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Abstract

This paper evaluates the joint impact of exclusive channels and revenue sharing on suppliers and retailers in a hybrid duopoly common retailer and exclusive channel model. The model bridges the gap in the literature on hybrid multichannel supply chains with bilateral complementary products and services with/without revenue sharing. The analysis indicates that, without revenue sharing, the suppliers are reluctant to form exclusive deals with the retailers, thus, no equilibrium results. With revenue sharing from the retailers to the suppliers, it can be an equilibrium strategy for the suppliers and retailers to form exclusive deals. Bargaining solutions are provided to determine the revenue sharing rates. Our additional results suggest forming exclusive deals becomes less desirable for the suppliers if revenue sharing is also in place under nonexclusivity. In our extended discussion, we also study the impact of channel asymmetry, an alternative model with fencing, composite package competition, and enhanced price-dependent revenue sharing.

Keyword: exclusive channels; channel competition; revenue-sharing; complementary goods

1 Introduction

Exclusive channel strategies are practiced in a variety of complementary goods markets. For example, in the wireless market, the iPhone, the mobile phone product of Apple, was designed to be used only through the

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service provider AT&T when the iPhone was first launched in 2007 (Koman, 2007; Yoffie and Slind, 2007). Similarly, in 2008, Google launched its GPhone in conjunction with an exclusive deal with T-Mobile, and Research in Motion entered into an exclusive deal with Verizon with its smart phone, Storm (Reuters, 2007). In the video game market, Capcom's Monster Hunter 3 game is designed to be played only on the Nintendo video game console (Thomson Financial, 2007). In the TV market, it is well known that some entertainment programs are aired through exclusive channels. In the e-book market, UR by Stephen King, for example, is sold exclusively in the format of Amazon's Kindle, rather than Barnes & Noble's Nook (Anand et al., 2009).

Intuitively, product suppliers, such as Apple, Capcom, and e-book publishers, may attain compensatory benefits, such as revenue sharing, from their complementary partners for sacrificing part of their potential market when committing to an exclusive deal. For example, the National Football League (NFL) required several forms of compensation, including rights fees and Sirius stock options when selling the exclusive rights to air NFL game audio on satellite radio to Sirius from 2004 to 2010 (Elberse et al., 2010). In the wireless world, it has been widely reported that Apple, iPhone's affiliated company, receives a portion of revenue from AT&T for every iPhone service (Koman, 2007; Yoffie and Slind, 2007), although the detailed financial terms of the deal are not obtainable due to commercial confidentiality.

Although a number of studies have discussed exclusive channels (e.g., Marx and Shaffer, 2007; O'Brien and Shaffer, 1993) and revenue sharing (e.g., Cachon and Lariviere, 2005; Foros et al., 2009), to the best of our knowledge, no existing literature has theoretically investigated the efficacy of a combination of exclusive channels and revenue sharing when competition exists in both categories of complementary goods. Without loss of generality, we refer to the sellers of some substitutable goods as suppliers (e.g., wireless phone manufacturers) who sell products (e.g., cellphones), and their complementary counterparts as retailers (e.g., service providers) who sell substitutable services (e.g., cellphone plans). The above industry practices motivate us to ask the following research question:

How does a combination of exclusive deals and revenue sharing impact suppliers and retailers in a competitive multichannel market, where the suppliers sell products and the retailers sell complementary goods/services simultaneously?

To answer this question, we introduce a stylized model with two suppliers and two retailers. Each supplier sells a single product while each retailer provides a single complementary service. Consumers can purchase a composite package of a product and a service from the four (2×2) potential combinations. However, not every potential package is available to the consumers, because a supplier-retailer pair may choose to form an exclusive deal, such that the package of the exclusive supplier's product and the other (rival) retailer's service becomes unavailable. Due to the complementary features of the products and services, we extend the established model of nonexclusive composite goods in Economides and Salop (1992) to four different channel structures: one with no exclusive channel, two with one exclusive channel, and one with two exclusive channels. This unique combination is different from that found in the extant literature on channel distribution and competition, and can be applied to a wide range of markets including wireless communication, TV, e-books, and video games. It is also worth noting that, different from traditional revenue sharing contracts where a retailer shares revenue with its supplier for selling the supplier's product (e.g., Cachon and Lariviere, 2005), in our model, the shared revenue comes from the retailer's own service simply because the supplier exclusively locks its product to the retailer's service. The model is then solved backwards in a three-stage game. First, both suppliers propose a contract, either exclusive or not, to the retailers. If there is revenue sharing in an exclusive deal, then the corresponding supplier and retailer also negotiate on the revenue sharing rate. Second, the retailers decide whether to accept the contract. Finally, all players engage in a pricing Nash game where the suppliers and the retailers simultaneously determine their respective product prices and service rates to maximizes their own profits.

Our study first shows that, without revenue sharing, forming exclusive deals cannot be an equilibrium. Intuitively, an exclusive deal without revenue sharing is always desired by a retailer, who benefits from a higher retail price due to the more monopolistic market resulting from the exclusive deal. But, the partnered supplier loses its edge in the exclusive deal without revenue sharing due to a lower product price and less demand and, hence, will be reluctant to form an exclusive deal with the retailer. Our analysis, however, indicates that forming exclusive deals can be Pareto efficient for the entire supply chain only if package substitutability is high; otherwise, selling the product non-exclusively is a more efficient solution.

We then prove that, with a revenue sharing mechanism, forming exclusive deals can be an equilibrium for both suppliers and both retailers. When package substitutability is high, a reasonable amount of the revenue shared from the retailer compensates the supplier and makes an exclusive deal mutually beneficial for the partnered supplier and retailer. This, however, places their rivals without an exclusive and revenue sharing deal in a disadvantageous situation, which stimulates them to form another exclusive deal. As our analysis demonstrates, the equilibrium revenue sharing rate decreases with package substitutability, because less intense package competition allows the retailers to share more with the suppliers. We can then characterize the negotiated revenue sharing rate via bargaining solutions. In an extended model with revenue sharing under exclusivity and nonexclusivity, we further show that forming exclusive deals becomes less desirable for the suppliers as the revenue sharing rate under nonexclusivity increases. The intuition is that a supplier's relative benefit from entering an exclusive deal diminishes as the difference in the revenue sharing rates under exclusivity and nonexclusivity reduces.

Our analysis also indicates that product prices in exclusive deals tend to be lower than in non-exclusive deals when package substitutability is low. This trend occurs because the supplier attains a relative advantage against the other (rival) supplier when switching to an exclusive deal, especially with revenue sharing, which creates an additional pricing cushion. However, the overall package price becomes higher with an exclusive deal(s) with/without revenue sharing, as fewer available packages give rise to less intense competition.

Our model is related to the research on channel distribution and competition, which has been extensively studied in recent years. The related multichannel literature examines factors such as service competition (Tsay and Agrawal, 2004a), channel distribution (Cai, 2010; Rangan, 1987), exclusion (Marx and Shaffer, 2007; O'Brien and Shaffer, 1993), and the impact of an Internet channel (Chiang et al., 2003; Liu et al., 2006). A comprehensive review of multichannel supply chains can be found in Cattani et al. (2004) and Tsay and Agrawal (2004b). Ingene and Parry (2004) also provide insightful discussions on channel distribution and coordination. Desai et al. (2001) analyze a design configuration with commonality on whether a component should be common or unique for the manufacturer. While sharing some similarities with the above work, our model can be considered an extension of McGuire and Staelin (1983), Choi (1996), and Economides and Salop (1992). Based on a model with two exclusive channels without revenue sharing, McGuire and Staelin (1983) provide an explanation as to why a supplier would want to use an intermediary retailer in the context of two supply chains, each having one supplier. Choi (1996) considers a model with two manufacturers and two retailers, where each manufacturer sets the wholesale price and supplies the same product to both retailers. In this duopoly common retailer channel model, two differentiated common retailers compete in the same market. However, the extant literature does not compare dual exclusive channels with a duopoly common-retailer or a mixed model of the two. Probably the most related study is Economides and Salop (1992) who consider four complementary products that can be combined into four composite goods. Their main model shares similar features with ours without exclusive channels. Nevertheless, the exclusive channels, revenue sharing, and bargaining in our model are distinct from theirs and the related extant literature.

Another closely related literature stream is on revenue sharing. Cachon and Lariviere (2005) perform a comprehensive analysis of the advantages and limitations of revenue sharing contracts. Tsay et al. (1999) document a variety of supply chain contracts including revenue sharing contracts. In practice, revenue sharing has been utilized by Blockbuster and its suppliers (Cachon and Lariviere, 2005) and is commonly seen in a royalty format in franchising companies (Desai and Srinivasan, 1996). Notably, price-dependent revenue sharing has also been successfully implemented in content messaging by wireless service companies and their content providers in Norway (Foros et al., 2009). The revenue sharing in our model is motivated by the exclusive deal between iPhone and AT&T and has not previously been discussed in the context of four different channel structures.

The third related area of study is bargaining in distribution channels. Bilateral bargaining was first developed by Nash (1950, 1953) and has been applied to a wide range of channel structures. For example, Zusman and Etgar (1981) use Nash bargaining theory to analyze a simple 3-level channel and examine the interrelations among individual dyadic contracts. Desai and Purohit (2004) consider two sellers whose decision is to offer fixed prices or to haggle over prices with customers (i.e., bargain prices with the customers). In the case of haggling by the seller, a detailed analysis of the disagreement point for customers is given. Shaffer (2002) characterizes negotiation using a model with multiple manufacturers and retailers. In a model with two manufacturers and two multi-product retailers under bilateral channel bargaining, Dukes et al. (2006) show that the manufacturers can benefit from cost asymmetry between the two retailers, even though the low-cost retailer has a better bargaining position than its rival retailer. See Iyer and Villas-Boas (2003), Myerson (1997), and O'Brien and Shaffer (2005) for more discussion on bargaining.

The remainder of this paper is organized as follows. We introduce the model in Section 2. In Section 3, we first discuss the impact of channel structures without revenue sharing and then demonstrate the efficacy of revenue sharing. We further provide bargaining solutions for the revenue sharing rate. Moreover, we extend our discussion to a different revenue sharing scheme where the retailers also share revenue with the suppliers in nonexclusive channels. We conclude in Section 4. Extensions to asymmetric suppliers/retailers, an alternative model with fencing, composite package competition, and a price-dependent revenue sharing contract are elaborated in the Appendix. All proofs are relegated to the Online Supplements.

2 The Model

To explore the efficacy of supply chain structures and revenue sharing, we consider a stylized model with two suppliers and two retailers. Each supplier manufactures a single product (i.e., supplier i produces product $i, i = 1, 2$), and each retailer provides a single service (i.e., retailer j provides service $j, j = a, b$). The services complement the products. While no single model can fully capture the entire reality of complementary goods markets, our model is intended to investigate a one-period game where consumers can freely combine either product with either service, if the suppliers and retailers do not form exclusive deal(s). Therefore, there are a total of $2 \times 2 = 4$ possible composite goods. These composite goods are referred to as *packages*, and the total price for each package is given by $P_{ij} = p_i + p_j$, where p_i is the price of product i and p_j is the rate of service j, $i = 1, 2, j = a, b$. Throughout this paper, we use i, j, and ij as subscripts to denote the corresponding supplier, retailer, and package/channel, respectively. We also use $\bar{j}$ to represent the rival retailer to j; for example, if $j = a$, then $\bar{j} = b$.

We study four channel structures, as detailed below and illustrated in Figure 1. Without loss of generality, we assume that in the exclusive deal(s), supplier 1 will only pair with retailer a and/or supplier 2 will only pair with retailer b. This assumption also allows us to study the noncooperative and bilateral bargaining games analytically.

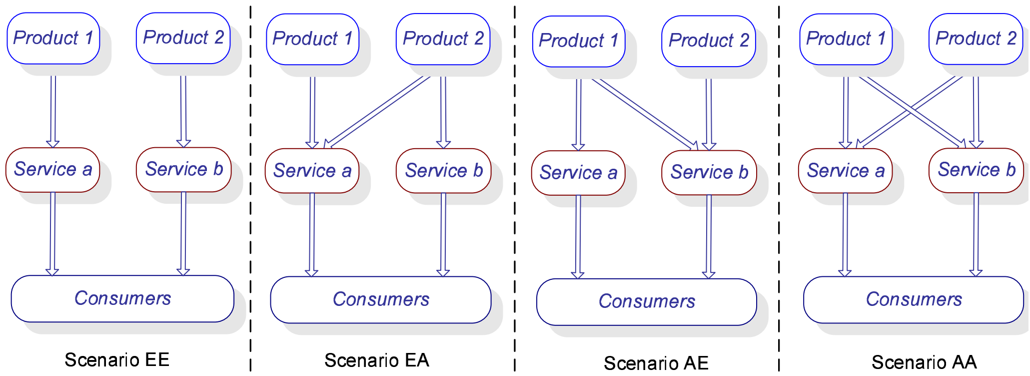

Figure 1: A competitive model with two suppliers and two retailers: Scenarios EE, EA, AE, and AA.

1. Scenario EE: supplier 1 partners exclusively with retailer a and supplier 2 partners exclusively with retailer b. Packages $1a$ and $2b$ are available.

2. Scenario EA: supplier 1 partners exclusively with retailer a while supplier 2 sells through both retailers. Packages $1a$, $2a$, and $2b$ are available.

3. Scenario AE: supplier 1 sells through both retailers while supplier 2 partners exclusively with retailer b. Packages $1a$, $1b$, and $2b$ are available.

4. Scenario AA: both suppliers 1 and 2 sell through both retailers. All packages are available.

Scenario EE is similar to the model in McGuire and Staelin (1983) in terms of channel structure, but differs in that we consider two packages including four complementary products/services, while McGuire and Staelin focus on a model with only two products. Scenario AA shares the same features as the model in Economides and Salop (1992). To the best of our knowledge, Scenarios EA and AE are relatively new to the literature. Note that in Scenarios EA and AE, given that supplier i sells exclusively through retailer j, there is another similar "exclusive" channel in terms of service, as retailer $\bar{j}$ sells only supplier $(3-i)$'s product. Due to the focus of this paper, we only refer to the exclusive *product* channel as the exclusive channel, which is consistent with the iPhone case. We use the superscripts EE, EA, AE and AA to denote the corresponding scenario throughout this paper.

