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Should competing suppliers with dual-channel supply chains adopt agency selling in an e-commerce platform?

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ABSTRACT

In this paper, we examine which of an agency selling or a wholesale contract offered by an e-commerce platform competing suppliers with typical dual-channel supply chains should adopt, where the products are not differentiated between a direct channel and an indirect platform channel, as in the case of digital goods. Specifically, we consider the situation in which each of two competing suppliers chooses its distribution strategy regarding whether it sells via a direct channel and/or an indirect channel via the platform. In addition, a supplier also chooses an agency selling contract or a wholesale contract if selling via the platform. Constructing and solving a game-theoretic model, we derive the primary result that, in equilibrium, one supplier sells products only via the direct channel, while the other supplier sells via both the direct channel and the platform channel through adopting a wholesale contract, even given the assumption of symmetric suppliers. This finding yields the managerial implication that a supplier selling products of the same quality between direct and platform channels in a competitive environment should not adopt agency selling but instead a regular wholesale contract when selling via a platform. Moreover, this finding reverses the conventional insight from existing models in previous studies that at least one competing supplier always adopts an agency contract when the suppliers are without their own direct sales channels.

1. Introduction

Currently, a wide variety of products ranging from technologically advanced industrial products to daily necessities including food and groceries are sold through online e-commerce platforms worldwide. Consequently, platform companies have experienced tremendous growth over the past decade. For example, Amazon announced that its net sales for 2020 increased 37.6% to $386 billion, compared with $281 billion in 2019. Reflecting the development of these e-commerce platforms, the US Department of Commerce has documented that online retail sales in the US were $791.7 billion in 2020, accounting for 14% of all retail sales in the US.[1] Likewise, in China, where the development of e-commerce has been especially rapid, online retail sales reached 11.76 trillion yuan in 2020, accounting for some 30% of total retail sales.[2] Accordingly, manufacturers increasingly regard these online e-commerce platforms as one of their essential sales channels.

While online retailers have typically played the role of simple resellers in the past, the rapid adoption of online shopping by consumers has induced major platform companies, including Amazon in the US, Taobao in China, and Flipkart in India, to introduce a sales format known as *marketplace* in addition to their traditional reseller format. Accordingly, when selling products or services through an online platform, a supplier needs to select between a wholesale contract or an agency contract, depending on whether the supplier wishes to sell products wholesale to the platform or use its marketplace. The essential difference between the two contracts is who has the right to determine the retail price. With the wholesale contract, while a supplier determines the wholesale price of its products, the platform company determines the retail price. Conversely, the retail price decision is delegated to the supplier in the agency contract, such that the supplier directly determines the retail price of its products based on the revenue-

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[1] https://www2.census.gov/retail/releases/historical/ecomm/20q4.pdf.

[2] https://ecommercetochina.com/china-e-commerce-growth-strategy.

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0377-2217/

sharing rules as determined by the royalty rates and commission fees set by the platform. A major benefit of agency selling to the supply chain is that it resolves the problem of double marginalization, unlike a wholesale contract, and thereby prevents a reduction in the transaction quantity.

Whereas this advantage has induced many manufacturers to adopt agency contracts when selling their products via e-commerce platforms, other manufacturers refuse. For example, in digital industries such as music, regular reselling remains the dominant selling format, with most record labels and artists having resale agreements with online music stores such as Spotify, iTunes, and AliMusic (Abhishek, Jerath & Zhang, 2016; Pu, Sun & Shao, 2020). Moreover, the marketplace channel has not been accepted by several e-commerce companies in other industries, including Everlane, an e-commerce fashion company in the US; VANCL, China's fourth-largest e-commerce apparel company; and JMEI, China's largest cosmetics platform (Yan, Zhao & Liu, 2018).

While the choice between agency and wholesale contracts has become an important issue for suppliers, a new factor has recently emerged that suppliers using platforms as their sales channels must consider when choosing the type of contract. That is, recent information technology (IT) developments have made it easier for manufacturing companies to open their own e-commerce sales channels, enabling them to sell their products directly to end-consumers without intermediation via a third-party platform. For example, Shopify, which is a Canadian company providing suppliers with technology services to construct their e-commerce platform for direct sales at low cost, has recently become available to manufacturers. This is now used by many well-known companies in a variety of industries, including food and beverages (Anheuser-Busch LLC, Nestlé S.A.), household products (Procter and Gamble), and publishers (HarperCollins, Penguin Books) (Hamamura & Zennyo, 2021). Major publishers, such as HarperCollins and Penguin Books, use Shopify as well as through external platforms such as Amazon and Kindle to sell both printed and electronic books directly to consumers. Even without these new IT services, major manufacturing companies in other industries, including personal computers, apparel products, and cosmetics, have long had their e-commerce channels for selling products directly to end-consumers (e.g., Hewlett-Packard, IBM, Nike, Estee Lauder) (Tsay & Agrawal, 2004). This use of both an own direct sales channel and an indirect channel by a manufacturer is usually referred to as a *dual-channel supply chain*.

Given that these dual-channel supply chains are now used by many suppliers, this paper investigates which of a wholesale contract or an agency contract offered by an e-commerce platform competing suppliers with typical dual-channel supply chains should choose, where products are not differentiated between a direct channel and an indirect platform channel, as in the case of digital goods. Specifically, we consider the situation in which each of two competing suppliers chooses its distribution strategy regarding whether to sell via a direct channel and/or an indirect channel via a platform. In addition, we consider whether a supplier chooses an agency selling contract or a wholesale contract when selling via the platform. Constructing and solving a game-theoretic model, we derive the primary result that, in equilibrium, one supplier sells products only via the direct channel, while the other supplier sells via both the direct channel and the platform channel by adopting the wholesale contract, even given the assumption of symmetric suppliers.[3]

[3] Note that because we assume the existence of two suppliers in our model, there arise two equilibria in total, in which one of the suppliers sells via the direct channel only and the other sells via both the direct channel and the platform channel by adopting the wholesale contract, and vice versa. That is, the two decisions are interchangeable between the two suppliers. See Section 4 for details.

The key finding from our model is that if there is no differentiation between channels, and therefore consumers perceive the direct and platform channels as substitutable, then the competing suppliers never adopt the agency contract. This finding holds regardless of how much the platform increases the supplier share of profits by lowering its royalty rate and thereby making the agency contract more attractive to suppliers. This result thus yields the managerial implication that a supplier selling products of the same quality between direct and platform channels, such as digital goods in a competitive environment, should adopt a regular wholesale contract, not agency selling when selling via a platform. Intuitively, if the supplier adopts a wholesale contract, not an agency contract, it may appear undesirable for the supplier because the problem of double marginalization usually arises. However, our results lie contrary to this intuition. In addition, it is also a notable result that even though we assume suppliers to be symmetric in our model, the equilibrium distribution strategy is asymmetric between suppliers. This asymmetric distribution channel strategy allows each supplier to differentiate itself from a rival supplier when selling through the platform. All these results are clearcut and robust because they are perfectly proved analytically, even without numerical analysis.

Furthermore, it is also noteworthy that our result reverses the conventional insight from existing models in previous studies that at least one of the competing suppliers always chooses an agency contract when the suppliers do not have their own direct sales channels. Specifically, our basic settings follow the stylized model in Tian, Vakharia, Tan and Xu (2018) that examines endogenous contract choice by suppliers in a platform supply chain. Tian et al. (2018) reveal that in equilibrium, two symmetric competing suppliers selling via a platform choose asymmetric contracts of the agency contract and the wholesale contract. Their model assumes the existence of two symmetric competing suppliers and one platform, and our model similarly uses this assumption as well. However, their model assumes that each supplier can sell only through the platform; that is, they consider only the existence of a single-channel supply chain. In contrast, we add the assumption that each supplier is also able to sell the same quality product through a direct sales channel as well as via the platform. In sum, by simply replacing the assumption of a single-channel supply chain with a dual-channel supply chain, we demonstrate that an agency contract is chosen by neither supplier, providing a new managerial insight gained in no existing study.

As a review of previous studies in the next section explains the contribution of this paper to the literature in detail, the main novelty of this study is that we investigate whether competing suppliers able to use their own direct sales channels choose either a wholesale contract or an agency contract when using an e-commerce platform. As discussed, the development of IT technologies has increased the number of suppliers with their own direct sales channels in addition to a platform channel in competitive environments. From this perspective, examination of which contract to choose when selling through an e-commerce platform, as analyzed in this paper, is an urgent concern for real-world suppliers, such that our findings will provide them with effective managerial guidelines in this regard.

The remainder of the paper is structured as follows. Section 2 reviews existing operational research (OR) papers developing game-theoretic models on how e-commerce platforms are used in supply chains, along with studies that address dual-channel supply chain management. Section 3 describes the basic setup of our model. Section 4 derives the equilibrium results of the main model in which suppliers compete in terms of quantity at the retail market level, and Section 5 provides a rationale behind the results derived from the model in detail. Section 6 conducts further analysis based on the main model to derive some managerial implications. Section 7 extends the model by considering an alternative scenario in which suppliers compete in terms of price at the retail level. Section 8 concludes the paper.

2. Literature review

2.1. Dual-channel supply chain and supplier encroachment

Studies of platform supply chain management originally closely relate to the research stream of dual-channel supply chain management, including applications of game theory (e.g., Alawneh & Zhang, 2018; Batarfi, Jaber & Zanoni, 2016; Bernstein, Song & Zheng, 2008; Cai, 2010; Cai, Zhang & Zhang, 2009; Cattani, Gilland, Heese & Swaminathan, 2006; Chen, Zhang & Sun, 2012; Chen, Liang, Yao & Sun, 2017; Chiang & Monahan, 2005; Chiang, Chhajed & Hess, 2003; Dumrongsiri, Fan, Jain & Moinzadeh, 2008; Heydari, Govindan & Aslania, 2019; Hua, Wang & Cheng, 2010; Huang & Swaminathan, 2009; Jiang, Liu, Shang, Yildirim & Zhang, 2018; Karray & Martín-Herrán, 2022; Kittaka, Matsushima & Saruta, 2022; Lee, Chang, Jean & Kuo, 2022; Li, Zhang, Chiu, Liu & Sethi, 2019; Li, Tan, Wang, Wei & Wu, 2021; Liu & Ke, 2020; Lu, Shi & Huang, 2018; Matsui, 2016, 2017, 2020, 2022; Modak & Kelle, 2019; Rodríguez & Aydın, 2015; Sun, Jiao, Guo & Yu, 2022; Xiao & Shi, 2016; Xiao, Choi & Cheng, 2014; Xiong, Yan, Fernandes, Xiong & Guo, 2012; Yan, Liu, Xu & He, 2020; Yang, Luo & Zhang, 2018; Yu, Sun & Guo, 2020; Yue & Liu, 2006; Zhang & Hezarkhani, 2021; Zhang, Tang, Zaccour & Zhang, 2019c; Zhou, Zhao & Wang, 2019; Zhu, Qian, Liu, Lu & Pardalos, 2023). In pioneering research, Chiang et al. (2003) investigate the advantages of a dual-channel supply chain for firms constituting the chain. Specifically, they develop a Stackelberg game model that involves a manufacturer and a retailer determining prices, finding that the dual-channel supply chain improves the manufacturer's profitability by mitigating the double marginalization arising in a retail channel. Chiang et al. (2003) also point out that the use of a dual-channel supply chain by the manufacturer does not necessarily disadvantage the retailer because it lowers the wholesale price. Cai (2010) examines the influence of channel structure on the profitability of a supplier, a retailer, and the entire supply chain, assuming a situation in which the supplier and the retailer utilize different supply chain structures. The channel structures considered are a direct channel, a traditional retail channel, and a dual channel, being a pair of both channels. By examining the revenue-sharing contracts often adopted in actual supply chains, Cai (2010) identifies the influence of differences in supply chain structure on the bargaining power of the supplier and the retailer.

Because the use of a dual-channel supply chain is also nowadays commonly referred to as *supplier encroachment* when considered from the retailer perspective, there exist studies dealing with the topic (e.g., Arya, Mittendorf & Sappington, 2007; Chen, Pun & Zhang, 2023; Cui, 2019; Guan, Gurnani, Geng & Luo, 2019; Guan, Liu, Chen & Wang, 2020; Ha, Long & Nasiry, 2016; Ha, Luo & Shang, 2022a; Huang, Guan & Chen, 2018; Li, Gilbert & Lai, 2014; Tong, Lu, Li & Ye, 2023; Wan, Chen & Li, 2023; Yoon, 2016; Zhang, Li, Zhang & Dai, 2019b; Zhang, Feng & Wang, 2021a; Zhang, Li, Liu & Sethi, 2021b). In this research stream, models are constructed from the viewpoint of a retailer or a buyer in the downstream that needs to compete with an upstream supplier or a manufacturer to examine how the former should cope with encroachment by the latter on retail markets.[4] Seminal work by Arya et al. (2007) reveals that a retailer can benefit from supplier encroachment into a retail market even when product differentiation, price discrimination, or synergies do not arise in direct sales. Encroachment causes the supplier to lower the wholesale price to preclude an excessive reduction in the retailer's demand for the product. The lowered wholesale price and intensified downstream competition alleviate double marginalization, which improves Pareto efficiency. Li et al. (2014) examine the effects of supplier encroachment in an uncertain situation in which a reseller has more accurate information than the supplier. They show that the opening of a direct channel by the supplier may trigger costly signaling behavior by the reseller as the reseller reduces its order quantity if the market size is small. This downward order distortion may exacerbate double marginalization. Consequently, supplier encroachment may exacerbate its own profitability, especially when the reseller has a significant efficiency advantage in the sales process and the market size is likely to be small. Ha et al. (2016) investigate the influence of manufacturer encroachment on a supply chain where preferences for product quality are heterogeneous across customers and the quality is endogenously determined. They show that when the manufacturer can flexibly adjust the quality, encroachment deteriorates the reseller's profitability in a wide range of environments. They also find that the manufacturer supplying differentiated products in two channels is willing to sell higher-quality products in its direct channel. On this basis, they conclude, contrary to the conventional wisdom, that quality differentiation does not necessarily benefit the manufacturer or the reseller.

