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Implications of Blockchain-Powered Marketplace of Preowned Virtual Goods

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Abstract
The first-sale doctrine, which protects consumers' rights to resell purchased products, has been recognized by the US Supreme Court since 1908. In recent years, consumers have begun to purchase an increasing amount of virtual goods, which renders the first-sale doctrine unclear. There are two main challenges leading to the uncertainty of the first-sale doctrine in the digital age: lack of proper technology, and economic implications for developers and consumers. The advent of the blockchain solves the technology challenge, as it can track provenance and establish the chain of custody. In this study, we construct an analytical model to investigate the economic impact of trading preowned virtual items. Specifically, our model captures the decentralized nature of blockchain technology by allowing consumer-to-consumer trading, and considers the possibility that consumers prefer preowned virtual items over new ones because preowned items may be upgraded between purchase and resale. Lawmakers seek to strike a balance between the interests of virtual item developers and individual consumers. We show that, surprisingly, the introduction of a blockchain-based preowned virtual item transaction can actually benefit both developer and consumer. The main intuition is that the developer can adjust the price when forward-looking consumers incorporate the expected future transaction into their purchase decision. Our analysis also reveals that developers are more willing to embrace the secondary market when they can take a cut during the transaction. Our results provide important policy implications to the burgeoning debate of the first-sale doctrine in the new digital world.

Keywords
Agency model, blockchain, distributed ledgers, preowned products trading, virtual good

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> If someone has copyright over some piece of your stuff, you can sell it without permission from the copyright holder because the copyright holder can only control the 'first-sale.' The Supreme Court has recognized this doctrine since 1908.
>
> —Marvin Ammori, Lawyer on Technology Policy

1 Introduction

The sweeping digitalization of goods has provided unparalleled opportunities for value creation in the business world. Virtual goods, which are digital representations of tangible objects in the physical world, are frequently used to enhance the consumer's experience in online gaming and social media. The current market size is near $32 billion (Elks, 2020), and according to Adroit Market Research, the global virtual goods market value is poised to reach $189.76 billion by 2025.[1] The expansion in the global virtual goods market is mainly driven by the rapid growth of online gamers who purchase virtual goods, such as in-game weapons or upgrades, using real money.

It seems logical for consumers to resell physical goods such as automobiles, electronics, furniture, and books. In the United States, the first-sale doctrine (17 US Code §109) protects the interests of physical product owners by allowing them to resell these items, even if they are copyrighted. The ability to resell preowned goods has significant impacts on consumer demand and firms' profitability. Nevertheless, it is *unclear* whether the first-sale doctrine should apply to digital content, as the legal profession is still debating its implications on consumer welfare and firm revenue.[2] This is a representative issue

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concerning whether the century-old stagnant law should be interpreted to adapt to an evolving technological landscape. One of the most critical and challenging issues here is how we can prevent piracy during such transactions. The argument that conveying the right to sell virtual items would promote piracy is based on the fact that illegally reproduced virtual items are difficult if not impossible to distinguish from reproductions that have been brought into circulation with the consent of the developer (Jütte, 2017). However, the recent emergence of blockchain technology may revolutionize the ownership of virtual goods, as it allows developers to track provenance and establish the chain of custody.

Blockchain technology is a form of distributed ledger, which can be considered as a decentralized database system. Traditional databases are centralized and usually consist of only one master copy; however, the distributed ledger is a decentralized and synchronized database across a consumer-to-consumer (C2C) network, in which each replicates and saves an identical copy of the ledger and updates itself independently (Hastig and Sodhi, 2020). Blockchain refers to a chain of "blocks" in a distributed database, a block being a set of records that has a pointer to data in another block, creating a link in a chain of such relations. Popular blockchain protocols include Ethereum, Hyperledger Fabric, and Ripple (Babich and Hilary, 2020). Due to its design, blockchain is resistant to modification of data and cannot be manipulated by any single group of people. As a result, blockchain-based games allow consumers to have secure ownership and full control over their digital assets (Barber, 2019).

An emerging number of game developers are embracing this new technology. Australian blockchain firm Immutable received $15 million in funding by Naspers Ventures and Galaxy Digital to create blockchain-based video games for gamers and a decentralized platform to game developers (Wood, 2019). The cryptocurrency company Ripple announced a $100 million fund for game developers to encourage them to integrate blockchain technology into their game design (Barber, 2019). Microsoft and blockchain gaming platform Enjin collaborated to create a reward scheme to promote blockchain-based games (Palmer, 2019). Recently, Forte, a blockchain platform dedicated to games, has partnered with five major game studios (Hi-Rez Studios, Netmarble, Magmic, nWay, and Deca Games) to make blockchain-based games, which are integrated with Forte's blockchain technology (Takahashi, 2020). Minecraft, a popular mobile game, recently integrated a blockchain plug-in to create a trusted marketplace for players to buy and sell their in-game items (Chan, 2020). In these examples, the main blockchain technology type is permissioned blockchain, which is very popular among game developers.[3]

The key focus of our study is to investigate the impact of the introduction of preowned sales (via blockchain technology) on developers' profit, and to provide guidance to regulators on the implications for consumers. The legal profession is still debating the resaleability of virtual items, so it is urgent and crucial for business research to provide theoretical support to guide the practice. In this study, we formulate a simple dynamic analytical model to capture the crucial aspects of the transaction of preowned virtual items. This simple setup allows the main insights to take center stage rather than the technical complexities inherent to a more general model. Consumers are forward-looking, and they can make endogenous decisions about whether to keep or sell their purchased virtual items. To capture the decentralized nature of blockchain technology, we allow consumers to trade their preowned virtual items in a frictionless C2C network. Unlike physical products, which always deteriorate with use, virtual items can actually appreciate with usage because many virtual items can be upgraded after purchase and/or during gameplay.[4] Our analysis provides critical guidance to practitioners and regulators by offering them actionable insights. Next, we highlight the key questions addressed in this study.

The first key question that we investigate is: *Does the developer prefer the introduction of blockchain technology to enable the transaction of preowned virtual items? If so, what are the conditions for the developer to do so?* There is a proliferation of examples of developers beginning to integrate blockchain technology into their virtual item development. As a result, the answer to our research question can shed light on this emerging issue. One may intuitively think that the developer cannot benefit from the introduction of a blockchain-based C2C market, as consumers can bypass the developer to purchase the preowned virtual item instead of a new one, which may be further amplified by the fact that consumers often prefer preowned to new items in the digital world. Surprisingly, we find that this is not always the case. Our analysis reveals that the developer can generate a higher profit with the introduction of a preowned virtual item C2C market. The intuition behind this result is that consumers are forward-looking and can incorporate the expected resale price into their initial willingness to pay. As a result, the developer can increase her revenue by charging a higher initial price, which may offset the revenue loss from fewer sales. This result provides the first theoretical evidence that the emergence of blockchain-based virtual items may not be coincidental. Rather, the virtual item developer may have taken the strategic interaction from the consumer into consideration when deciding whether to adopt blockchain technology.

Next, to gain a deeper understanding of the impact of preowned virtual item trading on consumers, we explore the following question: *Can the introduction of the secondary market for virtual items benefit consumers?* As we pointed out earlier, the answer to this question carries significant weight, as the legal profession is still undecided as to whether the first-sale doctrine should apply to virtual items. However, there is scant academic research to address this issue from an economic perspective. Among the ongoing legal deliberation, a focal issue is the implication to the consumer's interest if trading of preowned virtual items is allowed. In this study, we analytically show that preowned virtual item trading can benefit consumers joining at a later stage because they can choose between new products and preowned products. Interestingly, we find that although the virtual item trading always benefits the consumer in the second period, the same is not necessarily true for the consumer in the first period. This is the case when the first-period price becomes too high, which can in turn hurt the interest of the first-period consumer. Taking the first- and second-period consumers together, we find that virtual item trading can benefit the consumer by increasing their consumer surplus. Our results provide important policy and regulatory implications as we show that extending ownership in the digital world can benefit the consumer.

Moreover, it is also common for the developer to take a cut during the transaction of preowned virtual items. To accommodate this possibility, we consider this alternative setting in the extended model and raise the following research question: *Is it always beneficial for the developer to keep a higher revenue during the transaction of preowned virtual items?* The answer to this question is highly relevant to the developer who strives to increase her revenue. One might intuitively expect that the developer always prefers a higher value of revenue sharing proportion, as the developer can keep more revenue from the transaction of virtual items. Surprisingly, contrary to this intuition, our results reveal that the developer's profit is not always monotonic in increasing the revenue sharing proportion that she can keep. We find that the developer's profit first increases and then decreases in the revenue sharing proportion. This is because although the increase in revenue sharing proportion can benefit the developer in the second period, it may hurt the developer's profit in the first period, as consumers may lower their expectations for their virtual items. The managerial implication here is that the revenue sharing proportion can have a significant impact on the developer's profit. From a practical perspective, the developer should find a balance of the trade-off between second-period gain and first-period loss with an increase in revenue sharing proportion.