We denote the demand for package ij as $D_{ij}, ij = 1a, 1b, 2a, 2b$. To obtain demand functions for the different channel structures, we adopt the framework established by Ingene and Parry (2007) and employ a utility function of a representative consumer from the perspective of aggregate demand as follows:

$$U \equiv \sum_{ij}(\alpha_{ij} D_{ij} - D_{ij}^2/2) - \tau \sum_{ij \neq mn} D_{ij} D_{mn}/2 - \sum_{ij} P_{ij} D_{ij}, \tag{1}$$

where τ $(0 \leq \tau < 1)$ denotes package substitutability. Note that $\tau < 1$ is required by the second-order condition to obtain a maximum (Ingene and Parry, 2004). The above utility function reflects an income constraint where the marginal utility of income is one. If $\tau = 0$, the packages are completely monopolistic; as τ approaches 1, the packages converge towards being completely substitutable. The term α_{ij} reflects the consumer's preference for package ij and can be considered as a measure of how much the representative consumer initially values package ij. It is also equivalent to the initial base demand when all prices equal zero and package ij is the only available package. To obtain parsimony, we start with a symmetric setting by fixing $\alpha_{ij} = 1/4$ and study the impact of asymmetry in Section A.1. The symmetric setting has been widely adopted in the literature (e.g., Choi, 1996; Economides and Salop, 1992; McGuire and Staelin, 1983), especially for a complex model like ours. The main reason for choosing $\alpha_{ij} = 1/4$ is make it reusable in our discussion of asymmetric cases in Section A.1. All our qualitative results hold if we normalize α_{ij} to any other positive value. Note that α_{ij} is independent of the availability of the packages and package substitutability.

It is worth noting that a simpler form of this utility function was first introduced by Spence (1976), Dixit (1979), and Shubik and Levitan (1980) for models with two products. It has since been widely utilized in the economics, marketing, and operations management literature (see Ingene and Parry, 2007; Lus and Muriel, 2009; Singh and Vives, 1984; Xiao et al., 2008). The term "representative consumer" is drawn from the economic notion of "a fictional individual" (Mas-Colell et al., 1995, Chapter 4) and can be considered as a "theoretically average consumer" (Ingene and Parry, 2004, Chapter 11). The utility function implies that the value of using multiple substitutable packages is less than the sum of the separate values of using each package by itself (Samuelson, 1974). The consumer utility decreases as products become more substitutable. The utility function also encompasses the classical economic features of diminishing marginal rates of substitution and diminishing marginal utility.

The utility function specified in Eq. (1) provides the "logically consistent" demand curves when the number of distributors/channels changes (see Ingene and Parry, 2007). If there is no exclusive channel (Scenario AA), we have $ij = 1a, 1b, 2a, 2b$. If supplier 1 forms an exclusive deal with retailer a while supplier 2 and retailer b do not (Scenario EA), we have $ij = 1a, 2a, 2b$, and set $D_{1b} = 0$ in Eq. (1), as package $1b$ is not available owing to the exclusive deal. If supplier 2 forms an exclusive deal with retailer b while supplier 1 and retailer a do not (Scenario AE), we have $ij = 1a, 1b, 2b$, and $D_{2a} = 0$. If both $1a$ and $2b$ are exclusive (Scenario EE), we have $ij = 1a, 2b$, and $D_{1b} = D_{2a} = 0$. [1] In all these scenarios, maximizing Eq. (1) yields the demand for the available packages as follows:

$$D_{ij} = A_{ij} - \beta P_{ij} + \theta \sum_{mn \neq ij} P_{mn}, \tag{2}$$

where

$$\begin{aligned} A_{ij} &= \frac{(1+(N-2)\tau)\alpha_{ij} - \tau \sum_{mn\neq ij} \alpha_{mn}}{(1-\tau)(1+(N-1)\tau)}, \\ \beta &= \frac{1+(N-2)\tau}{(1-\tau)(1+(N-1)\tau)}, \\ \theta &= \frac{\tau}{(1-\tau)(1+(N-1)\tau)}, \end{aligned}$$

where N is the number of available packages. Everything else being equal, the demand for each package decreases with N. Obviously, price coefficient (β) and cross-price coefficient (θ) are affected by the package substitutability (τ) and the number of available packages (N). The demand intercept (A_{ij}) represents the "attractiveness" of package ij, which depends on the initial base demand (α_{ij}) and the total number of available packages (N) and the package substitutability (τ) (Ingene and Parry, 2004, Chapter 1). Desirably, the aggregate demand decreases in τ. This feature echoes the benefits of product differentiation, because more differentiated products/packages reach a larger customer base and consumers are less price-sensitive when purchasing a more unique item (Lus and Muriel, 2009; Talluri and van Ryzin, 2005, Chapter 8).

If there is a revenue sharing contract in the exclusive deal, the retailer needs to share a proportion of its corresponding service revenue with the supplier, because the customer who purchases the product has to buy the retailer's service. Let r_{ij} denote the revenue sharing rate that supplier i will obtain from its partner

[1] In Section A.2, we discuss an alternative model where consumers can still purchase an "excluded" package by incurring a switching cost.

retailer j if a customer purchases product i, and we have

$$r_{ij} = \begin{cases} r, & \text{if revenue sharing occurs between } i \text{ and } j \text{ in an exclusive deal,} \\ 0, & \text{otherwise.} \end{cases}$$

We discuss a different revenue sharing scheme where revenue sharing is also in place for nonexclusive channels in Section 3.4 and extend our discussion to price-dependent revenue sharing in Section A.4.

The operational and production costs for the two suppliers and the two retailers are normalized to zero for brevity, which has been adopted in the literature (McGuire and Staelin, 1983; Raju and Zhang, 2005). Consequently, supplier i's and retailer j's profit functions are

$$\begin{aligned} \Pi_i &= \sum_{j=a,b} (p_i + r_{ij}) D_{ij}, \ i = 1, 2, \\ \Pi_j &= \sum_{i=1,2} (p_j - r_{ij}) D_{ij}, \ j = a, b. \end{aligned} \tag{3}$$

We further denote $\Pi_{ij} = \Pi_i + \Pi_j$ and Π_{All} for the overall profit of the entire supply chain.

We configure this multichannel game into three stages. In the first stage, the channel structure is suggested by the suppliers via a contract (exclusive or not) with the retailers. If the exclusive deal(s) comes with a revenue sharing clause, the corresponding supplier and retailer will negotiate on the revenue sharing at the same time. In the second stage, the retailers decide whether to accept the contract. More specifically, in each channel, if the supplier proposes an exclusive contract and the retailer accepts it, then an exclusive deal is formed. However, if the retailer refuses or their negotiation on the revenue sharing rate fails, the supplier will sell through both retailers by default. If the supplier proposes a nonexclusive contract, then the retailer will have no choice but to follow a nonexclusive deal. It is straightforward that an exclusive deal will be formed only if both the supplier and the retailer benefit from such a deal. In the third stage, the retailers and the suppliers simultaneously determine their service rates and product prices, respectively, in each subgame (Scenarios EE, EA, AE, and AA). Note that in each scenario, each player maximizes its own profit in a Nash game, a game setting referred to as *independent ownership (IO) competition*. This game setting is widely employed in the extant marketing literature (see Economides and Salop, 1992; Ingene and Parry, 2004).[2] The solution to the three-stage game is a subgame perfect equilibrium and is solved by backward induction.

[2]In Section A.3, we study a benchmark game setting, composite package competition, where the ownership of the goods is transferred to each package such that each package optimizes its package profit (see Economides and Salop, 1992).

3 Channel Structures, Revenue Sharing, and Bargaining Solutions

To investigate the pure impact of channel structures on the players and the overall supply chain, we first explore the three-stage game without revenue sharing in Section 3.1. Motivated by the exclusive and revenue sharing deal between iPhone and AT&T, in Section 3.2, we employ revenue sharing to attain cooperation between suppliers and retailers in the exclusive deals. This allows us to investigate the potential equilibrium domain of exclusive deals under a given revenue sharing rate. We then provide bargaining solutions to determine the revenue sharing rate. We further extend our discussion to a different revenue sharing scheme where the retailers also share revenue with the suppliers in nonexclusive channels.

3.1 Effects of Channel Structures without Revenue Sharing

To single out the effects of channel structures, in this subsection we assume away revenue sharing ($r = 0$) and restore the feature from the next subsection. We first characterize each subgame/scenario in a Nash game and then study channel structure selection by the retailers and then by the suppliers. The unique equilibrium for each scenario, as illustrated in Table 1 in the Online Supplements, is solved from the four first-order conditions for both suppliers and both retailers. The entire game is solved backwards. Due to the symmetry, for brevity much of our discussion focuses on supplier 1 and retailer a, although supplier 2 and retailer b are also taken into consideration throughout the paper. Note that the equilibrium solutions of supplier 2 and retailer b in Scenarios EE and AA are the same as those of supplier 1 and retailer a, and the equilibrium solutions of supplier 2 and retailer b in Scenario EA are the same as those of supplier 1 and retailer a, respectively, in Scenario AE. We first compare the equilibrium prices of different scenarios in the following lemma.

Lemma 1 *If* $0 \leq \tau < 1/2$, *then*

$$p_1^{*EA} \leq p_1^{*AA} \leq p_1^{*EE} \leq p_1^{*AE} \quad \textit{and} \quad p_a^{*AE} \leq p_a^{*AA} \leq p_a^{*EE} \leq p_a^{*EA};$$

otherwise,

$$p_1^{*AA} \leq p_1^{*EA} \leq p_1^{*AE} \leq p_1^{*EE} \quad \textit{and} \quad p_a^{*AA} \leq p_a^{*AE} \leq p_a^{*EA} \leq p_a^{*EE}.$$

Lemma 1 indicates that product prices and service rates depend on package substitutability. If the packages are relatively more monopolistic than substitutable ($0 \leq \tau < 1/2$), the supplier charges a lower product price when entering an exclusive deal (i.e., $p_1^{*EA} \leq p_1^{*AA}$ and $p_1^{*EE} \leq p_1^{*AE}$). Otherwise, the reverse is true because of the more intense competition caused by stronger package substitutability, along with more available packages. On the other hand, the service rate is higher (i.e., $p_a^{*AE} \leq p_a^{*EE}$ and $p_a^{*AA} \leq p_a^{*EA}$ for any τ) when the retailer enters an exclusive deal, because the retailer becomes relatively more monopolistic and yields a greater demand due to the exclusive deal. This observation is supported by the fact that AT&T issued an expensive service plan for the iPhone, with a minimum monthly service rate of $59.99, $20 more than AT&T's standard wireless package (Yoffie and Slind, 2007).

Considering the package prices, we find that consumers have to pay higher package prices as a result of the exclusive deals between suppliers and retailers.

Theorem 1 *The package prices increase with the number of exclusive channels (i.e., $P_{1a}^{*AA} \leq P_{1a}^{*EA} = P_{1a}^{*AE} \leq P_{1a}^{*EE}$).*

The intuition behind Lemma 1 is clear, because fewer available packages lead to a more monopolistic market, which in turn pushes up the package prices. Nevertheless, as we will show in Section A.4 under price-dependent revenue sharing, the package prices can be lower with exclusive deals when package substitutability is low.

We now turn our attention to the channel structure selection by the suppliers and retailers. Comparing the profits of both suppliers and both retailers in different scenarios yields the following result.

Theorem 2 *Forming exclusive deals without revenue sharing is a weakly* dominant *strategy for both retailers; however, it is a* dominated *strategy for both suppliers. Thus, forming exclusive deals without revenue sharing* cannot *be an equilibrium.*

Theorem 2 suggests that a retailer will prefer an exclusive channel, regardless of whether the other supplier-retailer pair adopts an exclusive deal, provided that there is no revenue sharing. This result is supported by Lemma 1, in that the retailers can benefit from the more monopolistic market resulting from the exclusive deal(s) by charging higher service rates. In contrast, the suppliers will lose profits due to lower product prices and lower demand as a result of selling through an exclusive retailer. Therefore, no exclusive deal will be formed in this case, as it is not mutually beneficial for the suppliers or the retailers. This may explain why iPhone required a significant revenue sharing rate when promoting its exclusive deal (Yoffie and Slind, 2007). In a similar case, in 2005, Sprint agreed to pay approximately $50 million annually to be the NFL's exclusive wireless partner (Elberse et al., 2010).

An immediate question is whether the entire supply chain can benefit from an exclusive deal. Theoretically, an exclusive channel can be a mutually beneficial choice for both a supplier and a retailer only if the entire channel with the exclusive channel(s) is more Pareto efficient. Otherwise, there is no merit in forming an exclusive deal. The following theorem regarding overall supply chain efficiency provides a guideline for potential cooperation via revenue sharing.

Theorem 3 *For the entire supply chain, there exist two threshold values $\hat{\tau}_1$ and $\hat{\tau}_2$, such that*

$$\begin{cases} \text{AA dominates EA, AE and EE} & \text{if} \quad 0 \leq \tau < \hat{\tau}_1, \\ \text{EA and AE dominate EE and AA} & \text{if} \quad \hat{\tau}_1 \leq \tau < \hat{\tau}_2, \\ \text{EE dominates EA, AE, and AA} & \text{if} \quad \hat{\tau}_2 \leq \tau < 1. \end{cases}$$

Theorem 3 suggests that the entire supply chain can benefit from exclusive deals when package substitutability is high (i.e., $\tau \geq \hat{\tau}_2$ as illustrated in Figure 2). However, as shown in Theorem 2, the designated

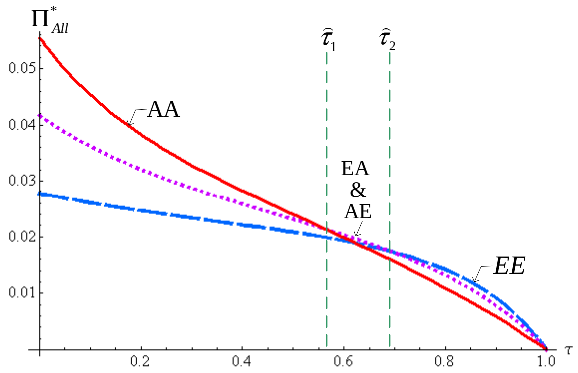

Figure 2: Entire supply chain profits in Scenarios EE, EA, AE, and AA.

supplier(s) in the exclusive deal(s) cannot benefit from the exclusive deal because of the noncooperative nature of the game, and the supplier(s) lose significant market share as they unilaterally stop selling through the other retailer. Ideally, if the additional supply chain profit from the exclusive deals can be redistributed among suppliers and retailers to generate sufficient incentives for suppliers and retailers to partner exclusively, then forming exclusive deals can be an equilibrium strategy for all players. However, the equilibrium will not occur without an additional contracting mechanism, such as revenue sharing. We next demonstrate that revenue sharing can indeed lead to such a mutually beneficial result from exclusive deals.

3.2 Impact of Revenue Sharing

Under revenue sharing, each retailer transfers a fixed payment of r to the exclusively partnered supplier for each package sold. Due to the complementary nature of our model, the revenue sharing works differently from the traditional models, for example, the famous Blockbuster revenue sharing deal, where Blockbuster shares partial revenue with its suppliers (i.e., movie studios) when the suppliers reduce the wholesale prices of their videos. In contrast, in the motivating example of the exclusive deal between iPhone and AT&T, the product and the service are complementary goods and the wholesaling is not mandatory, given that the supplier and the retailer determine their product price and service rate separately. AT&T shares revenue with iPhone because iPhone can be used only with AT&T. The profit functions are specified in Eq. (3). Following the game structure specified previously, we first characterize some properties of the equilibrium prices.

