* (δ) *is medium, and the platform's authentication fee* (f) *is medium.*

Otherwise, $CS^{AI} \leq CS^{AI}$*;*

(b) When the AI-based authentication service fee (f) *is low,* $SW^{AI} > SW^{B}$*;Otherwise,* $SW^{AI} > SW^{B}$*;Otherwise,* $SW^{AI} \leq SW^{B}$.

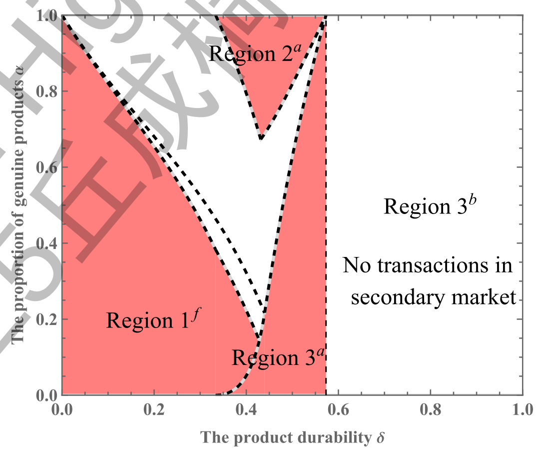

Figure 9 Consumer surplus and social welfare under case AI

We illustrate Proposition 6 in Figure 9. Proposition 6(a) shows that in Region 1[f], where product durability is low and the degree of counterfeiting is relatively high in most cases, consumers benefit from the C2C platform's AI-based authentication service when the authentication fee is low, resulting in higher consumer surplus compared with the benchmark. The low durability and the high degree of counterfeiting limits the manufacturer to charging a low price, and the platform's low authentication fee, which together enhance consumer surplus. In Region 2[a], where product durability is medium and the degree of counterfeit invasion is low, consumers' willingness to pay for used products is relatively high. If the authentication fee is low, pre-owned consumers can resell used products at higher prices, which in turn drives up the price of new products and reduces consumer surplus. Conversely, a high authentication fee allows the platform to capture a larger share of consumer surplus through service charges. Therefore, consumer surplus increases only when the authentication fee is set at a moderate level. In Region 3^a, where product durability is medium, a high authentication fee makes pre-owners less likely to resell used products, which negatively affects both the manufacturer and consumers. Conversely, a low authentication fee encourages pre-owners to sell used products at higher prices, which reduces consumer surplus. As a result, consumer surplus improves only when the authentication fee is set at a moderate level.

Proposition 6(b) suggests that, relative to the benchmark, the platform's AI-based authentication service enhances social welfare when the authentication fee remains low. By combating counterfeits in the secondary market, the AI-based authentication service can enhance the manufacturers' profit and consumer surplus under certain conditions. Even though consumer surplus can decrease when the proportion of counterfeiting products is low and the authentication fee is high, the manufacturer's profit and the C2C platform's revenue of authentication fee increase more significantly than the decrease in consumer surplus. Therefore, the platform's AI-based authentication service enhances social welfare when the platform's AI-based authentication fee is kept below a certain threshold.

In summary, since the C2C platform's AI-based authentication service can improve consumer surplus and social welfare, and generates revenue for the platform. We conclude that the C2C platform's AI-based authentication strategy can engender a win-win for consumers and the manufacturer.

6.2 Environmental Impact

After examining the social implications, we explore the impact of counterfeiting from the environment's perspective. The environmental impact in the production phase is $e_p(2D_{NN}^j + D_{NH}^j)$. In the use phase, it equals $e_n(2D_{NN}^j + D_{NH}^j) + e_u(D_{NH}^j + D_{WU}^j)$. The impact in the disposal phase is $e_d(2D_{NN}^j + D_{NH}^j)$. The total environmental impact is:

$$E^j = \underbrace{e_p(2D_{NN}^j + D_{NH}^j)}_{production} + \underbrace{e_n(2D_{NN}^j + D_{NH}^j) + e_u(D_{NH}^j + D_{WU}^j)}_{use} + \underbrace{e_d(2D_{NN}^j + D_{NH}^j)}_{disposal}.$$

Proposition 7. The Environmental Impact of Anti-counterfeiting Strategies

In the presence of secondary transactions, (a) when the proportion of genuine products in the secondary market, product durability, and the unit cost of implementing the blockchain traceability system are low (i.e., α, δ, and c are low), $E^{BT} > E^B$; otherwise, $E^{BT} < E^B$; (b) when the proportion of genuine products in the secondary market, product durability, and the AI-based authentication service fee are low (i.e., α, δ, and f are low), $E^{AI} > E^B$; otherwise, $E^{AI} < E^B$.

When either the manufacturer or the C2C secondary platform provides the anti-counterfeiting services, the manufacturer's profit improves under certain conditions, as shown in Propositions 3 and 4. While it raises the question of whether the two anti-counterfeiting strategies align with manufacturer' and consumers' environmental commitments and the broader goal of promoting reuse. Despite such strategies facilitating C2C transactions by reducing counterfeiting risk, they also increase overall product circulation by altering the substitution and usage between new and used products. At the same time, it stimulates repeat purchases, as consumers who resell used products gain both liquidity and space to acquire new ones. Our analysis shows that $E^{BT} > E^{B}$ and $E^{AI} > E^{B}$ in most situations, indicating that anti-counterfeiting strategies, though effective in combating counterfeits and expanding resale markets, tend to exacerbate environmental impact. Combining the results of Propositions 5 and 6, we conclude that although these strategies can create a win–win outcome for both manufacturers and consumers, they may do so at the cost of increased environmental impact under certain conditions.

7. Extension: Imperfect AI-Based Authentication

In practice, although Dewu (poizon.com) reports that its AI-based authentication service achieves an alignment rate of over 99.9999% with expert appraisers, not all C2C secondary platforms can fully eliminate counterfeit products through AI-based authentication. Due to issues such as AI hallucination and limited training data, some counterfeit products may still deceive the platforms' AI-based authentication systems. This section investigates the scenario where the C2C secondary platform provides an imperfect AI-based authentication. Specifically, counterfeits in the secondary market cannot be fully eliminated after the C2C secondary platform adopted AI-based authentication service (i.e., $\alpha \to \hat{\alpha}$ where $\alpha < \hat{\alpha} < 1$). Consumers' expected utility of used products becomes $\hat{\alpha}\delta v$. In the imperfect case MAI, the NN-type consumers derive the utility $V_{NN} = 2v - 2p_n^{MAI} + p_u^{MAI} - f$ and the WU-type consumers derive the utility $V_{WU} = \hat{\alpha}\delta v - p_u^{MAI}$. The manufacturer's profit function is:

$$\Pi^{MAI} = p_n^{MAI}\left(2D_{NN}^{MAI} + D_{NH}^{MAI}\right) \tag{3}$$

Lemma 4 shows the optimal price decisions and profits of the manufacturer under the case MAI, which are jointly determined by the genuine used product proportion under imperfect AI-based authentication service $\hat{\alpha}$, product durability δ, and the authentication service fee f,

Lemma 4. *When the C2C secondary platform provides an imperfect AI-based authentication service, the manufacturer's optimal prices and profit are as follows*[10]*:*

$$p_n^{MAI*} = \begin{cases} \dfrac{-2+\alpha\delta^2+f}{2\left(-2+\alpha\delta\right)} & 0 < f\left(\alpha,\delta\right) \le f\left(\alpha,\delta\right)_{11} \\ \dfrac{1+\delta}{2} & f\left(\alpha,\delta\right) < f\left(\alpha,\delta\right) \le 1 \end{cases},$$

[10] Due to the complexity of analysis, we only focus on interior solution.

[11] $f\left(\alpha,\delta\right) = \dfrac{-2+\alpha\delta^3\left(\alpha-3\right)+\delta^2\left(4-\alpha\right)+2\delta}{-3+\delta\left(\alpha-3\right)+2\delta^2\alpha}$.

$$
\Pi^{MAI*} = \begin{cases} \dfrac{\left(-2+\alpha\delta^2+f\right)^2}{4\left(\alpha\delta-2\right)\left(\alpha\delta^2-\delta-1\right)} & 0<f\left(\alpha,\delta\right)\le f\left(\alpha,\delta\right) \\ \dfrac{1+\delta}{4} & f\left(\alpha,\delta\right)<f\left(\alpha,\delta\right)\le 1 \end{cases}
$$

By comparing the equilibrium outcomes between case AI and case MAI, Proposition 8 demonstrates that the imperfect AI-based authentication paradoxically yields a higher profit for the manufacturer compared to the perfect AI-based authentication.

Proposition 8. *The manufacturer acquires a higher profit when the C2C secondary platform provides an imperfect AI-based authentication service if product durability is low to medium and the authentication service cost is low, i.e.,* $\Pi^{MAI*} > \Pi^{AI*}$ *when* $0 < \delta < \delta_2^{AI}$ *and* $0 < f\left(\alpha,\delta\right) \le \min\left\{ f_1^{AI}, f_3^{AI}, f\left(\alpha,\delta\right) \right\}$.

The intuition is that an imperfect AI-based authentication service cannot fully eliminate counterfeit products in the secondary market, resulting in only a limited quality-disclosure effect that diminishes the manufacturer's profit. However, our results find that the manufacturer can indeed benefit from the imperfect AI-based authentication compared to the perfect AI-based authentication. When product durability is low to medium and the authentication service cost is low, i.e., $0 < \delta < \delta_2^{AI}$ and $0 < f\left(\alpha,\delta\right) \le \min\left\{ f_1^{AI}, f_3^{AI}, f\left(\alpha,\delta\right) \right\}$, compared with case AI, more pre-owned consumers choose to resell their used products and repurchase new ones in case MAI for two main reasons: (i) a lower new product price $p_n^{MAI*} < p_n^{AI*}$, which leads to more demand for new products; (ii) enough secondhand demand from waited consumers $D_{WU}^{MAI*} > D_{WU}^{AI*}$ in Region 3[a]. Although the manufacturer charges a lower price, the increased secondhand demand leads to more repeat purchases for new products. This ultimately raises new product demand and enhances the manufacturer's profit. The implication is that when C2C secondary platforms provide AI-based authentication services, manufacturers may actually benefit from imperfect authentication—arising from AI hallucinations or limited training data—because it stimulates higher demand for both new and used products. We caution C2C secondary platforms that maximizing AI-based authentication reliability should not always be their top priority, as doing so not only entails substantial costs but may also reduce manufacturers' profits and consumer surplus. In some cases, an imperfect AI-based authentication service can, in fact, lead to higher overall profitability.

8. Conclusion and Managerial Insights

The prevalence of counterfeit products in secondary markets has prompted both manufacturers and C2C platforms to adopt measures to ensure product authenticity. This study examines the use of blockchain traceability systems by manufacturers and AI-based authentication services by C2C secondary platforms as strategies to combat counterfeiting in secondary markets. We develop a two-period model featuring strategic consumers, a branded manufacturer, and a C2C secondary platform.

By incorporating product durability, the extent of counterfeiting in the secondary market, and the unit costs of authentication, we examine the impacts of the manufacturer's blockchain traceability system and the C2C platform's AI-based authentication service on both primary and secondary market dynamics, as well as their broader social and environmental implications.