2.2. Platform supply chain

Following earlier research on the issue of dual-channel supply chain management, many papers have been published that develop OR models describing supply chains constituted by e-commerce platforms. In particular, the choice of an agency contract or a wholesale contract in platforms has recently become an important topic commanding the attention of researchers and practitioners alike. Previous studies have used game theory to analyze which contracts are chosen by supply chain members, including suppliers and e-commerce platforms (e.g., Abhishek et al., 2016; Avinadav, Chernonog, Meilijson & Perlman, 2022; Bender, Gal-Or & Geylani, 2021; De Giovanni, 2020; Ha, Tong & Wang, 2022b; Hagiu & Wright, 2015; He, He, Tang, Ma & Xu, 2022; Liu, Xu, Jing, Liu & Wang, 2023; Shen, Willems & Dai, 2019; Tan & Carrillo, 2017; Tian et al., 2018; Wei & Dong, 2022; Yan, Zhao & Xing, 2019; Yenipazarli, 2021; Zennyo, 2020; Zhang, Cao & He, 2019a; Zhang, Xu, Chen, Zhao & Liu, 2023). Assuming one upstream supplier and two downstream online retailers (also called e-tailers), Abhishek et al. (2016) theoretically explore the environment in which the e-tailers should use agency selling in place of traditional reselling. Abhishek et al. (2016) first show that agency selling results in lower retail prices and hence is more efficient than reselling. They then demonstrate that e-tailers prefer agency selling when sales from the electronic channel negatively affect demand in the traditional channel, whereas e-tailers prefer reselling when sales from the electronic channel significantly increase demand in the traditional channel. Furthermore, Abhishek et al. (2016) find that as competition among retailers intensifies, e-tailers prefer agency selling, and that positive externalities arising from the sales of the target product, including additional profits from the sale of related products, also influence their choice.

Tian et al. (2018) later consider the situation where two competing upstream suppliers sell through the same e-commerce platform downstream, thereby investigating endogenous strategic contract choice by the suppliers. They find that competition among upstream suppliers eliminates double marginalization and hence critically mitigates the advantage of an agency contract for both the intermediary and the supplier using a revenue-sharing mechanism. Their results further show that when the order fulfillment cost is high, and the products offered by suppliers are similar, sup-

[4] The most recent survey work by Tahirov and Glock (2022) published in this journal provides a review of previous studies on supplier encroachment.

pliers prefer a wholesale contract mode, whereas when the order fulfillment cost is low, and the products offered by suppliers are highly differentiated, suppliers prefer an agency contract. Finally, when the order fulfillment cost is more moderate, and the supplier products are similar, a hybrid mode is preferred. While Tian et al. (2018) provide the theoretical foundation for our model, unlike their model we assume the situation where two competing suppliers can also use their own direct channels for selling.

Most recently, several game-theoretic studies have emerged that address a variety of decision-making problems, including contract choice, by a supplier using a dual-channel supply chain that consists of both a direct channel and an e-commerce platform as an intermediate channel (e.g., Chen, Zhao, Yan & Zhou, 2021; Qin, Liu & Tian, 2021; Wei, Lu & Zhao, 2020; Yan et al., 2018; Zhang & Zhang, 2020; Zhang, Li, Liu & Sethi, 2021b; Zhang, Xu, Ke & Chen, 2022; Zhen & Xu, 2022; Zhen, Xu, Li & Shi, 2022). Yan et al. (2018) explore the situation in which not only a resale channel but also a marketplace channel should be introduced in a dual-channel supply chain consisting of a single manufacturer and an e-tailer, where there is a positive spillover effect from an online channel via the e-tailer to an offline channel. They find that the willingness to adopt a marketplace channel by the manufacturer increases and that of the e-tailer decreases with the degree of spillover. Based on this finding, they conclude that firms can attain a Pareto improvement through adopting a marketplace channel when spillover is moderate. Zhang and Zhang (2020) focus on the demand information sharing strategy used by an e-commerce platform with a supplier able to use a brick-and-mortar store channel given the choice of agency selling and reselling agreements. They find that when the supplier's cost of entry into the offline channel is either significantly large or small, the e-tailer shares demand information with the supplier under agency selling but keeps it private under reselling agreement. When the entry cost is more moderate, information uncertainty is small, and the degree of channel substitution is large, the e-tailer keeps the information private under agency selling but shares information under reselling to prevent the supplier from entering the offline channel. Assuming a dual channel that consists of a traditional channel and an online promotion channel operated by an e-tailer, Chen et al. (2021) investigate how the timing of pricing in the online promotion channel impacts a supplier's choice between agency selling and reselling contracts in an uncertain environment. They show that the timing of promotion pricing has no influence on the pricing decisions of the supplier in the agency sales contract, whereas it can induce the supplier to reduce prices under the reselling contract even lower than those under the agency selling contract. Their results reveal that in an uncertain market environment, considering the timing of promotional pricing fundamentally alters the intuition that the supplier prefers agency selling, which eliminates double marginalization, over reselling.

More recently, Zhang et al. (2021b) examine the effect of service investment in a supply chain consisting of a supplier and a service platform that mediates transactions between the supplier and consumers as well as resells products. They confirm spillover effects arising from investment in retail services by the platform, which not only increases supply chain profit but also transfers a portion of the increased profits to the supplier. Service investments by the platform then do not necessarily increase its profit but do increase that of the supplier. Consequently, investments by the platform do not necessarily preclude supplier encroachment; in some cases, they induce suppliers to encroach via the platform. Zhen and Xu (2022) consider the situation where both a manufacturer and a retailer can sell through a third-party platform and examine the impact of pricing strategy on the choice of the distribution channel structure. Specifically, they model a Stackelberg game in which the manufacturer is the leader in three channel structures: the manufacturer uses the platform channel, the retailer uses the platform channel, and both the manufacturer and the retailer use the platform channel. Their results show that the choice of pricing strategy, either uniform or differentiated, plays a significant role in the channel structure choice.

2.3. Contribution to the literature

Although this review finds many existing studies employ game-theoretic approaches in this research stream, none of these investigate the endogenous contract choice between agency and wholesale contracts in platform supply chains including two essential and realistic features: namely, (i) multiple competing suppliers, and (ii) dual-channel supply chains. Specifically, among the many studies reviewed, while Yan et al. (2018); Zhang et al. (2021b), and Chen et al. (2021) develop models examining contract choice by a supplier with a dual-channel supply chain consisting of a direct channel and an indirect platform channel, they incorporate only a single supplier, not multiple competing suppliers. On the other hand, while Tian et al. (2018) and Zennyo (2020) consider the existence of multiple competing suppliers, they only address single-channel supply chains where both suppliers sell only through the platform, not dual-channel supply chains. Given the existing models, our model incorporates both multiple competing suppliers and dual-channel supply chains, both essential features of contemporary supply chains, which allows us to address the problem of endogenous contract choice in an e-commerce platform channel. This consideration is the novelty of our model developed in this paper compared with the existing literature.

3. Model

In this section, we first describe the basic setup of our model. Fig. 1 depicts the structure of the supply chains we assume, and Table 1 summarizes the notations used in the model. The assumptions underpinning our model follow those of the stylized game-theoretic model presented by Tian et al. (2018) that investigates endogenous contract choice by competing suppliers selling through a platform. While Tian et al. (2018) assume a situation where two competing suppliers sell only through one platform with adopting either an agency or reselling agreement, our model adds the assumption that each of the two suppliers also has a direct channel through which it can sell directly to end-consumers. In other words, we incorporate the assumption that the two existing suppliers can use a direct channel in addition to the indirect (i.e., platform) channel into the stylized model of Tian et al. (2018). Importantly, the availability of dual channels for suppliers, which well reflects the contemporary e-commerce environment discussed in Section 1, leads to a conclusion dramatically different from that of preceding research. Because we assume two suppliers, we index them as Supplier 1 and Supplier 2 and suppose that these suppliers produce and sell differentiated products to end-consumers. We define Brand i as the product shipped from Supplier i (henceforth, $i = 1, 2$). Each supplier produces and sells products indirectly via a platform, which we refer to as the *platform channel*, and/or directly to consumers, which we refer to as the *direct channel*. The suppliers are assumed to incur the following total production and distribution costs. That is, the marginal cost for a supplier to sell a product via the direct channel and the platform channel is denoted by c^D and c^P, respectively, following previous dual-channel models considering supplier encroachment (e.g., Arya et al., 2007; Li et al., 2014; Zhang et al., 2021b).

In this paper, we assume typical dual-channel supply chains, in which consumers perceive the two channels as substitutable. That is, whereas the products are differentiated between suppliers as brands, they are undifferentiated across the two types of channels,

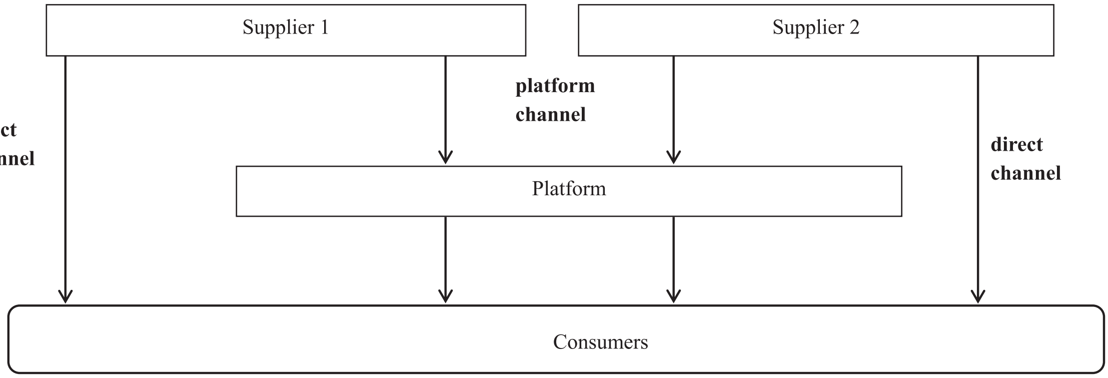

Fig. 1. Description of supply chains.
Note: An arrow indicates the direction of product flow. All the channels available to the two suppliers are depicted.

Table 1
Notation.

p_i	retail price of Brand i
p_i^P	retail price of Brand i in the platform channel
p_i^D	direct price of Brand i in the direct channel
q_i^P	demand for Brand i in the platform channel
q_i^D	demand for Brand i in the direct channel
Q_i	total demand for Brand i
w_i	wholesale price of Brand i
r	royalty rate specified in the agency selling contract ($0 < r < 1$)
c^P	marginal cost of supplying a product through the platform channel
c^D	marginal cost of supplying a product through the direct channel
c	marginal cost of supplying a product when $c^P = c^D$
a	intercept in the inverse demand function
b	slope of the inverse demand function
θ	substitutability between the two product brands ($0 < \theta < 1$)
i	subscript indicating the supplier or brand ($i = 1$ or 2)
j	subscript indicating the different supplier or brand from i
Π_i	profit of Supplier i
π	profit of the platform
S_i	distribution strategy of Supplier i
D	strategy of selling products only from the direct channel
W	strategy of selling products only from the platform channel with adopting a wholesale contract
A	strategy of selling products only from the platform channel with adopting an agency selling contract
DW	strategy of selling products from both the direct and platform channels with adopting a wholesale contract
DA	strategy of selling products from both the direct and platform channels with adopting an agency selling contract

as is the case with digital goods such as e-books, videos, and music. For example, and as discussed earlier, publishers usually supply the same quality of e-books both directly and indirectly through Amazon's platform with the use of Kindle. Similarly, videos and music are also usually supplied at the same quality across direct and indirect channels. Indeed, as long as the source file of the video or music (i.e., digital goods) itself is identical, the type of distribution channel does not influence the quality of the digital goods (e.g., picture or sound). As a result, consumers are likely to consider these digital goods substitutable between channels and thus simply purchase from the channel that offers the goods at the lowest price. Because this situation is realistic and thus important, our model focuses on the case of dual-channel supply chains with channel substitutability.[5] Therefore, consumers perceive that while products are differentiated between the two suppliers, the products of the same supplier are not differentiated between the two channels.

[5] Indeed, the model in very recent work by Hotkar and Gilbert (2021) also assumes perfect substitutability between the direct and reselling channels to reflect reality, which provides theoretical foundation for our model.