Lemma 2 *With revenue sharing, product prices decrease while service rates increase with the revenue sharing rate in Scenarios EE, EA, and AE. The package prices decrease in EA and AE but remain constant in EE as the revenue sharing rate grows.*

Lemma 2 shows that the product prices could be lower in an exclusive deal(s) after revenue sharing is employed, while service rates are pushed up, as the retailer(s) has to share revenue with the supplier(s). We, however, observe package prices decreasing with the revenue sharing rate in Scenarios EA and AE. This is because a higher revenue sharing rate renders additional advantages for the partnered supplier and retailer, which leads to a lower package price. Consequently, the price of their rival package reduces due to horizontal competition. On the contrary, in Scenario EE, the retailers increase their service rates by the amount of the shared revenue, thus package prices are restored to the level without exclusive deals. Therefore, consumers cannot benefit from revenue sharing in a dual-exclusive case (Scenario EE).

From the proof of Lemma 2, we can also infer that in Scenarios EE and AA, all players' profits are independent of the revenue sharing rate. With only one exclusive deal, such as in Scenario EA, the supplier's profit increases while the retailer's profit decreases as the revenue sharing rate grows. Intuitively, revenue sharing yields benefits to the supplier while it costs the retailer in the exclusive deal. The players not in the exclusive deal will be affected by revenue sharing too. For example, in Scenario AE, supplier 1 is pressured to reduce the product price because of supplier 2 doing so. Thus, supplier 1's profit decreases while retailer a's increases owing to the revenue sharing in the exclusive deal between supplier 2 and retailer b.

The major concern is whether the impact of revenue sharing in exclusive deals can lead to an equilibrium outcome where all players form exclusive deals. The following result affirms the answer.

Theorem 4 *For any given $\tau \in [0.34, 1)$, there exist $\hat{r}_1(\tau)$ and $\hat{r}_2(\tau)$ such that, forming exclusive deals is a subgame perfect equilibrium for all players (i.e., both suppliers and both retailers) as long as $\hat{r}_1(\tau) \le r \le \hat{r}_2(\tau)$.*

Theorem 4 demonstrates that forming exclusive deals with revenue sharing can be an equilibrium for all players. Without revenue sharing, as shown in Theorem 2, a supplier has no incentive to form an exclusive deal because, in doing so, the total demand for the supplier's product significantly decreases due to there being fewer available packages that contain the supplier's product. This relative disadvantage of less demand due to an exclusive deal, however, can be compensated and even surpassed by a reasonable amount of revenue being transferred from the retailer, such that both the supplier and the retailer are better off for forming an exclusive deal. Compared with Scenario AA, the first exclusive deal with revenue sharing yields additional profits to the corresponding supplier and retailer. However, this result comes at the cost of the other supplier-retailer pair when package substitutability is sufficiently high and consequently pressures them to forge another exclusive deal, which thus results in Scenario EE. The range of $\hat{r}_1(\tau) \le r \le \hat{r}_2(\tau)$ provides a guideline for such an equilibrium revenue sharing rate, if all players are determined to form exclusive deals. In general, the more substitutable the packages, the lower the revenue sharing rate required to sustain the equilibrium, because the retailers' profits decrease as package substitutability grows.

However, reaching equilibrium does not necessarily warrant maximal efficiency for the entire supply chain. We depict Theorem 4 in Figure 3 and compare it with Figure 2. We find the equilibrium area of

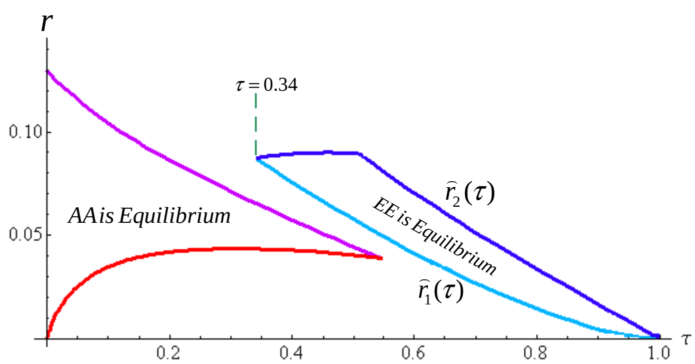

Figure 3: The equilibrium area of Scenarios EE with revenue sharing.

Scenario EE goes beyond the Pareto efficient area of Scenario EE as illustrated in Figure 2. With revenue sharing, the players are more inclined to form exclusive deals, due to the relative disadvantage of not doing so, when the other supplier-retailer pair forms an exclusive deal (i.e., in Scenarios EA and AE). From

Figure 3, we also observe that Scenario AA can be an equilibrium when channel substitutability is low, which is reasonable because the players prefer more available packages when those packages are sufficiently monopolistic. Note that we do not observe any equilibrium result for Scenarios EA and AE, because the disadvantaged players have incentives to unilaterally deviate to other scenarios. Nevertheless, it could be mutually beneficial for a supplier and a retailer to form an exclusive and revenue sharing deal on their own, although a single exclusive deal might not be stable in this symmetric competitive market.

3.3 Bargaining Solutions

In the above mentioned revenue sharing mechanism, the retailers in exclusive deals are required to transfer a fixed amount of revenue to the suppliers. Typically, the revenue sharing rate(s) is negotiated before being signed into the contract (in the first stage of the game). We first consider the case where only supplier 1 and retailer a negotiate for the exclusive deal. If their negotiation leads to an agreement, the destination scenario of the negotiation is EA; otherwise, they end up with Scenario AA. Thus, the negotiated revenue sharing rate can be solved by the classic Nash bargaining solution as follows:

$$\max_{r_{1a}} [\Pi_1^{EA}(r_{1a}) - \Pi_1^{AA}(r_{1a})][\Pi_a^{EA}(r_{1a}) - \Pi_a^{AA}(r_{1a})].$$

Substituting the third-stage solutions derived in the proof of Lemma 2 into the objective function above, we can obtain the Nash bargaining solution r_{1a}^{*EA}. Although the expression of r_{1a}^{*EA} is extremely lengthy, we can numerically observe that the revenue sharing rate, r_{1a}^{*EA}, decreases from 0.08 to 0 as τ increases from 0 to 1. Therefore, to obtain tractability, we also explore the egalitarian bargaining solution to obtain the revenue sharing rate as follows:

$$\Pi_1^{EA}(r_{1a}) - \Pi_1^{AA}(r_{1a}) = \Pi_a^{EA}(r_{1a}) - \Pi_a^{AA}(r_{1a}).$$

The egalitarian bargaining solution, introduced by Kalai and Smorodinsky (1975) and Kalai (1977), drops the scale invariance condition while including both the axiom of independence of irrelevant alternatives and the axiom of monotonicity (see Myerson, 1997, page 381). The egalitarian bargaining solution attempts to grant equal gain to both parties (see Dukes et al., 2006; Myerson, 1997, page 381). After substituting the third-stage solutions derived in the proof of Lemma 2 into the egalitarian bargaining solution function above, we obtain

$$r_{1a}^{*EA} = \frac{\sqrt{G_1} + G_2}{G_3},$$

where

$$G_1 = \left(45 + 61\tau - 73\tau^2 - 77\tau^3 + 32\tau^4 + 12\tau^5\right)^2 \left(432 + 1908\tau + 3001\tau^2 + 1998\tau^3 + 541\tau^4 + 68\tau^5 + 4\tau^6\right),$$

$$G_2 = -450 - 1755\tau - 1666\tau^2 + 1294\tau^3 + 2714\tau^4 + 761\tau^5 - 550\tau^6 - 308\tau^7 - 40\tau^8,$$
$$G_3 = 8\left(747 + 3231\tau + 4119\tau^2 - 75\tau^3 - 3266\tau^4 - 1268\tau^5 + 544\tau^6 + 288\tau^7 + 32\tau^8\right).$$

We can further observe that the revenue sharing rate, r_{1a}^{*EA}, decreases from 0.081 to 0 as τ increases from 0 to 1, which is very close to the Nash bargaining solution.

We now consider the second case where channels 1a and 2b are simultaneously involved in the negotiation of exclusive deals. As a result, in the negotiation stage neither supplier-retailer pair knows the other pair's negotiation outcome. Therefore, the members of each channel negotiate based on their perception of the negotiation outcome of the rival channel. We assume that a supplier-retailer pair negotiates on the revenue sharing rate conceiving that the other pair will reach an agreement. This assumption is in line with Dukes et al. (2006), O'Brien and Shaffer (1992, 2005), and Horn and Wolinsky (1988). It is also consistent with Theorem 4, in that EE will be an equilibrium as long as $\hat{r}_1(\tau) \leq r \leq \hat{r}_2(\tau)$ given $\tau \in [0.34, 1)$ and is supported by the following bargaining solution. Thus, the negotiated revenue sharing rates are given by the egalitarian bargaining solution of the following problems for channels 1a and 2b, respectively,

$$\Pi_1^{EE}(r_{1a}, r_{2b}) - \Pi_1^{AE}(r_{1a}, r_{2b}) = \Pi_a^{EE}(r_{1a}, r_{2b}) - \Pi_a^{AE}(r_{1a}, r_{2b}),$$
$$\Pi_2^{EE}(r_{1a}, r_{2b}) - \Pi_2^{EA}(r_{1a}, r_{2b}) = \Pi_b^{EE}(r_{1a}, r_{2b}) - \Pi_b^{EA}(r_{1a}, r_{2b}).$$

Based on the symmetry assumption, we obtain

$$r_{1a}^{*EE} \equiv r_{1a}^{*} = r_{2b}^{*} = \frac{T_1 - T_2\sqrt{2(1+\tau)}}{T_3},$$

where

$$T_1 = 225 + 855\tau + 690\tau^2 - 808\tau^3 - 1197\tau^4 - 131\tau^5 + 266\tau^6 + 92\tau^7 + 8\tau^8,$$
$$T_2 = 135 + 453\tau + 237\tau^2 - 547\tau^3 - 512\tau^4 + 74\tau^5 + 136\tau^6 + 24\tau^7,$$
$$T_3 = 252 + 1188\tau + 1704\tau^2 + 456\tau^3 - 460\tau^4 - 12\tau^5 + 56\tau^6 - 80\tau^7 - 32\tau^8.$$

We observe that the unique revenue sharing rate, r_{1a}^{*EE}, decreases from 0.13 to 0 as τ increases from 0 to 1. Comparing r_{1a}^{*EA} with r_{1a}^{*EE}, we find that $r_{1a}^{*EE} > r_{1a}^{*EA}, \forall \tau \in [0, 1)$. The difference between r_{1a}^{*EE} and r_{1a}^{*EA} decreases with τ and converges to zero as τ approaches 1. The above inequality suggests that the perception that the other supplier-retailer pair will reach an exclusive deal agreement poses a threat to the retailer. As a result, this retailer is willing to share more revenue with the partnered supplier.

It is worth noting that the above results come from bilateral negotiation, thus an agreement on r_{1a}^{*EA} or r_{1a}^{*EE} does not warrant an equilibrium outcome for the dual-exclusive channels (Scenario EE). Nevertheless, we find that $\hat{r}_1(\tau) \leq r_{1a}^{*EE} \leq \hat{r}_2(\tau)$ as long as $\tau \in [0.34, 1]$ which is located in the domain specified by

Theorem 4. Therefore, the egalitarian bargaining solution for revenue sharing can lead to an equilibrium outcome.

3.4 Impact of Revenue Sharing under Nonexclusivity

So far, we have studied the case where revenue sharing comes only with exclusive deals. Theoretically, one may wonder whether the players still have incentives to form exclusive deals if revenue sharing is also in place under nonexclusivity. To explore this situation, in this subsection, we assume both retailers share revenue with their suppliers regardless of whether or not there are exclusive deals. The new revenue sharing rate, r_{ij}, that supplier i will obtain from its partner retailer j is given by

$$r_{ij} = \begin{cases} r, & \text{if supplier } i \text{ and retailer } j \text{ form an exclusive deal,} \\ \rho r, & \text{otherwise; } 0 \leq \rho \leq 1, \end{cases}$$

where ρ represents the relative level of revenue sharing under nonexclusivity as compared with under exclusivity. We impose an additional constraint that $0 \leq \rho \leq 1$, which reflects the conventional wisdom that a supplier would demand a (weakly) higher revenue sharing rate under exclusivity than under nonexclusivity. To focus on the impact of revenue sharing under nonexclusivity and make our following discussion more interesting and comparable with our main model, we further assume that the given revenue sharing rate r satisfies $\hat{r}_1(\tau) \leq r \leq \hat{r}_2(\tau)$ as discussed in Theorem 4. It is easy to infer that our previously discussed revenue sharing scheme is a special case of this new revenue sharing scheme when $\rho = 0$.

Comparing the players' profits among scenarios in this new revenue sharing scheme results in the following observation.

Theorem 5 *For any given r satisfying $\hat{r}_1(\tau) \leq r \leq \hat{r}_2(\tau)$ given $\tau \in [0.34, 1)$, forming exclusive deals becomes less likely to be a subgame perfect equilibrium as the relative level (ρ) of revenue sharing under nonexclusivity increases.*

Theorem 5 indicates that the players' willingness to form exclusive deals is negatively affected by the relative revenue sharing level ρ in those nonexclusive channels. As suggested by Theorem 4, when $\rho = 0$, forming exclusive deals is a subgame perfect equilibrium for a given r satisfying $\hat{r}_1(\tau) \leq r \leq \hat{r}_2(\tau)$ for $\tau \in [0.34, 1)$. In contrast, when $\rho = 1$ (i.e., the revenue sharing rate is the same under exclusivity and nonexclusivity), all players' profits are independent of the revenue sharing rate. This somewhat surprising finding is caused by the symmetric channel structure of the complementary goods market. When the revenue sharing rate is the same in all channels, a supplier gains no advantage from entering an exclusive deal. Particularly, the package prices are independent of the revenue sharing rate, because the increase in service rates offsets the decrease in product prices. Thus, the demand and profits are equivalent to the case without revenue sharing. Recall in Theorem 2 without revenue sharing, forming exclusive deals is a dominated strategy for the suppliers. In the proof of Theorem 5, we show that supplier 1's profit difference between Scenario EE and Scenario AE decreases with ρ and changes from positive to negative. This property posits that a supplier's relative benefit from entering an exclusive deal diminishes as ρ increases and becomes negative as ρ crosses a threshold value. As a result, it becomes more likely that a supplier would unilaterally deviate from Scenario EE as ρ increases.