First, our results show that the presence of counterfeiting in the secondary market generates the value-shrinkage effect, reducing the manufacturer's profit. To combat counterfeiting, both the manufacturer's blockchain traceability system and the C2C secondary platform's AI-based authentication service create a quality-disclosure effect. This effect can benefit both the manufacturer and consumers under certain conditions. Specifically, we find that the manufacturer's implementation of a blockchain traceability system can expand the scope of secondary market transactions. However, it does not always guarantee a positive return for the manufacturer; benefits arise only under certain conditions. Besides the cost of implementing the blockchain traceability system, we identify two key features of secondary markets as the driving forces for the adoption of blockchain traceability systems: product durability and the extent of counterfeiting invasion.

Second, the C2C secondary platform's adoption of an AI-based authentication service also generates the quality-disclosure effect and expands the existence of secondary transactions. However, it simultaneously induces a demand-reduction effect due to the authentication fee, which may hinder transactions in the secondary market. The benefit that the manufacturer gains from the platform's AI-based authentication service depends jointly on the authentication fee, product durability, and the severity of counterfeiting. By extending our model, we examine the impact of imperfect AI-based authentication services, which may arise from AI hallucinations or limited training data. We find that, compared with a perfectly reliable AI-based authentication service, the manufacturer can achieve higher profits when the service is imperfect. These findings highlight that to combat counterfeiting, managers must carefully evaluate multiple factors, such as product durability, counterfeiting invasion degree, and unit cost for anti-counterfeiting, in order to design effective and sustainable strategies. For both the manufacturer and the platform, reducing costs for anti-counterfeiting technologies can facilitate the secondary and primary markets.

Finally, we unveil the social and environmental impact of the two anti-counterfeiting strategies. We find that both the manufacturer's blockchain traceability system, and the C2C secondary platform's AI-based authentication service can benefit the manufacturer, consumers, and social welfare under certain conditions depending on product durability, the degree of counterfeiting invasion, the unit cost of adopting blockchain traceability system, and the AI-based authentication fee. This highlights market regulators, and government, to carefully evaluate market conditions before promote firms to adopt anti-counterfeiting technologies. Counterintuitively, we find that the two anti-counterfeiting strategies do not always guarantee environmental benefits. Improvements in social welfare can come at the expense of increased environmental impact. Under certain conditions, both anti-counterfeiting technologies may exacerbate resource consumption through the production of new goods, as well as the consumption and transaction of used products.

Overall, our research highlights that anti-counterfeiting in the secondary market have far-reaching economic, social, and environmental impacts. Developing a socially responsible operational framework that balances economic interests, consumer protection, social welfare, and environmental sustainability, regulators can not only safeguard the interests of market participants but also promote broader social and environmental objectives.

Despite these insights, our study has limitations that offer opportunities for further research. First, in conspicuous industries, social factors, such as different consumers' desire for uniqueness and conformity, play critical roles in shaping manufacturer operations. Anti-counterfeiting can alter consumers' behavior and change the dynamics between the primary market and secondary markets. Future work could examine how social factors mitigate the effectiveness of anti-counterfeiting strategies. Second, the commission and authentication fees charged by C2C secondary platforms may alter the effectiveness of different anti-counterfeiting strategies. The platform's decisions regarding these fees merit further investigation. Third, future research can explore dynamic pricing across periods; it could yield richer insights into consumer behavior and the interaction between anti-counterfeiting technologies and market outcomes. Research on these extensions would offer more nuanced guidance for managers and policymakers seeking to align economic, consumer, and environmental objective.

Reference

Abbey, J. D., Blackburn, J. D., & Guide, V. D. R. (2015). Optimal pricing for new and remanufactured products. Journal of Operations Management, 36, 130–146.

Agrawal, V., Ferguson, M., Toktay, L. B., & Thomas, V. M. (2012). Is leasing greener than selling? Management Science, 58(3), 523–533.

Albano, G. L., & Lizzeri, A. (2001). Strategic certification and provision of quality. International Economic Review, 42(1), 267–283.

Alev, I., Agrawal, V. V., & Atasu, A. (2020). Extended producer responsibility for durable products. Manufacturing & Service Operations Management, 22(2), 364–382.

Ang, K. (2016, December 28). Good luck finding luxury brands like Louis Vuitton, Hermes or even Tesla on sale. MarketWatch. https://www.marketwatch.com/story/good-luck-finding-these-luxury-brands-on-sale-2016-12-28

Babich, V., & Hilary, G. (2020). OM Forum—Distributed ledgers and operations: What operations management researchers should know about blockchain technology. Manufacturing & Service Operations Management, 22(2), 223–240.

Bitran, G., & Caldentey, R. (2003). An overview of pricing models for revenue management. Manufacturing & Service Operations Management, 5(3), 203–229. https://doi.org/10.1287/msom.5.3.203.16031

Bulow, J. I. (1982). Durable-goods monopolists. Journal of Political Economy, 90(2), 314–332.

Chen, X., Farias, V. F., & Trichakis, N. (2019). On the efficacy of static prices for revenue management in the face of strategic customers. Management Science, 65(1), 249–266. https://doi.org/10.1287/mnsc.2017.2964

Cho, S. H., Fang, X., & Tayur, S. (2015). Combating strategic counterfeiters in licit and illicit supply chains. Manufacturing & Service Operations Management, 17(3), 273–289.

Choi, T. M. (2019). Blockchain-technology-supported platforms for diamond authentication and certification in luxury supply chains. Transportation Research Part E: Logistics and Transportation Review, 128, 17–29.

Cohen, M. C., Dahan, S., Khernamnuai, W., Shimao, H., & Touboul, J. (2023). The use of AI in legal systems: Determining independent contractor vs. employee status. Artificial Intelligence and Law, 1–30.

Cui, R., Li, M., & Zhang, S. (2022). AI and procurement. Manufacturing & Service Operations Management, 24(2), 691–706.

Cui, Y., Hu, M., & Liu, J. (2023). Value and design of traceability-driven blockchains. Manufacturing & Service Operations Management, 25(3), 1099–1116.

Cui, Y., Gaur, V., & Liu, J. (2024). Supply chain transparency and blockchain design. Management Science, 70(5), 3245–3263.

Desai, P., Koenigsberg, O., & Purohit, D. (2004). Strategic decentralization and channel coordination. Quantitative Marketing and Economics, 2, 5–22.

Dong, L., Jiang, P., & Xu, F. (2023). Impact of traceability technology adoption in food supply chain networks. Management Science, 69(3), 1518–1535.

Esenduran, G., Lu, L. X., & Swaminathan, J. M. (2020). Buyback pricing of durable goods in dual distribution channels. Manufacturing & Service Operations Management, 22(2), 412–428.

Fontana, R., Girod, S. J. G., & Králik, M. (2019). How luxury brands can beat counterfeiters. Harvard Business Review, 2019(5), 28.

Gao, Y. (2018). On the use of overt anti-counterfeiting technologies. Marketing Science, 37(3), 403–424.

Ghose, A., Smith, M. D., & Telang, R. (2006). Internet exchanges for used books: An empirical analysis of product cannibalization and welfare impact. Information Systems Research, 17(1), 3–19.

Ghose, A., Telang, R., & Krishnan, R. (2005). Effect of electronic secondary markets on the supply chain. Journal of Management Information Systems, 22(2), 91–120.

Grossman, G. M., & Shapiro, C. (1988). Foreign counterfeiting of status goods. The Quarterly Journal of Economics, 103(1), 79–100.

Grossman, G. M., & Shapiro, C. (1988). Counterfeit-product trade. American Economic Review, 78(1), 59–75.

Gursoy, D., Chi, O. H., Lu, L., & Nunkoo, R. (2019). Consumers' acceptance of artificially intelligent (AI) device use in service delivery. International Journal of Information Management, 49, 157–169.

Hou, T., Li, M., Tan, Y. R., & Zhao, H. (2024). Physician adoption of AI assistant. Manufacturing & Service Operations Management, 26(5), 1639–1655.

IKEA. (2024). Re-shop and re-use, pre-loved items, good for your pocket and good for the planet. IKEA. https://www.ikea.com/gb/en/offers/circular-hub-pub2eab7840

Iyengar, G., Saleh, F., Sethuraman, J., et al. (2024). Blockchain adoption in a supply chain with manufacturer market power. Management Science, 70(9), 6158–6178.

Iyengar, G., Saleh, F., Sethuraman, J., et al. (2022). Economics of permissioned blockchain adoption. Management Science.

Jiang, B., & Tian, L. (2018). Collaborative consumption: Strategic and economic implications of product sharing. Management Science, 64(3), 1171–1188.

Jiang, L., Dimitrov, S., & Mantin, B. (2017). P2P marketplaces and retailing in the presence of consumers' valuation uncertainty. Production and Operations Management, 26(3), 509–524.

Johnson, J. P. (2011). Secondary markets with changing preferences. The RAND Journal of Economics, 42(3), 555–574.

Kyung, N., & Kwon, H. E. (2025). Rationally trust, but emotionally? The roles of cognitive and affective trust in laypeople's acceptance of AI for preventive care operations. Production and Operations Management.

Lei, Y., Liu, Q., & Shum, S. (2022). Managing return policies with consumer resale. Naval Research Logistics, 69(2), 241–256.

Levi's. (2024). Levi's secondhand. Levi's. https://www.levi.com/US/en_US/blog/article/levis-secondhand

Li, J., Yang, X., Shi, V., et al. (2023). Partial centralization in a durable-good supply chain. Production and Operations Management.

Li, L., Fang, X., & Lim, Y. F. (2023). Asymmetric information of product authenticity on C2C e-commerce platforms: How can inspection services help? Manufacturing & Service Operations Management, 25(2), 631–647.

Liu, Q., & Zhang, D. (2013). Dynamic pricing competition with strategic customers under vertical product differentiation. Management Science, 59(1), 84–101. https://doi.org/10.1287/mnsc.1120.1580

Lizzeri, A. (1999). Information revelation and certification intermediaries. The RAND Journal of Economics, 30(2), 214–231.

OECD/EUIPO. (2021). Misuse of E-commerce for trade in counterfeits, illicit trade. OECD Publishing. https://doi.org/10.1787/1c04a64e-en

OECD/EUIPO. (2025). Mapping global trade in fakes 2025: Global trends and enforcement challenges, illicit trade. OECD Publishing. https://doi.org/10.1787/94d3b29f-en

Olsen, T. L., & Tomlin, B. (2020). Industry 4.0: Opportunities and challenges for operations management. Manufacturing & Service Operations Management, 22(1), 113–122.

Oraiopoulos, N., Ferguson, M. E., & Toktay, L. B. (2012). Relicensing as a secondary market strategy. Management Science, 58(5), 1022–1037.

Pang, C., Li, G., & Jiang, L. (2023). Leveraging strategic consumer behavior in consumer-to-consumer resale: From economic and environmental perspectives. Omega, 120, 102924.

Pang, C., Jiang, L., & Li, G. (2024). Cannibalization or enhancement: Effects of consumer-to-consumer resale with consumers' utility dependence. International Journal of Electronic Commerce, 28(3), 416–446.

Patagonia. (2024). Used Patagonia clothing and gear: Worn wear. https://wornwear.patagonia.com/

Pun, H., Swaminathan, J. M., & Hou, P. (2021). Blockchain adoption for combating deceptive counterfeits. Production and Operations Management, 30(4), 864–882.

Qian, Y. (2014). Counterfeiters: Foes or friends? How counterfeits affect sales by product quality tier. Management Science, 60(10), 2381–2400.