We assume that the two suppliers and one platform face the inverse demand function:[6]

$$p_i = a - b\big(Q_i + \theta Q_j\big) \qquad (i, j) = (1, 2) \text{ or } (2, 1), \tag{1}$$

where p_i denotes the price of one unit of Brand i and Q_i and Q_j represent total demand for Brands i and j, respectively. Hereafter, (i, j) denotes either (1, 2) or (2, 1) when both i and j simultaneously appear in one equation. Let q_i^P and q_i^D denote the quantities of Brand i sold via the platform and the direct channel, respectively. Because the supply and demand for Brand i must be equal, $Q_i = q_i^P + q_i^D$ holds. The parameter $\theta \in (0, 1)$ signifies the brand substitutability between Brands 1 and 2, and a and b are positive constants. Consumers perceive that the brands become differenti-

[6] This inverse demand function has the following theoretical foundation as detailed in Ingene and Parry (2004). We first assume that the representative consumer' utility function, U, is: $U = a(Q_1 + Q_2) - (b(Q_1^2 + Q_2^2) + 2b\theta Q_1 Q_2)/2$. Given the utility function, consumer surplus, S, is expressed as: $S = U - (p_1 Q_1 + p_2 Q_2) = a(Q_1 + Q_2) - (b(Q_1^2 + Q_2^2) + 2b\theta Q_1 Q_2)/2 - p_1 Q_1 - p_2 Q_2$. The consumer solves $\partial S/\partial Q_1 = \partial S/\partial Q_2 = 0$ to maximize S with respect to Q_1 and Q_2, yielding the inverse demand function of Eq. (1). Moreover, note that this inverse demand function coincides with the demand function in Tian, Vakharia, Tan, and Xu (2018, p. 1598) if we substitute the following values into exogenous parameters: $a = \theta$, $b = (1 + \gamma)/(1 + 2\gamma)$, and $\theta = \gamma/(1 + \gamma)$.

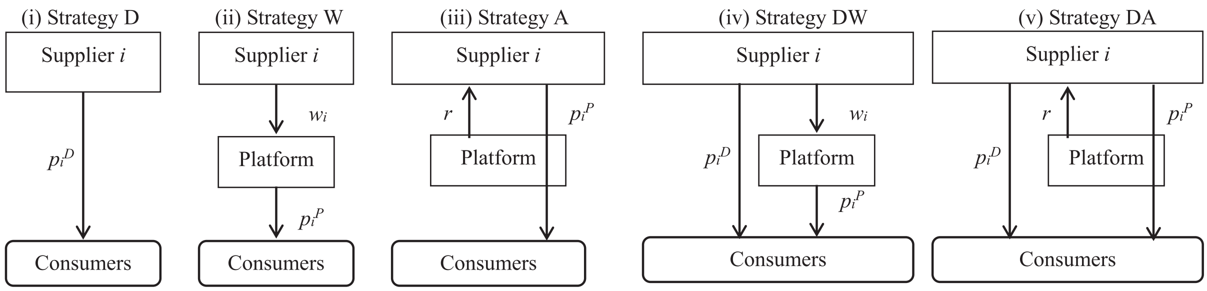

Fig. 2. Description of contract type.
Note: The five panels illustrate the five types of contracts each supplier can adopt in its dual-channel supply chain. An arrow indicates the direction in which monetary payment is requested.

ated as θ decreases. Eq. (1) indicates that the intercept a in the inverse demand function is the same for the two suppliers, and this assumption also follows the model presented by Tian et al. (2018).

Next, we consider the suppliers' decisions on channel and contract choices. First, each supplier decides whether to sell through the direct and/or the platform channel. Second, if a supplier decides to sell through the platform channel, the supplier also decides simultaneously whether to adopt an agency contract or a wholesale contract. To summarize, Supplier i chooses one of the following five distribution strategies regarding which channel and contract to use.

- Strategy D ...... The supplier sells only via the direct channel.
- Strategy W ...... The supplier sells only via the platform channel, adopting the wholesale contract.
- Strategy A ...... The supplier sells only via the platform channel, adopting the agency selling contract.
- Strategy DW ...... The supplier sells via both the direct channel and the platform channel, adopting the wholesale contract.
- Strategy DA ...... The supplier sells via both the direct channel and the platform channel, adopting the agency selling contract.

Fig. 2 illustrates how these five distribution strategies are used in a supply chain. Let S_i denote Supplier i's distribution strategy. The profit of Supplier i, Π_i, with adopting Strategies D, W, A, DW, and DA, is given as follows:

$$\Pi_i = \left(p_i^D - c^D\right)q_i^D, \qquad \text{if} \quad S_i = \mathrm{D}, \tag{2}$$

$$\Pi_i = \left(w_i - c^P\right)q_i^P, \qquad \text{if} \quad S_i = \mathrm{W}, \tag{3}$$

$$\Pi_i = (1-r)\left(p_i^P - c^P\right)q_i^P, \qquad \text{if} \quad S_i = \mathrm{A}, \tag{4}$$

$$\Pi_i = \left(p_i^D - c^D\right)q_i^D + \left(w_i - c^P\right)q_i^P, \qquad \text{if} \quad S_i = \mathrm{DW}, \tag{5}$$

$$\Pi_i = \left(p_i^D - c^D\right)q_i^D + (1-r)\left(p_i^P - c^P\right)q_i^P, \qquad \text{if} \quad S_i = \mathrm{DA}, \tag{6}$$

where w_i denotes the wholesale price of one unit of Brand i sold by Supplier i choosing the wholesale contract. p_i^D and p_i^P are the direct price in the direct channel and the retail price in the platform channel of one unit of Brand i, respectively. Eqs. (4) and (6) reflect the assumption that a supplier entering an agency selling contract pays some portion of its sales revenue to the platform as a royalty fee in accordance with the revenue-sharing rule specified by $r \in (0, 1)$. In other words, the platform receives a commission proportional to the revenue of the supplier at the rate of r. Although this rate usually varies across product categories, we assume that the suppliers in our model are charged the same royalty rate because they compete in an identical product category.[7]

Given these notations, the profit of the platform, π, under each combination of suppliers' strategies is:

$$\pi = \left(p_i^P - w_i\right)q_i^P + \left(p_j^P - w_j\right)q_j^P,$$
$$\text{if } \left(S_i, S_j\right) = (\mathrm{W}, \mathrm{W}), (\mathrm{W}, \mathrm{DW}), (\mathrm{DW}, \mathrm{W}), \text{ or } (\mathrm{DW}, \mathrm{DW}), \tag{7}$$

$$\pi = \left(p_i^P - w_i\right)q_i^P + r p_j^P q_j^P,$$
$$\text{if } \left(S_i, S_j\right) = (\mathrm{W}, \mathrm{A}), (\mathrm{W}, \mathrm{DA}), (\mathrm{DW}, \mathrm{A}), \text{ or } (\mathrm{DW}, \mathrm{DA}), \tag{8}$$

$$\pi = r\left(p_i^P q_i^P + p_j^P q_j^P\right), \qquad \text{if } \left(S_i, S_j\right) = (\mathrm{A}, \mathrm{A}) \text{ or } (\mathrm{DA}, \mathrm{A}), \tag{9}$$

$$\pi = \left(p_i^P - w_i\right)q_i^P, \qquad \text{if } \left(S_i, S_j\right) = (\mathrm{W}, \mathrm{D}) \text{ or } (\mathrm{DW}, \mathrm{D}), \tag{10}$$

$$\pi = r p_i^P q_i^P, \qquad \text{if } \left(S_i, S_j\right) = (\mathrm{A}, \mathrm{D}) \text{ or } (\mathrm{DA}, \mathrm{D}), \tag{11}$$

$$\pi = 0. \qquad \text{if } \left(S_i, S_j\right) = (\mathrm{D}, \mathrm{D}). \tag{12}$$

Using the system of functions described above, we consider the quantity- and price-setting scenarios, where the decision variable at the retail market level is quantity and price, respectively.[8] In the quantity-setting scenario, the wholesale price is determined first, and the quantity sold in the direct channel and the quantity sold in the platform channel are decided second. Meanwhile, in the price-setting scenario, the wholesale price is determined first, and the retail price in the platform channel and the direct price in the direct channel are decided second.

We now explain why we consider both quantity- and price-setting scenarios in our model. In the literature, two types of existing dual-channel supply chain models appear, where the decision variable at the retail level is either quantity or price. For instance, the dual-channel models constructed by Cai (2010), Chiang et al. (2003), and Matsui (2017) assume that the decision variable is price. By contrast, the supplier encroachment models by Arya et al. (2007), Hamamura and Zennyo (2021), Li et al. (2014), and Zhang et al. (2021b) assume that the decision variable is quantity. Thus, studies addressing the issue of supplier encroachment

[7] For instance, the royalty rate set by Amazon is 15% on books, video/DVDs, music, software, and video games; 8% on cameras, consumer electronics, cell phones, and video game consoles; and 6% on personal computers. (https://services.amazon.com/selling/pricing.htm).

[8] In economics, quantity- and price-setting scenarios are referred to as Cournot and Bertrand games, respectively, and the quantitative results of the two games are often compared as a pair.

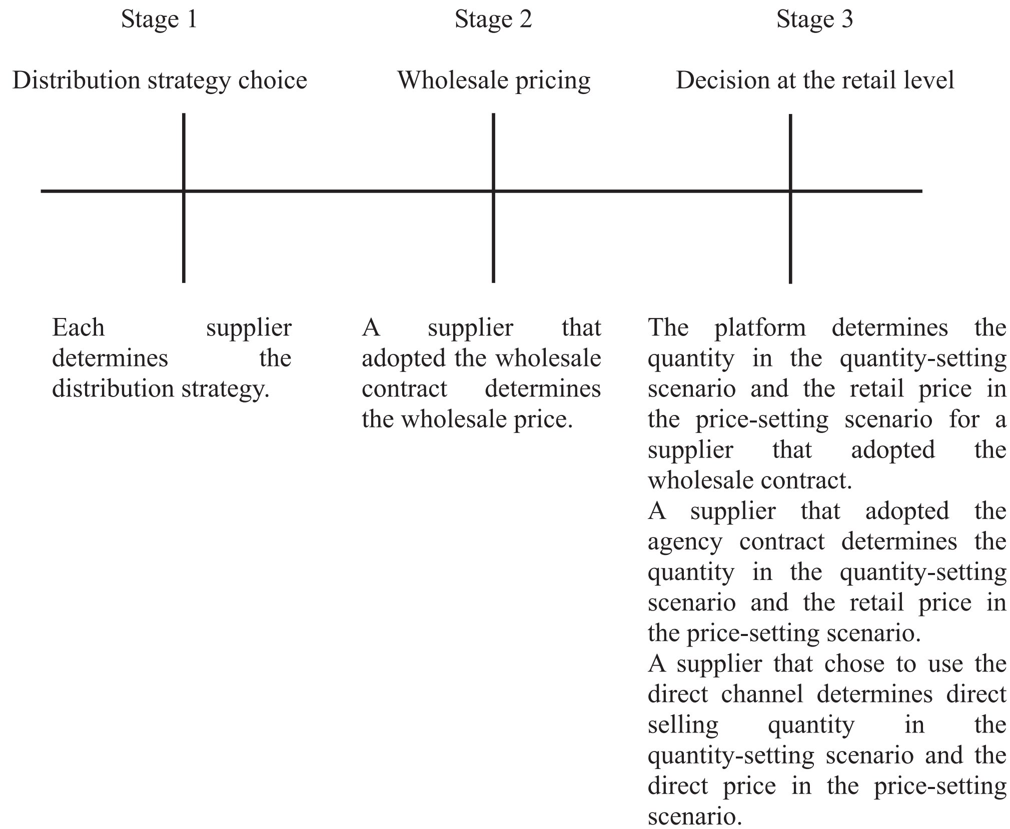

Fig. 3. Event timeline.

tend to assume quantity as the decision variable to describe the situation in which an upstream supplier takes a share in the retail market. In addition, Cabral (2000, p. 113) states that from an empirical perspective, the quantity-setting scenario is more appropriate when describing competition in industries such as automobiles and computers, where production capacity and output are more difficult to adjust. He also states that the price-setting scenario is more appropriate for describing competition in industries such as software and insurance, where production capacity and output can be adjusted more easily. Hence, Cabral's explanation suggests that the quantity-setting scenario is more appropriate for product manufacturing companies such as Procter and Gamble because their production capacity is more constrained and flexible production adjustment is more difficult. By contrast, book publishers such as HarperCollins and Penguin Books, as discussed in Section 1, are more likely to suit the price-setting scenario as books (especially e-books) are less constrained by production capacity and thus the production volume can be easily adjusted. For these theoretical and empirical reasons, we construct models for both the quantity- and price-setting scenarios, thereby relating this paper to both the academic literature and practical experience. In terms of the overall structure of the paper, the quantity-setting scenario is positioned as the main model, while the price-setting scenario is an extension of the main model. Importantly, the central result in this paper holds in both scenarios.

We assume the event timeline shown in Fig. 3 following Tian et al. (2018). First, at Stage 1, each of the two suppliers decides its distribution strategy from among Strategy D, W, A, DW, or DA. A supplier using the platform channel and choosing a wholesale contract then determines the wholesale price at Stage 2. Finally, either quantity or price competition takes place at the retail market level at Stage 3. That is, the platform determines the quantity in the quantity-setting scenario or the retail price in the price-setting scenario for a supplier adopting the wholesale contract. Moreover, in the quantity-setting scenario, a supplier adopting the agency contract determines the quantity in the platform channel, and a supplier using the direct channel determines the quantity in the direct channel. Meanwhile, in the price-setting scenario, a supplier adopting the agency contract determines the retail price, and a supplier using the direct channel determines the direct price. As our model is classified as a dynamic noncooperative game under complete information, the subgame perfect Nash equilibrium (SPNE) is adopted as the equilibrium concept. We derive the SPNE by solving the game using backward induction.