We have also conducted sensitivity analyses on different parameters. The first is the measurement of the difference between the new and the preowned products, which we term as the *upgrade ratio*. This upgrade ratio reflects the degree to which the consumer prefers the preowned item to the new item due to the upgrade of the virtual item. Our analysis reveals that the increase in this parameter has a different role in driving the developer's profit in different periods. It can benefit the developer in the first period but may hurt the developer in the second period, which leads to a unimodal profit function with respect to the change of this parameter. Another noteworthy parameter that we investigate is the depth of the virtual item. We define the depth of the virtual item as the endurance of the virtual item. It has been shown that consumers can lose interest after using the virtual item for a while. A higher value of depth indicates that the consumer maintains high engagement with the virtual item after usage. Interestingly, we find that an increase in this parameter has a positive role in both periods: It can increase first-period profit by enabling the developer to charge a higher price to begin with, but it can also improve second-period profit by reducing the competition from preowned items as more consumers choose to keep rather than trade their preowned items.

The rest of the paper is organized as follows. In the next section, we review the relevant literature and highlight our contributions with respect to past studies. In Section 3, we introduce the model setting. In Section 4, we analyze the base model, outline the intuition behind the main results, and conduct sensitivity analysis. In Section 5, we extend our base model by considering the alternative setting and network effects to verify the robustness of the main findings and obtain new insights. The paper concludes with managerial implications and possible directions for future research in Section 6.

2 Literature Review

Our study has points of contact with the literature in (i) pricing of virtual items in information systems (IS), (ii) durable products in marketing and operations, (iii) the agency pricing model, and (iv) blockchain applications in operations, but it also deviates from the existing literature in some essential aspects.

2.1 Pricing of Virtual Items

Our research is closely related to the pricing of virtual items or information goods in the IS area. In the early works of Bakos and Brynjolfsson (1999), the authors study the bundling strategy of information goods and argue that bundling unrelated information goods is a profitable strategy due to the law of large numbers. Sundararajan (2004) analyzes the optimal pricing for information goods with incomplete information. The author characterizes the conditions under which fixed-fee pricing and usage-based pricing are optimal. Huang and Sundararajan (2011) study the pricing of information goods with zero variable costs and positive periodic fixed costs. They show that the discontinuous cost structure can be accrued as a virtual constant variable cost. Considering the consumer's psychological behavior, Balasubramanian et al. (2015) compare the selling and pay-per-use pricing for information goods. They demonstrate that pay-per-use yields higher profits in the monopoly setting while a selling strategy yields higher profits in the duopoly setting. Tan et al. (2016) study pricing issues in the e-book industry. They find that due to the lack of inventory and zero marginal cost, the digital goods supply chain can be coordinated using a simple revenue sharing contract. Dou et al. (2017) investigate how firms should choose between selling and leasing when considering the impact of vintage depreciation and individual depreciation of information goods. In the context of digital music, Li et al. (2020) show that both advertisement revenue rate and consumers' reservation value for the music service can shape a music provider's choice between a subscription model and an ownership model. Guo et al. (2019) examine the impact of selling virtual currency on players' gameplay behavior. The authors find that selling virtual currency will reduce playing time for certain heavy players, whereas it boosts certain casual players' playing time. The existing studies on virtual items have not considered the possibility that virtual items can be resold on the market, mainly due to copyright concerns. Recent technology advancements, especially in blockchains, allow developers to have this option. We contribute to this stream of literature by studying the impact of the secondary market on the pricing of virtual items and consumer welfare.

2.2 Durable Goods

Second, our study contributes to the studies of durable goods in marketing and operations literature. In this stream of literature, most studies use a two-period setting. That is, products that are sold in the first period become used products and compete directly with the new products in the second period. Arya and Mittendorf (2006) show that a separated channel governed by the wholesale contract can perform better than a vertically integrated channel in terms of a firm's profit in the setting of durable goods manufacturing. This is because the channel discord can alleviate consumer's strategic behaviors (i.e., waiting for discounted prices in the near future). In a similar vein, Desai et al. (2004) replicate this result using a two-part tariff contract. Motivated by the textbook industry, Shulman and Coughlan (2007) study the impact of the secondary market on manufacturers and retailers. They identify the conditions under which a manufacturer should cease selling a new product in the second period. Yin et al. (2010) analyze the impact of the interaction between two sources of used goods channels on manufacturers' product upgrade and retailers' pricing decisions. He et al. (2016) demonstrate that product durability can affect the group's selling decisions of complementary manufacturers when consumers are forward-looking and patient. Esenduran et al. (2020) study the timing of manufacturers' buyback decision in the durable goods market. The authors find that compared to the postponement of buyback decision, precommitment to a buyback price may put a manufacturer at a disadvantage. There are two main differences between the current study and existing studies. To begin with, existing studies on durable goods have always assumed that the preowned product is inferior to the new product. This is true for physical durable products (e.g., automobiles, consumer electronics, and furniture). However, we consider a setting in which a preowned product can have a higher valuation than its new counterpart due to the unique upgrade feature in some information goods. Consequently, we find that the existence of the C2C secondary market can benefit the developer, in contrast to Yin et al. (2010) who find that the C2C secondary market cannot benefit the supplier. Second, we also consider the possibility of the agency pricing model that governs the transaction of preowned products in the C2C market, which has never been studied. Existing literature has considered only two-part tariffs and wholesale contracts. The agency pricing model has become highly popular in practice, and our analysis reveals its impact on the transaction of preowned products.

2.3 Agency Pricing Model

Third, our study also intersects the emerging stream of literature on agency pricing literature. There is a growing body of literature on agency pricing due to the rapid growth of the online marketplace in recent years. In the seminal work on the agency pricing model, Hao and Fan (2014) find that the product price in the agency pricing contract can be higher than that in the wholesale contract when there exists a complementary market. Abhishek et al. (2016) show that the cross-channel effect (i.e., brick-and-mortar retailing and online retailing) will influence the retailer's choice over agency pricing and wholesale pricing. In the context of online product reviews, Kwark et al. (2014) illustrate that the retailer can leverage the agency pricing model as a strategic tool to benefit from consumer reviews. Tan and Carrillo (2017) investigate the agency pricing model in the digital publishing industry and find that it can mitigate the double marginalization effect. Tian et al. (2018) explore a setting of upstream competition involving the agency pricing model. The authors find that the wholesale model can outperform the agency pricing model when the competition between the upstream suppliers is intense. In the context of mobile in-app advertising, Hao et al. (2017) find that the agency pricing model can lead to a higher app price than would be offered by the integrated platform found in traditional advertising. Geng et al. (2018) study the interaction between add-on pricing and distribution contracts. They find that the supplier prefers the add-on strategy to the bundling strategy under the agency pricing contract. Our study complements this emerging stream of literature by investigating the agency pricing model in the setting of preowned virtual item trading, which is not well understood.

2.4 Blockchain Applications in Operations

Fourth, our study contributes to the increasing application of blockchain technology in operations management. Blockchain technology gained significant hype among the public due to the surge of Bitcoin price in recent years. Fundamentally, blockchain technology is a form of distributed ledger (i.e., decentralized database system). Because the data are stored in a decentralized manner, the information in the blockchain is considered to be extremely safe and secure as no person or entities can tamper with the data. This novel technology leads to many new operational applications in the business world. For example, blockchain technology facilitates the adoption of "smart contracts" in which the contract terms can be automatically triggered based on specific verifiable events (Olsen and Tomlin, 2020). Choi et al. (2020) point out the critical role of customers' risk attitudes toward on-demand service pricing and illustrate the use of blockchain technology to identify the risk attitudes of individual customers. Hastig and Sodhi (2020) provide a conceptual framework regarding the successful implementation of blockchain-based supply chain traceability systems. Wang et al. (2021) illustrate how to design and implement a blockchain-based data-sharing marketplace for the supply chain. Both Shen et al. (2021) and Pun et al. (2021) explore the impact of the introduction of blockchain technology on combating the counterfeits problem in the supply chain. Interested readers can refer to Dutta et al. (2020) who provide a recent and comprehensive review of blockchain technology in supply chain operations. In contrast to the previous literature, which mainly considers the security features of the blockchain, we consider the network feature. That is, consumers can trade freely with each other through a blockchain-enabled C2C trading network. This is another important feature of the blockchain which is overlooked by the existing studies.

To the best of our knowledge, this is the first attempt to construct a theoretical model to study the impact of trading preowned virtual items through blockchain technology. Our study not only sheds light on the management of preowned virtual items but also provides practical guidance to virtual item developers and platforms. This study also makes a theoretical contribution to the literature by developing a simple analytical model in which preowned products can outperform new products in the digital world.