Rayon, A. (2024). Breaking the counterfeit supply chain: A global perspective. https://www.controlrisks.com/our-thinking/insights/breaking-the-counterfeit-supply-chain-a-global-perspective

Shen, B., Dong, C., & Minner, S. (2022). Combating copycats in the supply chain with permissioned blockchain technology. Production and Operations Management, 31(1), 138–154.

Stahl, K., & Strausz, R. (2017). Certification and market transparency. The Review of Economic Studies, 84(4), 1842–1868.

Tan, Y. (2022). Implications of blockchain-powered marketplace of preowned virtual goods. Production and Operations Management.

Tian, L., & Jiang, B. (2018). Effects of consumer-to-consumer product sharing on distribution channel. Production and Operations Management, 27(2), 350–367.

Tong, S., Jia, N., Luo, X., & Fang, Z. (2021). The Janus face of artificial intelligence feedback: Deployment versus disclosure effects on employee performance. Strategic Management Journal, 42(9), 1600–1631.

Wang, L., Huang, N., Hong, Y., et al. (2023). Voice-based AI in call center customer service: A natural field experiment. Production and Operations Management, 32(4), 1002–1018.

Yi, Z., Yu, M., & Cheung, K. L. (2022). Impacts of counterfeiting on a global supply chain. Manufacturing & Service Operations Management, 24(1), 159–178.

Yin, S., Ray, S., Gurnani, H., et al. (2010). Durable products with multiple used goods markets: Product upgrade and retail pricing implications. Marketing Science, 29(3), 540–560.

Zhou, Y., Gao, X., Luo, S., et al. (2022). Anti-counterfeiting in a retail platform: A game-theoretic approach. Transportation Research Part E: Logistics and Transportation Review, 165, 102839.

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My research motivation was partly inspired by my experience of encountering counterfeit sneakers on a second-hand platform. This led me to examine anti-counterfeiting strategies in such markets. By market survey, I identified two prominent approaches: the manufacturer's blockchain-based traceability system and the C2C secondary platform's AI-based authentication service. These observations raised the central research question of my study: what impacts do these anti-counterfeiting technologies generate for manufacturers, consumers, society, and the environment?

To this end, I first read papers related to the second-hand market from databases such as Elsevier and INFORMS, through which I identified three research questions. During this process, I found the research of Dr. Chen Pang, which closely related to my research topic. I then reached out to Dr. Pang and invited her to serve as my advisor for the S.-T. Yau High School Science Award competition. After several rounds of communication, during which she carefully assessed my research background and research questions, she kindly agreed to be my advisor and provided guidance on an entirely voluntary basis, without any remuneration.

Dr. Pang first directed me to relevant literature on the secondary market. In the research process, I learned how to model consumer purchasing behavior and how to apply backward induction for model analysis. Under her guidance, I developed consumer utility models under different anti-counterfeiting technologies, derived the corresponding demand functions and the manufacturer's profit functions, and obtained the optimal solutions using methods I had learned in my AP Calculus BC course.

During my research, I encountered several difficulties. The first challenge was how to solve optimal decision problems involving multiple parameters. Dr. Pang guided me in using the mathematical analysis software, i.e., Mathematica, to address these issues. The second difficulty arose in capturing the key features of AI-based authentication service. Initially, I attempted to incorporate AI hallucination directly into the model, which greatly increased its complexity. Dr. Pang suggested that, in the main model, I can focus on the impact of perfect AI-based authentication service, and then explore the imperfect AI-based authentication in the extended model. This approach not only simplified the core analysis but also led to several interesting findings in the extended model.

My prior training from courses such as AP Seminar and my earlier experience writing research papers for the Yuanpei Young Scholars summer program and the Youth Science and Technology Innovation Competition of Shaanxi Province give me many experiences for drafting the research structure. Dr. Pang reviewed my research structure and suggested that I can analyze the two anti-counterfeiting strategies as separate chapters, in order to facilitate comparisons to the benchmark. Under

her guidance, I prepared a draft of the report and sought her feedback. I then revised and completed the report based on her detailed comments.

In summary, the roles and responsibilities in this research were clearly divided between the student and the advisor, as follows:

Research Student	Advisor
Background research: Investigation of anti-counterfeiting strategies. **Formulation of research questions:** Identification of three research questions from economy, society, and environmental sustainability perspectives.	**Theoretical guidance:** Provided advice on identifying the key features of the two anti-counterfeiting technologies and guided the reading of relevant papers.
Theoretical foundation and literature review: Collected and reviewed relevant literature to clarify the contributions of the study.	**Theoretical guidance:** Assisted in understanding the interaction mechanisms between the second-hand and primary markets during literature review.
Model construction and solution: Built utility and profit functions, solved for optimal pricing and profits, compared different strategies with the benchmark, and identified their impact mechanisms.	**Computational guidance:** Instructed the student in using mathematical analysis software and methods for solving multi-parameter models; guided the development of an imperfect AI-based authentication model.
Research report writing: Designed the report structure, drafted the content, and revised the report based on the advisor's comments.	**Writing guidance:** Reviewed and refined the report structure and manuscript.

Appendix

Appendix A: Proofs of Lemmas

A.1 Proof of Lemma 1

Comparing the utilities in the benchmark, we find there are two possible scenarios: with secondary transactions or not.

Scenario 1: All consumer types of NN, NH, WU, WL exist in the market. In period 1, consumers with $v_2^B \le v \le 1$ purchase new products while consumers with $0 \le v < v_2^B$ wait. In period 2, consumers whose value meets $0 \le v < v_3^B = \frac{p_u^B}{\delta\alpha}$ prefer WL; consumers whose value meets $v_3^B \le v < v_2^B = \frac{p_n^B - p_u^B}{1+\delta-\delta\alpha}$ prefer WU; consumers whose value meets $v_2^B \le v < v_1^B = \frac{p_n^B - p_u^B}{1-\delta}$ prefer NH; and consumers whose value meets $v_1^B \le v \le 1$ prefer NN. Consumers are segmented as shown in Figure A.1.

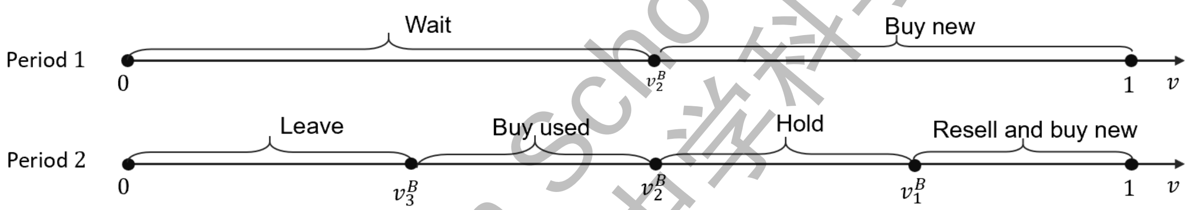

Figure A.1 Market segmentation of scenario 1 in benchmark

The market-clearing price $p_u^{B*}(p_n^B)$ of used products is achieved at:

$$\underbrace{1 - v_1^B}_{genuine\ supply} = \alpha \underbrace{(v_2^B - v_3^B)}_{genuine\ demand} \qquad (A.1)$$

which yields $p_u^{B*}(p_n^B) = \frac{\delta((-1+\delta)(-1+(-1+\alpha)\delta)+(-1-\delta+\alpha(-1+2\delta))p_n^B)}{-1-\delta+\alpha\delta^2}$.

The manufacturer's objective is to maximize the profit:

$$\max \Pi^B = p_n^B \left(\underbrace{1 - v_2^B}_{demand\ in\ period\ 1} + \underbrace{1 - v_1^B}_{demand\ in\ period\ 2} \right) \qquad (A.2)$$

$$\text{s.t. } 1 - v_1^B, v_1^B - v_2^B, v_2^B - v_3^B, v_3^B \ge 0.$$

By constructing the Lagrangian Function and applying the Karush–Kuhn–Tucker (KKT) conditions, we derive the optimal solutions in scenario 1 as follows:

$$p_n^B = \begin{cases} \dfrac{-1+\alpha\delta+\delta^2-\alpha\delta^2}{-1-\alpha-\delta+2\alpha\delta} & 0<\delta<\dfrac{1}{2} \text{ and } 0<\alpha<\alpha_{k1}^B \\ \dfrac{-2+\alpha\delta^2}{-4+2\alpha\delta} & 0<\delta<\delta_{k1}^B \text{ and } \max\{\alpha_{k1}^B, \alpha_{k2}^B\} \le \alpha < 1, \\ \dfrac{-1+\delta^2}{-1-\delta+\alpha\delta} & \dfrac{1}{2} \le \delta < 1 \text{ and } 0<\alpha<\min\{\alpha_{k2}^B, 1\} \end{cases}$$

$$\Pi^B = \begin{cases} \dfrac{(1-\delta)(-1-\delta+\alpha\delta)(-2\delta+\alpha(-2+3\delta))}{(1+\alpha+\delta-2\alpha\delta)^2} & 0<\delta<\dfrac{1}{2} \; and \; 0<\alpha<\alpha_{k1}^B \\ \dfrac{(-2+\alpha\delta^2)^2}{4(-2+\alpha\delta)(-1-\delta+\alpha\delta^2)} & 0<\delta<\delta_{k1}^B \; and \; \max\{\alpha_{k1}^B,\alpha_{k2}^B\}\le\alpha<1. \\ \dfrac{(-2+\alpha)\delta(-1+\delta^2)}{(-1+(-1+\alpha)\delta)^2} & \dfrac{1}{2}\le\delta<1 \; and \; 0<\alpha<\min\{\alpha_{k2}^B,1\} \end{cases}$$

where δ_{k1}^B is obtained from solving the equation $\frac{1+3\delta}{2\delta}-\frac{1}{2}\sqrt{\frac{8-7\delta-10\delta^2+9\delta^3}{\delta^3}}=1$ when $\delta\in(0,1)$. In addition, for ease of expression, this study defines the following parameters to replace some complex thresholds: $\alpha_{k1}^B=\frac{-2-2\delta+5\delta^2+3\delta^3}{2\delta^2(-3+4\delta)}-\frac{1}{2}\sqrt{\frac{4+8\delta-40\delta^2+24\delta^3+29\delta^4-34\delta^5+9\delta^6}{\delta^4(-3+4\delta)^2}}$ and $\alpha_{k2}^B=\frac{1+3\delta}{2\delta}-\frac{1}{2}\sqrt{\frac{8-7\delta-10\delta^2+9\delta^3}{\delta^3}}$[12].

Scenario 2: Only consumer types of NH and WL exist in the market under condition $p_n^B\ge\frac{-1+\delta^2}{-1-\delta+\alpha\delta}$ ($v_1^B\ge 1$ in Scenario 1). In period 1, consumers with $v_4^B\le v\le 1$ purchase new products while consumers with $0\le v<v_4^B$ wait. In period 2, consumers whose value meets $0\le v<v_4^B=\frac{p_n^B}{1+\delta}$ prefer WL; consumers whose value meets $v_4^B\le v\le 1$ prefer NH. Consumers are segmented as shown in Figure A.2.

