What type of contract should e-tailers offer sellers when facing internal competition

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Abstract
This paper investigates whether an e-tailer should act as a platform and offer customers the product of a seller who can reach customers only through the e-tailer, and if so, what type of contract to offer the seller: a proportional commission based on revenue or a fixed fee per unit sold. The e-tailer also chooses the product line design: offer only her own product, offer only the outside seller's product, or offer both her own product and the seller’s product. Intuitively, when the e-tailer’s product outperforms the seller’s product in terms of value-to-cost ratio, the e-tailer should not offer the seller’s product. However, non-intuitively, we also identify conditions in which the e-tailer remains better off not opening her platform to the seller even though the seller’s value-to-cost ratio is higher than the e-tailer’s and show how these conditions depend also on the consumers valuations. Regarding the type of contract to offer the seller, we find that most of the time, a proportional commission based on revenue is the best contract, guaranteeing the highest e-tailer profit. However, this is not always the case since there are situations when a fixed fee contract reduces the potential of internal competition.

Keywords Supply-chain management · Online platform · Contract · Channel strategy

1 Introduction

Internet and digital technology-based marketplaces can play a vital role in entrepreneurship development for small firms in developing countries that can widen their market to the international arena through Internet-based e-marketplace participation (Hossain et al. 2021). For some firms, for example for small farmers in developing countries who want to access distant markets, e-commerce could be the only viable option (Savrul et al. 2014; Sodhi 2015; Parvin et al. 2021). In fact, not only small firms
in developing countries are forced to turn to online platforms to access consumers. In the last two years, due to the COVID-19 pandemic, consumers have shifted their day-to-day shopping to digital channels such as Amazon. In the New York Times, Lauren Leatherby and David Gelles (New York Times 2020) showed that this dramatic shift caused department stores, fast fashion sellers, and other retail venues to close their physical locations. Given how suddenly the novel coronavirus outbreak escalated, for many of these businesses—particularly smaller sellers that did not have an established online presence—online platforms such as Amazon, eBay, and Etsy provided an attractive means of generating revenue as quickly as possible, without having to spend months designing and launching independent e-tail websites. Indeed, businesses need only collect photos and descriptions of their products to quickly begin selling via an existing platform.

On the other side of the supply chain, many of the largest online retailers opened their sites to serve as platforms for other sellers years ago. Amazon began allowing companies to sell products as early as 2001, and in 2009, Walmart announced Walmart Marketplace, which began offering nearly one million new items from a select group of outside retailers. Online retailers that choose to serve as platforms must decide how to manage internal competition that arises from offering the outside sellers’ compatible substitute products. Online retailers also must consider the type of contract to offer the other sellers. The two most common kinds of contracts offered by such platforms involve either revenue-sharing in which the platform takes a portion of the seller’s revenue or fixed fees in which the platform charges a fixed “rent” for each sale (Zhang et al. 2019). These decisions tend to have a significant impact on the online retailer’s revenue and profits.

Motivated by the real practice, we formulate a mathematical model to analyze the interaction between an e-tailer considering opening her existing platform and a seller who offers a substitutable product and can reach customers only through the e-tailer (the pronoun “he” represents the seller, and “she” represents the e-tailer). The e-tailer needs to decide on the product line design: whether to offer both her own original product and the seller’s product and thus face internal competition, offer only the seller’s product and thus refrain from internal competition and potential cannibalization, or not open her platform and sell only her own original product. If the e-tailer chooses to open her platform, she then must decide what kind of contract to offer the seller: a revenue sharing contract where the seller pays proportional commission based on his revenue or a fixed fee per unit sold. In addition, the seller and the e-tailer each need to decide on the selling price of their respective products. Specifically, we construct a two-stage game, where, first, the e-tailer makes the strategic decisions regarding (i) the operation mode and (ii) the contractual form. Then, in the second stage, the seller and e-tailer set their prices. In order to model the asymmetry in sales efficiency between the e-tailer and the outside seller it is further assumed that each party incurs a different unit cost. We make no preliminary hypothesis regarding which unit cost is higher.

Our main findings are as follows. (I) The conditions under which the online retailer chooses to open her existing platform to sellers are identified. As expected, we find that the e-tailer is better off not opening her platform when her own product outperforms the seller’s product in terms of value-to-cost ratio. However, non-intuitively, we also identify conditions in which the e-tailer remains better off not opening her platform and
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selling only her own product even though the e-tailer’s value-to-cost ratio is smaller than the seller’s. (II) Regarding the type of contract to offer, we find that most of the time, a proportional commission based on revenue is the best contract, guaranteeing the highest e-tailer profit. However, this is not always the case, and we identify the occasions when the fixed-fee contract is more profitable. (III) We further find that under the fixed-fee contract, the e-tailer always obtains the greatest benefit from being the leader in the pricing subgame, while under the proportional commission contract, it is never profitable for the e-tailer to set prices simultaneously with the seller. These findings are useful for e-tailers considering opening their online platforms to outside sellers and for businesses considering converting to online sales in order to reach consumers.

The remainder of this paper is arranged as follows. Section 2 gives the relevant background and previous research. The model formulation is described in Sect. 3. Analysis of the equilibrium pricing strategies and equilibrium operation mode is performed under the fixed-fee contract and under the proportional commission contract in subsections 3.1 and 3.2, respectively. A comparison between these two contracts is presented in subsection 3.3. Section 4 extends the analysis by modeling different pricing decision sequences and studying their effects on the e-tailer’s strategic decisions regarding mode of operation and type of contract. Finally, Sect. 5 concludes the paper. All proofs are relegated to the Appendix.

2 Literature review

In recent years, online retail platforms have been studied from different perspectives; see excellent surveys of the literature in Agatz et al. (2008), Melacini et al. (2018) and recently in Avinadav et al. (2022). Ryan et al. (2012) studied the conditions under which a single retailer that currently sells its product only through its own website chooses to contract with Amazon to sell its product through the online system. Mantin et al. (2014) considered an online platform that both sells products and allows third-party sellers to offer their products (e.g., Amazon), thus creating a duopolistic market in which the platform’s and seller’s products compete. Yan et al. (2018) explored whether the e-tailer should choose to sell through the online channel in addition to the conventional reseller channel. Yan et al. (2019) studied how sellers determine how sales inefficiency and a lack of information about demand affect the introduction of their products in online platforms. Perlman (2022) studied the pricing decisions of online retailer and compared them with those of offline retailers under the assumption that each retailer offers a competitive benefit.