3 The Model

In this study, we consider a two-period model in which a virtual goods developer (she) distributes virtual items through her own platform. In the first period, the consumer (he) can purchase only the new items, while in the second period, he also has the option to purchase preowned virtual items (if the developer enables blockchain technology) through a C2C market. Both the developer and consumers are rational and have full information. Consumers are also forward-looking in the sense that they can rationally anticipate the possibility of selling their preowned virtual items in the C2C market. Next, we introduce the basic model and lay out the assumptions in this study.

3.1 Virtual Goods Developer

There is a monopolistic developer who provides a virtual item over two periods. This two-period structure not only captures the fact that virtual items usually have a short life cycle but also allows us to study dynamic issues while retaining tractability. The developer's objective is to maximize her total profits over both periods. Apart from pricing decisions p_i $(i = 1, 2)$, the developer also needs to decide whether to introduce distributed ledger technology such as blockchain to enable the trading of preowned virtual items. Following the literature of information goods (Guo et al., 2019; Tan and Carrillo, 2017), we assume the marginal cost of the virtual items to be zero.

Unlike the physical goods market, in which the manufacturer cannot deter the trading of preowned products, the developer of a virtual item can easily prevent the trading of preowned virtual items by imposing a license instead of selling the ownership of the item in their transfer agreements. In this case, consumers are allowed to use the licensed item but cannot trade the preowned virtual item (Reis, 2015). However, if the developer introduces blockchain technology and allows the trading of preowned virtual items, consumers can trade their preowned virtual items among each other in a C2C (i.e., decentralized) market. In the model extension, we also consider a scenario where trading of preowned virtual items takes place through the developer's platform and the developer can take a proportion of the revenue through each transaction.

3.2 Consumer

Like Yin et al. (2010), we assume that there is a renewable consumer base. In each period, a unit mass of heterogenous consumers joins the market, and each consumer needs at most one unit of the virtual item. Consumer's valuation v is uniformly distributed on [0, 1].

In the first period, if the consumer purchases a new product, he can enjoy a utility of v if he keeps the virtual item for only one period. He can get a utility of $(1 + \gamma)v$ if he chooses to keep the product for the subsequent period, where γv represents the leftover utility in the second period. Here γ is a measurement of depth or endurance of the information product.[5] There are many examples showing that an individual consumer's valuation will decrease upon repeated use of information goods (i.e., $\gamma < 1$), which is the scope of the current study. This is especially true for digital games, for which consumers become disinterested soon after purchase (Ishihara and Ching, 2019; Shiller, 2013). As a result, $\gamma \in (0, 1)$, and a higher value of γ indicates that the virtual item can retain a high consumption value after repeated use. This is true when the information product is designed with intricacy and sophistication. In contrast, a lower value of γ denotes that the virtual item tends to depreciate quickly after repeated use. Note that this deprecation applies only to the individual who has experienced the product, not to the consumer who has not enjoyed the content.

Consumers are forward-looking when they make purchase decisions; that is, they take into account possible future resale value. Incorporating forward-looking behavior implies that we allow first-period consumers to either keep their products for two periods or sell their preowned virtual items to other consumers at the end of the first period. This scenario is applicable only when the developer enables the transaction of preowned virtual items. Otherwise, first-period consumers must keep their purchased products for both periods. Following the literature, we assume that consumers can form a rational expectation of the transaction price of the preowned item, $E[p_p]$, in a rational expectation equilibrium (Fudenberg and Tirole, 1991). Thus, the utility of the first-period consumer is

$$U_1 = v + \max\left\{E\left[p_p\right],\ \gamma v\right\} - p_1. \tag{1}$$

In the first period, a consumer will purchase if his net utility from buying the product is greater than not buying, which we normalize to zero. Unlike the majority of physical durable goods literature, which indicates that transactions of preowned items are not allowed among users but must go through a third-party intermediary (Esenduran et al., 2020; Jiang and Tian, 2018; Shulman and Coughlan, 2007), blockchain technology enables trading among consumers directly. Due to the nature of a C2C market, the market clearance mechanism is frictionless in the sense that the price of p_p is determined by the available preowned items on the market.

In the second period, a new batch of consumers enters the market. They have the choice of purchasing either a new product or a preowned one. Consumers will choose to purchase the product that brings them higher utility. If they purchase a new product, their utility is $U_{2n} = v - p_2$, where the subscript n denotes the new product.[6] Their utility from purchasing a preowned item is given by $U_{2u} = \lambda v - p_p$, where the subscript u denotes the preowned product, p_p is the realized preowned goods price, and λ is the upgrade ratio of the preowned item. In the existing literature of physical durable products (e.g., automobiles, consumer electronics, furniture), λ is always set to be less than 1 because physical products always deteriorate or depreciate after use. In contrast, a virtual item can appreciate in value with more use. For example, preowned virtual game equipment can be worth much more than its new equivalent because early consumers have made upgrades to the virtual item in the interim. Another relevant example is game accounts. Preowned accounts may contain rare items, skins, titles, and other virtual goods, which may attract other players to pay a premium for them. To reflect this unique feature of the virtual item, we focus on the case in which the preowned virtual item can be superior to the new product ($\lambda > 1$) in this study.[7] Essentially, λ denotes the average upgrade rate of the preowned item after first-period usage.

3.3 Demand Functions and Timing of The Model

In this subsection, we derive the demand functions for customers that consider purchasing in the first period and those that consider purchasing in the second period.

3.3.1 Customers that Consider Purchasing in the First Period. We first characterize the threshold at which consumers are indifferent between purchasing the product or not, v_{1n}. That is, the consumer's utility equals to 0 when consumer valuation is v_{1n}, that is, $v_{1n} + \max\{E[p_p], \gamma v_{1n}\} - p_1 = 0$. It is straightforward to see that high-valuation consumers will keep the product for use in the second period, while low-valuation consumers will choose to sell back to the market. As a result, we can get $v_{1n} = p_1 - E[p_p]$ because of $E[p_p] > \gamma v_{1n}$. Next, we can characterize the threshold at which consumers are indifferent between selling back to the market and keeping the product themselves, v_{1u}. The marginal consumer at this threshold should satisfy the condition $E[p_p] = \gamma v_{1u}$, which leads to $v_{1u} = E[p_p]/\gamma$. Thus, we can get the demand functions for the total purchase in the first period as $q_{1n} = 1 - v_{1n}$ and the number of available preowned products on the market as $q_{1u} = v_{1u} - v_{1n}$. We illustrate the different segments of consumers of the first period in Figure 1.[8]

3.3.2 Customers Who Consider Purchasing in the Second Period. Next, we characterize the demand functions in the second period. Consumers in the second period need to choose between purchasing a preowned virtual item or a new one. Similar to the derivation from the first period, we can show that $q_{2n} = v_{2u} - v_{2n}$, and $q_{2u} = 1 - v_{2u}$, for which the thresholds are provided in Figure 2. Due to the market-clearing mechanism, we get $q_{2u} = q_{1u}$, which leads to the expression of market clearance price for the preowned virtual item, $p_p = \frac{\gamma((\lambda-1)(1+p_1)+p_2)}{\lambda+\gamma\lambda-1}$. Substituting this value into q_{1n} and q_{2n}, we can get the following demand functions:

$$
\begin{aligned}
q_{1n} &= 1 - p_1 + \frac{\gamma\left[(\lambda-1)\left(1+p_1\right)+p_2\right]}{\lambda+\gamma\lambda-1}, \\
q_{2n} &= \frac{\gamma+\gamma p_1-(\gamma+\lambda+\gamma\lambda)p_2}{\lambda+\gamma\lambda-1}.
\end{aligned}
\tag{2}
$$

There are several features embedded in the current setting. First, consumers can make the endogenous decision in the end of the first period whether they will keep or sell a preowned virtual item based on its individual utility. This setting is not only different from the literature (Yin et al., 2010), in which this decision is exogenously given, but also allows us to better capture the dynamics of consumer behavior. Second, to reflect the decentralized nature of blockchain technology, instead of involving an intermediary in the transaction (Shulman and Coughlan, 2007), we set the trading of the preowned virtual items as among the users directly. Third, unlike their physical counterparts, which always depreciate or deteriorate, virtual items can appreciate with usage, and we capture this unique attribute. In suggesting the model above, great emphasis has been placed on the tractability of the analysis. Our objective here is to have a model that can capture crucial aspects of virtual item trading but is simple enough to permit closed-form solutions.

The model proceeds as follows. In the first stage, the developer decides whether to introduce blockchain technology to enable the transaction of preowned virtual items. If the developer allows the trading of preowned virtual items, consumers can trade them in a decentralized marketplace. Otherwise, consumers must purchase items from the developer and keep them. In the second and third stages, the developer determines the pricing of new virtual items sequentially. We summarize the notations in this study in Table 1.