4. Results

Based on the model setup in the previous section, we calculate the profit for each supplier resulting from each combination of distribution strategies. As overviewed, because existing models on supplier encroachment tend to consider a quantity-setting scenario, we derive the results of the quantity-setting scenario as the main model in this section. We summarize the equilibrium profits of a supplier derived in each combination of the distribution strategies in the Appendix, because they are lengthy in several combinations. Using the equilibrium profits of a supplier, we henceforth concentrate on the case in which operational efficiency is equal, such that both c^D and c^P take a positive value denoted by c to draw managerial implications.[9] Comparing the equilibrium

[9] In the literature, there exist models assuming different operational efficiency and distribution costs between the direct and indirect channels (e.g., Arya, Mittendorf, & Sappington, 2007; Zhang, Li, Liu, & Sethi, 2021b). Meanwhile, there also exist substantial models assuming identical operational efficiency for the two types of

Table 2
Payoff matrix for the two suppliers in the quantity competition.

	Distribution strategy	Supplier 2 D	W	A	DW	DA
Supplier 1	D	$(\Pi^{(D,D)}, \Pi^{(D,D)})$	$(\Pi^{(D,W)}, \Pi^{(W,D)})$	$(\Pi^{(D,A)}, \Pi^{(A,D)})$	$(\Pi^{(D,DW)}, \Pi^{(DW,D)})$	$(\Pi^{(D,DA)}, \Pi^{(DA,D)})$
	W	$(\Pi^{(W,D)}, \Pi^{(D,W)})$	$(\Pi^{(W,W)}, \Pi^{(W,W)})$	$(\Pi^{(W,A)}, \Pi^{(A,W)})$	$(\Pi^{(W,DW)}, \Pi^{(DW,W)})$	$(\Pi^{(W,DA)}, \Pi^{(DA,W)})$
	A	$(\Pi^{(A,D)}, \Pi^{(D,A)})$	$(\Pi^{(A,W)}, \Pi^{(W,A)})$	$(\Pi^{(A,A)}, \Pi^{(A,A)})$	$(\Pi^{(A,DW)}, \Pi^{(DW,A)})$	$(\Pi^{(A,DA)}, \Pi^{(DA,A)})$
	DW	$(\Pi^{(DW,D)}, \Pi^{(D,DW)})$	$(\Pi^{(DW,W)}, \Pi^{(W,DW)})$	$(\Pi^{(DW,A)}, \Pi^{(A,DW)})$	$(\Pi^{(DW,DW)}, \Pi^{(DW,DW)})$	$(\Pi^{(DW,DA)}, \Pi^{(DA,DW)})$
	DA	$(\Pi^{(DA,D)}, \Pi^{(D,DA)})$	$(\Pi^{(DA,W)}, \Pi^{(W,DA)})$	$(\Pi^{(DA,A)}, \Pi^{(A,DA)})$	$(\Pi^{(DA,DW)}, \Pi^{(DW,DA)})$	$(\Pi^{(DA,DA)}, \Pi^{(DA,DA)})$

Note: The first and the second variables in parentheses in each cell denote the profits of Suppliers 1 and 2, respectively. The circled profit represents the best-response strategy of the supplier. The dotted circle represents that the distribution strategy can be the best response, depending on the level of parameter values. Refer to the Appendix for the values of the equilibrium profits in the table.

profits between the combinations of distribution strategies yields the following proposition that identifies the best-response strategy of a supplier in response to a given strategy of the rival supplier.

Proposition 1.

(i) *Strategy DW is the best-response strategy of a supplier if the rival supplier chooses Strategy D or A.*
(ii) *Strategy D is the best-response strategy when* $\theta > 0.184$, *while Strategy DW is the best-response strategy when* $\theta < 0.184$ *if the rival supplier chooses Strategy W.*
(iii) *Strategy D is the best-response strategy of a supplier if the rival supplier chooses Strategy DW.*
(iv) *Strategy W is the best-response strategy when* $\theta > 0.845$, *while Strategy DW is the best-response strategy when* $\theta < 0.845$ *if the rival supplier chooses Strategy DA.*

Proposition 1 enables us to determine the combinations of distribution strategies constituting the SPNE. To easily identify the equilibrium distribution strategy, we construct the payoff matrix resulting from the distribution strategies of the two suppliers in Table 2 using Proposition 1, circling the payoff representing the best-response strategy. Because the left and right variables in parentheses for each cell in the table represent the profits of the own and rival supplier, respectively, the cell with both payoffs in parentheses circled constitutes the SPNE. Referring to Table 2, we obtain the following theorem that identifies the distribution strategies in equilibrium.

Theorem 1. *The following two pairs of distribution strategies of the suppliers constitute the SPNE.*

$$\left(S_i, S_j\right) = (\mathrm{DW}, \mathrm{D}), (\mathrm{D}, \mathrm{DW}) \qquad (i, j) = (1, 2),\ (2, 1).$$

Theorem 1 is our central result. This states that, in equilibrium, one supplier uses only the direct channel, while the other supplier uses both the direct channel and the platform channel after adopting the wholesale contract. Recall a key assumption of our model is that the two suppliers are completely symmetric as both have the same cost and demand structures and identical dual-channel supply chains, as shown in Fig. 1. Nevertheless, Theorem 1 suggests that the distribution strategies chosen in equilibrium are asymmetric between the suppliers, which is a notable result.

Moreover, Theorem 1 indicates that neither supplier chooses Strategy A or DA in the SPNE, meaning that agency selling is never used in our model, which is also a notable result. In the literature, the stylized model of endogenous contract choice in a platform supply chain by Tian et al. (2018), which assumes symmetry between the two suppliers, also produces the result that the two suppliers adopt asymmetric distribution strategies. However, their model shows that, in equilibrium, one supplier chooses the agency contract, and the other supplier the wholesale contract. By contrast, by adding the assumption that the suppliers have their own direct sales channels, we obtain the result that neither supplier chooses the agency contract, which critically differs from the result presented by Tian et al. (2018). Stated differently, in an environment where a direct sales channel is also available to a supplier, the conclusion significantly changes so that a supplier using the platform channel should differentiate itself from the rival supplier by using the wholesale contract, not the agency contract.

5. Rationale

5.1. Rationale behind no agency selling

Given the main results of the previous section, we now elaborate on the mechanism from whence the results are derived. Initially, we provide a rationale for why Strategy A and DA involving agency selling are dominated by Strategy D representing direct selling, as shown in Proposition 1. There are the following three important assumptions that lead to this result. First, recall that we consider the distribution of digital goods throughout our model. Particularly because the type of distribution channel does not influence the quality of digital goods (e.g., picture or sound) as long as the source file of the video or music itself is identical, consumers perceive these digital goods as being undifferentiated between channels and will therefore simply purchase from the channel that offers the lowest price. Given this consumer behavior, the first important assumption of our model is that (i) consumers perceive that the direct and platform channels used by Supplier i are

channels (e.g., Hamamura & Zennyo, 2021; Modak & Kelle, 2019; Yue & Liu, 2006). Following this literature, and given the purpose of this paper, we focus on the situation where operational efficiency is equal between channels.

perfectly substitutable. Next, the second important assumption of our model is that (ii) Supplier i determines both quantity in the direct channel (q_i^D) and quantity in the platform channel (q_i^P) simultaneously if using both the direct channel and the platform channel with agency selling, which follows from the major platform model considering agency selling by Tian et al. (2018). Finally, the third assumption is that (iii) the platform extracts a royalty fee equal to the retail price per unit of product multiplied by the royalty rate r if agency selling is used, which is also assumed in Tian et al. (2018).

Based on these three essential assumptions, the mechanism that leads to the result is explained as follows. Because of the assumption of (i), the equilibrium retail price of p_i determined based on the demand function of Eq. (1) is independent of through which channel products are sold. More specifically, as long as the total supply quantity of $Q_i = q_i^P + q_i^D$ is fixed, the retail price p_i does not change when only either q_i^P or q_i^D changes, because of channel substitutability for consumers. Moreover, the assumption of (ii) indicates that if a supplier sells through both direct and platform channels with agency selling, there arises no strategic interaction between the decision variables of q_i^P and q_i^D because the same Supplier i determines both q_i^P and q_i^D simultaneously while the platform makes no decision on quantity. Furthermore, the assumption of (iii) indicates that the margin per unit of the product for Supplier i in the direct channel is $p_i - c$ and the margin in the platform channel with agency selling is $(1-r)(p_i - c)$; namely, the marginal profit for Supplier i is always greater when selling via the direct channel (i.e., $p_i - c$) than when selling via the platform channel with agency selling (i.e., $(1-r)(p_i - c)$). Because of the three assumptions, if the supplier sells one unit of the product, the supplier can earn a higher profit margin by selling that one unit through a direct channel instead of through the platform with agency selling. As a result, it is always more profitable for the supplier to sell all quantity through the direct channel than through the platform channel with agency selling, with which the platform takes a portion of the marginal profit per unit product as a royalty fee. For the above reason, agency selling (Strategy A or DA) is strictly dominated by direct selling (strategy D) and hence is not chosen by the suppliers.

5.2. Rationale behind asymmetric equilibrium

Next, we provide the rationale why asymmetric distribution strategies can occur in equilibrium, even though the two competing suppliers assumed in the model are symmetric and the supply chain structure is identical. There are two essential assumptions that lead to this result: (i) the demand function is assumed as Eq. (1), and (ii) the supplier's wholesale price is determined at Stage 2, and suppliers' quantities in the respective channels are determined at Stage 3. To understand the mechanism for how the two assumptions lead to the asymmetric distribution strategies occurring in equilibrium, the concept of *strategic complements*, which has been originally proposed in the economics and game theory literature, is the key factor. Therefore, we first explain this concept in detail below.

First, Bulow, Geanakoplos and Klemperer (1985) originally define that strategic complements mean that the decision variables determined by players in a noncooperative game have the following characteristics. That is, if one player increases its decision variable, another player also increases its decision variable in response.[10] Stated differently, a positive correlation arises between the decision variables determined by players. After Bulow et al. (1985), the existing game-theoretic literature shows that the prices or margins determined by competing firms are strategic complements (e.g., Gal-Or, 1985). In our model, the assumptions of (i) and (ii) indicate that once a supplier determines quantity in Stage 3, the margin that the supplier earns is correspondingly determined based on the demand function of Eq. (1). Moreover, in Stage 2, a supplier determines the wholesale price, which is the margin in the platform channel. Therefore, the decision variables in our model are strategic complements.

Next, Gal-Or (1985) theoretically shows that if the decision variables of players in a noncooperative game are strategic complements, the *second-mover advantage* arises. That is, the player that sets its decision variable in a later move obtains a higher payoff than the player that sets its decision variable in an earlier move. This advantage of a later decision is called the second-mover advantage. To obtain the second-mover advantage, each player has an incentive to set its decision variable at a later period. In the context of our model, given the incentives of suppliers to obtain this second-mover advantage resulting from the strategic complements by delaying their decisions, simultaneous decisions become unstable and infeasible. As a result, suppliers prefer sequential decisions and hence determine their decision variables sequentially, not simultaneously.

Consistent with this logic, Hamilton and Slutsky (1990, p. 36, Theorem III) prove that players with a second-mover advantage have the incentive to make their decisions sequentially and therefore stagger the timing of their decisions. Moreover, van Damme and Hurkens (2004, p. 405) demonstrate that when two players set their decision variables sequentially, both the first and second movers achieve higher payoffs than when the players set decision variables simultaneously, irrespective of which player is the first mover. The application of the insights gained in the previous game-theoretic studies to our model suggests that the two suppliers have the incentive to stagger their decisions with respect to each other because the decision variables are strategic complements.

Meanwhile, the assumption of (ii) means that if the distribution strategies chosen by the two suppliers are asymmetric, the timing for them to obtain their respective margins is sequential not simultaneous. This is because the supplier choosing Strategy D determines its quantity (and the corresponding margin) in the direct channel at Stage 3, while the other supplier choosing Strategy DW determines its wholesale price (margin) in the platform channel at Stage 2, as shown by the event timeline in Fig. 3; namely, the timing for suppliers to make their respective decisions differs between Strategies D and DW. This also means that in our model, by choosing the asymmetric channel strategies of D and DW, the two suppliers can sequentially determine their respective prices and margins at different timings, which enables them to achieve higher profits given the strategic complementarity of their decision variables. That is, the insights gained in the game theory literature indicate that in the context of our model, the suppliers have the incentive to choose the asymmetric distribution strategies of (D, DW) or (DW, D), because these strategies enable them to make sequential but not simultaneous decisions. As a result, the suppliers choose asymmetric distribution strategies to obtain margins at different times in equilibrium. This is the rationale for why asymmetric not symmetric distribution strategies can occur in the SPNE.[11]

[10] The antonym of strategic complements is *strategic substitutes*, which means that if one player increases its decision variable, another player decreases its decision variable. Therefore, the decision variables characterized by strategic substitutes have a negative correlation between players, contrary to strategic complements.

[11] The definition of the SPNE, which we use as the equilibrium concept throughout this paper, is that all players choose their respective best-response strategies in all the stages constituting a dynamic game. Therefore, the state where both suppliers choose asymmetric distribution strategies as their respective best-response strategies corresponds to the SPNE in our model.