Other studies have examined the choice of whether to participate in an online sales platform. Kwark et al. (2017) studied the effect of online platforms providing a system for customer reviews on whether sellers chose the platforms or their own sites. Hagiu and Wright (2015) considered how information asymmetries relate to optimal tailoring of online marketing activities. Abhishek et al. (2016) studied the effects of competition between two e-tail platforms in the presence of positive and negative cross-channel
effects. Cao et al. (2020) studied whether a traditional retailer should become an e-tailer platform considering consumers returns and showed that this choice depends on the magnitude of the annual service fee that is affected by offline return strategy.

In practice, many different e-tailers offer the same seller’s product on their platforms. Such competition was studied by Abhishek et al. (2016) and by Wei et al. (2021). A supply chain of two competing sellers and a single e-tailer platform was studied by Kwark et al. (2017). The current work extends the literature by focusing on internal competition, that is the competition between the e-tailer’s own product and the seller’s product. Moreover, our model better captures the asymmetric relations between the parties. While prior studies normalized the e-tailer’s unit cost to zero, in this study the seller’s and e-tailer’s products have different unit costs and we make no assumption on which unit cost is higher.

Finally, while previous studies a-priori assumed that the platform and seller interacted via a contract involving either a fixed fee (Jiang et al. 2011; Mantin et al. 2014; Hagiu and Wright 2015) or a proportional commission from the revenue (Ryan et al. 2012; Abhishek et al. 2016; Kwark et al. 2017; Wei et al. 2021), in this study, the platform e-tailer strategically chooses the type of contract to offer to the seller, either a fixed fee per unit sold or a proportional commission based on revenue. To the best of our knowledge, only Zhang et al. (2019) have modeled the platform choice between these two contractual agreements. While Zhang et al. (2019) modeled the e-tailer as a distribution channel offering exclusively a single product of an outside seller, our model extends the literature by analyzing the internal competition generated when the e-tailer offers both her own product and the seller’s product via her online platform. Thus, we study both the e-tailer’s contract choice and the e-tailer’s strategic decision regarding the product line design in order to handle internal competition.

3 Model

Consider a seller denoted by $S$ who can reach customers only through a platform provided by an e-tailer. The e-tailer (denoted by $R$) chooses her product line design, i.e., she can operate her platform in one of three ways: offer only her own product, offer only the seller’s product, or offer both products. The e-tailer also decides on the form of the contract offered to the seller. We consider two types of contracts: (i) a fixed-fee contract, where the seller pays the e-tailer a fixed fee per unit sold, and (ii) a proportional commission contract, where the seller pays the e-tailer a percentage commission based on his revenue.

In the model, consumers are heterogeneous with respect to their consumption valuations of (their willingness to pay for) the product. Denote consumers’ valuations of the e-tailer’s own product by the random variable $v$. For simplicity, we assume that $v$ is uniformly distributed on the support $[0,1]$ (e.g., Chiang et al. 2003; Kogan et al. 2013; Ozinci et al. 2017; Perlman et al. 2019; Perlman 2021; Zhu et al. 2021). We assume that the product offered by the seller is less acceptable to consumers than the e-tailer’s own product since the seller is less recognizable and due to lack of reputation considering his service attributes such as delivery, reliability, and customer support (Ryan et al. 2012; Mantin et al. 2014; Li et al. 2018; Pi and Wang 2020). Thus, a
consumer’s valuation for a product obtained from the seller via the platform is $\theta v$, and $0 < \theta < 1$ denotes consumer acceptance of the seller’s product (e.g., Chiang et al. 2003).

Each consumer buys at most one unit of a product—the e-tailer’s own product ($R$) or the seller’s substitutable product ($S$)—or can choose not to buy at all ($Z$). The consumer’s utility under each option is defined as the difference between the consumer’s valuation of the product and the price of the product option. Let $p_R$ denote the price of e-tailer’s own product and $p_S$ denote the price of the seller’s product. Thus, the utility of the consumer who buys the e-tailer’s product is $u_R = v - p_R$, whereas the utility of a consumer who buy the seller’s product is $u_S = \theta v - p_S$. The consumer who does not buy at all obtains zero utility, i.e. $u_Z = 0$. Consumers are assumed to be rational and to choose the option that maximizes their utility. A consumer whose valuation is $v_{RS} = \frac{p_R - p_S}{1 - \theta}$ is indifferent as to whether to buy the e-tailer’s or the seller’s product, that is, $u_R = u_S$. A consumer whose valuation is $v = p_R$ is indifferent as to whether to buy the e-tailer’s product or not to buy at all (i.e. $u_R = u_Z = 0$), and a consumer whose valuation is $v = p_S$ is indifferent as to whether to buy the seller’s product or not to buy at all (i.e. $u_S = 0$). Based on the assumption that that $v$ is uniformly distributed on the support $[0, 1]$, demand functions can be constructed for each mode of operation, where constraints on the prices are applied to ensure positive demand. If the e-tailer does not act as a platform for the seller and offers only her own product, the market then becomes a monopolistic retailer market ($MR$) where only the e-tailer’s product is sold. Thus, consumers have only two options: they will buy the e-tailer’s product when their valuations are in the interval $[v^R, 1]$; otherwise, they will not buy. Thus, the demand functions for the seller and the e-tailer, respectively, are

$$D^M_{SR} = 0 \text{ and } D^M_{RS} = 1 - p_R \text{ for } 0 \leq p_R \leq 1$$  \hspace{1cm} (1)

If the e-tailer opens her platform to the seller and offers only the seller’s product, leading to a monopolistic seller market ($MS$), consumers with valuations in the interval $[v^S, 1]$ will buy the seller’s product and consumers with valuations in $[0, v^S]$ will not buy. Thus, the demand functions for the e-tailer and seller, respectively, are

$$D^M_{MS} = 0 \text{ and } D^M_{SM} = 1 - \frac{p_S}{\theta} \text{ for } 0 \leq p_S \leq \theta$$  \hspace{1cm} (2)