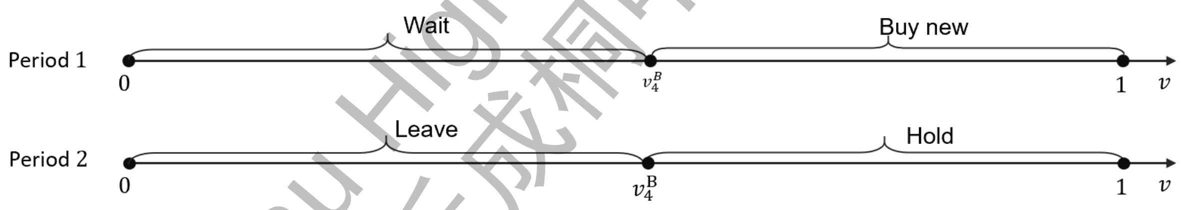

Figure A.2 Market segmentation of scenario 2 in benchmark

The manufacturer's objective is to maximize the profit:

$$\max \Pi^B = p_n^B\left(\underbrace{1-v_4^B}_{demand\ in\ period\ 1}\right) \tag{A.3}$$

$$\text{s.t. } 1-v_4^B, v_4^B\ge 0, p_n^B\ge\frac{-1+\delta^2}{-1-\delta+\alpha\delta}.$$

The optimal solutions under scenario 2 are obtained as follows:

$$p_n^B=\begin{cases} \dfrac{-1+\delta^2}{-1-\delta+\alpha\delta} & 0<\delta<\dfrac{1}{2} \; and \; \max\left\{\dfrac{-1+3\delta}{\delta},0\right\}<\alpha<1 \\ \dfrac{1+\delta}{2} & \dfrac{1}{3}<\delta<1 \; and \; 0<\alpha\le\min\left\{\dfrac{-1+3\delta}{\delta},1\right\} \end{cases},$$

[12] Superscripts $j\in\{B,BT,AI\}$ is to denote different cases and subscripts $K\in\{k1,k2,k3\ldots\}$ are used to denote different thresholds in each case.

$$\Pi^{B}=\begin{cases}\dfrac{(-2+\alpha)\delta(-1+\delta^{2})}{(-1+(-1+\alpha)\delta)^{2}} & 0<\delta<\dfrac{1}{2}\ and\ \max\left\{\dfrac{-1+3\delta}{\delta},0\right\}<\alpha<1\\[2ex] \dfrac{1+\delta}{4} & \dfrac{1}{3}<\delta<1\ and\ 0<\alpha\le\min\left\{\dfrac{-1+3\delta}{\delta},1\right\}\end{cases}.$$

By ruling out the overlapping areas, we finalize the optimal solution as shown in Lemma 1, where δ_1^B is obtained from solving the equation $\alpha_1^B=\alpha_2^B$ when $\delta\in(0,1)$ and δ_2^B is obtained from solving the equation $\frac{1+3\delta^2}{2\delta^2}-\frac{1}{2}\sqrt{\frac{1+8\delta-10\delta^2-8\delta^3+9\delta^4}{\delta^4}}=1$ when $\delta\in(0,1)$. For ease of expression, we define the following notations in place of some complex thresholds: $\alpha_1^B=\frac{-2-2\delta+5\delta^2+3\delta^3}{2\delta^2(-3+4\delta)}-\frac{1}{2}\sqrt{\frac{4+8\delta-40\delta^2+24\delta^3+29\delta^4-34\delta^5+9\delta^6}{\delta^4(-3+4\delta)^2}}$; $\alpha_2^B=\frac{3-6\delta-5\delta^2+12\delta^3}{1+5\delta-20\delta^2+16\delta^3}-2\sqrt{\frac{2-9\delta+12\delta^2-2\delta^3-6\delta^4+3\delta^5}{(1+5\delta-20\delta^2+16\delta^3)^2}}$; and $\alpha_3^B=\frac{1+3\delta^2}{2\delta^2}-\frac{1}{2}\sqrt{\frac{1+8\delta-10\delta^2-8\delta^3+9\delta^4}{\delta^4}}$.

In each scenario, we can obtain that $\frac{\partial\Pi^{B*}}{\partial\alpha}>0$. Namely, counterfeit products lead to the value-shrinkage effect for the manufacturer.

A.2 Proof of Lemma 2

By comparing the utilities in case BT, we find there are two possible scenarios: with secondary transactions or not.

Scenario 1: All consumer types of NN, NH, WU, WL exist in the market. In period 1, consumers with $v_2^{BT}\le v\le 1$ purchase new products while consumers with $0\le v<v_2^{BT}$ wait. In period 2, consumers whose value meets $0\le v<v_3^{BT}=\frac{p_u^{BT}}{\delta}$ prefer WL; consumers whose value meets $v_3^{BT}\le v<v_2^{BT}=p_n^{BT}-p_u^{BT}$ prefer WU; consumers whose value meets $v_2^{BT}\le v<v_1^{BT}=\frac{p_n^{BT}-p_u^{BT}}{1-\delta}$ prefer NH; consumers whose value meets $v_1^{BT}\le v\le 1$ prefer NN. Consumers are segmented as shown in Figure A.3.

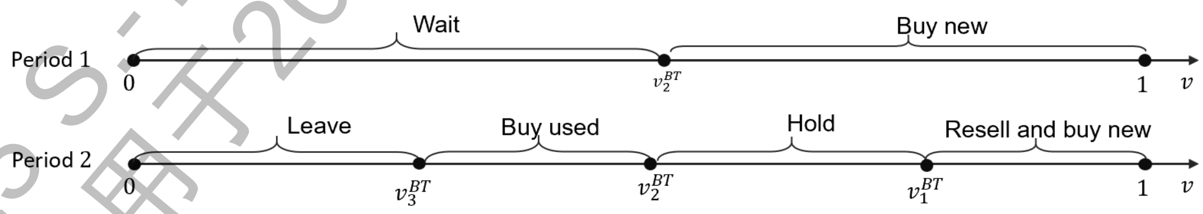

Figure A.3 Market segmentation of scenario 1 in case BT

The market-clearing price $p_u^{BT*}(p_n^{BT})$ of used products is achieved at:

$$\underbrace{1-v_1^{BT}}_{supply}=\underbrace{v_2^{BT}-v_3^{BT}}_{demand} \qquad (A.4)$$

which yields $p_u^{BT*}(p_n^{BT}) = \frac{\delta(1-\delta+(-2+\delta)p_n^{BT})}{-1-\delta+\delta^2}$.

The manufacturer's objective is to maximize the profit:

$$\max \Pi^{BT} = (p_n^{BT} - c)\left(\underbrace{1 - v_2^{BT}}_{demand\ in\ period\ 1} + \underbrace{1 - v_1^{BT}}_{demand\ in\ period\ 2}\right) \qquad (A.5)$$

$$\text{s.t. } 1 - v_1^{BT}, v_1^{BT} - v_2^{BT}, v_2^{BT} - v_3^{BT}, v_3^{BT} \geq 0.$$

The optimal solutions are obtained as follows:

$$p_n^{BT} = \begin{cases} \frac{c}{2} + \frac{-2+\delta^2}{2(-2+\delta)} & 0 < \delta < \delta_{k1}^{BT} \ and\ 0 < c \leq \frac{-2+2\delta+3\delta^2-2\delta^3}{-2+\delta} \\ 1-\delta^2 & 0 < \delta < 1\ and\ \max\left\{\frac{-2+2\delta+3\delta^2-2\delta^3}{-2+\delta}, 0\right\} < c < 1 \end{cases},$$

$$\Pi^{BT} = \begin{cases} \frac{\left(2+c(-2+\delta)-\delta^2\right)^2}{4\left(2+\delta-3\delta^2+\delta^3\right)} & 0 < \delta < \delta_{k1}^{BT} \ and\ 0 < c \leq \frac{-2+2\delta+3\delta^2-2\delta^3}{-2+\delta} \\ \delta\left(1-c-\delta^2\right) & 0 < \delta < 1\ and\ \max\left\{\frac{-2+2\delta+3\delta^2-2\delta^3}{-2+\delta}, 0\right\} < c < 1 \end{cases}.$$

where δ_{k1}^{BT} is obtained from solving the equation $\frac{-2+2\delta+3\delta^2-2\delta^3}{-2+\delta} = 0$ when $\delta \in (0,1)$.

Scenario 2: Only consumer types of NH and WL exist in the market under condition $p_n^{BT} \geq 1 - \delta^2$ ($v_1^{BT} \geq 1$ in Scenario 1). In period 1, consumers with $v_4^{BT} \leq v \leq 1$ purchase new products while consumers with $0 \leq v < v_4^{B}$ wait. In period 2, consumers whose value meets $0 \leq v < v_4^{BT} = \frac{p_n^{BT}}{1+\delta}$ prefer WL; consumers whose value meets $v_4^{BT} \leq v \leq 1$ prefer NH. Consumers are segmented as shown in Figure A.4.

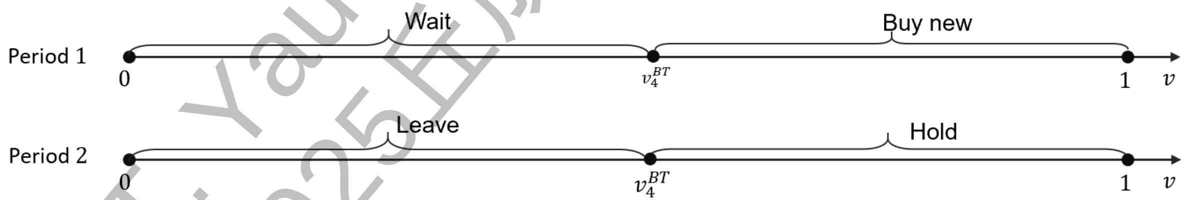

Figure A.4 Market segmentation of scenario 2 in case BT

The manufacturer's objective is to maximize the profit:

$$\max \Pi^{BT} = (p_n^{BT} - c)\left(\underbrace{1 - v_4^{BT}}_{demand\ in\ period\ 1}\right) \qquad (A.6)$$

$$\text{s.t. } 1 - v_4^{BT}, v_4^{BT} \geq 0, p_n^{BT} \geq 1 - \delta^2.$$

The optimal solutions are obtained as follows:

$$p_n^{BT}=\begin{cases}1-\delta^2 & 0<\delta<\frac{1}{2}\ and\ 0<c\le 1-\delta-2\delta^2\\ \frac{1}{2}(1+c+\delta) & 0<\delta<1\ and\ \max\{1-\delta-2\delta^2,0\}<c<1\end{cases},$$

$$\Pi^{BT}=\begin{cases}\delta(1-c-\delta^2) & 0<\delta<\frac{1}{2}\ and\ 0<c\le 1-\delta-2\delta^2\\ \frac{(1-c+\delta)^2}{4(1+\delta)} & 0<\delta<1\ and\ \max\{1-\delta-2\delta^2,0\}<c<1\end{cases}.$$

By ruling out the overlapping areas, we finalize the optimal solution as shown in Lemma 2, where δ_1^{BT} is obtained from solving the equation $1-\delta^2-\sqrt{\frac{-\delta^2-2\delta^3+\delta^5}{-2+\delta}}=0$ when $\delta\in(0,1)$. Note that $\delta_2^B=\delta_1^{BT}$.

A.3 Proof of Lemma 3

By comparing the utilities in case AI, we find there are two possible scenarios: with secondary transactions or not.