4 Results

To characterize the structural results and facilitate the comparison, we first study a benchmark case in which the trading of

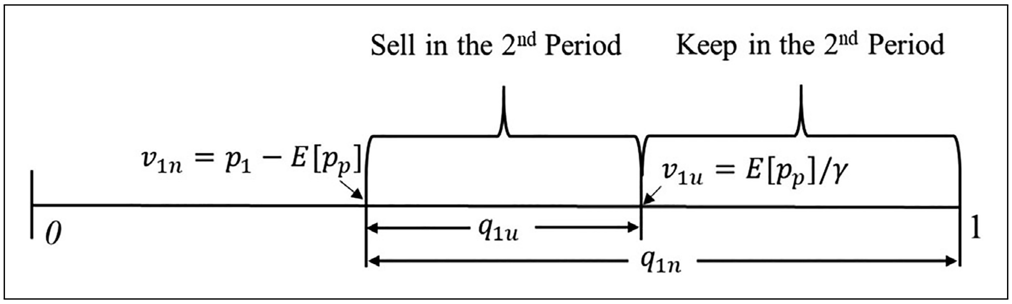

Figure 1. Consumer demand in period 1.

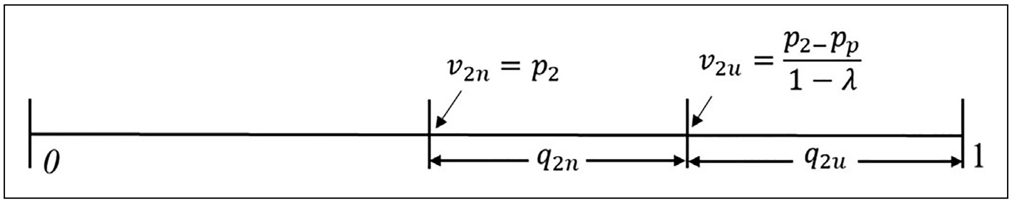

Figure 2. Consumer demand in period 2.

Table 1. Summary of notations.

Symbol	Definition
$i = 1, 2$	Product usage periods
λ	Upgrade ratio of preowned virtual item, $\lambda > 1$
γ	Depth or endurance of the virtual item, $\gamma \in (0, 1)$
v	Consumer's valuation for the virtual item, where $v \sim U(0, 1)$
p_i	Market price in period i (decision variable)
p_p	Market clearance price for the preowned virtual item on the C2C market
q_i	Product quantity in period i
π_i	The developer's profit in period i
cs	Total consumer surplus
U_i	Consumer's utility in period i
n	This subscript indicates the case of the new virtual item
u	This subscript indicates the case of the preowned virtual item
Ω	This superscript indicates the developer's pricing strategy, $\Omega \in \{BE, BA\}$, where BE and BA denote the benchmark case and base model, respectively

preowned virtual items is not allowed. This is followed by the analysis of our base model where the developer enables the trading of preowned virtual items. All proofs are provided in the Supporting Information Appendix.

4.1 Benchmark (BE)

To facilitate comparisons with the two-period model, we first analyze the case in which the developer disables the trading of preowned virtual items by shutting down the C2C market. That is, consumers can access only the primary market for new virtual items. Note that the absence of the C2C market makes the demand across two periods independent, and we can solve the model through backward induction. A simple analysis of the model yields the equilibrium outcome. We summarize the results for the benchmark case in the following lemma.

LEMMA 1. *When there is no preowned goods market for virtual items, the developer's equilibrium price, sales quantity, profit, and consumer surplus are*

(a) $p_{1n}^{BE} = \frac{1+\gamma}{2}$, $p_{2n}^{BE} = \frac{1}{2}$;

(b) $q_{1n}^{BE} = \frac{1}{2}$, $q_{2n}^{BE} = \frac{1}{2}$;

(c) $\pi_1^{BE} = \frac{1+\gamma}{4}$, $\pi_2^{BE} = \frac{1}{4}$, $\pi^{BE} = \frac{2+\gamma}{4}$;

(d) $cs_1^{BE} = \frac{1+\gamma}{8}$, $cs_2^{BE} = \frac{1}{8}$, $cs^{BE} = \frac{2+\gamma}{8}$.

When the developer shuts down the trading of preowned virtual items, Lemma 1 shows that the developer's profit is independent of the upgrade ratio λ. This is because consumers are not able to trade their preowned virtual item in this scenario. Further, both price and profit in the first period increase in the depth of the virtual item, γ. This result is in line with our expectation, as developers can charge a higher price when they release a higher quality product and subsequently generate higher profit.

4.2 Base Model (BA)

In this subsection, we consider a scenario in which the developer adopts blockchain technology for the virtual item, thus allowing preowned items to be traded. For notational convenience, we drop the superscript *BA* (which stands for the base model) here. We solve this base model beginning from the second period. The developer needs to decide the optimal pricing of the second period p_{2n} by considering the competition from preowned virtual goods trading. That is, the developer's decision problem in the second period can be expressed as $\max_{p_{2n}} \pi_2 = p_{2n}q_{2n}(p_{1n}, p_{2n})$. It can be readily shown:

$$p_{2n}^*\left(p_{1n}\right) = \frac{\gamma + \gamma p_{1n}}{2\left(\gamma + \lambda + \gamma\lambda\right)}. \tag{3}$$

One immediate observation here is that as the first-period price p_{1n} increases, the developer will also increase the second-period price p_{2n}. This is because $\frac{\partial q_{1u}}{\partial p_{1n}} < 0$; the available preowned product from the first period will decrease as the first-period price increases. That is, the developer faces less competition from the preowned product market in the second period. As a result, the developer can increase her profit by charging a higher price in the second period.

Next, we solve the first-period problem. Substituting the second-period price from Equation (3) into the first period, the profit-maximizing developer makes the decision on the optimal retail price p_{1n}. That is, the developer is facing the following profit-maximizing problem:

$$\max_{p_{1n}} \pi = \pi_1 + \pi_2^* = p_{1n}\, q_{1n} + \pi_2^*. \tag{4}$$

We summarize the equilibrium decisions in Lemma 2. The details of the derivation are provided in the Supporting Information Appendix.

LEMMA 2. *When the trading of preowned virtual items is allowed, the developer's equilibrium prices, sales quantity, and profits are*

(a)

$$p_{1n} = \frac{2(\lambda + \gamma\lambda - 1)(\gamma + \lambda + 2\gamma\lambda)}{k},$$

$$p_{2n} = \frac{2\gamma(1+\gamma)(3+2\gamma)\lambda^2 - (6-\gamma)\gamma^2 - 2\gamma(3-\gamma-3\gamma^2)\lambda}{2(\gamma+\lambda+\gamma\lambda)k},$$

$$p_p = \frac{\begin{array}{l}\gamma(2(1+\gamma)\lambda^2 - \gamma - 2\lambda)\\ \quad [2(1+\gamma)(3+2\gamma)\lambda^2 - (6-\gamma)\gamma + 2(3\gamma^2 - 3 + \gamma)\lambda]\end{array}}{2(\lambda+\gamma\lambda-1)(\gamma+\lambda+\gamma\lambda)k};$$

(b)

$$q_{1n} = \frac{\begin{array}{l}\gamma^2(4+(4-\gamma)\gamma) + 4\gamma[2+\gamma-\gamma^2(3+\gamma)]\lambda\\ \quad +4\{1+\gamma[\gamma((\gamma-3)\gamma-8)-2]\}\lambda^2\\ \quad +8[\gamma(2+\gamma)(\gamma+\gamma^2-1)-1]\lambda^3 + 4(1+\gamma)^2(1+2\gamma)\lambda^4\end{array}}{2(\lambda+\gamma\lambda-1)(\gamma+\lambda+\gamma\lambda)k},$$

$$q_{2n} = \frac{2(\gamma+\gamma^2)(3+2\gamma)\lambda^2 - (6-\gamma)\gamma^2 + 2(3\gamma^2-3+\gamma)\lambda\gamma}{2(\lambda+\gamma\lambda-1)k},$$

$$q_u = \frac{\begin{array}{l}\gamma^2[2+(5-\gamma)\gamma] + 2\gamma[5+\gamma(5-\gamma-3\gamma^2)] + 2(1+\gamma)\{4\\ \quad -\gamma[7+3\gamma(2+\gamma)]\}\lambda^2 - 4(4-\gamma)(1+\gamma)^2\lambda^3 + 8(1+\gamma)^3\lambda^4\end{array}}{2(\lambda+\gamma\lambda-1)(\gamma+\lambda+\gamma\lambda)k},$$

Table 2. Summary of comparative statics.

Parameters/ variables	λ	γ
p_1^*	↑	↑
p_2^*	↓	↑
p_p^*	↑	↑
q_{1n}^*	↑	Unimodal (↑ then ↓) or ↑
q_{2n}^*	↓	↑
q_u^*	↑	↓
π_1^*	↑	↑
π_2^*	↓	↑
π^*	U-shaped (↓ then ↑)	↑

Note: *U-shaped* means that a function first decreases and then increases, while *unimodal* means that a function first increases and then decreases (Banerjee, 2008).