The case in which the e-tailer opens her platform and offers both her own product and the seller’s product leads to a duopolistic market ($D$). For such a duopolistic market to exist, i.e., for demand for the products to exist, the condition $0 < v^S < v_{RS} < 1$ needs to hold. That is, consumers with valuations in the interval $[v^S, v_{RS}]$ buy the seller’s product, consumers with valuations in $[v_{RS}, 1]$ buy the e-tailer’s product, and consumers with valuations in $[0, v^S]$ do not buy at all.\footnote{When $v_{RS} \leq v^S$, no one buys the seller’s product and the market is reduced to a monopolistic retailer market.}

1
\[ D^D_R = 1 - \frac{p_R - p_S}{1 - \theta} \quad \text{and} \quad D^D_S = \frac{\theta p_R - p_S}{\theta(1 - \theta)} \quad \text{for} \quad \max(0, \theta + p_R - 1) \leq p_S \leq \theta p_R \]  

Denote by \( c_R \) and \( c_S \) the unit cost of the e-tailer’s product and the seller’s product, respectively. When the unit cost of the e-tailer’s product is greater than 1, which is the maximal valuation of the e-tailer’s product, the product is not profitable. Similarly, when the unit cost of the seller’s product is greater than \( \theta \), which is the maximal valuation of the seller’s product, the product is not profitable. To avoid triviality, we assume hereafter that \( c_R \leq 1 \) and \( c_S \leq \theta \).

We next specify the sequence of events and decisions in our model. First, the e-tailer chooses the market operation mode (\( MR, MS, \text{ or } D \)) and the contractual form (fixed fee or proportional commission) and its parameters. In the second stage, the seller and e-tailer set their prices based on the selected operation mode. Under \( MR \), the e-tailer chooses her product price; under \( MS \), the seller chooses his product price. When the chosen operation mode is \( D \), the e-tailer and the seller simultaneously choose their product prices (vertical Nash game). The assumption that the e-tailer and the seller compete à la Bertrand in the case of a duopolistic market is common in the literature (e.g., Ryan et al. 2013). In Sect. 4, we provide an analysis of different pricing decision sequences in which either the e-tailer or the seller acts as leader (e.g., Lou et al. 2020; Hu et al. 2021). The seller can choose not to use the e-tailer’s platform by setting a high price for his product so that demand for it does not exist. The parties are assumed to be risk-neutral and to maximize their expected profits. We focus on subgame-perfect equilibria in pure strategies. The game is solved by backward induction.

### 3.1 Fixed-fee contract

Under the fixed-fee contract, the e-tailer charges the seller a fixed rent denoted by \( f \) per unit sold. We start with the pricing subgame in which both the fixed fee and the operation mode (\( MR, MS, \text{ or } D \)) have already been chosen. Under the \( MR \) operation mode (offering only the e-tailer’s product), the e-tailer’s profit is determined by

\[ \pi_{MR}^R = D_{MR}^R (p_R - c_R) = (1 - p_R)(p_R - c_R) \]  

and there is no profit for the seller (because his product is not sold in the market). Under the \( MS \) operation mode (offering only the seller’s product), the e-tailer profits from charging the seller the per-unit fee. Thus, the e-tailer’s profit is

\[ \pi_{MS}^R = D_{MS}^R f = \left(1 - \frac{p_S}{\theta}\right) f \]  

and the seller’s profit is his net revenue after paying the unit cost and the e-tailer’s fee per unit sold:

\[ \pi_{MS}^S = D_{MS}^S (p_S - c_S - f) = \left(1 - \frac{p_S}{\theta}\right)(p_S - c_S - f) \]
Finally, under the $D$ operation mode (both products are offered), the e-tailer profits from sales of her product and from the per-unit fee charged to the seller. Thus, the e-tailer’s profit is determined by

$$
\pi^D_R = D^D_R (p_R - c_R) + D^{MD}^S f = \left(1 - \frac{p_R - p_S}{1 - \theta}\right) (p_R - c_R) + \left(\frac{\theta p_R - p_S}{\theta (1 - \theta)}\right) f
$$

and the seller’s profit is the net revenue after paying the unit cost and the unit fee:

$$
\pi^D_S = D^D_S (p_S - c_S - f) = \left(\frac{\theta p_R - p_S}{\theta (1 - \theta)}\right) (p_S - c_S - f)
$$

Note that $\pi^{MR}_R$ is a concave function of $p_R$ (Eq. 5), $\pi^{MS}_S$ is a concave function of $p_S$ (Eq. 6), and $\pi^D_R$ is a concave function of $p_R$ and a convex function of $p_S$ while $\pi^D_S$ is a concave function of $p_S$ and a convex function of $p_R$ (Eqs. 7 and 8). Solving the first-order conditions, we state.

**Proposition 1** For each operation mode, the subgame pricing equilibrium is unique and is given by:

(i) $p^{MR}_R = \frac{c_R + 1}{2}$ under $MR$ – offering only the e-tailer’s product.

(ii) $p^{MS}_S = \frac{c_S + f + 0}{2}$ under $MS$ – offering only the seller’s product.

(iii) $p^D_R = \frac{2c_R + c_S + 3f + 2 - 2\theta}{4 - \theta}$ and $p^D_S = \frac{(c_R + f)(1 + 2c_S + f) + \theta - \theta^2}{4 - \theta}$ under $D$ – offering both products.

Given the solution of the pricing subgame, we now obtain the optimal fixed fees set by the e-tailer to maximize her profit while acting as a platform under the $MS$ and $D$ operation modes. Under $MS$, the e-tailer’s profit $\pi^{MS}_R = \frac{f(\theta - c_S - f)}{2\theta}$ obtained by substituting equilibrium pricing strategy in Eq. (5) is a concave function of $f$ and the fixed fee that maximizes this profit is

$$
f^{MS*} = \frac{\theta - c_S}{2}
$$

Under the duopolistic market $D$, the e-tailer’s profit obtained by substituting the equilibrium pricing strategy in Eq. (7) is also a concave function of $f$ and the fixed fee that maximizes this profit is

$$
f^{D*} = \frac{\theta^2 (1 - c_R) + 8(\theta - c_S)}{2(8 + \theta)}
$$

Substituting the optimal fixed fees in Proposition 1 and checking under what conditions these prices satisfy the conditions for demand to exist in each operation mode, equilibrium pricing and the fixed-fee strategy are derived for each operation mode under the fixed-fee contract. The results are presented in Table 1.