Scenario 1: All consumer types of NN, NH, WU, WL exist in the market. In period 1, consumers with $v_2^{AI}\le v\le 1$ purchase new products while consumers with $0\le v<v_2^{AI}$ wait. In period 2, consumers whose value meets $0\le v<v_3^{AI}=\frac{p_u^{AI}}{\delta}$ prefer WL; consumers whose value meets $v_3^{AI}\le v<v_2^{AI}=p_n^{AI}-p_u^{AI}$ prefer WU; consumers whose value meets $v_2^{AI}\le v<v_1^{AI}=\frac{p_n^{AI}-p_u^{AI}+f}{1-\delta}$ prefer NH; consumers whose value meets $v_1^{AI}\le v\le 1$ prefer NN. Consumers are segmented as shown in Figure A.5.

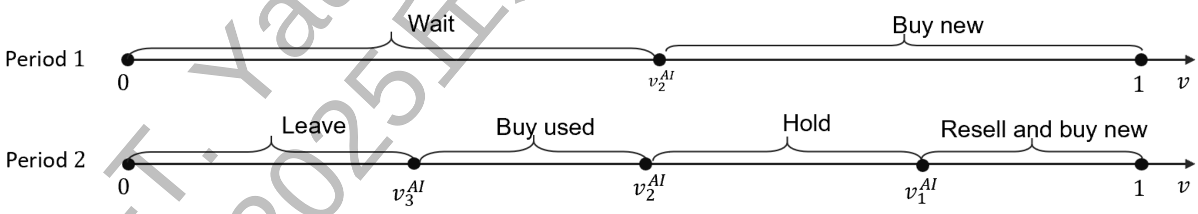

Figure A.5 Market segmentation of scenario 1 in case AI

The market-clearing price $p_u^{AI*}(p_n^{AI})$ of used products is achieved at:

$$\underbrace{1-v_1^{AI}}_{supply}=\underbrace{v_2^{AI}-v_3^{AI}}_{demand} \qquad (A.7)$$

which yields $p_u^{AI}=\frac{\delta(1-\delta-f+(-2+\delta)p_n^{AI})}{-1-\delta+\delta^2}$.

The manufacturer's objective is to maximize the profit:

$$\max \Pi^{AI}=p_n^{AI}\left(\underbrace{1-v_2^{AI}}_{demand\ in\ period\ 1}+\underbrace{1-v_1^{AI}}_{demand\ in\ period\ 2}\right) \qquad (A.8)$$

$$\text{s.t. } 1 - v_1^{AI}, v_1^{AI} - v_2^{AI}, v_2^{AI} - v_3^{AI}, v_3^{AI} \geq 0, p_u^{AI} \geq f > 0.$$

The analysis of these constraints shows that the manufacturer can maximize its profits under scenario 1 if and only if $0 < f < \frac{\delta-\delta^2}{1+\delta}$. The reason for this is that when $f \geq \frac{\delta-\delta^2}{1+\delta}$, two scenarios may occur in the market: a situation in which the price of the used product is too high, resulting in no buyers in the secondary market, and a situation in which the authentication service fee is too high, resulting in no sellers in the secondary market. Either scenario implies that transactions in the secondary market does not exist and that the reason for this is due to the high fee of authentication service. Therefore, this study does not consider the scenarios where f exceeds the assumed range because the purpose of C2C secondary platforms providing authentication services is to eliminate counterfeiting in the secondary market. In addition, the market structure realized by $f \geq \frac{\delta-\delta^2}{1+\delta}$ does not match with the purpose of this study to analyze the impact brought by the authentication service. Therefore, we make a technical assumption on the range of the value of f, i.e., $0 < f < \frac{\delta-\delta^2}{1+\delta}$.

The optimal solutions are obtained as follows:

$$p_n^{AI} = \begin{cases} \dfrac{-\delta+\delta^2-f+\delta^2 f}{-2\delta+\delta^2} & 0<\delta<\delta_{k1}^{AI} \text{ and } \dfrac{-2\delta^2+\delta^3}{-2-\delta+2\delta^2} < f < \dfrac{\delta-\delta^2}{1+\delta} \\ \dfrac{-2+\delta^2+f}{2(-2+\delta)} & 0<\delta<\delta_{k2}^{AI} \text{ and } 0<f \leq \min\left\{\dfrac{-2\delta^2+\delta^3}{-2-\delta+2\delta^2}, \dfrac{-2+2\delta+3\delta^2-2\delta^3}{-3-2\delta+2\delta^2}\right\} \\ 1-\delta^2-f(1+\delta) & \delta_{k1}^{AI}<\delta<1 \text{ and } \max\left\{\dfrac{-2+2\delta+3\delta^2-2\delta^3}{-3-2\delta+2\delta^2}, 0\right\} < f < \dfrac{\delta-\delta^2}{1+\delta} \end{cases}$$

$$\Pi^{AI} = \begin{cases} \dfrac{(1-\delta)(\delta-f)(\delta+f+\delta f)}{(2-\delta)\delta^2} & 0<\delta<\delta_{k1}^{AI} \text{ and } \dfrac{-2\delta^2+\delta^3}{-2-\delta+2\delta^2} < f < \dfrac{\delta-\delta^2}{1+\delta} \\ \dfrac{(-2+\delta^2+f)^2}{4(2+\delta-3\delta^2+\delta^3)} & 0<\delta<\delta_{k2}^{AI} \text{ and } 0<f \leq \min\left\{\dfrac{-2\delta^2+\delta^3}{-2-\delta+2\delta^2}, \dfrac{-2+2\delta+3\delta^2-2\delta^3}{-3-2\delta+2\delta^2}\right\} \\ (1+\delta)(1-\delta-f)(\delta+f) & \delta_{k1}^{AI}<\delta<1 \text{ and } \max\left\{\dfrac{-2+2\delta+3\delta^2-2\delta^3}{-3-2\delta+2\delta^2}, 0\right\} < f < \dfrac{\delta-\delta^2}{1+\delta} \end{cases}$$

where δ_{k1}^{AI} is obtained from solving the equation $\frac{-2\delta^2+\delta^3}{-2-\delta+2\delta^2} = \frac{\delta-\delta^2}{1+\delta}$ when $\delta \in (0,1)$ and δ_{k2}^{AI} is obtained from solving the equation $\frac{-2+2\delta+3\delta^2-2\delta^3}{-3-2\delta+2\delta^2} = 0$ when $\delta \in (0,1)$.

Scenario 2: Only consumer types of NH and WL exist in the market under condition $p_n^{AI} \geq 1 - \delta^2 - f(1+\delta)$ ($v_1^{AI} \geq 1$ in Scenario 1). In period 1, consumers with $v_4^{AI} \leq v \leq 1$ purchase new products while consumers with $0 \leq v < v_4^{AI}$ wait. In period 2, consumers whose value meets $0 \leq v < v_4^{AI} = \frac{p_n^{AI}}{1+\delta}$ prefer WL; consumers whose value meets $v_4^{AI} \leq v \leq 1$ prefer NH. Consumers are segmented as shown in Figure A.6.

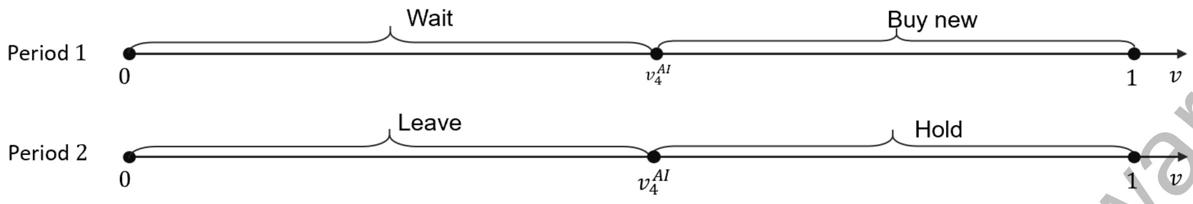

Figure A.6 Market segmentation of scenario 2 in case AI

The manufacturer's objective is to maximize the profit:

$$\max \Pi^{AI} = p_n^{AI}\left(\underbrace{1 - v_4^{AI}}_{demand\ in\ period\ 1}\right) \tag{A.9}$$

$$\text{s.t. } 1 - v_4^{AI}, v_4^{AI} \ge 0, p_n^{AI} \ge 1 - \delta^2 - f(1+\delta)$$

The optimal solutions are obtained as follows:

$$p_n^{AI} = \begin{cases} 1-\delta^2 - f(1+\delta) & 0<\delta\le\frac{1}{2} \text{ and } 0<f\le\min\left\{\frac{\delta-\delta^2}{1+\delta},\frac{1}{2}(1-2\delta)\right\} \\ \frac{1+\delta}{2} & \frac{1}{3}<\delta<1 \text{ and } \max\left\{\frac{1}{2}(1-2\delta),0\right\}<f<\frac{\delta-\delta^2}{1+\delta} \end{cases},$$

$$\Pi^{AI} = \begin{cases} (1+\delta)(1-\delta-f)(\delta+f) & 0<\delta\le\frac{1}{2} \text{ and } 0<f\le\min\left\{\frac{\delta-\delta^2}{1+\delta},\frac{1}{2}(1-2\delta)\right\} \\ \frac{1+\delta}{4} & \frac{1}{3}<\delta<1 \text{ and } \max\left\{\frac{1}{2}(1-2\delta),0\right\}<f<\frac{\delta-\delta^2}{1+\delta} \end{cases}.$$

By ruling out the overlapping areas, we finalize the optimal solution as shown in Lemma 3, where δ_1^{AI} is obtained from solving the equation $f_1^{AI} = f_2^{AI}$ when $\delta \in (0,1)$ and δ_2^{AI} is obtained from solving the equation $2 - \delta^2 - \sqrt{2 + 3\delta - 2\delta^2 - 2\delta^3 + \delta^4} = 0$ when $\delta \in (0,1)$. For ease of expression, we define the following notations in place of some complex thresholds: $f_1^{AI} = \frac{-2\delta^2+\delta^3}{-2-\delta+2\delta^2}$; $f_2^{AI} = \frac{\delta^2}{2(1+\delta)} + \frac{1}{2}\sqrt{\frac{-2\delta^2+3\delta^3+3\delta^4}{(-1+\delta)(1+\delta)^2}}$; and $f_3^{AI} = 2 - \delta^2 - \sqrt{2 + 3\delta - 2\delta^2 - 2\delta^3 + \delta^4}$.

Accordingly, substituting the solutions into the manufacturer's demand function, and using the FOC with regard to the authentication fee, we have $\frac{\partial D_{NN}^*}{\partial f} < 0$. Namely, the AI-based authentication service can lead to the demand demand-reduction effect for the manufacturer.

A.4 Proof of Lemma 4

By comparing the utilities in case MAI, we find there are two possible scenarios: with secondary transactions or not.

Scenario 1: All consumer types of NN, NH, WU, WL exist in the market. In period 1, consumers with $v_2^{MAI} \le v \le 1$ purchase new products while consumers with $0 \le v < v_2^{MAI}$ wait. In period 2, consumers whose value meets $0 \le v < v_3^{MAI} = \frac{p_u^{MAI}}{\delta\alpha}$ prefer WL; consumers whose value meets $v_3^{MAI} \le v < v_2^{MAI} = \frac{p_n^{BMAI} - p_u^{MAI}}{1+\delta-\delta\alpha}$ prefer WU; consumers whose value meets $v_2^{MAI} \le v < v_1^{MAI} = \frac{p_n^{MAI} - p_u^{MAI}}{1-\delta}$ prefer NH; and consumers whose value meets $v_1^{MAI} \le v \le 1$ prefer NN. Consumers are segmented as shown in Figure A.7.