(c)

$$\pi_1 = \frac{\begin{array}{l}(\gamma+\lambda+2\gamma\lambda)\{\gamma^2[4+(4-\gamma)\gamma] + 4\gamma[2+\gamma-\gamma^2(3+\gamma)]\lambda\\ \quad +4(1-2\gamma-8\gamma^2-3\gamma^3+\gamma^4)\lambda^2\\ \quad -8[1-\gamma(2+\gamma)(1-\gamma-\gamma^2)]\lambda^3 + 4(1+\gamma)^2(1+2\gamma)\lambda^4\}\end{array}}{(\gamma+\lambda+\gamma\lambda)k^2},$$

$$\pi_2 = \frac{\gamma^2[2(1+\gamma)(3+2\gamma)\lambda^2 - (6-\gamma)\gamma - 2(3-\gamma-3\gamma^2)\lambda]^2}{4(\lambda+\gamma\lambda-1)(\gamma+\lambda+\gamma\lambda)k^2},$$

$$\pi = \frac{\begin{array}{l}(2-\gamma)^2\gamma^2 + 4\gamma(2+\gamma-\gamma^2+\gamma^3)\lambda\\ \quad +4[1-(6-\gamma)\gamma^2(1+\gamma)]\lambda^2 - 8\\ \quad (1+\gamma)(1+2\gamma)[1+(1-\gamma)\gamma]\lambda^3 + 4(1+\gamma)^2(1+2\gamma)^2\lambda^4\end{array}}{4(\lambda+\gamma\lambda-1)(\gamma+\lambda+\gamma\lambda)k}.$$

where $k = 4(1+\gamma)\lambda^2 - (4-\gamma)\gamma - 4(1-\gamma-\gamma^2)\lambda$.

Lemma 2 presents the equilibrium results when the transaction of preowned virtual items is allowed. As we pointed out earlier, consumer surplus is one of the key concerns in this study. We also calculate consumer surplus in the base model and provide a detailed expression in the Supporting Information Appendix.

Next, we explore how different parameters affect the equilibrium results in the following two propositions. We characterize the following comparative statics results analytically. The proof is provided in the Supporting Information Appendix. For convenience, we summarize the results of all comparative statics in Table 2.

PROPOSITION 1. *As the upgrade ratio of virtual item λ increases, we find that*

(a) *the first-period price p_1^* will increase, while the second-period price p_2^* will decrease, and the preowned virtual item price p_p^* will increase;*
(b) *the first-period demand q_{1n}^* will increase, while the second-period new product demand q_{2n}^* will decrease, and the preowned item quantity q_u^* will increase;*

(c) *the first-period profit π_1^* will increase, while the second-period profit π_2^* will decrease, and the total profit π^* across both periods will first decrease then increase.*

Recall that the upgrade ratio λ denotes the enhancement of the virtual item after one period of use. This is a unique feature of virtual items, as physical products always deteriorate after use, while virtual items can increase in consumption value. The level of a game character or in-game equipment will upgrade as the consumer spends time playing with the virtual item. Consequently, the consumer who has not yet owned the virtual item will value the preowned virtual item more than the new item.

Proposition 1 shows that the upgrade ratio λ has a contrasting role in driving the developer's equilibrium profit in the first and second periods. To see the intuition of this result, we need to first understand the impact of λ on equilibrium pricing and demand. Two intertemporal effects occur along with the increase in λ in different periods. In the first period, with the increase in λ, consumers are willing to pay a higher price for the new product (i.e., $\frac{\partial p_1^*}{\partial \lambda} > 0$), as some anticipate that they will be able to sell their preowned virtual item for a better price at the end of the first period. For the same reason, more consumers are willing to purchase the product in the first period, as they can sell back to the C2C market at the end of their usage (i.e., $\frac{\partial q_1^*}{\partial \lambda} > 0$). In the second period, the developer faces more fierce competition from the increase in λ. This is because the new product becomes less attractive as preowned virtual items can provide higher consumption value. To respond, the developer's optimal response is to reduce the price of the new product in the second-period $\frac{\partial p_2^*}{\partial \lambda} < 0$. Because more preowned virtual items will flood the market, the equilibrium sales quantity will also drop in the second period (i.e., $\frac{\partial q_{2n}^*}{\partial \lambda} < 0$).

In summary, we find that the increase in the upgrade ratio λ has an opposite effect in the first period compared to the second period. Specifically, it can benefit the developer in the first period (i.e., $\frac{\partial \pi_1}{\partial \lambda} > 0$) while hurting the developer in the second period (i.e., $\frac{\partial \pi_2}{\partial \lambda} < 0$). As a result, total profit will first decrease then increase depending on the relative gain and loss from the first and second periods, respectively. Next, we investigate the impact of the depth of the virtual item γ.

PROPOSITION 2. *As the depth of the virtual item γ increases, we find that*

(a) *both the first-period price p_1^* and second-period price p_2^* will increase, and the preowned virtual item price p_p^* will also increase;*
(b) *the first-period demand q_{1n}^* will either be unimodal (i.e., first increase then decrease) when $\lambda < \lambda'$ or increase when $\lambda \geq \lambda'$, while the second-period new product demand q_{2n}^* will increase, and the preowned item quantity q_u^* will decrease;*
(c) *both the first-period profit π_1^* and the second-period profit π_2^* will increase, and consequently the total profit π^* across both periods will also increase.*

Recall that the depth of the virtual item γ reflects the endurance of the virtual item. A higher value of γ indicates that the virtual item can retain a high consumption value after repeated use. In practice, the value of γ is highly influenced by the design of the game. For example, players may still feel quite engaged (i.e., a relatively high value of γ) in a multiplayer online battle game even after playing for some time because there are an infinite number of team and opposing team combinations. In contrast, players may get tired easily (a relatively low value of γ) after finishing all levels in an action role-playing game. We find this parameter can make a significant impact on the developer's pricing decisions and subsequent profit.

To begin with, an increase in γ will result in an increase in p_1^* in the first period (i.e., $\frac{\partial p_1^*}{\partial \gamma} > 0$). This is because consumers are willing to pay a higher price for the virtual item, as they can retain a higher consumption value for the virtual item in the second period. Correspondingly, we can also show that more consumers will keep their purchased virtual item at the end of the first period (i.e., $\frac{\partial q_u^*}{\partial \gamma} < 0$). As a result, the decrease in the supply in the preowned virtual item leads to an increase in the equilibrium price of the preowned virtual item (i.e., $\frac{\partial p_p^*}{\partial \gamma} > 0$). Depending on the magnitude of the upgrade ratio, we can show that new product sales of the first period may either be unimodal in γ when $\lambda < \lambda'$ or increasing in γ when $\lambda \geq \lambda'$. The detailed expression of λ' is provided in the Supporting Information Appendix. To see the intuition of this result, recall that $q_1 = 1 - v_{1n} = 1 - p_1 + p_p$. Although both the first-period price p_1^* and preowned virtual item price p_p^* increase in γ in equilibrium, we find that when λ is relatively small (i.e., $\lambda < \lambda'$), it is possible for q_1^* to decrease in γ because p_1^* is more responsive to changes in γ than p_p^* (i.e., $\frac{\partial p_1^*}{\partial \gamma} > \frac{\partial p_p^*}{\partial \gamma}$). When λ becomes relatively large (i.e., $\lambda \geq \lambda'$), we can show that the optimal sales quantity in the first period always increases in γ.

Second, an increase in γ has a very interesting effect on the second period. It is in line with our expectation that the new product price can increase in the second period (i.e., $\frac{\partial p_2^*}{\partial \gamma} > 0$), as the developer is facing a lower level of competition from the preowned virtual item in the second period, which incentivizes her to increase the product price. Interestingly, we find that the optimal quantity also increases in γ (i.e., $\frac{\partial q_{2n}^*}{\partial \gamma} > 0$). The reason behind this result is that more consumers choose to keep their preowned items, which leads to fewer consumers selling their virtual items in the second period. Consequently, the new product can fill the gap created by the lack of available virtual items on the market.

Finally, we find that the developer prefers a higher value of γ (i.e., $\frac{\partial \pi}{\partial \gamma} > 0$) for two reasons. The first is because an increase in γ enables the developer to charge a higher price in the first period, and this higher margin always benefits the developer's profit in the first period (i.e., $\frac{\partial \pi_1}{\partial \gamma} > 0$). The second is that an increase in γ can improve the retention of the virtual item, which subsequently mitigates the fierce competition between the new product market and secondary market in the second period (i.e., $\frac{\partial \pi_2}{\partial \gamma} > 0$). Taken together, we find that a higher value of the depth or endurance of the virtual item can benefit the developer. We have illustrated how the upgrade ratio λ and depth of the virtual item γ impact the equilibrium result individually. In the next subsection, we investigate how these two parameters can jointly affect the firm's profit.