Table 3
Payoff matrix for the two suppliers in the price competition.

	Distribution strategy	Supplier 2: D	W	A	DW	DA
Supplier 1	D	$(\Pi^{(D, D)}, \Pi^{(D, D)})$	$(\Pi^{(D, W)}, \Pi^{(W, D)})$	$(\Pi^{(D, A)}, \Pi^{(A, D)})$	$(\Pi^{(D, DW)}, \Pi^{(DW, D)})$	$(\Pi^{(D, DA)}, \Pi^{(DA, D)})$
	W	$(\Pi^{(W, D)}, \Pi^{(D, W)})$	$(\Pi^{(W, W)}, \Pi^{(W, W)})$	$(\Pi^{(W, A)}, \Pi^{(A, W)})$	$(\Pi^{(W, DW)}, \Pi^{(DW, W)})$	$(\Pi^{(W, DA)}, \Pi^{(DA, W)})$
	A	$(\Pi^{(A, D)}, \Pi^{(D, A)})$	$(\Pi^{(A, W)}, \Pi^{(W, A)})$	$(\Pi^{(A, A)}, \Pi^{(A, A)})$	$(\Pi^{(A, DW)}, \Pi^{(DW, A)})$	$(\Pi^{(A, DA)}, \Pi^{(DA, A)})$
	DW	$(\Pi^{(DW, D)}, \Pi^{(D, DW)})$	$(\Pi^{(DW, W)}, \Pi^{(W, DW)})$	$(\Pi^{(DW, A)}, \Pi^{(A, DW)})$	$(\Pi^{(DW, DW)}, \Pi^{(DW, DW)})$	$(\Pi^{(DW, DA)}, \Pi^{(DA, DW)})$
	DA	$(\Pi^{(DA, D)}, \Pi^{(D, DA)})$	$(\Pi^{(DA, W)}, \Pi^{(W, DA)})$	$(\Pi^{(DA, A)}, \Pi^{(A, DA)})$	$(\Pi^{(DA, DW)}, \Pi^{(DW, DA)})$	$(\Pi^{(DA, DA)}, \Pi^{(DA, DA)})$

Note: The first and the second variables in parentheses in each cell denote the profits of Suppliers 1 and 2, respectively. The circled profit represents the best-response strategy of the supplier. The dotted circle represents that the distribution strategy can be the best response, depending on the level of parameter values. Refer to the Appendix for the values of the equilibrium profits in the table.

6. Managerial implications

As we have already derived the main results up to the previous section, we conduct further analysis to obtain managerial implications that can be used as decision guidelines for suppliers. While the central result of Theorem 1 shows that two asymmetric equilibria of strategies (D, DW) and (DW, D) arise, the theorem does not identify which of the two strategies (DW or D) is more advantageous for a supplier, meaning that the theorem does not provide a specific guideline for supplier decision-making. Therefore, it is worthwhile to examine which distribution strategy (DW or D) included in the equilibrium asymmetric distribution strategies is more profitable and hence should be chosen by a supplier. Using the equilibrium profits shown in the Appendix, we have the following theorem.

Theorem 2. *In the SPNE Strategies (D, DW) and (DW, D), the profit of the supplier choosing Strategy DW is greater than the profit of the supplier choosing Strategy D.*

Theorem 2 shows that it is more profitable for a supplier to choose Strategy DW over D in the asymmetric distribution strategy equilibrium. If the two suppliers decide their distribution strategies at the same time at Stage 1 as assumed in our original model, the result of Theorem 2 cannot be used as decision support because multiple equilibria occur as shown in Theorem 1. However, if the suppliers can determine their distribution strategies sequentially not simultaneously, such that one supplier determines the strategy first and the other determines the strategy second, the result of Theorem 2 provides the following practical implication as a guideline for decision-making by suppliers. More specifically, by slightly altering the assumption on the event at Stage 1 in Fig. 3, we consider the situation in which two suppliers sequentially, not simultaneously, determine their respective distribution strategies, in which one supplier decides its distribution strategy first and the other decides its distribution strategy later. This is also a realistic situation, because there is often the case that one supplier enters a specific digital goods market first and subsequently another supplier enters the same market. If the two suppliers encounter such a situation and thus need to sequentially choose their respective distribution strategies at Stage 1, we additionally obtain the following observation.

Observation 1. *If the two suppliers can choose their respective distribution strategies sequentially, the state in which the first-moving supplier chooses Strategy DW and the second-moving supplier chooses Strategy D is the SPNE.*

Observation 1 provides the important decision guideline that the supplier choosing its distribution strategy first and the supplier choosing its distribution strategy second should choose Strategies DW and D, respectively. Because these strategies are the best response strategies of the respective suppliers, the strategies constitute the SPNE. Therefore, Theorem 2 along with Observation 1 are also major findings because they can be used as a managerial guideline for the practical decision on which distribution strategy (DW or D) the first- and second-moving suppliers entering a specific digital goods market should respectively choose.

7. Extension: price competition scenario

Until now, we considered the quantity competition scenario at the retail market level as our main model. In this section, we extend the model by considering a price competition scenario as an extension and summarize the results. Here, recall that Tian et al. (2018), from which our model has borrowed major assumptions, assumed a price competition scenario at the retail market level. For this reason, the price competition scenario is also important because the scenario is more consistent with the model setting in Tian et al. (2018).

As in the main model, we focus on the situation where both c^D and c^P take a positive value of c to directly obtain managerial implications. Like Section 4, we summarize the equilibrium profits of a supplier for each combination of distribution strategies in the Appendix because they are lengthy in several combinations. Comparing the equilibrium profits in the Appendix gives the following proposition that identifies the best-response distribution strategy of a supplier.[12]

[12] Because we take the approach of constructing an economic model to describe price competition, the equilibrium economic profit is obtained as zero in several

Proposition 2.

(i) *Strategy DW is the best-response strategy of a supplier if the rival supplier chooses Strategy D or A.*
(ii) *Strategy D is the best-response strategy when* $\theta < 0.462$, *while Strategy DW is the best-response strategy when* $\theta > 0.462$ *if the rival supplier chooses Strategy W.*
(iii) *Strategy D is the best-response strategy of a supplier if the rival supplier chooses Strategy DW.*
(iv) *Strategy D and Strategy DW are the best-response strategies of a supplier if the rival supplier chooses Strategy DA.*

Like Proposition 1 listing the best-response strategies in the quantity-setting scenario, Proposition 2 enables us to determine the combination of distribution strategies that constitute the SPNE in the price-setting scenario. Table 3 shows the payoff matrix for the price-setting scenario, in which the optimal response strategies are circled. Observe that the optimal response strategies in the price-setting scenario shown in Table 3 differ slightly from those in the quantity-setting scenario shown in Table 2. Referring to Table 3, we identify the distribution strategies in equilibrium, as per the following theorem.

Theorem 3. *The following two pairs of distribution strategies for the suppliers constitute the SPNE.*

$$\left(S_i, S_j\right) = (\mathrm{DW}, \mathrm{D}), (\mathrm{D}, \mathrm{DW}) \qquad (i, j) = (1, 2),\ (2, 1).$$

Like Theorem 1 for the quantity-setting scenario considered in the main model, Theorem 3 states that in the price-setting scenario, one supplier uses only the direct channel, while the other supplier uses both the direct channel and the platform channel by adopting the wholesale contract in equilibrium. This means that even though the suppliers' best-response strategies in the price-setting scenario differ slightly from those in the quantity-setting scenario, the SPNE itself is the same for both scenarios; namely, Theorem 3 proves that in price competition, as in quantity competition, asymmetric distribution strategies occur in equilibrium, which reinforces the robustness of the central result in this paper. Moreover, like Theorem 1, Theorem 3 shows that neither supplier chooses Strategy A or DA. Consequently, Theorems 1 and 3 suggest that the conventional result of previous studies is reversed, regardless of the mode of competition.

8. Conclusions

Currently, many manufacturing companies are not only utilizing rapidly growing e-commerce platforms as important sales channels, but also they are opening their direct channels and selling directly to end-consumers using advanced IT technologies. Given that many suppliers are now using such dual-channel supply chains, this paper investigates whether a wholesale contract or an agency contract offered by an e-commerce platform is chosen by competing suppliers, in the situation where products are undifferentiated between the direct channel and the indirect platform channel, as is typically the case of digital goods.

The key result from our model is that if there is no differentiation between channels such that consumers perceive the direct and platform channels as substitutable, then neither of the competing suppliers chooses the agency contract. This result holds regardless of how much the platform increases the suppliers' share of profits by lowering its royalty rate and thereby making the agency contract more profitable to them. This yields the managerial implication that a supplier selling products of the same quality across channels, such as digital goods in a competitive environment, should adopt a regular wholesale contract, not an agency contract when selling through a platform. Intuitively, if a supplier adopts a wholesale contract, this appears undesirable for the supplier because the problem of double marginalization is likely to occur. However, our results lie contrary to this intuition. Moreover, it is also a notable result that even though suppliers are assumed to be symmetric regarding demand and cost conditions in our model, their distribution strategies emerging in equilibrium are asymmetric. These asymmetric distribution channel strategies allow a supplier to differentiate itself from the rival supplier if the former sells through the platform. Because we have obtained all our main results and implications clearly in analytical form solely by solving our model, we do not conduct numerical analysis in this paper.

It is also noteworthy that our result reverses the conventional insight from existing models that at least one of the competing suppliers always chooses the agency contract when the suppliers lack their own direct sales channels (e.g., Tian et al., 2018; Zennyo, 2020). Specifically, existing studies show that, in equilibrium, two competing suppliers selling via a platform choose asymmetric contracts of the agency and wholesale contracts. While previous models assume the existence of two symmetric competing suppliers and one platform, they also assume that each supplier can sell only through the platform as a single-channel supply chain. Our model adds the realistic assumption that each supplier can sell the same quality product through its own direct sales channel as well as through the platform. To summarize, by simply changing the assumption of a single-channel supply chain to a dual-channel supply chain, we show that the agency contract is never chosen, providing a novel managerial insight.

We also need to reflect on an important assumption in the model that the platform channel provides the same quality product to consumers as the direct channel, as also assumed in Hotkar and Gilbert (2021). Stated differently, our equilibrium result arises when typical Cournot or Bertrand competition takes place between the direct and indirect platform channels. Indeed, in the case of digital goods such as e-books, videos, and music, the same picture and sound quality are usually offered in both the direct and indirect channels. Accordingly, consumers are likely to perceive such digital goods as being undifferentiated across channels and will therefore simply purchase from the channel that offers the lowest price. Hence, our results provide useful practical implications for real-world suppliers of digital goods like publishers and music labels considering whether to open their own channels. Indeed, as discussed in the introduction, music companies still tend not to adopt agency contracts. Publishers such as Penguin Books and HarperCollins in the US are now selling the same quality of e-books not only through Amazon, but also through their own direct channels using the technology services provided by Shopify. Hachette Book Group is another of the largest US publishers currently selling books through a dual-channel supply chain. The intense negotiations between Hachette and Amazon on the terms of trade for books over the seven months from April to November 2014 are well known and often cited as a case where a supplier won some concessions from a giant platform (Sternad, 2019). Because suppliers using platform channels have increasingly become able to open direct channels with low-cost technologies, how to utilize e-commerce platforms effectively for indirect sales is now an urgent issue for such suppliers. The results of this study provide useful managerial guidelines for general suppliers that have

cases. Here, we must note that even if the economic profit of a firm is zero in equilibrium, the firm has an incentive to operate because its accounting profit can be calculated as positive. This is because economic profit is defined as the excess profit that remains after subtracting dividend payments to shareholders from accounting profit. Indeed, it is common in economic models for the economic profit of a firm to be zero in the long-run equilibrium. For a more detailed explanation see, for example, Besanko, Dranove, and Shanley (2017, p. 28), a leading text on how economic models can be applied to practical strategic management.

dual-channel supply chains concerning which sales channels and contracts they should choose if they aim to manage platform supply chains in addition to direct sales successfully.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ejor.2023.06.030.

Appendix

In the proofs shown in this Appendix, we use the four inverse demand functions below obtained by inserting $Q_i = q_i^P + q_i^D$ $(i = 1, 2)$ into Eq. (1). In addition, for convenience, we distinguish the price on the left-hand side by attaching the superscripts P and D. That is, p_i^P is the retail price of Brand i determined in the platform channel and p_i^D is the direct price of the brand in the direct channel.

$$\begin{cases} p_1^P = a - b\left(q_1^P + q_1^D + \theta\left(q_2^P + q_2^D\right)\right), & (A1) \\ p_1^D = a - b\left(q_1^D + q_1^P + \theta\left(q_2^D + q_2^P\right)\right), & (A2) \\ p_2^P = a - b\left(q_2^P + q_2^D + \theta\left(q_1^P + q_1^D\right)\right), & (A3) \\ p_2^D = a - b\left(q_2^D + q_2^P + \theta\left(q_1^D + q_1^P\right)\right), & (A4) \end{cases}$$

For simplicity, we refer to p_i^D and p_i^P as the *direct price* and the *retail price* of Brand i, respectively, throughout the appendix.