It is worth noting, however, that the retailers prefer exclusive deals for any $\rho \in [0, 1]$ given $\hat{r}_1(\tau) \leq r \leq \hat{r}_2(\tau)$, as shown in the proof of Theorem 5. In addition, their desire for exclusive deals is strengthened as ρ increases. This is intuitive because, without an exclusive deal with its partner supplier, a retailer's profit decreases with a higher revenue sharing rate under nonexclusivity. As a result, this (nonexclusive) retailer can benefit more from exclusively selling a supplier's product when ρ is higher. However, the relative advantage that this retailer gains by forming an exclusive deal is at the cost of its partnered supplier. As shown previously, when ρ is larger than a threshold value, exclusive deals are no longer attractive to the suppliers and, hence, EE is not a subgame perfect equilibrium.

4 Conclusion and Discussion

This paper develops a hybrid model with duopoly common retailers and exclusive channels to evaluate the impact of exclusive channels and revenue sharing on suppliers and retailers in a competitive multichannel market with complementary goods. The products are complementary to the services, therefore, there are four potential substitutable packages. We compare four different channel structures with/without revenue sharing. Our analysis establishes a theoretical framework to analyze similar multichannel competition in a complementary goods market.

This paper characterizes the game behavior in noncooperative and cooperative environments to explore the players' profit-maximization behavior and achieve optimal Pareto efficiency for the entire supply chain. We first demonstrate that without revenue sharing, it is a dominated strategy for both suppliers to form exclusive deals. However, if the retailers share a portion of their revenues with the suppliers, forming exclusive channels can be an equilibrium strategy for both suppliers and both retailers. We also provide bargaining solutions to determine the revenue sharing rate through negotiation. In an extended model with revenue sharing under both exclusivity and nonexclusivity, we further show that forming exclusive deals becomes less likely to be an equilibrium as the relative revenue sharing level under nonexclusivity increases.

Our extended discussion, as presented in the Appendix, indicates that, if a supplier/retailer is much stronger than its rival in the market, the supplier/retailer will be reluctant to form an exclusive and revenue sharing deal. We also analyze an alternative model with fencing and demonstrate that a price-out strategy is equivalent to an exclusive deal in our main model.

We further consider composite package competition, where both players in the same package maximize the overall profit of the package. Our results demonstrate that, compared with the base model, overall supply chain efficiency is lower under composite package competition when package substitutability is sufficiently high. This occurs because the horizontal competition intensifies as the externalities between package partners are internalized under composite package competition.

Moreover, our analysis suggests that a revenue sharing rate that is associated with the product price and the service rate can yield more profits for the suppliers and the retailers. Indeed, enhanced by price-dependent revenue sharing, the entire supply chain becomes more efficient such that it outperforms the one with integrated channels in the entire feasible domain. This result occurs because price-dependent revenue sharing provides a cushion to lessen the horizontal competition among packages.

However, as no single model can capture every relevant aspect of an actual scenario, we hope that our paper provides a stylized, yet flexible, framework that opens up numerous possibilities for generalization on this topic. Due to the complexity of the model, to capture some important managerial insights, parsimony has been kept in mind when constructing the model, though undoubtedly some interesting and important marketing mixes had to be deliberately left out.

Demand function and channel structure. Although the underlying utility function in our model has been widely adopted in the existing literature, as Ingene and Parry (2004) point out, other factors, such as uncertainty, can affect game behavior. In addition, other nonlinear utility functions would allow us to examine more aspects of the model. As Ingene and Parry (2004) suggest, dual channels may be sufficient to capture many important features of market competition. However, a multi-supplier-multi-retailer model may better describe most complementary goods markets. Although it may be very difficult to gain any analytical insights from such a model, some simulation or empirical analysis could provide additional managerial insights. Furthermore, it may be useful to consider more than one product/service owned by each supplier/retailer.

Subsidies and other promotions. Competition in the wireless market is so intense that companies continuously provide rebates, coupons, and online discounts to promote their products/services both with and without exclusive channels. As a result, consumers may get free phones or even payback for cheaper models. In a preliminary analysis based on our model, by assuming both retailers provide uniform subsidies to the consumers, we find that the players' profits and the overall supply chain efficiency are the same as those in a model without subsidies. This result is intuitive because the subsidy providers simply increase the product prices/service rates on the same scale as the subsidies to compensate for the revenue loss. However, we can easily conjecture that if the retailers/suppliers discriminate against consumers by providing different subsidies to different groups, the entire supply chain's profits can increase. This is consistent with the conventional wisdom that price discrimination enhances revenue. Some marketing tools, such as non-instant rebates, can be used for that purpose, and we believe that our main managerial insights would hold under subsidies and other promotions.

Dynamic settings. Although, for tractability, one-period models have been widely adopted in the marketing literature, in reality, the market status of the players, including their bargaining power, is changing over time. It is also arguable that the change of channel structure may have delayed effects on future demand. Accordingly, related research questions might include: How does the diffusion speed and/or the lifespan of certain products affect exclusive deals? How does one incorporate customers' awareness of a product into the dynamics of the demand function? Is product innovation significantly affected by exclusive deals? To understand these issues, a more dynamic and complicated model needs to be studied and the analysis will be much more challenging.

Contract formats. This paper shows that revenue sharing can be utilized to further enhance supply chain efficiency. However, revenue sharing is not the only contract that can fulfill the task. We believe that other contract formats, such as two-part tariffs (Ingene and Parry, 2004; Raju and Zhang, 2005) and quantity discount schedules (Jeuland and Shugan, 1983), can also improve the performance of similar supply chains, although they are not well documented in a model with complementary goods.

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Appendix

In this appendix, we extend our discussion to asymmetric suppliers/retailers, an alternative model with fencing, composite package competition, and an enhanced price-dependent revenue sharing mechanism.

A.1 Asymmetric Suppliers/Retailers

In the foregoing analysis, the symmetry assumption has been imposed for the purpose of tractability. In reality, consumer preference for one supplier's product might be higher than that for the other one, which would positively affect the consumption of the particular service. In this subsection, we investigate the impact of asymmetries of suppliers and retailers in the presence of revenue sharing, as shown in Sections 3.2. We define u_i as the percentage of consumers preferring product i to $3-i$, while v_j denotes the percentage of consumers preferring service j to $\bar{j}$. We have $u_i + u_{3-i} = 1$ and $v_j + v_{\bar{j}} = 1$. Thus, in line with Dukes and Liu (2010), the relative base demand for package ij can be rewritten as

$$\alpha_{ij} = u_i \times v_j.$$

We incorporate this new base demand into the utility function of Eq. (1) and follow the same analysis procedures as in Section 3.2. Due to the computational complexity, we only illustrate the impact of asymmetry on supplier 1 and retailer a through Figures 4 and 5. To examine whether Scenario EE is a mutually beneficial choice for both supplier 1 and retailer a, we compare their corresponding profits between Scenarios EE and AE as u_1 and v_a vary, respectively. Thus, we first fix $v_a = 1/2$ and let u_1 float in Figure 4, and then fix $u_1 = 1/2$ and let v_a float in Figure 5.

Figures 4 and 5 demonstrate that forming exclusive deals can still be an equilibrium for all players, which is consistent with Theorem 4. On the one hand, the result further indicates that the retailer can benefit from partnering with a more powerful supplier in the exclusive deal; whereas this supplier cannot benefit from such an exclusive deal when it becomes sufficiently more powerful than the rival supplier, as illustrated

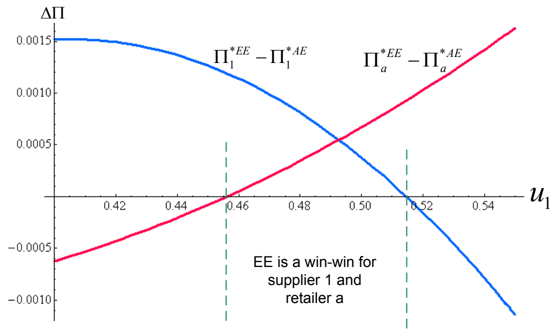

Figure 4: Profit comparison with asymmetric suppliers (u), where $\tau = 0.6$ and $r = 0.05$.

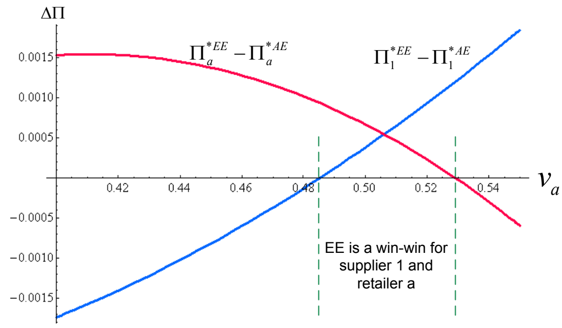

Figure 5: Profit comparison with asymmetric retailers (v), where $\tau = 0.6$ and $r = 0.05$.

in Figure 4. On the other hand, as depicted in Figure 5, the supplier benefits from partnering with a more powerful retailer in the exclusive deal; whereas the retailer will be reluctant to form such an exclusive deal as it becomes sufficiently more powerful than the rival retailer. This is supported by the fact that iPhone was eager to form an exclusive deal with the biggest service carrier in a country when it was first launched, as its market share was relatively small. However, not every retailer is willing to form such an alliance. For example, China Mobile, whose market share is 70% in China, declined an exclusive deal with iPhone in 2007 (Chan, 2008).

A.2 An Alternative Model with Fencing

Our previous discussion was based on a stylized model with exclusive channels, where consumers cannot utilize the exclusive product with another service outside the exclusive deal. This is a reasonable assumption, especially in the wireless market of the U.S. and other countries, because it is illegal to hack an exclusive product to make it usable with a non-exclusive service.[3] However, the exclusivity might be mitigated by different versions in other countries. For example, Deutsche Telekom AG's T-Mobile was picked to exclusively sell iPhone at US$557 to its customers in Germany. Nevertheless, T-Mobile also sold an unlocked iPhone for US$1,478, which can be used with other service carriers (Pearce, 2007). In this sense, iPhone is no longer purely exclusive but becomes a phone with fencing against its undesired market segment. For consumers wanting to cross the fence, a switching cost will be incurred. In the above T-Mobile example, a switching cost of $921 can be considered prohibitively high and our original model sustains for this situation. Nevertheless, this paper is positioned for a wider application beyond the wireless market; for example,

[3]If hacking is possible, the hacking cost can be considered as the switching cost in this alternative model.

using a bankcard in a non-network ATM normally triggers a transaction cost. In another related example, an e-book reader who only has Nook and wishes to read an exclusive Kindle e-book must incur extra costs to transform the Kindle e-book format to be compatible with Nook. Hereby, we elaborate an alternative model with fencing.

In this alternative model with fencing, consumers have access to all four packages. The "exclusive" channel is the one with fencing, and the switching cost is equivalent to the disutility (e.g., penalty or transaction cost) incurred by the switchers. If there is no exclusive channel, consumers can freely select any package. However, if product i is sold exclusively through its partnered retailer, consumers incur a switching cost if a different retailer is chosen. We denote the switching cost as s_{ij} which can be written as:

$$s_{ij} = \begin{cases} k, & \text{if } i \text{ is exclusively sold through } \bar{j}, \\ 0, & \text{otherwise}. \end{cases}$$

For tractability, we assume the same switching cost k for all packages in the exclusive deals, which is typical in the finance market, as in the example of ATMs and bankcards. Note that this assumption does not change our results qualitatively. Thus, the original utility function of Eq. (1) is changed to

$$U \equiv \sum_{ij}(\alpha_{ij}D_{ij} - D_{ij}^2/2) - \tau \sum_{ij \neq mn} D_{ij}D_{mn}/2 - \sum_{ij}(P_{ij} + s_{ij})D_{ij}. \tag{A-1}$$

Maximization of Eq. (A-1) yields the demand for each channel as follows:

$$D_{ij} = A_{ij} - \beta(P_{ij} + s_{ij}) + \theta \sum_{mn \neq ij}(P_{mn} + s_{mn}), \tag{A-2}$$

where

$$\begin{aligned} A_{ij} &= \frac{(1+2\tau)\alpha_{ij} - \tau \sum_{mn \neq ij} \alpha_{mn}}{(1-\tau)(1+3\tau)}, \\ \beta &= \frac{1+2\tau}{(1-\tau)(1+3\tau)}, \\ \theta &= \frac{\tau}{(1-\tau)(1+3\tau)}. \end{aligned}$$

Without loss of generality, we assume the revenue from the switching costs goes to the suppliers.[4] The profit functions are given by

$$\Pi_i = \sum_{j=a,b}(p_i + r_{ij} + s_{ij})D_{ij},$$

[4]We can prove that all qualitative results hold even if the revenue from the switching cost goes to either the retailers or a third party.

$$\Pi_j \quad = \quad \sum_{i=1,2} (p_j - r_{ij}) D_{ij}. \tag{A-3}$$

As revenue sharing does not alter our qualitative results, we let $r_{ij} = 0$.

We now introduce a *price-out strategy* to study the corner solution where, as the switching cost grows, demand for package $1b$ and/or package $2a$ in Scenarios EE, EA, and AE approaches zero, respectively. For example, the retailer or the supplier, such as T-Mobile Germany or Apple, can set a switching cost high enough to *price-out* the demand for package $1b$ in Scenario EA. The same technique was originally introduced by O'Brien and Shaffer (1993) for a scenario with two suppliers and a common retailer. In the following, we first compare Scenarios EE, EA, AE, and AA assuming that the switching cost is sufficiently low, and then utilize a price-out strategy in Scenarios EE, EA, and AE.

Theorem 6 *In Scenarios EE, EA, AE, and AA with fencing, consider the entire supply chain.*

1. *For any switching cost lower than that of the price-out strategy, the overall supply chain efficiency is higher with more nonexclusive packages (i.e.,* $\Pi^{*EE}_{All} \leq \Pi^{*EA}_{All} = \Pi^{*AE}_{All} \leq \Pi^{*AA}_{All}$*).*
2. *Using the price-out strategy, this alternative model with fencing converges to our main model with exclusive channel(s).*

Intuitively, if the switching cost equals zero, all scenarios perform the same as Scenario AA. As the switching cost grows, the entire supply chain profit in Scenario EE decreases (more significantly than in Scenarios EA and AE), thus Scenarios AA, AE, and EA outperform Scenario EE. The inferiority of Scenario EE to Scenarios EA/AE is attributed to lower demand in the entire supply chain due to higher switching costs.

In the corner solution using the price-out strategy, we observe that all the equilibrium solutions of this alternative model are the same as those in Lemma 1. That is to say, *the price-out strategy restores all the features of our main model with exclusive channel(s)* specified in Section 2. In fact, both models have zero demand for the unavailable packages, because the price-out switching cost completely blocks demand for those undesired packages. Therefore, all previous analyses with exclusive channel(s) hold for the case with fencing, as long as the switching cost is set sufficiently high to block switching demand.