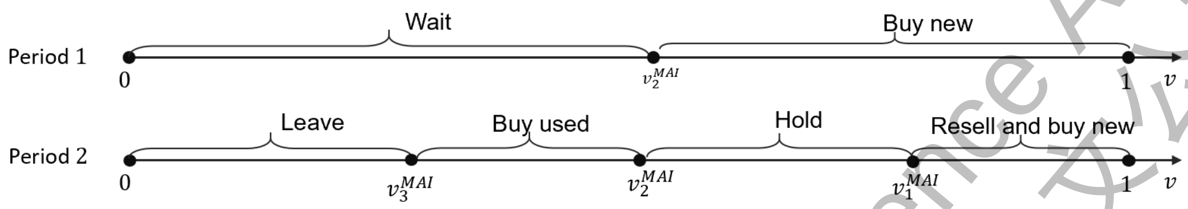

Figure A.7 Market segmentation of scenario 1 in case MAI

The market-clearing price $p_u^{MAI*}(p_n^{MAI})$ of used products is achieved at:

$$\underbrace{1 - v_1^{MAI}}_{genuine\ supply} = \alpha\underbrace{\left(v_2^{MAI} - v_3^{MAI}\right)}_{genuine\ demand} \qquad (A.10)$$

which yields $p_u^{MAI*}(p_n^{MAI}) = \frac{\delta((-1+\delta)(-1+(-1+\alpha)\delta)+(-1-\delta+\alpha(-1+2\delta))p_n^{MAI})}{-1-\delta+\alpha\delta^2}$.

The manufacturer's objective is to maximize the profit:

$$\max \Pi^{MAI} = p_n^{MAI}\left(\underbrace{1 - v_2^{MAI}}_{demand\ in\ period\ 1} + \underbrace{1 - v_1^{MAI}}_{demand\ in\ period\ 2}\right) \qquad (A.11)$$

$$\text{s.t. } 1 - v_1^{MAI}, v_1^{MAI} - v_2^{MAI}, v_2^{MAI} - v_3^{MAI}, v_3^{MAI} \ge 0.$$

By constructing the Lagrangian Function and applying the Karush–Kuhn–Tucker (KKT) conditions, we identify the optimal solutions in scenario 1 as follows:

$$p_n^B = \begin{cases} \dfrac{-1+\alpha\delta+\delta^2-\alpha\delta^2}{-1-\alpha-\delta+2\alpha\delta} & 0<\delta<\dfrac{1}{2}\ and\ 0<\alpha<\alpha_{k1}^B \\ \dfrac{-2+\alpha\delta^2}{-4+2\alpha\delta} & 0<\delta<\delta_{k1}^B\ and\ \max\left\{\alpha_{k1}^B,\alpha_{k2}^B\right\}\le\alpha<1, \\ \dfrac{-1+\delta^2}{-1-\delta+\alpha\delta} & \dfrac{1}{2}\le\delta<1\ and\ 0<\alpha<\min\left\{\alpha_{k2}^B,1\right\} \end{cases}$$

$$\Pi^B = \begin{cases} \dfrac{(1-\delta)(-1-\delta+\alpha\delta)(-2\delta+\alpha(-2+3\delta))}{(1+\alpha+\delta-2\alpha\delta)^2} & 0<\delta<\dfrac{1}{2}\ and\ 0<\alpha<\alpha_{k1}^B \\ \dfrac{(-2+\alpha\delta^2)^2}{4(-2+\alpha\delta)(-1-\delta+\alpha\delta^2)} & 0<\delta<\delta_{k1}^B\ and\ \max\left\{\alpha_{k1}^B,\alpha_{k2}^B\right\}\le\alpha<1. \\ \dfrac{(-2+\alpha)\delta(-1+\delta^2)}{(-1+(-1+\alpha)\delta)^2} & \dfrac{1}{2}\le\delta<1\ and\ 0<\alpha<\min\left\{\alpha_{k2}^B,1\right\} \end{cases}$$

where δ_{k1}^{MAI} is obtained from solving the equation $\frac{1+3\delta}{2\delta} - \frac{1}{2}\sqrt{\frac{8-7\delta-10\delta^2+9\delta^3}{\delta^3}} = 1$ when $\delta \in (0,1)$. In addition, for ease of expression, this study defines the following parameters to replace some complex thresholds: $\alpha_{k1}^{MAI}=\frac{-2-2\delta+5\delta^2+3\delta^3}{2\delta^2(-3+4\delta)}-\frac{1}{2}\sqrt{\frac{4+8\delta-40\delta^2+24\delta^3+29\delta^4-34\delta^5+9\delta^6}{\delta^4(-3+4\delta)^2}}$ and $\alpha_{k2}^{MAI}=\frac{1+3\delta}{2\delta}-\frac{1}{2}\sqrt{\frac{8-7\delta-10\delta^2+9\delta^3}{\delta^3}}$[13].

Scenario 2: Only consumer types of NH and WL exist in the market under condition $p_n^{MAI}\geq\frac{-1+\delta^2}{-1-\delta+\alpha\delta}$ ($v_1^{MAI}\geq 1$ in Scenario 1). In period 1, consumers with $v_4^{MAI}\leq v\leq 1$ purchase new products while consumers with $0\leq v<v_4^{MAI}$ wait. In period 2, consumers whose value meets $0\leq v<v_4^{MAI}=\frac{p_n^{MAI}}{1+\delta}$ prefer WL; consumers whose value meets $v_4^{MAI}\leq v\leq 1$ prefer NH. Consumers are segmented as shown in Figure A.8.

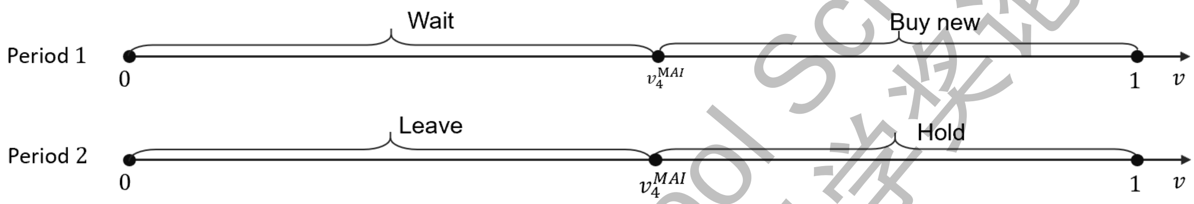

Figure A.8 Market segmentation of scenario 2 in benchmark

The manufacturer's objective is to maximize the profit:

$$\max \Pi^{MAI}=p_n^{MAI}\left(\underbrace{1-v_4^{MAI}}_{demand\ in\ period\ 1}\right) \qquad (A.12)$$

$$\text{s.t. } 1-v_4^{MAI}, v_4^{MAI}\geq 0, p_n^{MAI}\geq\frac{-1+\delta^2}{-1-\delta+\alpha\delta}.$$

The optimal solutions under scenario 2 are obtained as follows:

$$p_n^B=\begin{cases}\frac{-1+\delta^2}{-1-\delta+\alpha\delta} & 0<\delta<\frac{1}{2}\ and\ \max\left\{\frac{-1+3\delta}{\delta},0\right\}<\alpha<1\\ \frac{1+\delta}{2} & \frac{1}{3}<\delta<1\ and\ 0<\alpha\leq\min\left\{\frac{-1+3\delta}{\delta},1\right\}\end{cases},$$

$$\Pi^B=\begin{cases}\frac{(-2+\alpha)\delta(-1+\delta^2)}{(-1+(-1+\alpha)\delta)^2} & 0<\delta<\frac{1}{2}\ and\ \max\left\{\frac{-1+3\delta}{\delta},0\right\}<\alpha<1\\ \frac{1+\delta}{4} & \frac{1}{3}<\delta<1\ and\ 0<\alpha\leq\min\left\{\frac{-1+3\delta}{\delta},1\right\}\end{cases}.$$

By ruling out the overlapping areas, we finalize the optimal solution as shown in Lemma 1, where δ_1^{MAI} is obtained from solving the equation $\alpha_1^{MAI}=\alpha_2^{MAI}$ when $\delta\in(0,1)$ and δ_2^{MAI} is obtained from solving the equation $\frac{1+3\delta^2}{2\delta^2}-\frac{1}{2}\sqrt{\frac{1+8\delta-10\delta^2-8\delta^3+9\delta^4}{\delta^4}}=1$ when $\delta\in(0,1)$. For ease of expression, we define the following notations in place of some complex thresholds: $\alpha_1^{MAI}=$

[13] Superscripts $j\in\{B,BT,AI,MAI\}$ is to denote different cases and subscripts $K\in\{k1,k2,k3\ldots\}$ are used to denote different thresholds in each case.

$\frac{-2-2\delta+5\delta^2+3\delta^3}{2\delta^2(-3+4\delta)} - \frac{1}{2}\sqrt{\frac{4+8\delta-40\delta^2+24\delta^3+29\delta^4-34\delta^5+9\delta^6}{\delta^4(-3+4\delta)^2}}$; $\alpha_2^{MAI} = \frac{3-6\delta-5\delta^2+12\delta^3}{1+5\delta-20\delta^2+16\delta^3} - 2\sqrt{\frac{2-9\delta+12\delta^2-2\delta^3-6\delta^4+3\delta^5}{(1+5\delta-20\delta^2+16\delta^3)^2}}$; and $\alpha_3^{MAI} = \frac{1+3\delta^2}{2\delta^2} - \frac{1}{2}\sqrt{\frac{1+8\delta-10\delta^2-8\delta^3+9\delta^4}{\delta^4}}$.

Appendix B: Proofs of Propositions

B.1 Proof of Proposition 1

First, we derive the manufacturer's profit in the market without counterfeit products (Case N).

- **Scenario 1:** For consumers, they have the following choices: NN, NH, WU, and WL. Comparing the utilities of the four choices, we can obtain their choices. For consumers whose valuation satisfy $0 \le v < v_3^N = \frac{p_u^N}{\delta}$, they choice WL; for consumers whose valuation satisfy $v_3^N \le v < v_2^N = p_n^N - p_u^N$, they choose WU; for consumers whose valuation satisfy $v_2^N \le v < v_1^N = \frac{p_n^N - p_u^N}{1-\delta}$, they choose NH; and for consumers whose valuation satisfy $v_1^N \le v \le 1$, they choose NN. When $1 - v_1^N, v_1^N - v_2^N, v_2^N - v_3^N, v_3^N \ge 0$, all the four types consumer exist in the market, and there are transactions of used products. We illustrate the market segmentation in Figure B1.

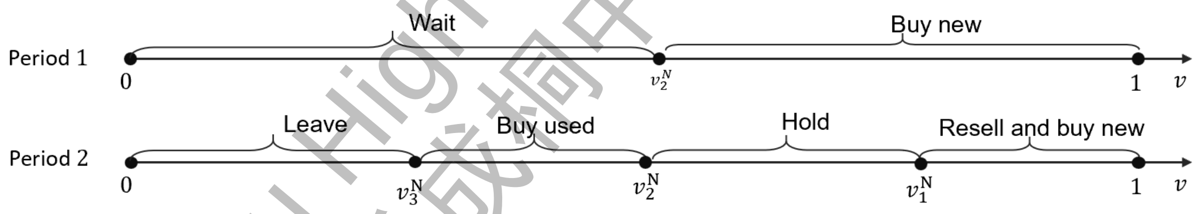

Figure B.1 Market segment with used transactions

We obtain the supply and demand of the used products are the in the secondary market as $1-v_1^N$ and $v_2^N - v_3^N$, respectively. By equaling the demand and supply, we derive the market clearing price of used product, i.e., $p_u^N = \dfrac{\delta\left(1-\delta+\left(-2+\delta\right)p_n^N\right)}{-1-\delta+\delta^2}$.