Equilibrium profit of a supplier in each distribution strategy combination under quantity competition in Section 4 and its derivation process

The equilibrium profits of a supplier in each distribution strategy combination in quantity competition are as follows. The first notation in the superscript parentheses attached to Π signifies the strategy chosen by the own supplier, and the second notation signifies the strategy chosen by the rival supplier.

$$\Pi^{(\mathrm{D,D})} = \frac{\left(a - c^D\right)^2}{b(2+\theta)^2}$$

$$\Pi^{(\mathrm{D,W})} = \frac{\left(\left(8-\theta^2\right)\left(a - c^D\right) - 2\theta\left(a - c^P\right)\right)^2}{16b\left(4-\theta^2\right)^2}$$

$$\Pi^{(\mathrm{D,A})} = \frac{\left(2\left(a - c^D\right) - \theta\left(a - c^P\right)\right)^2}{b\left(4-\theta^2\right)^2}$$

$$\Pi^{(\mathrm{D,DW})} = \frac{\left(\left(20 - 6\theta - 5\theta^2 + \theta^3\right)\left(a - c^D\right) - \theta\left(4-\theta^2\right)\left(a - c^P\right)\right)^2}{4b\left(20 - 10\theta^2 + \theta^4\right)^2}$$

$$\Pi^{(\mathrm{D,DA})} = \frac{\left((r-\theta)\left(a - c^D\right) + (1-r)\theta\left(a - c^P\right)\right)^2}{br^2\left(2-\theta^2\right)^2}$$

$$\Pi^{(\mathrm{W,D})} = \frac{\left(2\left(a - c^P\right) - \theta\left(a - c^D\right)\right)^2}{8b\left(4-\theta^2\right)}$$

$$\Pi^{(\mathrm{W,W})} = \frac{(1-\theta)\left(a - c^P\right)^2}{2b(2-\theta)^2(1+\theta)}$$

$$\Pi^{(\mathrm{W,A})} = \frac{(2-\theta-r\theta)^2\left(a - c^P\right)^2}{8\left(4-(1+r)\theta^2\right)}$$

$$\Pi^{(\mathrm{W,DW})} = \frac{(1-\theta)\left(2\theta(1+\theta)\left(a - c^D\right) + \left(20+8\theta-3\theta^2\right)\left(a - c^P\right)\right)^2}{2b(1+\theta)\left(40-13\theta^2\right)^2}$$

$$\Pi^{(\mathrm{W,DA})} = \frac{\left((r+3\theta(1-r))\left(a - c^P\right) - (3-r)\theta\left(a - c^D\right)\right)^2}{8br^2\left(1-\theta^2\right)}$$

$$\Pi^{(\mathrm{A,D})} = \frac{(1-r)\left(2\left(a - c^P\right) - \theta\left(a - c^D\right)\right)^2}{b\left(4-\theta^2\right)^2}$$

$$\Pi^{(\mathrm{A,W})} = \frac{(1-r)\left(8-2\theta-(1+r)\theta^2\right)\left(a - c^P\right)^2}{16\left(4-(1+r)\theta^2\right)^2}$$

$$\Pi^{(\mathrm{A,A})} = \frac{(1-r)\left(a - c^P\right)^2}{b(2+\theta)^2}$$

$$\Pi^{(\mathrm{A,DW})} = \frac{(1-r)\left(\left(20-4\theta-(5+2r)\theta^2+\theta^3\right)\left(a - c^P\right) - \theta\left(6-(1+r)\theta^2\right)\left(a - c^D\right)\right)^2}{4b\left(20-2(5+2r)\theta^2+(1+r)\theta^4\right)^2}$$

$$\Pi^{(\mathrm{A,DA})} = \frac{(1-r)\left(((1-\theta)r+\theta)\left(a - c^P\right) - \theta\left(a - c^D\right)\right)^2}{br^2\left(2-\theta^2\right)^2}$$

$$\begin{aligned}\Pi^{(\mathrm{DW,D})} = \Big(&(2-\theta)(2+\theta)^2\left(a - c^P\right)^2 \\ &+ \left(18-\theta-4\theta^2-\theta^3\right)\left(a - c^D\right)^2 \\ &- 2\left(8+4\theta-3\theta^2-\theta^3\right)\left(a - c^D\right)\left(a - c^P\right)\Big) \\ &\times (2-\theta)/\left(4b\left(20-10\theta^2+\theta^4\right)\right)\end{aligned}$$

$$\begin{aligned}\Pi^{(\mathrm{DW,W})} = \Big(&8(1+\theta)\left(180-118\theta^2+19\theta^4\right)\left(a - c^D\right)^2 \\ &+ \left(640+320\theta-454\theta^2-282\theta^3+57\theta^4+43\theta^5\right)\left(a - c^P\right)^2 \\ &- 8(1+\theta)\left(160+10\theta-106\theta^2-\theta^3+18\theta^4\right)\left(a - c^D\right) \\ &\times\left(a - c^P\right)\Big)/\left(2b(1+\theta)\left(40-13\theta^2\right)^2\right)\end{aligned}$$

$$\begin{aligned}\Pi^{(\mathrm{DW,A})} = \Big(&\left(a - c^D\right)^2\left(6-(1+r)\theta^2\right)^2 - 2(16+(10-8r)\theta \\ &- 2(5+2r)\theta^2 - \left(1-r-2r^2\right)\theta^3 + (1+r)\theta^4) \\ &\times\left(a - c^D\right)\left(a - c^P\right) \\ &+ \left(16-3\theta^2+4r^2\theta^2-2\theta^3+\theta^4-4r\theta\left(4-\theta^2\right)\right)\left(a - c^P\right)^2\Big) \\ &/\left(4b\left(20-2(5+2r)\theta^2+(1+r)\theta^4\right)\right)\end{aligned}$$

$$\begin{aligned}\Pi^{(\mathrm{DW,DW})} = \ &(2(5-\theta)^2\left(3-\theta^2\right)\left(6-3\theta^2-\theta^3\right)\left(a - c^P\right)^2 \\ &+ (1+\theta)\left(405-360\theta-99\theta^2+120\theta^3+15\theta^4\right.\end{aligned}$$

$$-16\theta^5-\theta^6\big)\big(a-c^D\big)^2 -2(1+\theta)\big(180-135\theta-78\theta^2+54\theta^3+20\theta^4-7\theta^5-2\theta^6\big) \times\big(a-c^D\big)\big(a-c^P\big)\big)/\big(b(1+\theta)\big(30-3\theta-11\theta^2 -\theta^3+\theta^4\big)^2\big)$$

$$\Pi^{(DW,DA)}=\Big(\big(\theta^2\big(21-6\theta^2+\theta^4\big)+2r\theta\big(3-8\theta-9\theta^2+5\theta^3+2\theta^4-\theta^5\big) +r^2\big(9-8\theta-8\theta^2+14\theta^3-4\theta^5+\theta^6\big)\big)\big(a-c^D\big)^2 -2\big(\theta^2\big(21-6\theta^2+\theta^4\big)+r\theta\big(11-29\theta-14\theta^2+11\theta^3 +3\theta^4-2\theta^5\big)+r^2\big(4-7\theta+\theta^2+13\theta^3-3\theta^4-3\theta^5+\theta^6\big)\big) \times\big(a-c^D\big)\big(a-c^P\big) +\big(\theta^2\big(21-6\theta^2+\theta^4\big)+2r\theta\big(8-21\theta-5\theta^2+6\theta^3+\theta^4-\theta^5\big) +r^2\big(4-16\theta+17\theta^2+10\theta^3-5\theta^4-2\theta^5+\theta^6\big)\big)\big(a-c^P\big)^2\Big) /\big(2br^2\big(1-\theta^2\big)\big(5-2\theta^2\big)\big)$$

$$\Pi^{(DA,D)}=\frac{(1-r)\big(c^D-c^P\big)\big((2-r\theta)\big(a-c^D\big)-2(1-r)\big(a-c^P\big)\big)}{br^2\big(2-\theta^2\big)}$$

$$\Pi^{(DA,W)}=\frac{(1-r)\big(c^D-c^P\big)\big(\big(4-(1+r)\theta^2\big)\big(a-c^D\big)-\big(\big(4-\theta^2\big)(1-r)+r\theta\big)\big(a-c^P\big)\big)}{4br^2\big(1-\theta^2\big)}$$

$$\Pi^{(DA,A)}=\frac{(1-r)\big(c^D-c^P\big)\big(2\big(a-c^D\big)-(2-(2-\theta)r)\big(a-c^P\big)\big)}{br^2\big(2-\theta^2\big)}$$

$$\Pi^{(DA,DW)}=\big(\big(a-c^D\big)\big(10-5\theta^2-\theta^4-r\theta\big(3+2\theta-2\theta^2-\theta^3\big)\big) -\big(10-5\theta^2-\theta^4-r\big(10-2\theta-5\theta^2+\theta^3-\theta^4\big)\big) \times\big(a-c^P\big)\big)(1-r)\big(c^D-c^P\big)/\big(2br^2\big(1-\theta^2\big)\big(5-2\theta^2\big)\big)$$

$$\Pi^{(DA,DA)}=\frac{(1-r)\big(c^D-c^P\big)\big(ra-c^D+(1-r)c^P\big)}{b(1+\theta)r^2}$$

Below, we summarize how to derive the equilibrium profits resulting from each combination of distribution strategies. The objective functions (i.e., profits) are sequentially maximized with the use of backward induction to obtain the SPNE for each of the distribution strategies. In this summary, as an example, we show the solving process in the case of (DW, A). We first substitute $q_2^D=0$ into Eqs. (A1)–(A4). Then, substituting the inverse demand functions into the suppliers' profits of Π_1 and Π_2, we express the profits as the functions of q_1^D, q_1^P, q_2^P, and w_1. At Stage 3, Suppliers 1 and 2 and the platform maximize their respective profits by solving $\partial\Pi_1/\partial q_1^D=\partial\Pi_2/\partial q_2^P=\partial\pi/\partial q_1^P=0$. After substituting q_1^D, q_1^P, and q_2^P derived at Stage 3 and the inverse demand functions into Π_1 and Π_2, we solve $\partial\Pi_1/\partial w_1=0$ at Stage 2 to yield w_1. Finally, inserting q_1^D, q_1^P, q_2^P, and w_1 derived above into Π_1 and Π_2 yields the equilibrium profits. Similarly, in each case of distribution strategies other than (DW, A), we can obtain equilibrium profits by sequentially maximizing the objective functions of the suppliers' and platform's profits. For further details, see the detailed derivation process of equilibrium profit in the online Supplementary Material file. □

Proof of Proposition 1.

After evaluating the profits by the combinations of strategies summarized above at $c^D=c^P=c$, we calculate the difference in profits between the distribution strategies. Using $0<\theta<1$ and $0<r<1$, each sign of the difference in profits resulting from different combinations of the distribution strategies can be determined as positive or negative, as shown in the series of inequalities below. In the following, we prove Cases (i), (ii), (iii), and (iv) in this proposition in turn.

Proof of (i): Strategy DW is the best-response strategy of a supplier when the rival supplier chooses Strategy D or A.

The eight inequalities given as follows with the use of the profits shown above prove (i) in this proposition.

$$\Pi^{(DW,D)}-\Pi^{(D,D)}=\theta^4(a-c)^2/\big(4b(2+\theta)^2\big(20-10\theta^2+\theta^4\big)\big)>0$$

$$\Pi^{(DW,D)}-\Pi^{(W,D)}=(2-\theta)\big(20-\theta^4\big)(a-c)^2/\big(8b(2+\theta) \times\big(20-10\theta^2+\theta^4\big)\big)>0$$

$$\Pi^{(DW,D)}-\Pi^{(A,D)}=\big(\theta^4+4r\big(20-10\theta^2+\theta^4\big)\big)(a-c)^2 /\big(4b(2+\theta)^2\big(20-10\theta^2+\theta^4\big)\big)>0$$

$$\Pi^{(DW,D)}-\Pi^{(DA,D)}=5(2-\theta)^2(a-c)^2/\big(4b\big(20-10\theta^2+\theta^4\big)\big)>0$$

$$\Pi^{(DW,A)}-\Pi^{(D,A)}=\theta^2\big(r\big(4-\theta^2\big)-\theta\big)^2(a-c)^2 /\big(4b(2+\theta)^2\big(20-2(5+2r)\theta^2+(1+r)\theta^4\big)\big) >0$$

$$\Pi^{(DW,A)}-\Pi^{(W,A)}=\big(80(1-(1-r)\theta)+4\big(5-24r+3r^2\big)\theta^2 -48r^2\theta^3-\big(4-18r-26r^2+4r^3\big)\theta^4 +4(1+r)\big(1+2r^2\big)\theta^5-\big(1+3r+5r^2+3r^3\big)\theta^6\big) \times(a-c)^2/\big(8b\big(4-(1+r)\theta^2\big) \times\big(20-2(5+2r)\theta^2+(1+r)\theta^4\big)\big)>0$$

Although it seems difficult to determine that the sign of $\Pi^{(DW,A)}-\Pi^{(W,A)}$ is positive, it can be determined by taking the following steps. First, because $\Pi^{(DW,A)}-\Pi^{(W,A)}$ is a cubic function with respect to r, the solution of r from $\Pi^{(DW,A)}-\Pi^{(W,A)}=0$ is obtained analytically as functions of θ. These values of r, expressed as functions of θ, do not fall into the range of 0 and 1 in the interval of $0<\theta<1$. This means that the sign of $\Pi^{(DW,A)}-\Pi^{(W,A)}$ is the same within the region of $0<r<1$ and $0<\theta<1$ regardless of the values of the parameters θ and r. Substituting any combination of θ satisfying $0<\theta<1$ and r satisfying $0<r<1$ into $\Pi^{(DW,A)}-\Pi^{(W,A)}$ gives a positive value, which determines $\Pi^{(DW,A)}-\Pi^{(W,A)}$ as positive.

$$\Pi^{(DW,A)}-\Pi^{(A,A)}=\frac{\big(\theta^4-r^2\theta^4\big(4-\theta^2\big)+2r\big(40-20\theta^2-4\theta^3+2\theta^4+\theta^5\big)\big)(a-c)^2}{4b(2+\theta)^2\big(20-2(5+2r)\theta^2+(1+r)\theta^4\big)}>0.$$

The sign of $\Pi^{(DW,A)}-\Pi^{(A,A)}$ can be determined by taking the following steps. First, because $\Pi^{(DW,A)}-\Pi^{(A,A)}$ is a quadratic function with respect to r, the solutions of r from $\Pi^{(DW,A)}-\Pi^{(A,A)}=0$ are obtained analytically as functions of θ. These values of r expressed as the functions of θ do not fall into the range of 0 and 1 in the interval of $0<\theta<1$. This means that the sign of $\Pi^{(DW,A)}-\Pi^{(A,A)}$ is the same within the region of $0<r<1$ and $0<\theta<1$ regardless of the values of the parameters θ and r. Substituting any combination of θ satisfying $0<\theta<1$ and r satisfying

$0<r<1$ into $\Pi^{(DW,A)}-\Pi^{(A,A)}$ gives a positive value, which determines $\Pi^{(DW,A)}-\Pi^{(A,A)}$ as positive.

$$\Pi^{(DW,A)}-\Pi^{(DA,A)}=(2-\theta)\left(10-5\theta-2(1-r)r\theta^2-r^2\theta^3\right)\times(a-c)^2/\left(4b\left(20-2(5+2r)\theta^2+(1+r)\theta^4\right)\right)>0$$

Proof of (ii): When the other rival supplier chooses Strategy W, Strategy D is the best-response strategy when $\theta>0.184$, while Strategy DW is the best-response strategy when $\theta<0.184$.