4.3 Effect of the C2C Market for Preowned Virtual Items

We now compare the models presented in Sections 4.1 and 4.2 to investigate whether the developer would enable the transaction of preowned virtual items. To determine if the developer would like to introduce blockchain technology, we compare the developer's equilibrium profits under the benchmark model when there is no secondary market to the base model when there is a preowned virtual item market. We summarize the finding in Proposition 3.

PROPOSITION 3. *Compared with the benchmark case when preowned virtual items are not allowed to be traded, the presence of a C2C preowned virtual item market in the base model can benefit the developer when* $\frac{\sqrt{13}-1}{6} < \gamma < 1$ *and* $\lambda > \underline{\lambda}$. *Otherwise, the developer prefers not having a secondary market for the preowned virtual item.*

The detailed expression of $\underline{\lambda}$ is provided in the Supporting Information Appendix. Proposition 3 shows that the transaction of preowned virtual items can actually benefit the developer. This result is new to the literature and unique to the upgrade feature of virtual items. Although the existing literature in physical goods has shown that the existence of a secondary market may benefit the upstream supplier or manufacturer, their result holds only when there is a channel structure (Shulman and Coughlan, 2007; Yin et al., 2010) or the consumer can sell their purchased product and make an additional purchase of upgraded product (Ghose et al., 2005; Hendel and Lizzeri, 1999). Our study is the first to show the positive role of a secondary market with a C2C setting, and in the scenario where consumers do not need to purchase additional products in the second period. It is crucial to point out that this result is unique to the virtual item (i.e., $\lambda > 1$) and is significant to the rapid development of blockchain technology. Yin et al. (2010) conclude that the presence of a C2C preowned physical goods market (i.e., $\lambda \leq 1$) results in lower profits for the supplier. Indeed, we have verified that when $\lambda \leq 1$ (i.e., physical products), the introduction of a secondary market always hurts the developer's profitability in our setting.[9]

The intuition of our result is also different from the existing literature. Existing literature has shown that one of the main reasons that the secondary market can benefit the manufacturer is because the secondary market enables better price discrimination of consumers in the second period. That is, the manufacturer can charge a higher price for the new product to extract from high-valuation consumers as low-valuation consumer demand is fulfilled by the used product. However, this intuition does not apply to virtual items. We have shown in the Supporting Information Appendix that $p_2 < p_p$ when $\lambda > 1$, while $p_2 > p_p$ when $\lambda \leq 1$. Essentially, our result holds true when the competition between new and preowned virtual items (i.e., $\lambda > 1$) in the second period is fiercer than the competition of physical products (i.e., $\lambda < 1$). Further, the high-valuation consumer will purchase the preowned virtual item while the low-valuation consumer will purchase the new product from the developer.

The main reason driving our result is that the existence of the secondary market can increase value to first-period consumers. Specifically, we note that our result holds true when both the depth of the virtual item γ and upgrade ratio λ are relatively high. When the value of λ is relatively high, it can attract more consumers to purchase the virtual item in the first period, as consumers can rationally expect that they can sell back their preowned items in the end of the first period. When the value of γ is relatively high, more consumers will choose to keep their purchased product at the end of the first period, which can mitigate the competition between new and preowned items in the second period. As a result, when both values become relatively high, they jointly improve the valuation of the product and expand the initial purchase. Next, we discuss the impact of the introduction of a secondary market on consumer surplus, which leads to the next proposition.

PROPOSITION 4. *Compared with the benchmark model when the transaction of preowned virtual items is not allowed, second-period consumers always strictly benefit from the existence of the C2C market, while the first-period consumer may or may not benefit. Taken together, consumers overall can always benefit from the existence of a preowned virtual item C2C market.*

From Proposition 4, we find that overall consumer surplus is strictly higher when the transaction of preowned virtual items is enabled. More specifically, we find that the consumer in the second period always benefits from the introduction of the secondary market. There are two reasons behind this finding. First, consumers have more choice, as they can choose to purchase the new product from the developer or the preowned item from another user. Second, as we show above, the introduction of the secondary market will squeeze the price of the new product in the second period, which benefits the consumer. Taking these two factors together, we find that the transaction of preowned virtual items can always improve consumer surplus in the second period. This result does not always hold in the first period: On the one hand, consumers benefit from the option to sell back their purchased item, while on the other hand, the developer can strategically increase the price, as she expects that some consumers will trade their preowned items at the end of the first period. As a result, depending on loss and gain, the consumer surplus may or may not increase in the first period.

The implication of this result is quite significant to lawmakers interpreting the first-sale doctrine in the digital era. Our results here suggest that introducing blockchain-based technology can always benefit the consumer but only sometimes improve the profitability of the developer. If lawmakers extend the first-sale doctrine to the virtual item unconditionally, it may improve the consumer's welfare but may not be widely welcomed by virtual item developers, as some may become worse off and hurt their subsequent product release or innovation. On the other hand, if lawmakers completely disable the first-sale doctrine for virtual items, the consumer's interest will suffer and the developer's profitability may or may not improve. Taken together, our research suggests that it is better for lawmakers to make the regulation flexible and delegate the decision to the individual developer to create a better balance between the interest of consumers and developers. In practice, if the developer would like to enable the transaction of preowned virtual items, she can introduce blockchain-based technology to allow the secure transaction of preowned virtual items. If the developer prefers not to allow the transaction of preowned virtual items, she can impose a license instead of selling when transferring the virtual item to the consumer.

5 Model Extensions

In this section, we extend our base model along two dimensions. First, we consider the scenario that the developer can earn a proportion of the revenue from the transaction of preowned virtual item. Second, we include the network effects, which is a feature in the information goods. We demonstrate that our results from the base model are robust to the alternative model specifications.

5.1 Transaction Through the Developer

In the base model, we focus on the case that consumers can freely trade their preowned products with each other (i.e., decentralized exchange). In this extension, we consider an alternative scenario where the developer, in addition to receiving the revenue from new product sales, can also take a proportion of the revenue from the transaction of the preowned product (i.e., centralized exchange). This is a reasonable assumption, as the developer can take a cut of each trade by facilitating the transaction (Barber, 2019). For example, the virtual card developer shares a proportion of the revenue with the blockchain technology provider (Dotson, 2019). To accommodate this possibility, we assume that the developer can keep β proportion of the revenue from the transaction of preowned virtual items, while the consumer gets $1-\beta$. Further, to reflect the reality that the consumer can typically keep the majority of the revenue from selling their preowned product, we assume $\beta \leq \frac{1}{2}$ without loss of generality.

This revenue sharing model is commonly known as the agency pricing model in the literature (Feng et al., 2020; Geng et al., 2018; Tan and Carrillo, 2017). It will affect the consumer's decision in the first period directly through the change in the consumer's utility, while making an impact on the second-period consumer's decision indirectly through the price change. Further, the developer's profit in the second period contains the revenue from sales of both new and preowned products. To illustrate, the consumer's utility in the first period becomes $v + \max\{(1-\beta)E[p_p],\ \gamma v\} - p_1$, and developer's profit in the second period is $\pi_2 = p_{2n}q_{2n} + \beta p_{2u}q_{2u}$. We can solve this setting in a similar manner as in the base model. The equilibrium outcome is quite complex. Because of analytical intractability, we study the impact of revenue sharing proportion β through extensive numerical study in this subsection. One of the key issues is whether the existence of a centralized secondary market of virtual items can benefit the developer as in the base model. We reach the following observations from extensive numerical analysis.

Observation 1. *The developer's profit is higher with the centralized secondary market than without when both the value of upgrade ratio λ and depth of the virtual item γ are relatively high.*

Figure 3 illustrates the impact of β on the developer's choice between adopting or forgoing blockchain technology. The shaded region denotes the area in which the developer obtains higher profit with the centralized secondary market than the benchmark case (*BE*). We find that when both the value of λ and γ are relatively high (i.e., upper-right corner), the developer is better off with the centralized secondary market of virtual items. This result is consistent with the finding in the base model. Compared with the base model, we find that the developer is more likely to enable the transaction of preowned virtual items under this scenario. To see the intuition of this result, the developer has one more source of revenue in this case. Clearly, the inclusion of the revenue from the transaction of preowned virtual items can mitigate the fierce competition between the new and preowned products in the second period. As a result, the developer is more likely to embrace and accept the existence of the transaction of preowned virtual items in this case. Our intuition may suggest that the developer always prefers a higher value of β, which is the proportion of the revenue that the developer can keep from each preowned virtual item transaction. Nevertheless, and interestingly, we find that the developer's profit is not actually monotonic in the value of the revenue sharing proportion β, which leads to our next observation.