The manufacturer's profit obtained from new products is $\Pi^N = p_n^N\, (\underbrace{1-v_2^N}_{\text{Demand in period 1}} + \underbrace{1-v_1^N}_{\text{Demand in period 2}}) = p_n^N(2-v_1^N-v_2^N)$. Using backward induction, we obtain the optimal price (i.e., p_n^N) of new products and the corresponding profit (i.e.,

Π^N) of the manufacturer[14].

$$p_n^N = \begin{cases} \dfrac{-2+\delta^2}{2(-2+\delta)} & 0<\delta\le\delta_{k1}^N \\ 1-\delta^2 & \delta_{k1}^N<\delta<1 \end{cases}, \text{ and } \Pi^N = \begin{cases} \dfrac{\left(-2+\delta^2\right)^2}{4\left(2+\delta-3\delta^2+\delta^3\right)} & 0<\delta\le\delta_{k1}^N \\ \delta-\delta^3 & \delta_{k1}^N<\delta<1 \end{cases}.$$

- **Scenario 2:** When the new product is sufficiently high, no pro-owners will resell their used products and there is no transaction in the secondary market. For consumers whose valuation satisfy $0 \le v < v_4^N = \frac{p_n^N}{1+\delta}$, they choose WL; and for consumers whose valuation satisfy $v_4^N \le v \le 1$, they prefer NH. If and only if $p_n^N \ge 1-\delta^2$, NN is dominated by NH. The market segmentation is show in Figure A1.2.

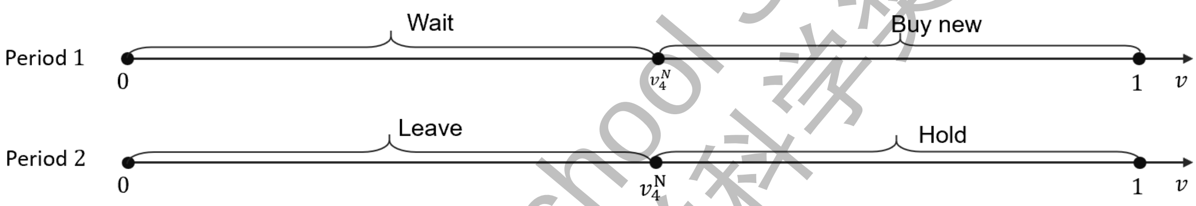

Figure B.2 Market segment without used transactions

For the manufacturer, it sells new products only in period 1 and the profit is $\Pi^N = p_n^N(1-v_4^N)$. The optimal price and profit of the manufacturer are:

$$p_n^N = \begin{cases} 1-\delta^2 & 0<\delta\le\dfrac{1}{2} \\ \dfrac{1+\delta}{2} & \dfrac{1}{2}<\delta<1 \end{cases} \text{ and } \Pi^N = \begin{cases} \delta-\delta^3 & 0<\delta\le\dfrac{1}{2} \\ \dfrac{1+\delta}{4} & \dfrac{1}{2}<\delta<1 \end{cases}.$$

Here, δ_1^N is the solution of $\frac{(-2+\delta^2)^2}{4(2+\delta-3\delta^2+\delta^3)} = \frac{1+\delta}{4}$.

Second, we compare the manufacturer's profit without counterfeit products (Case N), and that with counterfeit products (Case B, see Lemma 1). In the region (Region 1 and 2 in Figure 3) that transaction of used goods exists, we obtain that $\Pi^{N*} \ge \Pi^{B*}$. Namely, in the presence of the secondary market, the existence of counterfeit products hurts the manufacturer's profit.

14 δ_{k1}^N is the solution of $\frac{-2+\delta^2}{2(-2+\delta)} = 1-\delta^2$.

B.2 Proof of Proposition 2

In the benchmark case, transactions of used products exist in Region 1 and 2 of Figure 3. When the manufacturer offers blockchain traceability, the conditions of existence of transactions of used product is $0 < \delta < \delta_2^B$ (See Figure 4). By comparing the thresholds of δ for the existence of transactions of used products in the benchmark case (δ is within Region 1 and 2 of Figure 3), with the conditions when the manufacturer provides BT system, we can find that the thresholds of δ in the benchmark is always less than δ_2^B. In other words, the existence of the secondary transactions expands in the region $\frac{1}{3} < \delta < \delta_2^B$ *and* $0 \leq c < 1 - \delta^2 - \sqrt{\frac{-\delta^2-2\delta^3+\delta^5}{-2+\delta}}$ when the manufacturer provides BT system.

B.3 Proof of Proposition 3

Comparing the equilibrium profits between benchmark case B and case BT in Lemma 1 and Lemma 2, the following conditions can be obtained by solving $\Pi^{BT*} > \Pi^{B*}$:

(a) When δ and α are in Region 1 (Figure 5), $\Pi^{BT*} > \Pi^{B*}$ when $0 < c < c_1$, where

$$c_1 = \frac{\delta^2-2}{\delta-2} - 2\sqrt{\frac{3\alpha^2\delta^5-8\alpha^2\delta^4+4\alpha^2\delta^3+3\alpha^2\delta^2-2\alpha^2\delta-5\alpha\delta^5+9\alpha\delta^4+4\alpha\delta^3-9\alpha\delta^2-\alpha\delta+2\alpha+2\delta^5-2\delta^4-4\delta^3+2\delta^2+2\delta}{(\delta-2)(2\alpha\delta-\alpha-\delta-1)^2}};$$

(b) When δ and α are in Region 2 (Figure 5), $\Pi^{BT*} > \Pi^{B*}$ when $0 < c < c_2$, where

$$c_2 = \frac{-2+\delta^2}{-2+\delta} - \sqrt{\frac{-4-4\delta+4\delta^2+4\alpha\delta^2+4\alpha\delta^3-4\alpha\delta^4-\alpha^2\delta^4-\alpha^2\delta^5+\alpha^2\delta^6}{(-2+\delta)(2+2\delta-\alpha\delta-3\alpha\delta^2+\alpha^2\delta^3)}};$$

(c) When δ and α are in Region 3[a] (Figure 5), $\Pi^{BT*} > \Pi^{B*}$ when $0 < c < c_3$, where

$$c_3 = \frac{-2+\delta^2}{-2+\delta} - \sqrt{\frac{-1-2\delta+\delta^3}{-2+\delta}};$$

(d) When δ and α are in Region 3[b] (Figure 5), $\Pi^{BT*} < \Pi^{B*}$ always holds. The reason is that the offering blockchain traceability that incurs a cost for each unit product will result in a profit loss for the manufacturer since secondary transactions do not exist at this point under both case B and case BT.

B.4 Proof of Proposition 4

Comparing the equilibrium profits between benchmark case B and case AI in Lemma 1 and Lemma 3, the following conditions can be obtained by solving $\Pi^{AI*} > \Pi^{B*}$.

(a) When δ and α are in Region 1 (Figure 7), it can be derived by solving for $\Pi^{AI*} > \Pi^{B*}$: when δ and α are in Region 1[b] (i.e., $0 < \delta < \frac{1}{3}$ and $0 < \alpha < \alpha_2$, or $\frac{1}{3} \leq \delta < \delta_3$ and $\alpha_2^B < \alpha < \alpha_2$), $0 < f < f_1$; when δ and α are in Region 1[c] (i.e., $0 < \delta < \delta_1^B$ and $\max\{\alpha_2, \alpha_2^B\} \leq \alpha < \alpha_1^B$), $0 < f \leq f_2$. It should be pointed out that $f_1 > f_2$. For ease of expression, $\alpha_2 = \frac{2-3\delta-4\delta^2+3\delta^3}{2+\delta-8\delta^2+4\delta^3}$; $f_1 = \frac{-\delta+\alpha\delta+\delta^2-\alpha\delta^2}{-1-\alpha-\delta+2\alpha\delta}$; and $f_2 = 2 - \delta^2 - 2\sqrt{-\frac{3\alpha^2\delta^6-14\alpha^2\delta^5+20\alpha^2\delta^4-5\alpha^2\delta^3-8\alpha^2\delta^2+4\alpha^2\delta-5\alpha\delta^6+19\alpha\delta^5-14\alpha\delta^4-17\alpha\delta^3+17\alpha\delta^2+4\alpha\delta-4\alpha+2\delta^6-6\delta^5+10\delta^3-2\delta^2-4\delta}{(2\alpha\delta-\alpha-\delta-1)^2}}$.

(b) When δ and α are in Region 2 (Figure 7), it can be derived by solving for $\Pi^{AI*} > \Pi^{B*}$: $0 < f < f_3$, where $f_3 = 2 - \delta^2 - \sqrt{\frac{\alpha^2\delta^7-3\alpha^2\delta^6+\alpha^2\delta^5+2\alpha^2\delta^4-4\alpha\delta^5+12\alpha\delta^4-4\alpha\delta^3-8\alpha\delta^2+4\delta^3-12\delta^2+4\delta+8}{\alpha^2\delta^3-3\alpha\delta^2-\alpha\delta+2\delta+2}}$;

(c) When δ and α are in Region 3[a] (Figure 7), it can be derived by solving for $\Pi^{AI*} > \Pi^{B*}$: $\frac{1}{3} < \delta < \delta_1^{AI}$ and $0 < f < f_2^{AI}$, or $\delta_1^{AI} \leq \delta < \delta_2^{AI}$ and $0 < f < f_3^{AI}$.

B.6 Proof of Proposition 5

(a) CS under case B is: when δ and α are in Region 1 and Region 2 of Figure 3 , $CS^B = \int_{v_3^B}^{v_2^B} V_{WU}^B \, dv + \int_{v_2^B}^{v_1^B} V_{NH}^B \, dv + \int_{v_1^B}^{1} V_{NN}^B \, dv$; when δ and α are in Region 3, $CS^B = \int_{v_4^B}^{1} V_{NH}^B \, dv$.

The CS under case BT is: when δ and c are in Region 1 and 2 of Figure 5, $CS^{BT} = \int_{v_3^{BT}}^{v_2^{BT}} V_{WU}^{BT} \, dv + \int_{v_2^{BT}}^{v_1^{BT}} V_{NH}^{BT} \, dv + \int_{v_1^{BT}}^{1} V_{NN}^{BT} \, dv$; when δ and c are in Region 3[a], $CS^{BT} = \int_{v_4^{BT}}^{1} V_{NH}^{BT} \, dv$. Proposition 5(a) can be derived by comparing the CS of case B and case BT. The following conclusions can be obtained by solving $CS^{BT} > CS^B$(See Figure 8).