The four differences in profits between suppliers' distribution strategies given as follows prove (ii) in this proposition.

$$\Pi^{(DW,W)}-\Pi^{(D,W)}=\theta^2\left(1280-5440\theta-7888\theta^2-2008\theta^3+695\theta^4+239\theta^5\right)(a-c)^2/\left(16b(2+\theta)^2(1+\theta)\times\left(40-13\theta^2\right)^2\right)$$

Solving the equation that this formula is equal to zero with respect to θ, we can determine that $\Pi^{(DW,W)}-\Pi^{(D,W)}$ is positive if $\theta<0.184$ and negative if $\theta>0.184$.

$$\Pi^{(DW,W)}-\Pi^{(W,W)}=\left(1600-1600\theta-680\theta^2+1080\theta^3-107\theta^4-182\theta^5+51\theta^6\right)(a-c)^2/\left(2b(2-\theta)^2\left(40-13\theta^2\right)^2\right)>0$$

$$\Pi^{(DW,W)}-\Pi^{(DA,W)}=\left(800+400\theta-630\theta^2-370\theta^3+73\theta^4+51\theta^5\right)\times(a-c)^2/\left(2b(1+\theta)\left(40-13\theta^2\right)^2\right)>0$$

$$\Pi^{(D,W)}-\Pi^{(A,W)}=\left(265+128\theta-16(11+4r)\theta^2-16(5+3r)\theta^3+4\left(6+5r+r^2\right)\theta^4+4\left(3+4r+r^2\right)\theta^5+(1+r)^2\theta^6\right)\times r(a-c)^2/\left(16b(2+\theta)^2\left(4-(1+r)\theta^2\right)^2\right)>0$$

This sign is determined by taking the following steps. First, because $265+128\theta-16(11+4r)\theta^2-16(5+3r)\theta^3+4(6+5r+r^2)\theta^4+4(3+4r+r^2)\theta^5+(1+r)^2\theta^6$ in the numerator of $\Pi^{(D,W)}-\Pi^{(A,W)}$ is a quadratic function with respect to r, the solution of r from $\Pi^{(D,W)}-\Pi^{(A,W)}=0$ is obtained analytically as functions of θ. However, the functions take only imaginary values in the interval of $0<\theta<1$. This means that the sign of $\Pi^{(D,W)}-\Pi^{(A,W)}$ is the same within the region of $0<r<1$ and $0<\theta<1$ regardless of the values of the parameters θ and r. Substituting any combination of $\theta\in(0,1)$ and $r\in(0,1)$ into $\Pi^{(D,W)}-\Pi^{(A,W)}$ gives a positive value, which determines $\Pi^{(D,W)}-\Pi^{(A,W)}$ as positive, meaning that Strategy A cannot be the best-response strategy when the rival supplier chooses Strategy W.

Proof of (iii): Strategy D is the best-response strategy of a supplier if the rival supplier chooses Strategy DW.

The four differences in profits between the suppliers' distribution strategies given as follows prove (iii) in this proposition.

$$\Pi^{(D,DW)}-\Pi^{(DW,DW)}=\theta^3\left(30000-17200\theta-4680\theta^2+6905\theta^3-8225\theta^4-219\theta^5+3775\theta^6-217\theta^7-619\theta^8+47\theta^9+37\theta^{10}-4\theta^{11}\right)\times(a-c)^2/\left(4b(1+\theta)\left(30-3\theta-11\theta^2-\theta^3+\theta^4\right)^2\left(20-10\theta^2+\theta^4\right)^2\right)$$

Numerically solving the equation that this value is equal to 0 for θ shows that θ has no solution between $0<\theta<1$. This means that the sign of $\Pi^{(D,DW)}-\Pi^{(DW,DW)}$ is the same within the region of $0<\theta<1$ regardless of the value of the parameter θ. Substituting any $\theta\in(0,1)$ into $\Pi^{(D,DW)}-\Pi^{(DW,DW)}$ gives a positive value, meaning that $\Pi^{(D,DW)}-\Pi^{(DW,DW)}>0$ holds irrespective of the value of θ.

$$\Pi^{(D,DW)}-\Pi^{(W,DW)}=(320000-624000\theta^2+192000\theta^3+450800\theta^4-202400\theta^5-153700\theta^6+77920\theta^7+24245\theta^8-12995\theta^9-1184\theta^{10}+796\theta^{11}-42\theta^{12}+2\theta^{13})(a-c)^2/\left(4b(1+\theta)\left(40-13\theta^2\right)\left(20-10\theta^2+\theta^4\right)^2\right)$$

Numerically solving the equation that this value is equal to 0 for θ finds that θ has no solution between $0<\theta<1$. This means that the sign of $\Pi^{(D,DW)}-\Pi^{(W,DW)}$ is the same within the region of $0<\theta<1$ regardless of the value of the parameter θ. Substituting any $\theta\in(0,1)$ into $\Pi^{(D,DW)}-\Pi^{(W,DW)}$ gives a positive value, meaning that $\Pi^{(D,DW)}-\Pi^{(W,DW)}>0$ holds irrespective of the value of θ.

$$\Pi^{(D,DW)}-\Pi^{(A,DW)}=\left(\frac{\left(20-10\theta-5\theta^2+2\theta^3\right)^2}{4b\left(20-10\theta^2+\theta^4\right)^2}-\frac{(1-r)\left(20-10\theta-(5+2r)\theta^2+(2+r)\theta^3\right)^2}{4b\left(20-2(5+2r)\theta^2+(1+r)\theta^4\right)^2}\right)\times(a-c)^2$$

The numerator of $\Pi^{(D,DW)}-\Pi^{(A,DW)}$ is expressed as a quadratic function with respect to r. Solving the equation that this value is equal to 0 for r shows that r has no real solution in the interval of $0<\theta<1$. This means that the sign of $\Pi^{(D,DW)}-\Pi^{(A,DW)}$ is the same within the region of $0<r<1$ and $0<\theta<1$ regardless of the values of the parameters θ and r. Substituting any combination of $\theta\in(0,1)$ and $r\in(0,1)$ into $\Pi^{(D,DW)}-\Pi^{(A,DW)}$ gives a positive value, meaning that $\Pi^{(D,DW)}-\Pi^{(A,DW)}>0$ holds irrespective of the values of θ and r.

$$\Pi^{(D,DW)}-\Pi^{(DA,DW)}=\left(20-10\theta-5\theta^2+2\theta^3\right)^2(a-c)^2/\left(4b\left(20-10\theta^2+\theta^4\right)^2\right)>0$$

Proof of (iv): When the other rival supplier chooses Strategy DA, Strategy W is the best-response strategy when $\theta>0.845$, while Strategy DW is the best-response strategy when $\theta<0.845$.

The four differences in profits between the suppliers' distribution strategies given as follows prove (iv) in this proposition.

$$\Pi^{(DW,DA)}-\Pi^{(D,DA)}=\theta^2\left(4-3\theta-\theta^2+\theta^3\right)^2(a-c)^2/\left(4b\left(2-\theta^2\right)^2\left(1-\theta^2\right)\left(5-\theta^2\right)\right)>0$$

$$\Pi^{(DW,DA)}-\Pi^{(A,DA)}=\left(\theta^2\left(4-3\theta-\theta^2+\theta^3\right)^2+4r(1-\theta)^3\left(5+5\theta-2\theta^2-2\theta^3\right)\right)\times(a-c)^2/\left(4b\left(2-\theta^2\right)^2\left(1-\theta^2\right)\left(5-2\theta^2\right)\right)>0$$

$$\Pi^{(DW,DA)}-\Pi^{(DA,DA)}=\left(5-10\theta+7\theta^2-2\theta^3+\theta^4\right)(a-c)^2/\left(4b\left(1-\theta^2\right)\left(5-2\theta^2\right)\right)>0$$

These three inequalities imply that neither Strategy D, A, nor DA is the best-response strategy if the other rival supplier chooses Strategy DA.

$$\Pi^{(DW,DA)} - \Pi^{(W,DA)} = \left(5 - 4\theta^2 - 12\theta^3 + 10\theta^4\right)(a-c)^2 / \left(8b\left(1-\theta^2\right)\left(5-2\theta^2\right)\right)$$

This value is positive if $\theta < 0.845$ and negative if $\theta > 0.845$. Therefore, Strategy W is the best-response strategy when $\theta > 0.845$, while Strategy DW is the best-response strategy when $\theta < 0.845$. □

Proof of Theorem 1.

Table 2 shows the payoff matrix at Stage 1. The circled payoffs represent each supplier's best-response strategy. Because the variable on the left in parentheses represents Supplier 1′s profit and the variable on the right represents Supplier 2′s profit, the cell with both payoffs in parentheses circled corresponds to the SPNE. □

Proof of Theorem 2**.**

Evaluating the equilibrium profits of suppliers at $c^D = c^P = c$, we have the following inequality:

$$\Pi^{(DW,D)} - \Pi^{(D,DW)} = \theta^3\left(20 - 15\theta + \theta^3\right)(a-c)^2 / \left(4b\left(20 - 10\theta^2 + \theta^4\right)^2\right) > 0,$$

which proves this theorem. □

Proof of Observation 1.

If the assumption in Fig. 3 is altered such that two suppliers sequentially choose their respective distribution strategies at Stage 1, the following strategies constitute the SPNE in the dynamic game; namely, if the second-moving supplier chooses Strategy D, the first-moving supplier correctly anticipates this choice based on backward induction, choosing Strategy DW. Conversely, if the second-moving supplier chooses Strategy DW, the first-moving supplier chooses Strategy D in anticipating the rival supplier's choice. Therefore, if the first-moving supplier chooses Strategy DW, it obtains $\Pi^{(DW,D)}$ as its profit (i.e., payoff). Alternatively, if the first-moving supplier chooses Strategy D, it obtains $\Pi^{(D,DW)}$ as its profit. Because Theorem 2 shows that $\Pi^{(DW,D)} > \Pi^{(D,DW)}$ holds, the first-moving supplier chooses Strategy DW and then the second-moving supplier chooses Strategy D as the best-response strategy. Consequently, these sequential choices of the distribution strategies constitute the SPNE in the dynamic game. □

Equilibrium profit of a supplier in each distribution strategy combination under price competition in Section 7 **and its derivation process**

The equilibrium profits of a supplier in each distribution strategy combination in price competition are as follows. The first notation in the superscript parentheses attached to Π signifies the strategy chosen by the own supplier, and the second notation signifies the strategy chosen by the rival supplier.