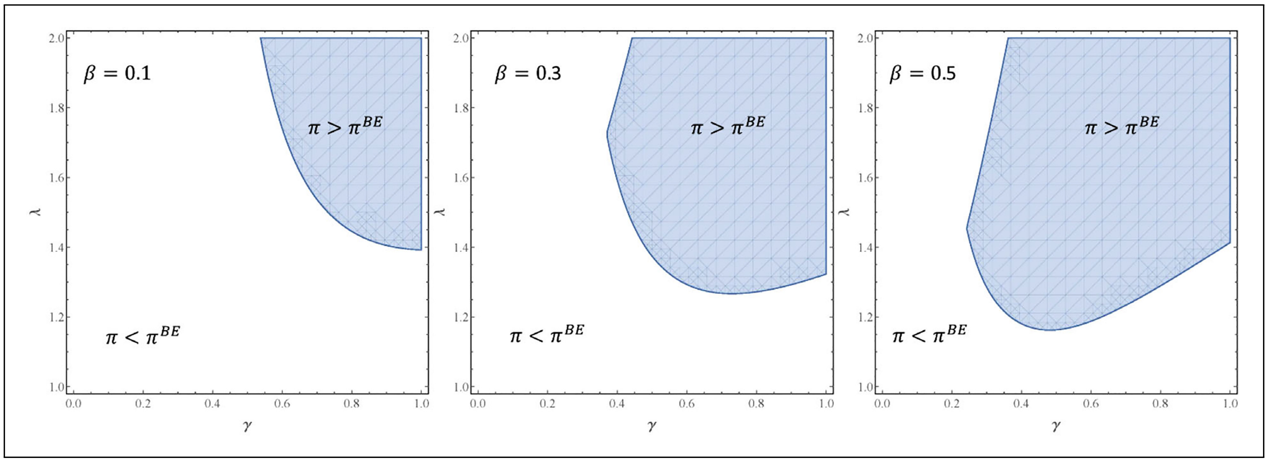

Figure 3. Comparison of the profit between with and without secondary market of virtual item. *Note*: The vertical axis is the value of λ, which we restrict between 1 and 2 for illustration. The horizontal axis is the value of γ, which ranges between 0 and 1. The values of the revenue sharing proportion β are 0.1, 0.3, and 0.5, in the left, middle, and right subfigures, respectively.

OBSERVATION 2. *The developer's profit is not always monotonic in the revenue sharing proportion β.*

Figure 4 presents the impact of the revenue sharing commission β on developer's profit. Note that we have conducted extensive numerical analyses and find that this result is robust to a variety of different parameter settings.[10] We find that the developer's profit first increases and then decreases the value of β when the value of γ is relatively high. There are two opposite dynamics, one direct and one indirect, that interplay with each other as an increase in β to drive this result. On the one hand, a higher value of β indicates that the developer can keep more revenue from the transaction of preowned virtual items, which benefits the developer in the second period. On the other hand, a higher β also leads to a decrease in the new product price in the first period because consumers cannot recoup as much as before from trading their preowned virtual items, which hurts the developer's profit in the first period. Essentially, the developer needs to find a balance of the trade-off between second-period gain and first-period loss, in which a higher value of γ tilts the trade-off toward the latter effect. As a result, the developer's profit first increases and then decreases in the revenue sharing proportion β. We also observe that developer's profit increases in the value of γ. This result is consistent with the base model, as consumers are willing to pay a higher price to own a virtual item with high endurance.

5.2 Network Effects

To ensure analytical clarity, we abstract away from the network effects in the base model. However, for products such as virtual items, they may exhibit the network effects. That is, the utility of the consumption of virtual item increases as the number of consumers grows. For example, consumers may have higher willingness to pay for the online games if there are more players participating in the game. This could be because a large number of players can reduce the waiting time of the matching process or improve the social interaction among the players. As a result, a natural and interesting extension of our base model is to examine the role of network effects on the introduction of blockchain-based preowned virtual item transaction.

We denote the consumer utility function with network effects by $\hat{U}$. In the presence of the network effects, the consumer's utility in the first period becomes $\widehat{U_1} = v + \delta q_{1n} + \max\{E[p_p],\ \gamma v + \delta(q_{1n} + q_{2n})\} - p_1$, where $\delta \in [0, 1]$ denotes the strength of the network effects. Note that the above utility function degenerates to the base model when $\delta = 0$. The consumer's utility in the second period becomes $\widehat{U_{2n}} = v + \delta(q_{1n} + q_{2n}) - p_2$ and $\widehat{U_{2u}} = \lambda v + \delta(q_{1n} + q_{2n}) - p_p$ for purchasing the new product and preowned products, respectively. The other model settings are identical to the base model. Following the extant studies in the space of network effects (Cheng and Liu, 2012; Dou et al., 2017), we adopt the rational expectation equilibrium concept here. That is, consumers form common expectations about the network size and this expectation is consistent with the actual demand in equilibrium. Similar to the base model, we first characterize the result when the trading of preowned virtual items is not allowed and compare that with the case when trading is enabled. Due to the technical complexity of this setting, we resort to the numerical analysis to conduct the analysis here.

Through the numerical analysis, we find that considering the network effects does not change the core insight from the base model. That is, the introduction of blockchain enabled preowned virtual items can still benefit the developer when certain conditions are met. In addition, this extension of network effects also leads to the following new finding.

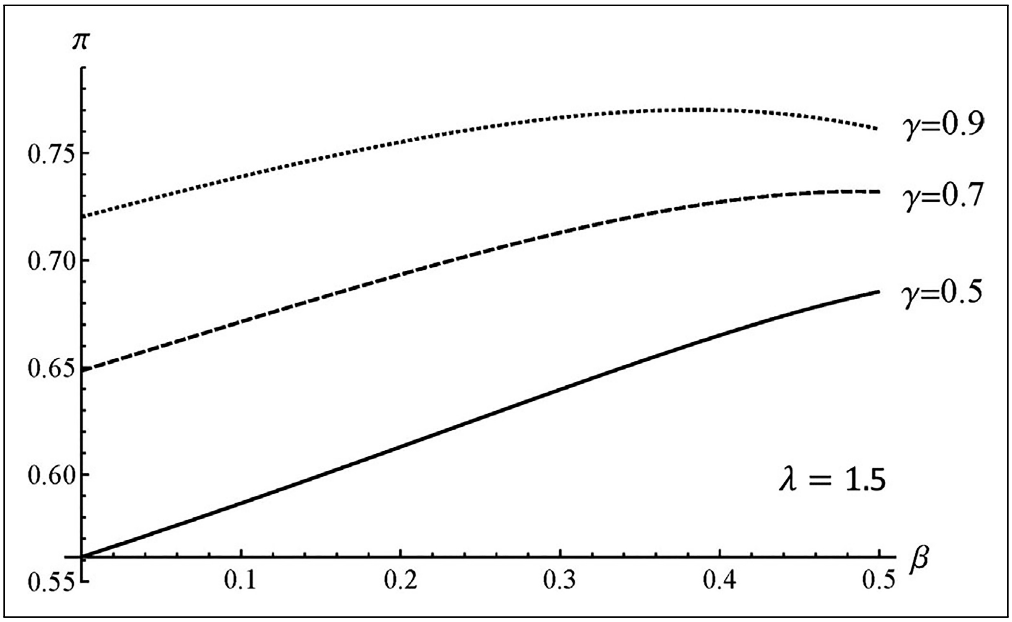

Figure 4. Impact of revenue sharing commission β on developer's profit ($\lambda = 1.5$).

OBSERVATION 3. *The developer's total profit across both periods may first decrease then increase in the depth of the virtual item* γ.

Figure 5 illustrates the impact of γ on developer's profit. We find that when the strength of network effects is small, the developer's total profit will always increase in the depth of the virtual item. However, when the strength of network effects becomes relatively large, the developer's total profit may first decrease then increase in the depth of the virtual item. This result is in sharp contrast with the base model in which we find that the total profit will always increase in the depth of the virtual item γ. It is clear that when the strength of the network effects δ is relatively small, the value generated from the network effects will not be significant enough to alter the results. However, when the strength of the network effects becomes relatively large, it may change the consumer's behavior and subsequently change the developer's profit.

To understand the intuition of this result, we can focus on the term $\gamma v + \delta(q_{1n} + q_{2n})$, which is the retention value if the consumer chooses to keep their virtual item in the second period. Specifically, when the depth of the virtual item, γ, is relatively small, the value from the network effects $\delta(q_{1n} + q_{2n})$ dominates the leftover utility γv. An increase in γ will increase the price in the first period and subsequently reduce the quantity, q_{1n}. As a result, more consumers will choose to sell their preowned virtual item, which increases the competition during the second period and makes the developer worse off. When the depth of the virtual item becomes large enough, the leftover utility γv will dominate the value of the network effects $\delta(q_{1n} + q_{2n})$. Then the same intuition from the base model carries over and we find that the increase in the depth of the virtual item will improve the developer's total profits.