It follows from Table 1 that the e-tailer’s profits in equilibrium can be sorted by size as follows.
Table 1 Outcomes of the e-tailer’s pricing and fee decisions for each operation mode

| Operation Mode | MR | MS | D |
|----------------|----|----|---|
| Existence conditions | $c_R < 1$ | $c_S < \theta$ | $\frac{c_S}{\theta} < c_R < 1 - \frac{6(\theta - c_S)}{8 - \theta - \theta^2} \equiv \overline{C}_R$ |
| Price | $p_R^* = \frac{c_R + 1}{2}$ | n/a | $\frac{3c_R\theta + 8c_R\theta + \theta + 8 - 2c_S}{16 + 2\theta}$ |
| | $p_S^* = \frac{c_S + 3\theta}{4}$ | $\frac{(c_R + 1)\theta^2 + (4c_R + 8)\theta + 4c_S}{16 + 2\theta}$ |
| Fixed fee | n/a | $\frac{\theta - c_S}{2}$ | $\frac{\theta^2(1 - c_R) + 8(\theta - c_S)}{2(8 + \theta)}$ |
| Sales volume | $D_R^* = \frac{1 - c_R}{2}$ | n/a | $\left(1 - \frac{6(\theta - c_S)}{8 - \theta - \theta^2} - c_R\right) \frac{8 - \theta - \theta^2}{2(1 - \theta)(8 + \theta)}$ |
| | $D_S^* = \frac{\theta - c_S}{4}$ | $\frac{(\theta + 2)(c_R - c_S)}{(1 - \theta)(8 + \theta)}$ |
| Profit | $\pi_R^* = \frac{(1 - c_R)^2}{4}$ | $\frac{(\theta - c_S)^2}{8\theta}$ | $4c_S^2 + \left(8 + 8c_R^2 - c_R(8c_S + 16)\right)\theta + \left(14c_R - 3c_R^2 - 7\right)\theta^2 - (1 - c_R)^2\theta^3$ |
| | $\pi_S^* = n/a$ | $\frac{(\theta - c_S)^2}{16\theta}$ | $\frac{(\theta + 2)(c_R - c_S)^2}{\theta(1 - \theta)(8 + \theta)^2}$ |

Lemma 1 (i) $\pi_{R}^{D^*} \geq \pi_{R}^{MR^*}$ (where $\pi_{R}^{D^*} = \pi_{R}^{MR^*}$ for $c_R = c_S/\theta$)
(ii) $\pi_{R}^{D^*} > \pi_{R}^{MS^*}$
(iii) $\pi_{R}^{MR^*} > \pi_{R}^{MS^*}$ if and only if $c_R < 1 - \frac{\theta - c_S}{\sqrt{2}\theta}$

Proof: See Appendix 1.

It follows from Lemma 1(i) and Lemma 1(ii) that as long as the existence conditions of a duopolistic market hold (i.e., $c_S/\theta < c_R < \overline{C}_R$) the e-tailer is better off employing a duopolistic market where both products are sold ($D$). However, when the duopolistic market cannot exist, because the sales volume of either the e-tailer’s own product or the seller’s product would have shrunk to zero under the duopolistic market, the e-tailer’s decision on the mode of operation is not straightforward. In fact, the decision depends on the condition presented in Lemma 1(iii).

Finally, the e-tailer chooses the product line design, i.e., she decides whether offering only her own product, only the seller’s product, or both products is more profitable. By Lemma 1 and the existence conditions presented in Table 1, the equilibrium strategy is given in Theorem 1.

Theorem 1 Let $\overline{C}_R \equiv 1 - \frac{6(\theta - c_S)}{8 - \theta - \theta^2}$. Under a fixed-fee contract, the equilibrium operation mode is:

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MR – offering only the e-tailer’s product – when $c_R < \frac{c_S}{\theta}$ or $C_R < c_R < 1 - \frac{\theta - c_S}{\sqrt{2\theta}}$.

MS – offering only the seller’s product – when $c_R > \max(C_R, 1 - \frac{\theta - c_S}{\sqrt{2\theta}})$.

D – offering both products – when $\frac{c_S}{\theta} < c_R < C_R$.

The following managerial insights are derived from Theorem 1. When the e-tailer’s product outperforms the seller’s product in terms of the value-to-cost ratio, i.e., for every customer with some valuation $\bar{v}$, the value-to-cost ratio $\frac{\bar{v}}{c_R} > \frac{\bar{v}}{c_S}$, the e-tailer’s best strategy is selling her own products (MR).

When the e-tailer’s unit cost is relatively high (i.e., $\frac{c_S}{\theta} < c_R < C_R$), it becomes beneficial for the e-tailer to open her platform and offer both her own product and the seller’s product up to the unit-cost threshold point at which all consumers prefer the seller’s product and the sales volume of the e-tailer’s product shrinks to zero (i.e., $c_R = C_R$) due to that internal competition. Non-intuitively, even if the e-tailer’s value-to-cost ratio is smaller than the seller’s, there are conditions under which the e-tailer’s best choice is not to open her platform. In fact, there is an interval in the e-tailer’s cost ($C_R < c_R < 1 - \frac{\theta - c_S}{\sqrt{2\theta}}$) for which the e-tailer’s best choice is not to open her platform but to sell only her own product and avoid internal competition (i.e., the e-tailer’s best strategy is MR). Note that this interval exists only if $C_R < 1 - \frac{\theta - c_S}{\sqrt{2\theta}}$.

Since $C_R = 1 - \frac{6(\theta - c_S)}{8 - \theta - \theta^2}$ and $c_S < \theta$, this latter condition holds only if consumer acceptance of the seller’s product is greater than the consumer acceptance threshold $\theta > \theta^* \approx 66.145\%$. An interesting managerial insight arises when the consumer acceptance of the seller’s product is relatively high, that is when the two products are perceived almost identical in value. If the e-tailer’s cost increases to a level where a duopolistic market is no longer feasible due to having no demand for the e-tailer’s product, the e-tailer is surprisingly better off selling only her own product rather than selling the superior product (in terms of value to cost ratio) offered by the seller. This phenomenon is illustrated in Fig. 1.