It is worth noting that this alternative model with fencing provides a more flexible extension of our original model. Recall the results in Figure 2, which are equivalent to the outcomes of the price-out strategy with fencing in this alternative model. If $\tau \geq 0.6901$, the players may employ the price-out strategy in both exclusive channels; if $0.5633 \leq \tau < 0.6901$, the price-out strategy is implemented in only one channel while zero switching cost is utilized in other channels; and if $\tau < 0.5633$, the players remove the fencing from all packages. As a result, the entire supply chain obtains Pareto efficiency in the entire domain (i.e., $\tau \in [0, 1)$).

A.3 Composite Package (CP) Competition

So far throughout the paper, our main focus has been on the *independent ownership (IO) competition* where each player maximizes its own profit. To provide a useful benchmark for "understanding the basic economic forces" (Economides and Salop, 1992), we explore composite package (CP) competition, where each composite package is assumed to be produced by a different firm ij, $ij = 1a, 1b, 2a, 2b$. In this sense, the product and service are integrated in the same package. Extending from Economides and Salop (1992)'s focus on a case similar to Scenario AA of this paper, we explore all four scenarios, EE, EA, AE, and AA. Due to the centralization feature of each package, no revenue sharing ensues under CP competition. We hence compare the four scenarios under IO competition and CP competition without revenue sharing. The comparison provides an insight into why firms would maximize their own profits noncooperatively rather than their joint channel profits cooperatively in a complementary goods market.

Again, we start from equilibrium prices.

Lemma 3 *In CP competition, the package prices increase with the number of exclusive channels (i.e., $P_{1a}^{*AA} \leq P_{1a}^{*EA} = P_{1a}^{*AE} \leq P_{1a}^{*EE}$). The package prices are always lower than those in IO competition for all scenarios EE, EA, AE, and AA.*

The first part of this lemma is similar to Theorem 1, because the fewer the available packages resulting from greater numbers of exclusive channels, the more monopolistic the market. In fact, CP competition is similar to competition among integrated channels in terms of packages. The comparison of the package prices under CP competition with those under IO competition suggests package competition becomes more intense horizontally without vertical externalities, which leads to lower package prices in CP competition.

Similar to Theorem 3, we compare the overall supply chain efficiency of different scenarios in CP competition.

Lemma 4 *For the entire supply chain in CP competition, there exist two threshold values $\hat{\tau}_3$ and $\hat{\tau}_4$, such that*

$$\begin{cases} \textit{AA dominates EA, AE and EE} & \textit{if} \quad 0 \leq \tau < \hat{\tau}_3, \\ \textit{EA and AE dominate EE and AA} & \textit{if} \quad \hat{\tau}_3 \leq \tau < \hat{\tau}_4, \\ \textit{EE dominates EA, AE, and AA} & \textit{if} \quad \hat{\tau}_4 \leq \tau < 1. \end{cases}$$

Comparing this result with Theorem 3, we notice that it is more likely for Scenario EE to outperform other scenarios in CP than in IO competition, because $\hat{\tau}_4 = 0.4468 < \hat{\tau}_2 = 0.6901$. This is because the horizontal competition among packages is more intense in CP competition due to the lack of an intermediary vertical cushion, which becomes more apparent as package substitutability grows. Therefore, when package substitutability is high, reducing the number of competing packages in CP competition is more efficient in improving overall supply chain efficiency than that in IO competition. Nevertheless, when package substitutability is sufficiently low, the benefit of package price reduction outweighs that of intensified horizontal package competition. As a result, Scenario AA becomes more efficient in CP than in IO competition. To show this, we compare the best performance among all scenarios of CP competition with the best performance among all scenarios of IO competition in the following.

Theorem 7 *Among all scenarios, EE, EA, AE, and AA, for the entire supply chain, the best CP case outperforms the best IO case if and only if package substitutability is sufficiently low.*

While we might have expected better performance from an integrated package channel structure, Theorem 7 is somewhat counterintuitive. The explanation is that while the externalities between package partners are internalized, the more intense horizontal competition reduces the players' profits. This observation is supported by Lemma 3 where the package prices become lower in CP competition than in IO competition. The horizontal competition effect is particularly apparent when the packages are relatively more substitutable. As the packages become more monopolistic, the entire supply chain benefits from fewer externalities in CP competition and, thus, outperforms the one in IO competition. We more vividly illustrate Theorem 7 in Figure 6, which shows that the IO case outperforms the CP case as long as $\tau > 0.1429$; otherwise, the reverse is true.

As ownership in CP competition is vague, we cannot induce the individual optimal selection of the channel structure without knowing the revenue redistribution structure among the players. Nevertheless, with an appropriately-defined payment transfer mechanism, whether forming exclusive deals is a better

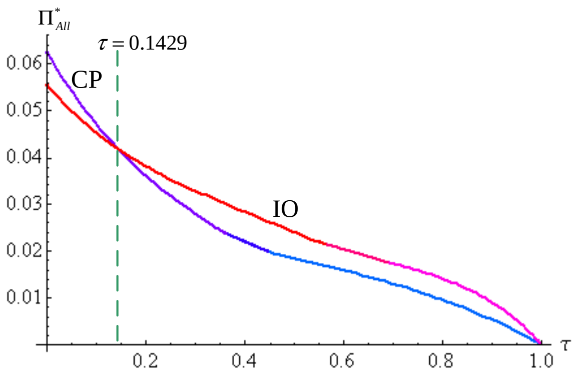

Figure 6: Comparison of the best performance of entire supply chain among all scenarios between CP and IO competition.

choice can be determined accordingly. From Theorem 3 and Lemma 4, we can infer that the entire supply chain with exclusive channels can outperform the one without. If we allow the players to select the best case in any situation under IO and CP competition, Theorems 3 and 7 suggest the players would choose to form exclusive deals under IO competition rather than CP competition.

A.4 Enhanced Revenue Sharing and Supply Chain Efficiency

Motivated by the revenue sharing employed by Blockbuster (Cachon and Lariviere, 2005) and wireless content messaging (Foros et al., 2009), we hereby propose a price-dependent revenue sharing scheme. The following discussion is provided to shed some light on the possibility of enhancing supply chain efficiency and to attract more comprehensive analyses on similar areas in the future.

To showcase the efficacy of enhanced revenue sharing, we focus on Scenario EE.[5] We compare three cases: Case IO, Case CP, and Case O. *Case IO* is in IO competition. *Case CP* is in CP competition, which resembles an integrated version of McGuire and Staelin (1983), where the supplier and the retailer are vertically integrated in each exclusive channel. Case O is an *optimized* case where our enhanced revenue sharing mechanism is implemented. We use superscripts IO, CP, and O to denote Cases IO, CP, and O, respectively. We assume the shared revenue is associated with the unit revenue difference between the

[5]It is worth noting that enhanced revenue sharing becomes computationally intractable in Scenarios EA and AE. Moreover, ownership for the exclusive channel coordination is ambiguous in asymmetric channel structures.

service and the product, as the product and the service are *complementary*.[6] We have

$$r_{ij} = r_0 + \eta(p_j - p_i), \quad ij = \{1a, 2b\}, \tag{A-4}$$

where η is a price coefficient. A base revenue sharing rate r_0 is similar to the revenue sharing discussed in Section 3.2. It is reasonable to argue that the retailer will share more revenue with the supplier if its service rate is higher or if the supplier is willing to reduce its product price to boost demand, or vice versa. We apply the above price-dependent revenue sharing to Scenario EE and find a value of η that optimizes the profit of each individual channel.

Lemma 5 *In Case O, each channel of EE is optimized when*

$$\eta^* = \frac{1-2\tau}{2-2\tau}.$$

The optimal profits are given by

$$\Pi_1^{*EE} = \Pi_a^{*EE} = \frac{1}{128+128\tau}.$$

Note that this revenue sharing mechanism optimizes each exclusive channel, as well as the entire supply chain. Given the symmetric setting, the revenue sharing rate does not appear in the players' profits, because these equally powerful players in the same channel claim their profit shares by adjusting their own prices/rates symmetrically, conditional on the revenue sharing contract.

Comparing Case O with Cases IO and CP, we obtain the following result.

Theorem 8 *For the entire supply chain in Scenario EE, Case O outperforms Cases IO and CP.*

The result of comparing Case O with Case IO is relatively straightforward. This is because enhanced revenue sharing provides a price-dependent interactive cushion between the supplier and the retailer in each exclusive deal. If the packages are more substitutable (i.e., $\tau > 1/2$), the suppliers will be willing to reduce the revenue sharing rate to lessen the retailers' pressure on revenue sharing; if the packages are more monopolistic (i.e., $\tau < 1/2$), the retailers will share more of the revenue resulting from the relatively higher service rates with the suppliers.

[6]This revenue sharing mechanism is not the only one that can optimize the entire supply chain of Scenario EE. For example, an alternative revenue sharing mechanism can be $r_{ij} = r_0 - \eta p_i$ or $r_{ij} = r_0 + \eta p_j$. However, these alternative mechanisms do not equally distribute the additional revenue among the players, a feature that resembles the symmetric Nash bargaining result.

The better performance of Case O over Case CP in the entire domain is worth emphasizing. As we previously argued, Case CP is an integrated version of Scenario EE. An integrated channel is normally considered the ultimate result of any coordination, which is true for single-channel supply chains. However, this conventional picture is altered under channel competition. As Theorem 8 demonstrates, Case O always dominates Case CP. This result occurs because, after erasing the internal externalities, the integrated channels can compete more intensely horizontally. As illustrated in Figure 7, Case IO outperforms Case CP when

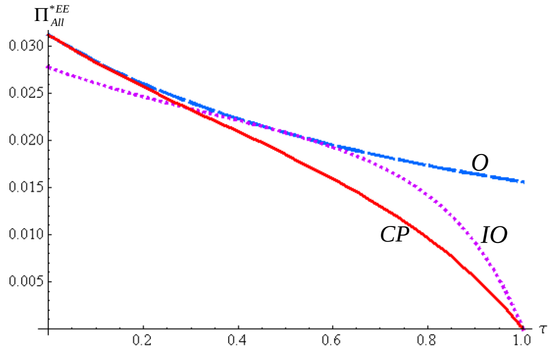

Figure 7: Entire supply chain profit comparison in Scenario EE under O, IO, and CP.

the packages are sufficiently substitutable, which is consistent with McGuire and Staelin (1983) although in a different setting. Enhanced revenue sharing provides a price-dependent cushion against fierce horizontal competition and, thus, enables each exclusive channel, as well as the entire supply chain, to eventually dominate the integrated dual-channel Case CP in the entire domain.

Figure 7 delivers additional messages. First, Case O is equivalent to Case CP if the packages are purely monopolistic, as the horizontal competition disappears. Second, Case O is equivalent to Case IO when $\tau = 1/2$. This is because the price-dependent cushion of enhanced revenue sharing is suppressed at this middle point. Otherwise, Case O has more advantages over Case IO as the packages become either more monopolistic or more substitutable. The effectiveness of enhanced revenue sharing becomes more significant as the packages converge to pure substitutes. This result suggests that enhanced revenue sharing can significantly buffer horizontal competition as package substitutability grows.

Consider the package prices. As previously demonstrated in Lemmas 1 and 3, package prices in Scenario EE are strictly higher than those in Scenario AA in both IO and CP competition. However, as we show next, if enhanced revenue sharing is employed, higher package price concerns in exclusive deals can be alleviated, if package substitutability is relatively low.

Corollary 1 *In Case O, $P^{*EE}_{1a} < P^{*AA}_{1a}$, if and only if $\tau < 1/3$.*

Corollary 1 implies that whether the package prices in exclusive deals are higher than those without exclusive deals depends on the package substitutability. If the package substitutability is high, the concern of higher package prices due to exclusive deals is substantially supported in Case O. However, if package substitutability is low, forming exclusive deals is therefore encouraged in terms of consumer welfare. Nevertheless, exclusive deals reduce the number of consumer choices and are not Pareto efficient in terms of overall supply chain efficiency when the packages are sufficiently monopolistic.

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Online Supplements

Proof of Lemma 1: To compare equilibrium prices/rates, we need to solve the Nash equilibrium of the second stage game for Scenarios EE, EA, AE, and AA, respectively (see Economides and Salop, 1992). Following Eq. (2), in Scenario EE, the demand for each package is given by

$$\begin{aligned}
D_{1a}^{EE} &= \frac{1}{4(1+\tau)} - \frac{p_1+p_a}{(1-\tau)(1+\tau)} + \frac{\tau(p_2+p_b)}{(1-\tau)(1+\tau)}, \\
D_{2b}^{EE} &= \frac{1}{4(1+\tau)} - \frac{p_2+p_b}{(1-\tau)(1+\tau)} + \frac{\tau(p_1+p_a)}{(1-\tau)(1+\tau)}, \\
D_{ij}^{EE} &= 0, \quad ij = 1b, 2a.
\end{aligned}$$

In Scenario EA, the demand for each package is given by

$$\begin{aligned}
D_{1a}^{EA} &= \frac{1}{4(1+2\tau)} - \frac{(1+\tau)(p_1+p_a)}{(1-\tau)(1+2\tau)} + \frac{\tau(2p_2+p_a+p_b)}{(1-\tau)(1+2\tau)}, \\
D_{2a}^{EA} &= \frac{1}{4(1+2\tau)} - \frac{(1+\tau)(p_2+p_a)}{(1-\tau)(1+2\tau)} + \frac{\tau(p_1+p_2+p_a+p_b)}{(1-\tau)(1+2\tau)}, \\
D_{2b}^{EA} &= \frac{1}{4(1+2\tau)} - \frac{(1+\tau)(p_2+p_b)}{(1-\tau)(1+2\tau)} + \frac{\tau(p_1+p_2+2p_a)}{(1-\tau)(1+2\tau)}, \\
D_{1b}^{EA} &= 0.
\end{aligned}$$

In Scenario AE, the demand for each package is given by

$$\begin{aligned}
D_{1a}^{AE} &= \frac{1}{4(1+2\tau)} - \frac{(1+\tau)(p_1+p_a)}{(1-\tau)(1+2\tau)} + \frac{\tau(p_1+p_2+2p_b)}{(1-\tau)(1+2\tau)}, \\
D_{1b}^{AE} &= \frac{1}{4(1+2\tau)} - \frac{(1+\tau)(p_1+p_b)}{(1-\tau)(1+2\tau)} + \frac{\tau(p_1+p_2+p_a+p_b)}{(1-\tau)(1+2\tau)}, \\
D_{2b}^{AE} &= \frac{1}{4(1+2\tau)} - \frac{(1+\tau)(p_2+p_b)}{(1-\tau)(1+2\tau)} + \frac{\tau(2p_1+p_a+p_b)}{(1-\tau)(1+2\tau)}, \\
D_{2a}^{AE} &= 0.
\end{aligned}$$