$$\Pi^{(D,D)} = (1-\theta)(a-c)^2 / \left(b(2-\theta)^2(1+\theta)\right)$$

$$\Pi^{(D,W)} = (1-\theta)\left(4+\theta-2\theta^2\right)^2(a-c)^2 / \left(4b(2-\theta)^2(1+\theta)\left(2-\theta^2\right)^2\right)$$

$$\Pi^{(D,A)} = (1-\theta)(a-c)^2 / \left(b(2-\theta)^2(1+\theta)\right)$$

$$\Pi^{(D,DW)} = (1-\theta)\left(4+2\theta-\theta^2\right)^2(a-c)^2 / \left(16b(1+\theta)\left(2-\theta^2\right)^2\right)$$

$$\Pi^{(D,DA)} = (1-\theta)(a-c)^2/(4b(1+\theta))$$

$$\Pi^{(W,D)} = (1-\theta)(2+\theta)(a-c)^2 / \left(4b(2-\theta)(1+\theta)\left(2-\theta^2\right)\right)$$

$$\Pi^{(W,W)} = (1-\theta)(a-c)^2 / \left(2b(2-\theta)^2(1+\theta)\right)$$

$$\Pi^{(W,A)} = (1-\theta)\left(2+(1-r)\theta - r\theta^2\right)^2(a-c)^2 / \left(4b(1+\theta)\left(2-\theta^2\right)\left(4-(1+r)\theta^2\right)\right)$$

$$\Pi^{(W,DW)} = (1-\theta)\left(4+2\theta-\theta^2\right)^2(a-c)^2 / \left(2b(1+\theta)\left(8-5\theta^2\right)^2\right)$$

$$\Pi^{(W,DA)} = (1-\theta)(a-c)^2/(8b(1+\theta))$$

$$\Pi^{(A,D)} = (1-r)(1-\theta)(a-c)^2 / \left(b(2-\theta)^2(1+\theta)\right)$$

$$\Pi^{(A,W)} = (1-r)(1-\theta)\left(8+6\theta-(3+r)\theta^2-(2+r)\theta^3\right)^2(a-c)^2 / \left(4b(1+\theta)\left(2-\theta^2\right)^2\left(4-(1+r)\theta^2\right)^2\right)$$

$$\Pi^{(A,A)} = (1-r)(1-\theta)(a-c)^2 / \left(b(2-\theta)^2(1+\theta)\right)$$

$$\Pi^{(A,DW)} = (1-r)(1-\theta)\left(4+2\theta-\theta^2\right)^2(a-c)^2 / \left(16b(1+\theta)\left(2-\theta^2\right)^2\right)$$

$$\Pi^{(A,DA)} = (1-r)(1-\theta)(a-c)^2/(4b(1+\theta))$$

$$\Pi^{(DW,D)} = (1-\theta)(2+\theta)^2(a-c)^2 / \left(8b(1+\theta)\left(2-\theta^2\right)\right)$$

$$\Pi^{(DW,W)} = (4+3\theta)^2(1-\theta)\left(2-\theta^2\right)(a-c)^2 / \left(2b(1+\theta)\left(8-5\theta^2\right)^2\right)$$

$$\Pi^{(DW,A)} = (1-\theta)(2+\theta)^2(a-c)^2 / \left(8b(1+\theta)\left(2-\theta^2\right)\right)$$

$$\Pi^{(DW,DW)} = (1-\theta)(a-c)^2 / \left(b(2-\theta)^2(1+\theta)\right)$$

$$\Pi^{(DW,DA)} = (1-\theta)(a-c)^2/(4b(1+\theta))$$

$$\Pi^{(DA,D)} = 0$$

$$\Pi^{(DA,W)} = 0$$

$$\Pi^{(DA,A)} = 0$$

$$\Pi^{(DA,DW)} = 0$$

$$\Pi^{(DA,DA)} = 0$$

Below, we summarize how to derive the equilibrium profits resulting from each combination of distribution strategies. The objective functions (i.e., profits) are sequentially maximized through the use of backward induction to obtain the SPNE in each case of the distribution strategies. In this summary, as an example, we show the solving process in the case of (DW, A). We first substitute $q_2^D = 0$ into Eqs. (A1)–(A4) and solve the equations for q_1^D, q_1^P, and q_2^P, obtaining the demand functions. Then, substituting the demand functions into the suppliers' profits of Π_1 and Π_2, we express the profits as the functions of p_1^D, p_1^P, p_2^P, and w_1. At Stage 3, Suppliers 1 and 2 and the platform maximize their respective profits by solving $\partial\Pi_1/\partial p_1^D = \partial\Pi_2/\partial p_2^P = \partial\pi/\partial p_1^P = 0$. After substituting these p_1^D, p_1^P, and p_2^P derived at Stage 3 and the demand functions into Π_1 and Π_2, we solve $\partial\Pi_1/\partial w_1 = 0$ at Stage 2 to yield w_1. Finally, inserting p_1^D, p_1^P, p_2^P, and w_1 derived above into Π_1 and Π_2 yields the equilibrium profits. Similarly, in each case of distribution strategies other than (DW, A), we obtain the equilibrium profits by sequentially maximizing the objective functions of the suppliers' and platform's profits. For further details, see the detailed derivation process of equilibrium profit in the online Supplementary Material file. □

Proof of Proposition 2**.**

With the use of $0 < \theta < 1$ and $0 < r < 1$, each sign of the difference in profits resulting from different combinations of distribution strategies can be determined as positive or negative, as shown in the series of inequalities below. In the following, we prove Cases (i), (ii), (iii), and (iv) in this proposition in turn.

Proof of (i): Strategy DW is the best-response strategy of a supplier when the rival supplier chooses Strategy D or A.

The next eight inequalities with the use of the profits shown above prove (i) in this proposition.

$$\Pi^{(DW,D)} - \Pi^{(D,D)} = \theta^4(1-\theta)(a-c)^2 \Big/ \left(8b(2-\theta)^2(1+\theta)\left(2-\theta^2\right)\right) > 0$$

$$\Pi^{(DW,D)} - \Pi^{(W,D)} = (1-\theta)(2+\theta)(a-c)^2/(8b(2-\theta)(1+\theta)) > 0$$

$$\Pi^{(DW,D)} - \Pi^{(A,D)} = (1-\theta)\left(8r\left(2-\theta^2\right)+\theta^4\right)(a-c)^2 \Big/ \left(8b(2-\theta)^2(1+\theta)\left(2-\theta^2\right)\right) > 0$$

$$\Pi^{(DW,D)} - \Pi^{(DA,D)} = (1-\theta)(2+\theta)^2(a-c)^2 \Big/ \left(8b(1+\theta)\left(2-\theta^2\right)\right) > 0$$

$$\Pi^{(DW,A)} - \Pi^{(D,A)} = \theta^4(1-\theta)(a-c)^2 \Big/ \left(8b(2-\theta)^2(1+\theta)\left(2-\theta^2\right)\right) > 0$$

$$\begin{aligned}\Pi^{(DW,A)} - \Pi^{(W,A)} = &\Big(8+8(1+r)\theta-2\left(1-4r+r^2\right)\theta^2 \\ &-4\left(1+r^2\right)\theta^3-\left(1+r+2r^2\right)\theta^4\Big) \\ &\times(1-\theta)(a-c)^2 \\ &\Big/\left(8b(1+\theta)\left(2-\theta^2\right)\left(4-(1+r)\theta^2\right)\right) > 0\end{aligned}$$

$$\Pi^{(DW,A)} - \Pi^{(A,A)} = (1-\theta)\left(8r\left(2-\theta^2\right)+\theta^4\right)(a-c)^2 \Big/ \left(8b(2-\theta)^2(1+\theta)\left(2-\theta^2\right)\right) > 0$$

$$\Pi^{(DW,A)} - \Pi^{(DA,A)} = (1-\theta)(2+\theta)^2(a-c)^2 \Big/ \left(8b(1+\theta)\left(2-\theta^2\right)\right) > 0$$

Proof of (ii): When the other rival supplier chooses Strategy W, Strategy D is the best-response strategy when $\theta < 0.462$, while Strategy DW is the best-response strategy when $\theta > 0.462$.

The following four inequalities prove (ii) in this proposition.

$$\begin{aligned}\Pi^{(DW,W)} - \Pi^{(D,W)} = &\left(-64+112\theta+152\theta^2-177\theta^3\right. \\ &\left.-108\theta^4+96\theta^5+24\theta^6-18\theta^7\right) \\ &\times\theta^3(1-\theta)(a-c)^2 \\ &\Big/\left(4b(2-\theta)^2(1+\theta)\left(2-\theta^2\right)^2\left(8-5\theta^2\right)^2\right) > 0\end{aligned}$$

By solving $\theta^3(1-\theta)(-64+112\theta+152\theta^2-177\theta^3-108\theta^4+96\theta^5+24\theta^6-18\theta^7) = 0$ with respect to θ, we can determine that the left-hand side is negative if $\theta < 0.462$ and positive if $\theta > 0.462$.

$$\begin{aligned}\Pi^{(DW,W)} - \Pi^{(W,W)} = &(1-\theta)\left(64-72\theta^2+16\theta^3+21\theta^4-9\theta^5\right) \\ &\times(a-c)^2\Big/\left(2b(2-\theta)^2\left(8-5\theta^2\right)^2\right) > 0\end{aligned}$$

$$\begin{aligned}\Pi^{(DW,W)} - \Pi^{(A,W)} = &(1-\theta)\Big(r^3\theta^4\left(8(1+\theta)-5\theta^2(1+\theta)\right)^2 \\ &-\theta^3(2+\theta)^2\left(64-112\theta-152\theta^2+177\theta^3\right. \\ &\left.+108\theta^4-96\theta^5-24\theta^6+18\theta^7\right) \\ &+r^2\theta^2\left(-1024-1792\theta+1088\theta^2+3136\theta^3\right. \\ &+112\theta^4-1916\theta^5-439\theta^6+488\theta^7+151\theta^8 \\ &\left.-48\theta^9-18\theta^{10}\right) \\ &+r\left(4096+6144\theta-6912\theta^2-13312\theta^3\right. \\ &+3136\theta^4+11104\theta^5+532\theta^6-4616\theta^7 \\ &\left.-881\theta^8+1010\theta^9+296\theta^{10}-96\theta^{11}-36\theta^{12}\right)\Big) \\ &\times(a-c)^2\Big/\Big(4b(1+\theta)\left(8-5\theta^2\right)^2\left(2-\theta^2\right)^2 \\ &\times\left(4-(1+r)\theta^2\right)^2\Big) > 0\end{aligned}$$

Although it seems difficult to determine that the sign of $\Pi^{(DW,W)} - \Pi^{(A,W)}$ is positive, the sign can be determined by taking the following steps. First, because $\Pi^{(DW,W)} - \Pi^{(A,W)}$ is a cubic function with respect to r, the solution of r from $\Pi^{(DW,W)} - \Pi^{(A,W)} = 0$ is obtained analytically as a function of θ. Solving the equation $\Pi^{(DW,W)} - \Pi^{(A,W)} = 0$ for r yields only one real solution. This real solution of r, expressed as the function of θ, does not fall into the range 0 and 1 in the interval of $0 < \theta < 1$. This means that the sign of $\Pi^{(DW,W)} - \Pi^{(A,W)}$ is the same within the region of $0 < r < 1$ and $0 < \theta < 1$ regardless of the values of the parameters θ and r. Substituting any combination of θ satisfying $0 < \theta < 1$ and r satisfying $0 < r < 1$ into $\Pi^{(DW,W)} - \Pi^{(A,W)}$ gives a positive value, which determines $\Pi^{(DW,W)} - \Pi^{(A,W)}$ as positive.

$$\Pi^{(DW,W)} - \Pi^{(DA,W)} = (4+3\theta)^2(1-\theta)\left(2-\theta^2\right)(a-c)^2 \Big/ \left(2b(1+\theta)\left(8-5\theta^2\right)^2\right) > 0$$

Proof of (iii): Strategy D is the best-response strategy of a supplier if the rival supplier chooses Strategy DW.

The following four inequalities prove (iii) in this proposition.

$$\Pi^{(D,DW)} - \Pi^{(DW,DW)} = \theta^3(1-\theta)\left(16-8\theta^2+\theta^3\right)(a-c)^2 \Big/ \left(16b(2-\theta)^2(1+\theta)\left(2-\theta^2\right)^2\right) > 0$$

$$\begin{aligned}\Pi^{(D,DW)} - \Pi^{(W,DW)} = &(1-\theta)\left(4+2\theta-\theta^2\right)^2\left(32-48\theta^2+17\theta^4\right) \\ &\times(a-c)^2\Big/\left(16b(1+\theta)\left(2-\theta^2\right)\left(8-5\theta^2\right)^2\right) \\ &> 0\end{aligned}$$

$$\Pi^{(D,DW)} - \Pi^{(A,DW)} = r(1-\theta)\left(4+2\theta-\theta^2\right)^2(a-c)^2 \Big/ \left(16b(1+\theta)\left(2-\theta^2\right)^2\right) > 0$$

$$\Pi^{(D,DW)} - \Pi^{(DA,DW)} = (1-\theta)\left(4+2\theta-\theta^2\right)^2(a-c)^2 \Big/ \left(16b(1+\theta)\left(2-\theta^2\right)^2\right) > 0$$

Proof of (iv): Strategy D and Strategy DW are the best-response strategies of a supplier if the other rival supplier chooses Strategy DA.

The following one equation and three inequalities prove (iv) in this proposition.

$$\Pi^{(DW,DA)} - \Pi^{(D,DA)} = 0$$

$$\Pi^{(DW,DA)} - \Pi^{(W,DA)} = (1-\theta)(a-c)^2/(8b(1+\theta)) > 0$$

$$\Pi^{(DW,DA)} - \Pi^{(A,DA)} = r(1-\theta)(a-c)^2/(4b(1+\theta)) > 0$$

$$\Pi^{(DW,DA)} - \Pi^{(DA,DA)} = (1-\theta)(a-c)^2/(4b(1+\theta)) > 0$$

□

Proof of Theorem 3.

Table 3 shows the payoff matrix at Stage 1. The circled payoffs represent each supplier's best-response strategy. Because the variable on the left in parentheses represents Supplier 1′s profit and the variable on the right represents Supplier 2′s profit, the cell with both payoffs in parentheses circled corresponds to the SPNE. □

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