Fig. 1 The e-tailer’s preferred operation mode under the fixed-fee contract as a function of $\theta$ and $c_R$, where $c_S < \theta < 1$ and $0 < c_R < 1$. Red – only e-tailer’s product (MR); Blue – both products (D); Green – only seller’s product (MS) (colour figure online)
Denote by $\Pi_R^*$ and $\Pi_S^*$, respectively, the profits of the e-tailer and the seller in equilibrium under a fixed-fee contract. (Note that $\Pi$ denotes the profit at equilibrium given the optimal operation mode is selected whereas $\pi$ denotes the profit for each operation mode.) By Theorem 1 and Table 1, these profits are represented by the following piecewise functions given in Corollary 1.

**Corollary 1** Under a fixed-fee contract, the profits of the e-tailer and the seller in equilibrium are

\[
\Pi_R^* = \begin{cases} 
\frac{(1-c_R)^2}{4} & \text{or } 1 - \frac{6(\theta-c_S)}{8-\theta-\theta^2}c_R 1 - \frac{\theta-c_S}{\sqrt{2\theta}} \\
\frac{(\theta-c_S)^2}{8\theta} & c_R \max \left(1 - \frac{6(\theta-c_S)}{8-\theta-\theta^2}, 1 - \frac{\theta-c_S}{\sqrt{2\theta}} \right)
\end{cases}
\]

and

\[
\Pi_S^* = \begin{cases} 
\frac{(\theta-c_S)^2}{16\theta} & c_R > \max \left(1 - \frac{6(\theta-c_S)}{8-\theta-\theta^2}, 1 - \frac{\theta-c_S}{\sqrt{2\theta}} \right) \\
\frac{(\theta+2)^2(c_R\theta-c_S)^2}{\theta(1-\theta)(8+\theta)^2} & \frac{c_S}{\theta} < c_R < 1 - \frac{6(\theta-c_S)}{8-\theta-\theta^2}
\end{cases}
\]

### 3.2 Proportional commission contract

Under the proportional commission contract, the seller pays a rate $\lambda$ on his revenue to the e-tailer. We start with the pricing subgame in which the e-tailer has already selected the commission rate and market operation mode. The notation $P$ is used to denote equilibrium and related measures under the proportional commission contract in order to distinguish these calculations from those under the fixed-fee contract. If the e-tailer offers only the seller’s product (i.e., the $PMS$ operation mode), the e-tailer receives a share of the seller’s revenue. Therefore,

\[
\pi_{PMS}^* = D_{MS} S \lambda \ p_S = \left(1 - \frac{p_S}{\theta}\right) \lambda \ p_S
\]

and the seller’s profit equals his remaining share of the revenue minus his cost:

\[
\pi_{PMS}^* = D_{MS} S (1 - \lambda) p_S - c_S) = \left(1 - \frac{p_S}{\theta}\right) ((1 - \lambda) p_S - c_S)
\]

If the e-tailer offers both her own product and the seller’s product (i.e., the $PD$ operation mode), the e-tailer’s profit is

\[
\pi_{PD}^* = D_{MD} R (p_R - c_R) + D_{MD} S \lambda \ p_S
\]

\[
= \left(1 - \frac{p_R - p_S}{1-\theta}\right)(p_R - c_R) + \left(\frac{\theta p_R - p_S}{\theta(1-\theta)}\right) \lambda \ p_S
\]

and the seller’s profit is

\[
\pi_{PD}^* = \left(\frac{\theta p_R - p_S}{\theta(1-\theta)}\right) ((1 - \lambda) p_S - c_S)
\]
Proposition 2 For each operation mode, the subgame pricing equilibrium is unique and is given by:

(i) $p_{MR}^R = \frac{c_R + \theta (1-\lambda)}{2(1-\lambda)}$ under $MR$ – offering only the e-tailer’s product.

(ii) $p_{PMS}^S = \frac{c_S + \theta (1-\lambda)}{2(1-\lambda)}$ under $PMS$ – offering only the seller’s product.

(iii) $p_{PD}^R = \frac{2c_R (1-\lambda) + c_S (1+\lambda) - 2(1-\lambda) (1-\lambda)^2 \theta}{4(1-\lambda) - (1-\lambda)^2 \theta}$ and $p_{PD}^S = \frac{2c_S (1-\lambda) + (1+c_R) \theta - (1-\lambda)^2 \theta}{4(1-\lambda) - (1-\lambda)^2 \theta}$ under $PD$ – offering both products.

When we substitute the solution of the pricing subgame in Eq. (11), the e-tailer’s profit is $\pi_{PMS}^R = \frac{\lambda (\theta^2 (1-\lambda)^2 - c_S^2)}{4\theta (1-\lambda)^2}$, which is a concave function of $\lambda$. Thus, when we solve the first-order condition, the optimal proportional commission set by the e-tailer under the $MS$ operation mode (selling only the seller’s product) market is given by

$$\lambda_{PMS*} = 1 - \frac{c_S^{2/3}}{3^{1/3} c_S^{2/3}} \left[ \left( \frac{\sqrt{3}\sqrt{c_S^2 + 27\theta^2} - 9\theta}{3\sqrt{3}\sqrt{c_S^2 + 27\theta^2} - 9\theta} \right)^{1/3} \right]$$

(15)

If the e-tailer operates under the $PD$ mode, the optimal proportional commission is a unique root of the quadratic polynomial function (given in Appendix 2) that falls between zero and one. Since the closed-form solution of $\lambda_{PD*}$ is a long expression, we must resort to numerical analysis to obtain the e-tailer’s profit when she sells both her own product and the seller’s product ($D$ operation mode) and the e-tailer’s strategic decision regarding the mode of operation.