In Scenario AA, the demand for each package is given by

$$\begin{aligned}
D_{1a}^{AA} &= \frac{1}{4(1+3\tau)} - \frac{(1+2\tau)(p_1+p_a)}{(1-\tau)(1+3\tau)} + \frac{\tau(p_1+2p_2+p_a+2p_b)}{(1-\tau)(1+3\tau)}, \\
D_{1b}^{AA} &= \frac{1}{4(1+3\tau)} - \frac{(1+2\tau)(p_1+p_b)}{(1-\tau)(1+3\tau)} + \frac{\tau(p_1+2p_2+2p_a+p_b)}{(1-\tau)(1+3\tau)}, \\
D_{2a}^{AA} &= \frac{1}{4(1+3\tau)} - \frac{(1+2\tau)(p_2+p_a)}{(1-\tau)(1+3\tau)} + \frac{\tau(2p_1+p_2+p_a+2p_b)}{(1-\tau)(1+3\tau)}, \\
D_{2b}^{AA} &= \frac{1}{4(1+3\tau)} - \frac{(1+2\tau)(p_2+p_b)}{(1-\tau)(1+3\tau)} + \frac{\tau(2p_1+p_2+2p_a+p_b)}{(1-\tau)(1+3\tau)}.
\end{aligned}$$

Following Eq. (3) without revenue sharing, we have

$$\Pi_i = \sum_{j=a,b} p_i D_{ij}, \ i = 1, 2,$$

$$\Pi_j \quad = \quad \sum_{i=1,2} p_j D_{ij},\ j = a, b.$$

To prove that there exists a unique equilibrium, following Cachon and Netessine (2004), we define the Hessian matrix as:

$$H \equiv \begin{bmatrix} \frac{\partial^2 \Pi_1}{\partial p_1^2} & \frac{\partial^2 \Pi_1}{\partial p_1 \partial p_2} & \frac{\partial^2 \Pi_1}{\partial p_1 \partial p_a} & \frac{\partial^2 \Pi_1}{\partial p_1 \partial p_b} \\ \frac{\partial^2 \Pi_2}{\partial p_1 \partial p_2} & \frac{\partial^2 \Pi_2}{\partial p_2^2} & \frac{\partial^2 \Pi_2}{\partial p_2 \partial p_a} & \frac{\partial^2 \Pi_2}{\partial p_2 \partial p_b} \\ \frac{\partial^2 \Pi_a}{\partial p_1 \partial p_a} & \frac{\partial^2 \Pi_a}{\partial p_2 \partial p_a} & \frac{\partial^2 \Pi_a}{\partial p_a^2} & \frac{\partial^2 \Pi_a}{\partial p_a \partial p_b} \\ \frac{\partial^2 \Pi_b}{\partial p_1 \partial p_b} & \frac{\partial^2 \Pi_b}{\partial p_2 \partial p_b} & \frac{\partial^2 \Pi_b}{\partial p_a \partial p_b} & \frac{\partial^2 \Pi_b}{\partial p_b^2} \end{bmatrix}.$$

Therefore, for Scenarios EE, EA, AE, and AA, we obtain their respective Hessian matrix as follows:

$$H^{EE} = \frac{1}{(1-\tau)(1+\tau)} \begin{bmatrix} -2 & \tau & -1 & \tau \\ \tau & -2 & \tau & -1 \\ -1 & \tau & -2 & \tau \\ \tau & -1 & \tau & -2 \end{bmatrix}.$$

$$H^{EA} = \frac{1}{(1-\tau)(1+2\tau)} \begin{bmatrix} -2(1+\tau) & 2\tau & -1 & \tau \\ 2\tau & -4 & -(1-2\tau) & -1 \\ -1 & -(1-2\tau) & -4 & 2\tau \\ \tau & -1 & 2\tau & -2(1+\tau) \end{bmatrix}.$$

$$H^{AE} = \frac{1}{(1-\tau)(1+2\tau)} \begin{bmatrix} -4 & 2\tau & -1 & -(1-2\tau) \\ 2\tau & -2(1+\tau) & \tau & -1 \\ -1 & \tau & -2(1+\tau) & 2\tau \\ -(1-2\tau) & -1 & 2\tau & -4 \end{bmatrix}.$$

$$H^{AA} = \frac{1}{(1-\tau)(1+3\tau)} \begin{bmatrix} -4(1+\tau) & 4\tau & -(1-\tau) & -(1-\tau) \\ 4\tau & -4(1+\tau) & -(1-\tau) & -(1-\tau) \\ -(1-\tau) & -(1-\tau) & -4(1+\tau) & 4\tau \\ -(1-\tau) & -(1-\tau) & 4\tau & -4(1+\tau) \end{bmatrix}.$$

First, from the Hessian matrixes, we can see each player's objective function is concave in its own decision variable. So the existence of Nash equilibrium holds. Moreover, according to Cachon and Netessine (2004) (Theorem 6), there is a unique Nash equilibrium, if $H + H^T$ is negative definite, which is true for all above scenarios given $\tau \in [0, 1)$. One can easily verify this conclusion from the above Hessian matrixes. For brevity, we omit the determinants.

We can then obtain the best response pricing function for each player given the other prices from their corresponding first order condition. Due to limited space, we hereby show only Scenario EE. Computation of Scenarios EA, AE, and AA follows the same procedure. In Scenario EE, the best response pricing functions for suppliers 1 and 2 and retailers a and b are given, respectively, by

$$\begin{aligned}
p_1 &= \frac{1}{8}\left(1-\tau+4\tau p_2-4p_a+4\tau p_b\right), \\
p_2 &= \frac{1}{8}\left(1-\tau+4\tau p_1+4\tau p_a-4p_b\right), \\
p_a &= \frac{1}{8}\left(1-\tau-4p_1+4\tau p_2+4\tau p_b\right), \\
p_b &= \frac{1}{8}\left(1-\tau+4\tau p_1-4p_2+4\tau p_a\right).
\end{aligned}$$

Combining the best response functions above, we can obtain equilibrium prices and then profits, as shown in Table 1. Due to symmetry, we provide only results for supplier 1 and retailer a. The equilibrium solutions of supplier 2 and retailer b in Scenarios EE and AA are the same as those of supplier 1 and retailer a. The equilibrium solutions of supplier 2 and retailer b in Scenario EA are the same as those of supplier 1 and retailer a, respectively, in Scenario AE. We can also show that all equilibria are located inside the feasible domain, since all demands under the equilibrium prices are nonnegative. Note that the demand under equilibrium can be computed by plugging the equilibrium prices into the above demand functions, which is skipped for brevity.

Table 1: Equilibrium solutions in Scenarios EE, EA, AE, and AA under.

	p_1^*	p_a^*	Π_1^*	Π_a^*
EE	$\frac{1-\tau}{12-8\tau}$	$\frac{1-\tau}{12-8\tau}$	$\frac{1-\tau}{16(3-2\tau)^2(1+\tau)}$	$\frac{1-\tau}{16(3-2\tau)^2(1+\tau)}$
EA	$\frac{3-\tau-2\tau^2}{4(9+5\tau-6\tau^2)}$	$\frac{3+\tau-4\tau^2}{36+20\tau-24\tau^2}$	$\frac{(1-\tau)(1+\tau)(3+2\tau)^2}{16(1+2\tau)(9+5\tau-6\tau^2)^2}$	$\frac{(1-\tau)(3+4\tau)^2}{8(1+2\tau)(9+5\tau-6\tau^2)^2}$
AE	$\frac{3+\tau-4\tau^2}{36+20\tau-24\tau^2}$	$\frac{3-\tau-2\tau^2}{4(9+5\tau-6\tau^2)}$	$\frac{(1-\tau)(3+4\tau)^2}{8(1+2\tau)(9+5\tau-6\tau^2)^2}$	$\frac{(1-\tau)(1+\tau)(3+2\tau)^2}{16(1+2\tau)(9+5\tau-6\tau^2)^2}$
AA	$\frac{1-\tau}{4(3-\tau)}$	$\frac{1-\tau}{4(3-\tau)}$	$\frac{(1-\tau)(1+\tau)}{8(3-\tau)^2(1+3\tau)}$	$\frac{(1-\tau)(1+\tau)}{8(3-\tau)^2(1+3\tau)}$

We next compare the prices. For supplier 1, we have

$$\begin{aligned}
p_1^{*EE}-p_1^{*EA} &= \frac{\tau\left(5-7\tau+2\tau^2\right)}{4\left(27-3\tau-28\tau^2+12\tau^3\right)} \geq 0, \\
p_1^{*EE}-p_1^{*AA} &= \frac{(1-\tau)\tau}{4\left(9-9\tau+2\tau^2\right)} \geq 0, \\
p_1^{*AE}-p_1^{*EA} &= \frac{(1-\tau)\tau}{2\left(9+5\tau-6\tau^2\right)} \geq 0,
\end{aligned}$$

$$
\begin{aligned}
p_1^{*AE} - p_1^{*AA} &= \frac{\tau\left(2-\tau-\tau^2\right)}{2\left(27+6\tau-23\tau^2+6\tau^3\right)} \geq 0, \\
p_1^{*EE} - p_1^{*AE} &= -\frac{\tau\,(1-\tau)(1-2\tau)}{4\left(27-3\tau-28\tau^2+12\tau^3\right)}, \\
p_1^{*EA} - p_1^{*AA} &= -\frac{\tau\,(1-\tau)(1-2\tau)}{2\left(27+6\tau-23\tau^2+6\tau^3\right)},
\end{aligned}
$$

in which the inequalities can be verified easily given $\tau \in [0, 1)$. For example, the numerator of the first inequality is positive as $5 - 7\tau + 2\tau^2$ is decreasing in τ and its value is positive when τ approaches 1; the same argument leads to the positiveness of the denominator. And it is also easy to verify that when $\tau > 1/2$, the right hand sides of the last two equations are positive whereas they are negative when $\tau < 1/2$. Thus, we obtain the result regarding p_1^* as shown in Lemma 1. Similar reasoning leads to the result regarding p_a^* as shown in Lemma 1. □

Proof of Theorem 1: Continuing with Lemma 1, we consider the prices for packages. Based on Table 1, we have

$$
\begin{aligned}
P_{1a}^{*EE} - P_{1a}^{*EA} &= \frac{(1-\tau)\tau}{27-3\tau-28\tau^2+12\tau^3} \geq 0, \\
P_{1a}^{*EA} - P_{1a}^{*AE} &= 0, \\
P_{1a}^{*EA} - P_{1a}^{*AA} &= \frac{\tau\left(1+2\tau-3\tau^2\right)}{2\left(27+6\tau-23\tau^2+6\tau^3\right)} \geq 0,
\end{aligned}
$$

where the inequalities follow from that $\tau \in [0, 1)$. Thus, the theorem is proved. □

Proof of Theorem 2: Recall the sequence of moves by the players in each channel. The supplier first suggests a channel structure (exclusive or not) to the retailer. Then if the supplier suggests an exclusive deal with the retailer, the retailer determines whether to accept it; otherwise, if the supplier decides to sell its product through both retailers, then the retailer has no choice but to accept the contract. Note that in this stage, if the retailer refuses to form an exclusive deal with the supplier, the supplier will just sell its product through both retailers. Finally, both the supplier and retailer set their prices. Both channels proceed simultaneously with the above sequence. We solve the game backwards.

To prove that forming an exclusive deal is a weakly dominant strategy for the retailers, we need to show that, a retailer is not worse off with an exclusive deal, regardless of whether the other supplier-retailer pair forms an exclusive deal. Similarly, if forming an exclusive deal is dominated for both suppliers, no supplier would choose an exclusive deal regardless of the other supplier-retailer pair's strategy. Due to the symmetry, we only show this result for retailer a and supplier 1. For retailer a, it is sufficient to prove that Scenario EE outperforms Scenario AE and Scenario EA outperforms Scenario AA, provided that supplier 1 offers an exclusive deal. Hence, based on the analysis of retailer a, for supplier 1, it suffices to show that its profit under EE is less than that under AE and its profit under EA is less than that under AA. Based on Table 1, for retailer a,

$$\begin{aligned}
\Pi_a^{*EE} - \Pi_a^{*AE} &= \frac{(1-\tau)\left(\frac{1}{(3-2\tau)^2} - \frac{(1+\tau)^2(3+2\tau)^2}{(1+2\tau)(9+5\tau-6\tau^2)^2}\right)}{16(1+\tau)} \geq 0, \\
\Pi_a^{*EA} - \Pi_a^{*AA} &= \frac{1}{8}(1-\tau)\left(\frac{(3+4\tau)^2}{(1+2\tau)\left(9+5\tau-6\tau^2\right)^2} - \frac{1+\tau}{(3-\tau)^2(1+3\tau)}\right) \geq 0.
\end{aligned}$$

The above inequalities become equalities only when $\tau = 0$. For supplier 1,

$$\begin{aligned}
\Pi_1^{*EE} - \Pi_1^{*AE} &= \frac{1}{16}(1-\tau)\left(\frac{1}{(3-2\tau)^2(1+\tau)} - \frac{2(3+4\tau)^2}{(1+2\tau)\left(9+5\tau-6\tau^2\right)^2}\right) < 0, \\
\Pi_1^{*EA} - \Pi_1^{*AA} &= \frac{1}{16}(1-\tau)(1+\tau)\left(\frac{(3+2\tau)^2}{(1+2\tau)\left(9+5\tau-6\tau^2\right)^2} - \frac{2}{(3-\tau)^2(1+3\tau)}\right) < 0.
\end{aligned}$$

Thus, no matter whether the other channel forms an exclusive deal, it is weakly dominant and, thus, optimal for retailer a to seek an exclusive deal with supplier 1. However, the reverse is true for supplier 1. Consequently, supplier 1 will not offer an exclusive deal contract to retailer a and, thus, forming exclusive deals without revenue sharing cannot be an equilibrium. □

Proof of Theorem 3: From Table 1, we obtain the total profit for the entire supply chain including both suppliers and both retailers as follows:

$$\begin{aligned}
\Pi_{All}^{*EE} &= \frac{1-\tau}{4(3-2\tau)^2(1+\tau)}, \\
\Pi_{All}^{*EA} &= \Pi_{All}^{*AE} = \frac{27+42\tau-21\tau^2-44\tau^3-4\tau^4}{8(1+2\tau)\left(9+5\tau-6\tau^2\right)^2}, \\
\Pi_{All}^{*AA} &= \frac{(1-\tau)(1+\tau)}{2(3-\tau)^2(1+3\tau)}.
\end{aligned}$$

We then visualize the proof in Figure 2. We define $\hat{\tau}_1$ as the intersection point between Scenarios AA and EA and $\hat{\tau}_2$ as the intersection point between Scenarios EE and EA. There, solving the single crossing points between AA and EA/AE by setting $\Pi_{All}^{*AA} = \Pi_{All}^{*EA}$ and between EA and EE by setting $\Pi_{All}^{*EE} = \Pi_{All}^{*EA}$ yields $\hat{\tau}_1 = 0.5633$ and $\hat{\tau}_2 = 0.6901$, respectively. We then observe that AA dominates Scenarios EA, AE, and EE when $0 \leq \tau < \hat{\tau}_1$; Scenarios EA and AE dominate EE and AA when $\hat{\tau}_1 \leq \tau < \hat{\tau}_2$; and Scenario EE dominates EA, AE, and AA, if $\hat{\tau}_2 \leq \tau < 1$. □

Proof of Lemma 2: With revenue sharing, the profit functions are given by Eq. (3). The demand functions are the same as those in the proof of Lemma 1. Because the Hessian matrixes are independent of the revenue sharing rate, they are identical to those in Lemma 1. Therefore, similar to the proof of Lemma 1, we obtain unique equilibrium solutions in Table 2.