6 Conclusions

In this paper, we study the implications of the transaction of preowned virtual items. Our research is motivated by the ongoing debate of the applicability of the first-sale doctrine in the digital world. The first-sale doctrine has been protecting consumers' interests for over a century by allowing individual consumers to trade their used items, but technology has changed the environment dramatically because it was first established. Due to unreliable technology concerns and uncertainty of economic implications, lawmakers are hesitant to adopt the first-sale doctrine in a digital world. This is a representative issue concerning whether old laws should be reinterpreted to adapt to evolving technology.

The emergence of blockchain technology has resolved the piracy and technological issues of digital resales by allowing developers to track provenance and chain of custody. Virtual item developers have been embracing this technology, which allows true ownership for virtual item consumers. Despite the popularity of trading used virtual items, its economic impact remains unclear. To respond, we construct an analytical model to investigate the implication of used virtual item trading on developers and consumers. Specifically, our two-period model captures a unique feature of virtual items: They can be upgraded after purchase, so used items may have greater value than new ones. As a result, consumers in the later period prefer the used virtual item to the new item. We also capture the decentralized nature of blockchain technology by allowing consumers to trade virtual items directly among each other. The setup of our model allows the main insights to take center

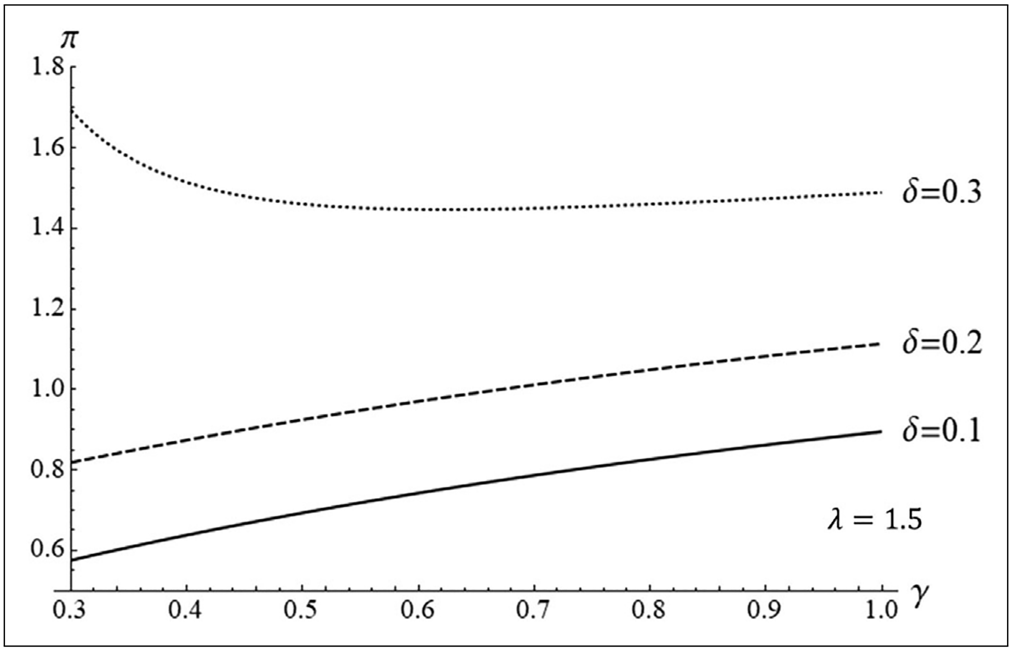

Figure 5. Impact of network effects and depth of the virtual item on developer's profit ($\lambda = 1.5$).

stage rather than the technical complexities inherent to a more general model.

Our research reveals several important and interesting theoretical findings. First, our study shows that the introduction of preowned virtual item trading can improve the profitability of the developer under certain conditions. This result is quite surprising in the sense that physical goods suppliers can never become better off by introducing a secondary market for used items. For virtual items, the competition between preowned products and new products is fiercer than for physical products, as consumers may prefer upgraded preowned items to new items. The main intuition driving the result is that consumers are forward-looking and can anticipate the potential increase in trade value of virtual items in the later periods, which incentivizes early consumers to pay a premium in the first period. Moreover, we find that the developer's gain is not at the cost of the consumer. Our results show that consumer surplus will actually increase with the introduction of preowned virtual item trading. The main intuition of this result is that first-period consumers have the opportunity to trade their preowned virtual items, while second-period consumers benefit directly from the introduction of preowned virtual items because it drives down the price of new items. Another interesting finding has to do with the impact of the revenue sharing proportion. We consider an alternative setting in which the developer can take a cut of the transaction of a preowned virtual item. We find that the developer is more willing to embrace blockchain technology to facilitate the transaction of preowned virtual items, as this gives them a second stream of revenue on top of selling the new items alone. However, our analysis also reveals that the developer's profit does not monotonically increase in the revenue sharing proportion that the developer can keep; when the revenue sharing proportion becomes too high, it will discourage the consumer's purchase in the first period, which hurts the developer.

Our study also provides significant and relevant insights for policymakers and regulators. To begin with, our study sheds light on the impact of preowned virtual item transactions on developers and consumers. It provides evidence that extending the first-sale doctrine to the digital world can always benefit the consumer but may or may not improve the profitability of the developer. To balance the interest between the developer and consumer, our results suggest that regulators can delegate the right to the developer. It should be the developer's choice whether or not to introduce blockchain technology to facilitate the transaction of preowned virtual items. If the developer chooses not to allow the transaction of preowned virtual items, she can impose a license instead of selling when transferring the virtual item to a new consumer. In this scenario, the consumer can use but not trade the item. Second, we find that allowing the developer to take a cut during the transaction can further incentivize her to accept the resale of virtual items. The implication of this result is that if lawmakers are leaning toward adapting the first-sale doctrine for virtual items, they may need to revise the doctrine to allow the developer to take a cut of the transaction of the preowned virtual item. Finally, although we focus on virtual goods in this study, which are used mainly in online communities and games, the implication can also resonate with other, broader categories of digital goods including digital books, music, movies, and other digital goods.

We briefly note a few limitations of this study and provide some directions for future research. To begin with, we consider a two-period model to simplify the analysis and facilitate comparisons. Future research can extend the current study to a multiple-period or continuous-time setting to analyze the nuance of dynamic pricing in this setting. Second, based on the practice, we focus on the situation that the developer reaches the consumer directly through her own platform or through a third-party platform. It may be interesting to consider other incentive contracts in this setting. Third, to gain sharp insights, we focus on the scenario in which the upgrade ratio across all consumers is identical. An interesting direction for exploration is to investigate the impact of the heterogeneity of upgrade ratio on developer's profit and consumer surplus. Fourth, to ensure the analytical clarity, we abstract away the setup cost of blockchain technology. Future research should look into the impact of the setup cost on preowned virtual goods marketplace. Notwithstanding these limitations, the current study presents the first step in understanding how the introduction of blockchain technology may affect developer profit and consumer surplus, and contributes to the burgeoning debate of the first-sale doctrine in the new digital world.

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Notes

1. See https://www.adroitmarketresearch.com/press-release/virtual-goods-market.
2. In Europe, the Court of Justice of the European Union made a ruling that upholds the owner's right to resell used software (Khoury, 2014), while in the United States, the court has ruled that MP3 files purchased from iTunes cannot be resold (Reis, 2015). To date, it is still open to question whether the first-sale doctrine can be applied to digital files at large.
3. There are three categories of the blockchain technology: public, private, permissioned. In a public blockchain, anyone can join and participate in the core activities. In a private blockchain, only invited and verified users can join the network. The majority of digital product developers adopt a permissioned blockchain, which has features in common with both public and private. For example, the blockchain game developer gamesd.app (https://www.gamesd.app) supports more permissioned blockchains than the other two types.
4. Motivated by the practice, we focus on the virtual items in this study. Virtual item is a subcategory of digital goods and is mainly used in online communities and games.
5. $1 - \gamma$ is also commonly known as the individual depreciation rate, which comes from the fact that consumers' consumption value will diminish as they become satiated with the virtual item. Further, consistent with the literature, we assume that there is no residual value of the virtual item after two time periods due to the short life cycle of information products (Dou et al., 2017).
6. Because of the fairness concern in the virtual item, we focus on the scenario that the firm releases the same version of the virtual item instead of the upgraded version across different time periods. We thank the anonymous reviewer for raising this excellent point.
7. For completeness, we also analyze the case of $\lambda \leq 1$, available in the Supporting Information Appendix. Essentially, this scenario represents physical goods that will depreciate with use.
8. When the value of individual depreciation rate γ is low enough, it is possible that all the first-period consumers will sell back their purchased products to the market and no consumers will keep their products. We find that our main qualitative insights still hold. To focus on the more interesting case, we restrict our attention to the scenario in which both segments (i.e., sell back and keep) of the consumers exist.
9. We provide the detailed analysis in the Supporting Information Appendix.
10. The additional analysis can be found in the Supporting Information Appendix.

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