Our numerical study includes a broad range of parameter values where $c_R$, $c_S$, and $\theta$ vary between zero and one with a lag of 0.05. Once again, we find that, under a proportional commission contract, the e-tailer is better off operating under the $MR$ mode for $c_R < \frac{c_S}{\theta}$. As expected, regardless of contract type, if the e-tailer’s product outperforms the seller’s product in terms of value-to-cost ratio, the e-tailer’s best strategy is clearly to sell only her own product. Similar to the result obtained under the fixed fee contract, also under the proportional commission contract, if the e-tailer cost increases to a level where a duopolistic market is no longer feasible due to having no demand to the e-tailer product, there exists a threshold level of consumer acceptance so that above that threshold the retailer chooses to sell her own product although it is inferior to the seller’s product in terms of value to cost ratio. Interestingly, we find that the consumer acceptance threshold under the proportional commission contract is always higher than the consumer acceptance threshold under the fixed fee contract. Using an illustrative example, Fig. 2 depicts how the interaction between $c_R$, $c_S$, and $\theta$ affects the e-tailer’s choice of operation mode. Figure 2a was generated by setting $c_S = 0.2$, $0 \leq c_R \leq 1$, and $0.2 \leq \theta \leq 1$; Fig. 2b by setting $c_R = 0.4$ and $0 \leq c_S \leq \theta \leq 1$; and Fig. 2c by setting $\theta = 0.8$, $0 \leq c_R \leq 1$, and $0 \leq c_S \leq 0.8$. Note that the consumer acceptance threshold under the proportional commission contract, $\theta_{P*} \approx 75\%$, is higher than the threshold under the fixed-fee contract ($\theta^* = 66.145\%$).
3.3 Comparison of contract types

As previously discussed, the e-tailer decides which contract to offer the seller by choosing the type of contract that maximizes her profit. To compare the e-tailer’s profits under the contracts, we must resort to numerical analysis and the results are presented in Fig. 3. The large green areas depict the combinations of $c_R$, $c_S$, and $\theta$ for which the e-tailer obtains the highest profit under the proportional commission contract and the red areas depict the combinations for which the e-tailer obtains the highest profit under the fixed-fee contract. Specifically, Fig. 3a was generated by setting $c_S = 0.2$, $0 \leq c_R \leq 1$, and $0.2 \leq \theta \leq 1$; Fig. 3b by setting $c_R = 0.4$ and $0 \leq c_S \leq \theta \leq 1$; and Fig. 3c by setting $\theta = 0.8$, $0 \leq c_R \leq 1$, and $0 \leq c_S \leq 0.8$. As demonstrated in Fig. 3, the proportional commission contract is usually preferable.

This result is also supported by real-life examples where platforms such as Amazon and Apple can be seen implementing the proportional commission type of contract in many of their interactions with sellers. However, there are rare occasions in which
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the fixed-fee contract is the preferred contract since it maximizes the e-tailer’s profit. Specifically, these involve combinations of \( c_R, c_S, \) and \( \theta \) for which, under a fixed-fee arrangement, the e-tailer’s best strategy is to sell both products (\( D \) operation mode) while offering both products cannot be done under the proportional commission contract (\( PD \) operation mode) because there is no demand for both products under these parameters’ values. Thus, there are occasions in which the e-tailer can open her platform to an outside seller and sell both products (which in turn increases her profit) only if the contract is a fixed-fee contract. This result is demonstrated in Fig. 4, in which, for a given seller’s cost \( c_S \), the preferred operation mode is depicted as a function of \( \theta \) and \( c_R \) (see also the red area depicted in Fig. 3a).

Figure 4a depicts the preferred operation modes under the fixed-fee contract, Fig. 4b the preferred operation modes under the proportional commission contract, and Fig. 4c the preferred operation modes under both contracts and highlights areas that overlap. Specifically, the purple area depicts the combinations of \( c_R, c_S, \) and \( \theta \) for which the e-tailer can offer both products (\( D \) operation mode) under the fixed-fee contract but chooses to offer only her own product (\( MR \)) under the proportional commission. The green area depicts the combinations of \( c_R, c_S, \) and \( \theta \) for which the e-tailer can offer both products (\( D \) under the fixed-fee contract but chooses to offer only the seller’s product under the proportional commission (\( PMS \)). In both cases (the purple and green areas) the e-tailer gains the highest profit in the fixed fee contract, and these are the only cases where the fixed fee contract outperforms the proportional contract (if and only if condition).

4 Different pricing decision sequences

The above analysis was performed under the assumption that when the e-tailer decides to offer both products (i.e., operate a duopolistic market), the parties (e-tailer and seller) simultaneously decide their prices (vertical Nash game). In this section we consider different pricing decision sequences and study their effects on the e-tailer’s strategic decisions regarding mode of operation and type of contract.
First, the case in which the e-tailer is the leader who sets her price \( (p_R) \) first and the seller then responds by setting his price \( (p_S) \) is studied. This case is termed the *e-tailer Stackelberg* game. The reverse case in which the seller is the leader is termed the *seller Stackelberg* game. Hereafter, we denote by the superscripts \( eS \), \( sS \), and \( N \) the outcomes in the e-tailer Stackelberg game, the seller Stackelberg game, and the vertical Nash game, respectively.

### 4.1 Fixed-fee contract

Under the assumption that the e-tailer chooses a fixed-fee contract, the equilibrium pricing and contract fee are derived both for the *e-tailer Stackelberg* game and for the *seller Stackelberg* game. These results and related measures in equilibrium are provided in Table 2. Note that the results when the e-tailer offers only her own product and when the e-tailer offers only the outside seller’s product are the same as in Sect. 3 and are presented in Table 1 (under \( MR \) and \( MS \), respectively).