Table 2: Equilibrium solutions in Scenarios EE, EA, AE, and AA with revenue sharing.

	p_1^*	p_a^*	Π_1^*	Π_a^*
EE	$\frac{1-\tau}{12-8\tau}-r$	$\frac{1-\tau}{12-8\tau}+r$	$\frac{1-\tau}{16(3-2\tau)^2(1+\tau)}$	$\frac{1-\tau}{16(3-2\tau)^2(1+\tau)}$
EA	$\frac{C_2-4rC_3}{4C_1}$	$\frac{C_4+4rC_5}{4C_1}$	$\frac{(1+\tau)(C_2+4rC_6)^2}{16(1+\tau-2\tau^2)C_1{}^2}$	$\frac{C_4{}^2-2rC_7-8r^2C_8}{8(1+\tau-2\tau^2)C_1^2}$
AE	$\frac{C_4-4rC_9}{4C_1}$	$\frac{C_2+4rC_{10}}{4C_1}$	$\frac{(C_4-4rC_9)^2}{8(1+\tau-2\tau^2)C_1{}^2}$	$\frac{(1+\tau)(C_2+4rC_{10})^2}{16(1+\tau-2\tau^2)C_1^2}$
AA	$\frac{1-\tau}{4(3-\tau)}$	$\frac{1-\tau}{4(3-\tau)}$	$\frac{(1-\tau)(1+\tau)}{8(3-\tau)^2(1+3\tau)}$	$\frac{(1-\tau)(1+\tau)}{8(3-\tau)^2(1+3\tau)}$

In Table 2, we have

$$
\begin{aligned}
C_1 &= 45+106\tau+33\tau^2-44\tau^3-12\tau^4>0,\\
C_2 &= 15+22\tau-13\tau^2-20\tau^3-4\tau^4\geq 0,\\
C_3 &= 33+71\tau+20\tau^2-24\tau^3-8\tau^4>0,\\
C_4 &= 15+32\tau-5\tau^2-34\tau^3-8\tau^4\geq 0,\\
C_5 &= 21+48\tau+13\tau^2-22\tau^3-8\tau^4>0,\\
C_6 &= 12+35\tau+13\tau^2-20\tau^3-4\tau^4>0,\\
C_7 &= 90+717\tau+1980\tau^2+1838\tau^3-1050\tau^4-2899\tau^5-1316\tau^6+288\tau^7+304\tau^8+48\tau^9\geq 0,\\
C_8 &= 603+3741\tau+8204\tau^2+6196\tau^3-2519\tau^4-5673\tau^5-1488\tau^6+920\tau^7+432\tau^8+48\tau^9>0,\\
C_9 &= 6+21\tau+17\tau^2-4\tau^3-4\tau^4>0,\\
C_{10} &= 3+12\tau+9\tau^2-8\tau^3-4\tau^4>0.
\end{aligned}
$$

Constraints are imposed for nonnegative marginal profits (product price plus shared revenue) and demands as follows:

$$r\leq\hat{r}_0\equiv\min\left\{\frac{C_4}{4C_9},\frac{3-5\tau^2+2\tau^3}{4\left(3+6\tau-\tau^2-2\tau^3\right)}\right\}=\frac{3-5\tau^2+2\tau^3}{4\left(3+6\tau-\tau^2-2\tau^3\right)},$$

where the first item guarantees nonnegative prices in Scenarios EA and AE and the second item guarantees nonnegative demand for package $2a$ in Scenario EA and package $1b$ for Scenario AE. Other marginal profits and demands are all nonnegative. From Table 2 and the above equations, it is quite obvious that, with revenue sharing, product prices decrease while service rates increase with the revenue sharing rate in Scenarios EE, EA, and AE. Consider the package price of P_{1a}^*.

$$
\begin{aligned}
\frac{dP_{1a}^{*EE}}{dr} &= 0,\\
\frac{dP_{1a}^{*EA}}{dr} &= -\frac{12+23\tau+7\tau^2-2\tau^3}{C_1}<0,
\end{aligned}
$$

$$
\begin{aligned}
\frac{dP_{1a}^{*AE}}{dr} &= -\frac{3+9\tau+8\tau^2+4\tau^3}{C_1} < 0, \\
\frac{dP_{1a}^{*AA}}{dr} &= 0.
\end{aligned}
$$

Thus, package prices decrease with the revenue sharing rate in Scenarios EA and AE. □

Proof of Theorem 4: To show that forming exclusive deals is a subgame perfect equilibrium, we must demonstrate that no player will unilaterally deviate from Scenario EE in the first stage of the game. For supplier 1 and retailer a, Scenario EE must be no worse than Scenario AE; for supplier 2 and retailer b, Scenario EE must be no worse than Scenario EA. Due to the symmetry, $\Pi_1^{*AE} = \Pi_2^{*EA}$ and $\Pi_a^{*AE} = \Pi_b^{*EA}$. Hence, it is sufficient to prove that both supplier 1 and retailer a prefer Scenario EE to AE. Comparing the profits from Table 2,

$$
\begin{aligned}
\Delta\Pi_1^{EEAE} \equiv \Pi_1^{*EE} - \Pi_1^{*AE} &= \frac{1-\tau}{16(3-2\tau)^2(1+\tau)} - \frac{(C_4-4rC_9)^2}{8(1+\tau-2\tau^2)\,{C_1}^2}, \\
\Delta\Pi_a^{EEAE} \equiv \Pi_a^{*EE} - \Pi_a^{*AE} &= \frac{1-\tau}{16(3-2\tau)^2(1+\tau)} - \frac{(1+\tau)(C_2+4rC_{10})^2}{16(1+\tau-2\tau^2)\,C_1^2}.
\end{aligned}
$$

We need to identify the region of τ where $\Delta\Pi_1^{EEAE} \geq 0$ and $\Delta\Pi_a^{EEAE} \geq 0$ so that EE is an equilibrium. To this end, we take the second derivatives with respect to r as follows:

$$
\begin{aligned}
\frac{d^2\Delta\Pi_1^{EEAE}}{dr^2} &= -\frac{4(1+2\tau)\left(6+9\tau-\tau^2-2\tau^3\right)^2}{(1-\tau)C_1^2} < 0, \\
\frac{d^2\Delta\Pi_a^{EEAE}}{dr^2} &= -\frac{2(1+\tau)(1+2\tau)\left(3+6\tau-3\tau^2-2\tau^3\right)^2}{(1-\tau)C_1^2} < 0.
\end{aligned}
$$

Thus, both $\Delta\Pi_1^{EEAE}$ and $\Delta\Pi_a^{EEAE}$ are strictly concave in r. Solving $\Delta\Pi_1^{EEAE} = 0$ and $\Delta\Pi_a^{EEAE} = 0$ yields two roots for each, respectively. The equations for the roots are very lengthy, thus they are omitted here. The roots depend on a single parameter, τ. Moreover, we can show that the smaller root of $\Delta\Pi_1^{EEAE} = 0$ is larger than that of $\Delta\Pi_a^{EEAE} = 0$ whereas the larger root of $\Delta\Pi_1^{EEAE} = 0$ is larger than that of $\Delta\Pi_a^{EEAE} = 0$. As a result, we can identify the area defined by $\hat{r}_1(\tau) \leq r \leq \hat{r}_2(\tau)$, under which EE is the equilibrium, where $\hat{r}_1(\tau)$ is the smaller root of $\Delta\Pi_1^{EEAE} = 0$ and $\hat{r}_2(\tau)$ is the minimum of the larger root of $\Delta\Pi_a^{EEAE} = 0$ and $\hat{r}_0$ (defined in Lemma 2), as illustrated in Figure 3. Note that the complexity of $\hat{r}_1(\tau)$ and $\hat{r}_2(\tau)$ are mainly due to the asymmetry of Scenario AE and the game setting that players need to determine four prices simultaneously in a Nash game. From our previous discussion, we can easily infer that the retailer will prefer not to form an exclusive deal with the supplier as long as $r > \hat{r}_a(\tau)$, which results in non-exclusive deal (regardless whether the supplier offers exclusive contract) between the supplier and retailer. Similarly, if $r < \hat{r}_1(\tau)$, even if the retailer prefers to form an exclusive deal with the supplier, the supplier prefers to sell its product through both retailers. Hence, in both cases, forming an exclusive deal is not an equilibrium. Furthermore, the starting point of the overlapping area is given by $\tau = 0.34$ solved from $\hat{r}_1(\tau) = \hat{r}_2(\tau)$, and the ending point is at $\tau = 1$. $\square$

Proof of Theorem 5: It is sufficient to show that either a supplier or a retailer is more inclined to deviate from Scenario EE as ρ grows. Note the profit functions in Eq. (3) continue to hold for this new revenue sharing scheme. Due to the symmetry, $\Pi_1^{*AE} = \Pi_2^{*EA}$ and $\Pi_a^{*AE} = \Pi_b^{*EA}$. To show whether either a supplier or a retailer will deviate from Scenario EE, similar to the proof of Theorem 4, it is sufficient to prove that either supplier 1 or retailer a will unilaterally deviate from Scenario EE to Scenario AE. We compute players' profits and compare them as follows:

$$\begin{aligned}
\Delta\Pi_1^{EEAE} \equiv \Pi_1^{*EE} - \Pi_1^{*AE} &= \frac{1-\tau}{16(3-2\tau)^2(1+\tau)} - \frac{(C_4 - 4(1-\rho)rC_9)^2}{8(1+\tau-2\tau^2)C_1{}^2}, \\
\Delta\Pi_a^{EEAE} \equiv \Pi_a^{*EE} - \Pi_a^{*AE} &= \frac{1-\tau}{16(3-2\tau)^2(1+\tau)} - \frac{(1+\tau)(C_2 + 4(1-\rho)rC_{10})^2}{16(1+\tau-2\tau^2)C_1^2}.
\end{aligned}$$

When $\rho = 0$, the functions above are the same as those in Theorem 4, such that for any given r satisfying $\hat{r}_1(\tau) \leq r \leq \hat{r}_2(\tau)$ for $\tau \in [0.34, 1)$,

$$\Delta\Pi_1^{EEAE} \geq 0 \text{ and } \Delta\Pi_a^{EEAE} \geq 0.$$

When $\rho = 1$, the above case is equivalent to that in Theorem 2, such that for any r, we have

$$\begin{aligned}
\Delta\Pi_1^{EEAE} &= \frac{1}{16}(1-\tau)\left(\frac{1}{(3-2\tau)^2(1+\tau)} - \frac{2(3+4\tau)^2}{(1+2\tau)(9+5\tau-6\tau^2)^2}\right) < 0, \\
\Delta\Pi_a^{EEAE} &= \frac{(1-\tau)\left(\frac{1}{(3-2\tau)^2} - \frac{(1+\tau)^2(3+2\tau)^2}{(1+2\tau)(9+5\tau-6\tau^2)^2}\right)}{16(1+\tau)} \geq 0.
\end{aligned}$$

Moreover, it is clear that $\Delta\Pi_1^{EEAE}$ is decreasing in ρ while $\Delta\Pi_a^{EEAE}$ is increasing in ρ since C_1, C_2, C_4, C_9, and C_{10} are all positive as demonstrated in the proof of Theorem 4 and $C_4 - 4(1-\rho)rC_9 > 0$ given $\hat{r}_1(\tau) \leq r \leq \hat{r}_2(\tau)$. Combining these results, we can easily infer that retailer a always prefers an exclusive deal given $\hat{r}_1(\tau) \leq r \leq \hat{r}_2(\tau)$ for $\tau \in [0.34, 1)$. However, supplier 1's preference of exclusive deal hinges upon the relative level (ρ) of revenue sharing under nonexclusivity. Furthermore, there exists a unique threshold value $\widehat{\rho}$ of ρ, such that supplier 1 no longer prefers EE to AE when $\widehat{\rho} < \rho \leq 1$, where $\widehat{\rho}$ is the value of ρ solved by $\Delta\Pi_1^{EEAE} = 0$. Overall, it is more likely for supplier 1 to deviate from EE (i.e., EE will be no longer an equilibrium) as ρ grows. $\square$

Proof of Theorem 6: Because the Hessian matrixes of the profit functions in Eq. (A-3) are independent of the revenue sharing rate and the fencing costs, they are identical to H^{AA} as in Lemma 1. Using the same techniques in the proof of Lemma 1, we obtain the unique equilibrium solutions for Scenarios EE, EA,

Table 3: Equilibrium solutions in Scenarios EE, EA, AE, and AA with fencing.

	p_1^*	p_a^*	Π_{All}^*
EE	$\frac{1-\tau}{4(3-\tau)}-\frac{k}{2}$	$\frac{1-\tau}{4(3-\tau)}$	$\frac{(1-\tau)^2(1+\tau)-2k^2(3-\tau)^2(1+3\tau)}{2(3-\tau)^2(1+2\tau-3\tau^2)}$
EA	$\frac{1-\tau}{4(3-\tau)}-\frac{k}{2}$	$\frac{2+2\tau-4\tau^2+k\left(3+8\tau-3\tau^2\right)}{8(3+5\tau-2\tau^2)}$	$\frac{8(1+\tau)\left(1+\tau-2\tau^2\right)^2-k^2(3-\tau)^2(1+3\tau)(5+\tau(18+17\tau))}{16(1-\tau)(1+3\tau)(3+(5-2\tau)\tau)^2}$
AE	$\frac{1-\tau}{4(3-\tau)}$	$\frac{2+2\tau-4\tau^2-k\left(3+8\tau-3\tau^2\right)}{8(3+5\tau-2\tau^2)}$	Π_{All}^{*EA}
AA	$\frac{1-\tau}{4(3-\tau)}$	$\frac{1-\tau}{4(3-\tau)}$	$\frac{(1-\tau)(1+\tau)}{2(3-\tau)^2(1+3\tau)}$