(1) when δ and α are in Region 1[d], if $0 < \delta < \frac{1}{3}$, $0 < \alpha < \alpha_3$ and $0 < c < c_8$, or $\frac{1}{3} \leq \delta < \delta_4$, $\alpha_2^B < \alpha < \alpha_3$ and $0 < c < c_8$, then $CS^{BT} > CS^B$, where δ_4 is obtained from

solving the equation $\alpha_2^B = \alpha_3$ when $\delta \in (0,1)$. Specifically, as shown in Figure B.3, the two conditions correspond to when δ and α are in Region 1[d], where $\alpha_3 = \frac{28\delta^6-67\delta^5-7\delta^4+82\delta^3-10\delta^2-24\delta+4}{40\delta^6-124\delta^5+67\delta^4+96\delta^3-80\delta^2-8\delta+12} + 2\sqrt{\frac{6\delta^{12}-49\delta^{11}+146\delta^{10}-158\delta^9-71\delta^8+249\delta^7-14\delta^6-226\delta^5+45\delta^4+144\delta^3-56\delta^2-32\delta+16}{(40\delta^6-124\delta^5+67\delta^4+96\delta^3-80\delta^2-8\delta+12)^2}}$; $c_8 = \frac{\delta^2-2}{\delta-2} - 2\sqrt{\frac{11\alpha^2\delta^6-32\alpha^2\delta^5+13\alpha^2\delta^4+28\alpha^2\delta^3-17\alpha^2\delta^2-6\alpha^2\delta+4\alpha^2-15\alpha\delta^6+33\alpha\delta^5+8\alpha\delta^4-39\alpha\delta^3-\alpha\delta^2+10\alpha\delta+5\delta^6-7\delta^5-10\delta^4+9\delta^3+7\delta^2}{(\delta-2)^2(2\alpha\delta-\alpha-\delta-1)^2}}$.

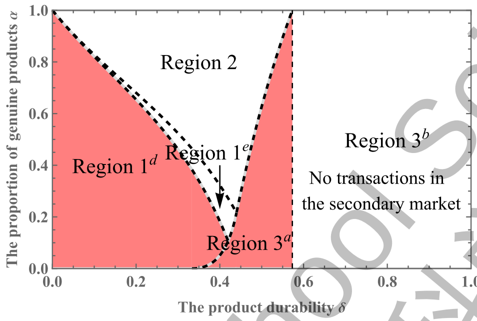

Figure 8 Regions in Proposition 5

(2) when δ and α are in Region 3[a], $0 < c < \min\left\{1-\delta^2-\sqrt{\frac{-\delta^2-2\delta^3+\delta^5}{-2+\delta}}, c_9\right\}$, where $c_9 = \frac{-2+\delta^2}{-2+\delta} - \sqrt{\frac{2+3\delta-6\delta^2-6\delta^3+5\delta^4}{(-2+\delta)^2}}$.

(b) SW under case B is: $SW^B = CS^B + \Pi^{B*}$. The CS under case BT is: $SW^{BT} = CS^{BT} + \Pi^{BT*}$. Proposition 5(b) can be derived by comparing the SW of case B and case BT. The following conclusions can be obtained by solving $SW^{BT} > SW^B$.

(1) when δ and α are in Region 1 of Figure 5, $0 < c < c_{10}$, where $\boldsymbol{c_{10}} = \frac{\delta^2-2}{\delta-2} - 2\sqrt{\frac{5\alpha^2\delta^6-4\alpha^2\delta^5-27\alpha^2\delta^4+38\alpha^2\delta^3-\alpha^2\delta^2-14\alpha^2\delta+4\alpha^2-5\alpha\delta^6-5\alpha\delta^5+36\alpha\delta^4-5\alpha\delta^3-35\alpha\delta^2+2\alpha\delta+8\alpha+\delta^6+5\delta^5-10\delta^4-11\delta^3+11\delta^2+8\delta}{3(\delta-2)^2(2\alpha\delta-\alpha-\delta-1)^2}}$;

(2) when δ and α are in Region 2 of Figure 5, $0 < c < c_{11}$, c_{11} exists but the expression is complex;

(3) when δ and α are in Region 3[a] of Figure 5, $0 < c < \min\left\{\frac{-2+\delta^2}{-2+\delta} - \sqrt{\frac{6+9\delta-10\delta^2-10\delta^3+7\delta^4}{3(-2+\delta)^2}}, 1-\delta^2-\sqrt{\frac{-\delta^2-2\delta^3+\delta^5}{-2+\delta}}\right\}$.

B.7 Proof of Proposition 6

(a) CS under case AI is: when δ and f are in Region 1 and 2, $CS^{AI}=\int_{v_3^{AI}}^{v_2^{AI}} V_{WU}^{AI}\,dv+\int_{v_2^{AI}}^{v_1^{AI}} V_{NH}^{AI}\,dv+\int_{v_1^{AI}}^{1} V_{NN}^{AI}\,dv$; when δ and f are in Region 3a, $CS^{AI}=\int_{v_4^{AI}}^{1} V_{NH}^{AI}\,dv$. Proposition 6(a) can be derived by comparing the CS of case B and case AI. The following conclusions can be obtained by solving $CS^{AI}>CS^{B}$.

(1) when δ and α are in Region 2^{a} of Figure 9 (i.e., $\delta_5<\delta<\delta_2^B$ and $\alpha_4<\alpha<1$), if $f_7<f<f_8$, then $CS^{AI}>CS^{B}$. Due to the complexity of α_4, f_7 and f_8, it is difficult to give specific expressions, so Figure B.4 is used to intuitively react Region 2^{a}.

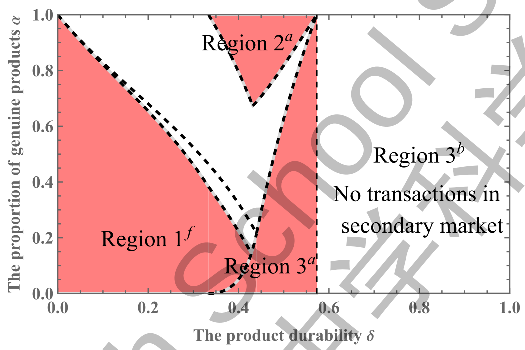

Figure 9 Regions in Proposition 6

(2) when δ and α are in Region 1^{f} of Figure 9 (i.e., $0<\delta<\delta_6$ and $0<\alpha<\alpha_5$), if $f_9<f<f_{10}$, then $CS^{AI}>CS^{B}$. Due to the complexity of α_5, f_{c9} and f_{10}, it is difficult to give specific expressions, so Figure B.4 is used to intuitively react Region 1^{f}.

(3) when δ and α are in Region 3^{a} of Figure 9, if $0<f<f_{11}$, then $CS^{AI}>CS^{B}$.

(b) SW under case AI is $SW^{AI}=CS^{AI}+\Pi^{AI*}+\Pi_P$. Π_P is the platform's revenue from the authentication fee. Proposition 6(b) can be derived by comparing the SW of case B and case AI. The following conclusions can be obtained by solving $SW^{AI}>SW^{B}$.

(1) when δ and α are in Region 1 of Figure 5, $0<f<f_{11}$. f_{11} is an upper bound composed of multiple thresholds. Due to its complexity, the specific expression is not given in this paper[15].

(2) when δ and α are in Region 2 of Figure 5, $0<f<f_{12}$. f_{12} is an upper bound composed of multiple thresholds. Due to its complexity, the specific expression is not given in

[15] If interested, please send the authors an email for the specific formulation.

this paper[15].

(3) when δ and α are in Region 3[a] of Figure 5, $0 < f < f_{13}$. f_{13} is an upper bound composed of f_2^{AI} and f_3^{AI} in Lemma 6.

B.8 Proof of Proposition 7

The environmental impact in case B[16] is $E^B = e_p(2D_{NN}^B + D_{NH}^B) + e_n(2D_{NN}^B + D_{NH}^B) + e_u(D_{NH}^B + D_{WU}^B) + e_d(2D_{NN}^B + D_{NH}^B)$, in case BT is $E^{BT} = e_p(2D_{NN}^{BT} + D_{NH}^{BT}) + e_n(2D_{NN}^{BT} + D_{NH}^{BT}) + e_u(D_{NH}^{BT} + D_{WU}^{BT}) + e_d(2D_{NN}^{BT} + D_{NH}^{BT})$, and in case AI is $E^{BTAI} = e_p\left(2D_{NN}^{AI} + D_{NH}^{AI}\right) + e_n\left(2D_{NN}^{AI} + D_{NH}^{AI}\right) + e_u\left(D_{NH}^{AI} + D_{WU}^{AI}\right) + e_d\left(2D_{NN}^{AI} + D_{NH}^{AI}\right)$.

(a) By comparing the environmental impacts between case B and case BT, we derive the conditions when $E^{BT} > E^B$:

(1) In Figure 3: when δ and α are in Region 1, $0 < c < c_{12}(\delta, \alpha)$, where c_{12} is a polynomial function of δ and α; (2) when δ and α are in Region 2, $0 < c < c_{13}(\delta, \alpha)$, where c_{13} is a polynomial function of δ and α; Due to its complexity and save space, the specific expression of $c_{12}(\delta, \alpha)$ and $c_{13}(\delta, \alpha)$ are not given in this paper[15].

(b) By comparing the environmental impacts between case B and case AI, we find the conditions when $E^{AI} > E^B$:

(1)In Figure 5: when δ and α are in Region 1[a], $0 < f < f_{14}(\delta, \alpha)$, where f_{14} is a polynomial function of δ and α; (2) when δ and α are in Region 1[b] (i.e., $0 < \delta < \frac{1}{3}$ and $0 < \alpha < \alpha_2$, or $\frac{1}{3} \leq \delta < \delta_3$ and $\alpha_2^B < \alpha < \alpha_2$), $0 < f_c < f_{15}(\delta, \alpha)$, where f_{15} is a polynomial function of δ and α; (3) when δ and α are in Region 2, $0 < f_c < f_{16}(\delta, \alpha)$, where f_{16} is a polynomial function of δ and α. Due to its complexity and save space, the specific expression of $f_{14}(\delta, \alpha)$, $f_{15}(\delta, \alpha)$, and $f_{16}(\delta, \alpha)$ are not given in this paper[15].

B.9 Proof of Proposition 8

We only focus on the interior solutions of cases AI and MAI when comparing the profits

[16] In Region 3[a], secondary transactions are absent in the Benchmark case. To enable an apples-to-apples comparison, we exclude this region from the analysis of environmental impact. If this region were included, the adoption of anti-counterfeiting strategies would further exacerbate environmental damage.

due to the complexity. The aim is to find a profitable area for the imperfect authentication service. By comparing the equilibrium profits (interior solutions) between benchmark case AI and case MAI in Lemma 3 and Lemma 4, the following condition can be obtained by solving $\Pi^{MAI*} > \Pi^{AI*}$: When δ and α are in Region 1 of Figure 5, (i.e., $0 < \delta < \delta_2^{AI}$ and $0 < f \leq \min\{f_1^{AI}, f_3^{AI}\}$), $0 < f \leq \min\{f_1^{AI}, f_3^{AI}, f(\hat{\alpha}, \delta)\}$, where δ_2^{AI} is obtained from solving the equation $2 - \delta^2 - \sqrt{2 + 3\delta - 2\delta^2 - 2\delta^3 + \delta^4} = 0$ when $\delta \in (0,1)$, $f_1^{AI} = \frac{-2\delta^2+\delta^3}{-2-\delta+2\delta^2}$, $f_3^{AI} = 2 - \delta^2 - \sqrt{2 + 3\delta - 2\delta^2 - 2\delta^3 + \delta^4}$, and $f(\hat{\alpha}, \delta) = \frac{-2\hat{\alpha}\delta^3(\hat{\alpha}-3)+\delta^2(4-\hat{\alpha})+2\delta}{-3+\delta(\hat{\alpha}-3)+2\delta^2\hat{\alpha}}$.