### Table 2 Equilibrium pricing, contract fee, and related measures in a Stackelberg game

| E-tailer stackelberg | Seller stackelberg |
|----------------------|--------------------|
| Existence conditions | \( \frac{c_f}{T} < c_R < 1 - \frac{\theta-cS}{2\theta} \equiv \bar{c}_R \) |
| Price | \( \frac{\theta-cS}{2} \) |
| \( p^*_R \) | \( \frac{c_R+1}{2} \) |
| \( p^*_S \) | \( \frac{c_S+\theta(c_S+2)}{4} \) |
| Fixed fee | \( \frac{\theta-cS}{2} \) |
| \( f^*_R \) | \( \frac{\theta^3-\theta^2(c_R+5)+\theta(8+cS)-8cS}{2(8-5\theta+\theta^2)} \) |
| Sales volume | \( \left(1 - \frac{\theta-cS}{2\theta} - c_R\right) \left(\frac{2-\theta}{\theta(1-\theta)}\right) \) |
| \( D^*_R \) | \( \left(1 - \frac{(2-\theta)(3-\theta)(\theta-cS) - c_R}{8-7\theta+\theta^2}\right) \left(\frac{8-7\theta+\theta^2}{2(1-\theta)(8-5\theta+\theta^2)}\right) \) |
| \( D^*_S \) | \( \frac{c_R\theta-cS}{4\theta(1-\theta)} \) |
| Profit | \( \frac{c^2 + \theta(2 + 2c^2_R - 2cR(cs + 2))}{\theta(2c^2_R - 4cR + 2)} - \frac{2\theta(2\theta) - \theta cR}{4\theta(1-\theta)} \) |
| \( \pi^*_R \) | \( \frac{(c\theta-cS)^2}{4\theta(1-\theta)} \) |
| \( \pi^*_S \) | \( \frac{2(2-\theta)(c\theta-cS)^2}{\theta(1-\theta)(8-5\theta+\theta^2)} \) |
In both Stackelberg games, sorting the e-tailer’s profits under each operation mode by size is consistent and complies with the conditions stated in Lemma 1 (see Appendix 3). That is, the results of Lemma 1 hold regardless of the sequence of pricing decisions.

Denote by $C_{eS}^R \equiv 1 - \frac{\theta - cS}{2 - \theta}$, $C_{sS}^R \equiv 1 - \frac{(2 - \theta)(3 - \theta)(\theta - cS)}{8 - 7\theta + \theta^2}$, and $C_{N}^R \equiv 1 - \frac{6(\theta - cS)}{8 - 7\theta + \theta^2}$ the e-tailer’s unit-cost thresholds at which the sales volume of the e-tailer’s product shrinks to zero due to the internal competition in the e-tailer Stackelberg game, the seller Stackelberg game, and the vertical Nash game, respectively.

By algebraic manipulations, it can be shown that the conditions in the following proposition hold.

**Proposition 3** $C_{eS}^R \geq C_{sS}^R \geq C_{N}^R$. An interesting managerial insight follows from Proposition 3. If the pricing decision sequence is such that the e-tailer sets her product price first (before the seller), i.e., the e-tailer Stackelberg, this pricing sequence allows the e-tailer to sell both products and maintain this product line (the duopolistic market) for higher unit costs than when she sets price second (after the seller), which in turn is maintained for higher unit costs than when the parties set prices simultaneously.

When the e-tailer offers both products in her product line, i.e., operates a duopolistic market in equilibrium, the following holds:

**Proposition 4** $\pi_{eS}^R \geq \pi_{N}^R \geq \pi_{sS}^R$.

*Proof:* See Appendix 4.

It follows from Proposition 4 that if the operation mode is offering both products, the e-tailer’s highest profit is obtained if the e-tailer is the Stackelberg leader in the pricing subgame, and the e-tailer’s lowest profit is obtained if the seller is the Stackelberg leader in that game.

Denote by $\Pi_{eS}^R$, $\Pi_{sS}^R$, and $\Pi_{N}^R$ the e-tailer’s profit in equilibrium under a fixed-fee contract for the e-tailer Stackelberg game, the seller Stackelberg game, and the vertical Nash game, respectively. By Lemmas 1 and Propositions 3 and 4, we state.

**Theorem 2**

(i) $\Pi_{eS}^R \geq \Pi_{N}^R$

(ii) $\Pi_{eS}^R \geq \Pi_{sS}^R$

(iii) $\Pi_{sS}^R \geq \Pi_{N}^R$ if and only if $C_{N}^R \leq cR \leq C_{sS}^R$

The managerial insight from Theorem 2 is that under a fixed-fee contract the e-tailer’s highest profit is obtained in the e-tailer Stackelberg game. That is, the e-tailer is most profitable when she acts as leader of the supply chain, dictating not only the fixed fee charged to the seller ($f$) and the market operation mode, but also her product price ($pR$).
4.2 Proportional commission contract

The e-tailer Stackelberg (denoted by the superscript $PeS^*$) and the seller Stackelberg (denoted by the superscript $PsS^*$) games are now studied under the proportional commission contract. Denote by $C_{R}^{PeS}$, $C_{R}^{PsS}$, and $C_{R}^{PN}$ the e-tailer unit cost thresholds at which, due to internal competition, the sales volume of the e-tailer’s product shrinks to zero for each pricing decision sequence in the e-tailer Stackelberg game, the seller Stackelberg game, and the vertical Nash game, respectively. Through a numerical experiment, we show that the following conjecture holds for the proportional commission contract.

Conjecture 1 The e-tailer’s profits in equilibrium under the proportional commission contract can be sorted by size:

(i) $\prod_{R}^{PeS^*} \geq \prod_{R}^{PN^*}$

(ii) $\prod_{R}^{PsS^*} \geq \prod_{R}^{PeS^*}$ if and only if $\frac{C_{R}^{PsS}}{C_{R}^{PeS}} \leq c_{R} \leq \frac{C_{R}^{PN}}{C_{R}^{PsS}}$

(iii) $\prod_{R}^{PsS^*} \geq \prod_{R}^{PN^*}$ if and only if $\frac{C_{R}^{PN}}{C_{R}^{PsS}} \leq c_{R} \leq \frac{C_{R}^{PsS}}{C_{R}^{PeS}}$.

Conjecture 1 indicates that, under the proportional commission contract, it is never profitable for the e-tailer to set prices simultaneously with the seller. Depending on the values of the three model parameters, the e-tailer’s highest profit is achieved when the e-tailer acts either as a Stackelberg leader or as a follower in the pricing subgame.

5 Conclusions

In a supply chain consisting of a platform e-tailer who sells her own product and an outsider seller who has to use the e-tailer’s platform to reach consumers, we studied the e-tailer’s decision regarding opening her platform to the outside seller. In such deliberations, the e-tailer chooses between three operation modes: sell only her own product, sell only the seller’s product, or sell both her own product and the seller’s product. The e-tailer also chooses what type of contract to offer to the seller—a fixed fee per unit sold or a proportional commission based on revenue—and the parameters of the contract.

Based on the values of the three model parameters, different unit costs for each of the products, and customer acceptance of the seller’s product, we show that the proportional commission based on revenue is usually the preferred contract. However, there are parameter value combinations for which a fixed-fee contract is preferred because it enables the e-tailer to sell both her own product and the seller’s product (operate the duopolistic market), while this would not be the case under the proportional commission contract since there would not be demand for both products due to the internal competition. We further show that under the fixed-fee contract, the e-tailer always obtains the greatest benefit from being the leader in the pricing subgame, while under the proportional commission contract, it is never profitable for the e-tailer to set prices simultaneously with the seller.

While in the current paper, the consumer choice model is one-dimensional, an interesting extension would be to model the product valuations for each product.
independently and construct a two-dimensional consumer choice model. Second, our models were analyzed under a complete information setting. Extension of our work that could capture asymmetric information with respect to the unit costs of the products would likely be an interesting avenue of future research.

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Appendix 1

(i) \[ \pi^M_{D*} - \pi^M_{R*} = \frac{(c_R \theta - c_S)^2}{\theta(1-\theta)(\theta+8)} \geq 0 \]

(ii) \[ \pi^M_{D*} - \pi^M_{S*} = \frac{(\theta + 7)c_s^2}{8(1-\theta)(\theta+8)} + \frac{(16 - 14\theta - 16c_R - 2\theta^2)c_s}{8(1-\theta)(\theta+8)} \]

Since the coefficient of this quadratic function is positive and it has no real roots, thus \( \pi^M_{D*} - \pi^M_{S*} > 0 \).

(iii) \[ \pi^M_{R*} - \pi^M_{S*} = \frac{c_R^2}{4} - \frac{c_R}{2} - \frac{\theta^2 - 2\theta(c_R + 1) + c_r^2}{8\theta} \text{, which is positive if and only if} \]

\[ c_R < 1 - \frac{\theta - c_S}{\sqrt{2\theta}}. \]

Appendix 2

\( \lambda^{PM D*} \) is the unique root of \( f(Z) \), where

\[
f(Z) = -\theta^3(1-\theta)(1+c_R)(1-\theta+c_R)Z^4 + 2\theta^2\left(\theta^3(c_R+2) - \theta^2(c_r^2 + 3c_R + 2) - \theta(2 + (2c_R + 2)c_R + 2c_r^2 + c_2^2 + 4c_R + 2)\right)Z^3 - 6\theta\left(\theta^4 - \theta^2(c_r^2 + 4c_R + 2c_2 + 3) + \theta(2c_r^2 + (4 - 2c_2)c_R - c_r^2 + 2c_2 + s) + 2s\right)Z^2 + \left(\theta^5(4 - 2c_r) + 2\theta^4\left(2c_r^2 + 3c_R + 2\right) - 4\theta^3\left(2c_r^2 + (7 - c_2)c_R + 4c_R + 5\right) + \left(6\theta^2(2c_r^2 + c_2^2 + 4c_R + 2) + 16\theta c_R(1 - c_R - c_2) + 16c_2\right)\right)Z - \theta^5(1 - c_R) - \theta^4\left(c_r^2 + 3c_R + 2\right) + \theta^3\left(3c_r^2 10c_R + 4c_2 + 7\right) - 2\theta^2\left(2c_r^2 + (4 + 6c_2)c_R - c_r^2 - 6c_2 + 2\right) + 4\theta c_2(4c_R - 5c_2 - 4) + 16c_2\]

Appendix 3

For any e-tailer Stackelberg game, we have:

(i) \[ \pi^{eSM D*}_{R} - \pi^{eSM*}_{R} = \frac{(c_R \theta - c_S)^2}{8\theta(1-\theta)} \geq 0 \]
(ii) $\pi^e_{R}^{SMD} - \pi^e_{R}^{SMS} = \frac{c_s^2}{8(1-\theta)} + \frac{2(1-\theta - c_R)c_S}{8(1-\theta)}$

\[+ \frac{\theta^2 - (3 - 4c_R + c_R^2)\theta + 2(1 - 2c_R + c_R^2)}{8(1-\theta)}\]

Since the coefficient of this quadratic function is positive and it has no real roots, thus $\pi^e_{R}^{SMD} - \pi^e_{R}^{SMS} > 0$.

The proof of (iii) is analogous to that of Lemma 1(iii).

For any seller Stackelberg game, we have:

(i) $\pi^s_{R}^{SMD} - \pi^s_{R}^{SM} = \frac{(2(1-\theta)(c_R\theta - c_S)^2}{4(1-\theta)(8-5\theta + \theta^2)} \geq 0$

(ii) $\pi^s_{R}^{SMD*} - \pi^s_{R}^{SMS*} = \frac{(5 - 4\theta + \theta^2)c_s^2}{8(1-\theta)(8 - 5\theta + \theta^2)} + \frac{2(8 - 8c_R + (8c_R - 13)\theta + (6 - 2c_R)^2 - \theta^3)c_S}{8(1-\theta)(8 - 5\theta + \theta^2)}$

\[+ \frac{\theta^4 + (4c_R - 8)\theta^3 + (4c_R^2 - 24c_R + 25)\theta^2 - (18c_R^2 - 52c_R + 34)\theta + 16(1 - c_R)^2)}{8(1-\theta)(8 - 5\theta + \theta^2)}\]

Since the coefficient of this quadratic function is positive and it has no real roots, thus $\pi^s_{R}^{SMD} - \pi^s_{R}^{SMS} > 0$.

The proof of (iii) is analogous to that of Lemma 1(iii).

Appendix 4

$\pi^e_{R}^{NMD} - \pi^e_{R}^{NMD} = \frac{(c_R\theta - c_S)^2}{8(1-\theta)(8 + \theta)} \geq 0$

$\pi^s_{R}^{NMD} - \pi^s_{R}^{SMD} = \frac{(8 - \theta)^2(c_R\theta - c_S)^2}{4(1-\theta)(8 + \theta)(8 - 5\theta + \theta^2)} \geq 0$

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