AE, and AA, as illustrated in Table 3. Comparing the profits of the entire supply chain in Scenarios EE, EA (same as AE), and AA, we have

$$\begin{aligned}\Delta\Pi_{All}^{EAAA} \equiv \Pi_{All}^{*EA} - \Pi_{All}^{*AA} &= -\frac{k^2\left(5+18\tau+17\tau^2\right)}{16(1-\tau)(1+2\tau)^2} \le 0,\\ \Delta\Pi_{All}^{EAEE} \equiv \Pi_{All}^{*EA} - \Pi_{All}^{*EE} &= \frac{k^2\left(11+46\tau+47\tau^2\right)}{16(1-\tau)(1+2\tau)^2} \ge 0.\end{aligned}$$

This proves the first item of the theorem. We now consider the corner solution. In line with O'Brien and Shaffer (1993) and Ingene and Parry (2004) (Chapter 10), we adopt a price-out strategy where the switching cost k_i is set at a price such that demand for the undesirable package(s) in Scenarios EE, EA, and AE becomes zero. In Scenario EE, the values of k is set such that $D_{1b}^{EE} = D_{2a}^{EE} = 0$. In Scenario EA, $D_{1b}^{EA} = 0$, and in Scenario AE, $D_{2a}^{EA} = 0$. We replace the switching cost with the equivalence of product prices and service rates in the profit functions. For example, in Scenario EA, the price-out switching cost is set at

$$\bar{k}^{EA}(\tau) = \frac{1-\tau-4(1+\tau)p_1+8\tau p_2+8\tau p_a-4p_b-4\tau p_b}{4+8\tau}.$$

Placing this price-out switching cost into the corresponding demand functions, we resolve the first-order conditions and obtain the price-out switching cost as follows:

$$\bar{k}^{EA}(\tau) = \frac{3+4\tau-\tau^2-6\tau^3}{36+92\tau+16\tau^2-48\tau^3}.$$

The same price-out switching cost is applied to Scenario AE. For Scenario EE,

$$\bar{k}^{EE}(\tau) = \frac{1-\tau}{12+4\tau-8\tau^2}.$$

Based on the above price-out strategy, we then solve the equilibrium prices/rates and profits and obtain exactly the same solutions as those in Table 1. This demonstrates that the alternative model with price-out strategy is equivalent to our main model with exclusive channels as specified in Section 2. □

Proof of Lemma 3: In composite package (CP) competition, each package is determined to optimize its package profit (see Economides and Salop, 1992). The demand functions are given by Eq. (2) and are the same as those in the proof of Lemma 1 while combining p_i and p_j into P_{ij}. For example, in Scenario EE,

$$\begin{aligned} D_{1a}^{EE} &= \frac{1}{4(1+\tau)} - \frac{P_{1a}}{(1-\tau)(1+\tau)} + \frac{\tau P_{2b}}{(1-\tau)(1+\tau)}, \\ D_{2b}^{EE} &= \frac{1}{4(1+\tau)} - \frac{P_{2b}}{(1-\tau)(1+\tau)} + \frac{\tau P_{1a}}{(1-\tau)(1+\tau)}. \end{aligned}$$

The profit of package ij is thus given by

$$\Pi_{ij} = P_{ij} D_{ij},$$

where in Scenario EE, $ij = 1a, 2b$; in Scenario EA, $ij = 1a, 2a, 2b$; in Scenario AE, $ij = 1a, 1b, 2b$; and in Scenario AA, $ij = 1a, 1b, 2a, 2b$. Through reasoning similar to the proof of Lemma 1, we obtain the following Hessian matrixes.

$$H^{EE} = \begin{bmatrix} \frac{\partial^2 \Pi_{1a}}{\partial P_{1a}^2} & \frac{\partial^2 \Pi_{1a}}{\partial P_{1a} \partial P_{2b}} \\ \frac{\partial^2 \Pi_{2b}}{\partial P_{1a} \partial P_{2b}} & \frac{\partial^2 \Pi_{2b}}{\partial P_{2b}^2} \end{bmatrix} = \frac{1}{(1-\tau)(1+\tau)} \begin{bmatrix} -2 & \tau \\ \tau & -2 \end{bmatrix}.$$

$$H^{EA} = \begin{bmatrix} \frac{\partial^2 \Pi_{1a}}{\partial P_{1a}^2} & \frac{\partial^2 \Pi_{1a}}{\partial P_{1a} \partial P_{2a}} & \frac{\partial^2 \Pi_{1a}}{\partial P_{1a} \partial P_{2b}} \\ \frac{\partial^2 \Pi_{2a}}{\partial P_{1a} \partial P_{2a}} & \frac{\partial^2 \Pi_{2a}}{\partial P_{2a}^2} & \frac{\partial^2 \Pi_{2a}}{\partial P_{2a} \partial P_{2b}} \\ \frac{\partial^2 \Pi_{2b}}{\partial P_{1a} \partial P_{2b}} & \frac{\partial^2 \Pi_{2b}}{\partial P_{2a} \partial P_{2b}} & \frac{\partial^2 \Pi_{2b}}{\partial P_{2b}^2} \end{bmatrix} = \frac{1}{(1-\tau)(1+2\tau)} \begin{bmatrix} -2(1+\tau) & \tau & \tau \\ \tau & -2(1+\tau) & \tau \\ \tau & \tau & -2(1+\tau) \end{bmatrix}.$$

$$H^{AE} = \begin{bmatrix} \frac{\partial^2 \Pi_{1a}}{\partial P_{1a}^2} & \frac{\partial^2 \Pi_{1a}}{\partial P_{1a} \partial P_{1b}} & \frac{\partial^2 \Pi_{1a}}{\partial P_{1a} \partial P_{2b}} \\ \frac{\partial^2 \Pi_{1b}}{\partial P_{1a} \partial P_{1b}} & \frac{\partial^2 \Pi_{1b}}{\partial P_{1b}^2} & \frac{\partial^2 \Pi_{1b}}{\partial P_{1b} \partial P_{2b}} \\ \frac{\partial^2 \Pi_{2b}}{\partial P_{1a} \partial P_{2b}} & \frac{\partial^2 \Pi_{2b}}{\partial P_{1b} \partial P_{2b}} & \frac{\partial^2 \Pi_{2b}}{\partial P_{2b}^2} \end{bmatrix} = \frac{1}{(1-\tau)(1+2\tau)} \begin{bmatrix} -2(1+\tau) & \tau & \tau \\ \tau & -2(1+\tau) & \tau \\ \tau & \tau & -2(1+\tau) \end{bmatrix}.$$

$$\begin{aligned} H^{AA} &= \begin{bmatrix} \frac{\partial^2 \Pi_{1a}}{\partial P_{1a}^2} & \frac{\partial^2 \Pi_{1a}}{\partial P_{1a} \partial P_{1b}} & \frac{\partial^2 \Pi_{1a}}{\partial P_{1a} \partial P_{2a}} & \frac{\partial^2 \Pi_{1a}}{\partial P_{1a} \partial P_{2b}} \\ \frac{\partial^2 \Pi_{1b}}{\partial P_{1a} \partial P_{1b}} & \frac{\partial^2 \Pi_{1b}}{\partial P_{1b}^2} & \frac{\partial^2 \Pi_{1b}}{\partial P_{1b} \partial P_{2a}} & \frac{\partial^2 \Pi_{1b}}{\partial P_{1b} \partial P_{2b}} \\ \frac{\partial^2 \Pi_{2a}}{\partial P_{1a} \partial P_{2a}} & \frac{\partial^2 \Pi_{2a}}{\partial P_{1b} \partial P_{2a}} & \frac{\partial^2 \Pi_{2a}}{\partial P_{2a}^2} & \frac{\partial^2 \Pi_{2a}}{\partial P_{2a} \partial P_{2b}} \\ \frac{\partial^2 \Pi_{2b}}{\partial P_{1a} \partial P_{2b}} & \frac{\partial^2 \Pi_{2b}}{\partial P_{1b} \partial P_{2b}} & \frac{\partial^2 \Pi_{2b}}{\partial P_{2a} \partial P_{2b}} & \frac{\partial^2 \Pi_{2b}}{\partial P_{2b}^2} \end{bmatrix} \\ &= \frac{1}{(1-\tau)(1+3\tau)} \begin{bmatrix} -2(1+2\tau) & \tau & \tau & \tau \\ \tau & -2(1+2\tau) & \tau & \tau \\ \tau & \tau & -2(1+2\tau) & \tau \\ \tau & \tau & \tau & -2(1+2\tau) \end{bmatrix}. \end{aligned}$$

Similarly, according to Cachon and Netessine (2004), there is a unique Nash equilibrium in each scenario, because $H + H^T$ is negative definite for all above Hessian matrixes given $\tau \in [0, 1)$.

To obtain the equilibrium result, we then solve the first-order conditions with respect to package prices. For example, in Scenario EE, the packages' best response pricing functions are given by

$$\begin{aligned} P_{1a} &= \frac{1}{8}\left(1 - \tau + 4\tau P_{2b}\right), \\ P_{2b} &= \frac{1}{8}\left(1 - \tau + 4\tau P_{1a}\right). \end{aligned}$$

Due to symmetry, we show the unique equilibrium result for package $1a$ only, as illustrated in Table 4.

Table 4: Equilibrium solutions in Scenarios EE, EA, AE, and AA under CP competition.

	EE	EA	AE	AA
P^*_{1a}	$\frac{1-\tau}{4(2-\tau)}$	$\frac{1-\tau}{8}$	$\frac{1-\tau}{8}$	$\frac{1-\tau}{8+4\tau}$
Π^*_{1a}	$\frac{1-\tau}{16(2-\tau)^2(1+\tau)}$	$\frac{1-\tau^2}{64+128\tau}$	$\frac{1-\tau^2}{64+128\tau}$	$\frac{1+\tau-2\tau^2}{16(2+\tau)^2(1+3\tau)}$

Similar to that of Lemma 1, all equilibria are inside the feasible domain given $\tau \in [0, 1)$. Comparing the prices in Table 4, we can easily conclude $P^{*AA}_{1a} = P^{*EA}_{1a} = P^{*AE}_{1a} = P^{*EE}_{1a}$.

We define $\Delta P_{1a} \equiv P^{*CP}_{1a} - P^{*IO}_{1a}$ and denote the scenarios to the superscripts. We compare prices between IO and CP competition in all scenarios as follows:

$$\begin{aligned} \Delta P^{EE}_{1a} &= -\frac{1-\tau}{4\left(6 - 7\tau + 2\tau^2\right)} < 0, \\ \Delta P^{EA}_{1a} &= -\frac{3 + 4\tau - \tau^2 - 6\tau^3}{8\left(9 + 5\tau - 6\tau^2\right)} < 0, \\ \Delta P^{AE}_{1a} &= -\frac{3 + 4\tau - \tau^2 - 6\tau^3}{8\left(9 + 5\tau - 6\tau^2\right)} < 0, \\ \Delta P^{AA}_{1a} &= -\frac{1 + 2\tau - 3\tau^2}{4\left(6 + \tau - \tau^2\right)} < 0. \end{aligned}$$

Again, due to the symmetry, package prices for $1b, 2a$, and $2b$ follow the same pattern. □

Proof of Lemma 4: From Table 4, we obtain the total profit for the entire supply chain including all packages as follows:

$$\Pi^{*EE}_{All} = \frac{1-\tau}{8(2-\tau)^2(1+\tau)},$$

$$\begin{aligned}\Pi_{All}^{*EA} &= \Pi_{All}^{*AE} = \frac{3(1-\tau^2)}{64+128\tau},\\ \Pi_{All}^{*AA} &= \frac{1+\tau-2\tau^2}{4(2+\tau)^2(1+3\tau)}.\end{aligned}$$

We define $\hat{\tau}_3$ as the intersection point between Scenarios AA and EA and $\hat{\tau}_4$ as the intersection point between Scenarios EE and EA. Solving the single crossing points between AA and EA/AE by setting $\Pi_{All}^{*AA} = \Pi_{All}^{*EA}$ and between EA and EE by setting $\Pi_{All}^{*EE} = \Pi_{All}^{*EA}$ yields $\hat{\tau}_3 = 0.3621$ and $\hat{\tau}_4 = 0.4468$, respectively. Similar to Figure 2, we observe that AA dominates Scenarios EA, AE, and EE when $0 \leq \tau < \hat{\tau}_3$; Scenarios EA and AE dominate EE and AA when $\hat{\tau}_3 \leq \tau < \hat{\tau}_4$; and Scenario EE dominates EA, AE, and AA, if $\hat{\tau}_4 \leq \tau < 1$. □

Proof of Theorem 7: Define $\Delta\Pi_{CPIO} = \Pi_{All}^{*CP} - \Pi_{All}^{*IO}$. We have

$$\begin{aligned}\Delta\Pi_{CPIO}^{EE} &= \frac{1-5\tau+6\tau^2-2\tau^3}{8(1+\tau)\left(6-7\tau+2\tau^2\right)^2},\\ \Delta\Pi_{CPIO}^{EA} &= \frac{27-66\tau-324\tau^2-98\tau^3+389\tau^4+180\tau^5-108\tau^6}{64(1+2\tau)\left(9+5\tau-6\tau^2\right)^2},\\ \Delta\Pi_{CPIO}^{AA} &= \frac{1-8\tau+7\tau^2}{4(3-\tau)^2(2+\tau)^2}.\end{aligned}$$

Since there is only one independent variable τ in all equilibrium profits, we can use a two-dimension graph to visually compare all profits for the entire supply chain in different scenarios. We observe that Π_{All}^{*CP} and Π_{All}^{*IO} have a single crossing point for each scenario during $\tau \in [0, 1)$. Setting $\Delta\Pi_{CPIO} = 0$ for the above equations yields the single crossing points at $\tau = 0.2929, 0.2037, 0.1429$ for Scenarios EE, EA/AE, and AA, respectively. In other words, CP outperforms IO only if $\tau < 0.2929$ in Scenario EE, or if $\tau < 0.2037$ in Scenario EA/AE, or if $\tau < 0.1429$ in Scenario AA. As shown in Theorem 3 and Lemma 4, Scenario AA outperforms other scenarios for both IO and CP cases, as long as $\tau < 0.3621$. Therefore, the best of CP, either Scenario EE, EA/AE, or AA, outperforms the best of IO as long as $\tau < 0.1429$. When $\tau > 0.1429$, we can combine all scenarios in both IO and CP cases and then compare them. For a shortcut, we can also prove it visually, because we find the best of IO and the best of CP have a single crossing point, as uniquely illustrated in Figure 6. Therefore, the best of IO outperforms the best of CP if and only if $\tau \geq 0.1429$. □

Proof of Lemma 5: The computation process is similar to that of IO competition with revenue sharing, as shown in the proof of Lemma 2, except that we replace the original r with the new revenue sharing functions in Eq. (A-4). The new Hessian matrix is

$$H^{EE} = \frac{1}{2(1-\tau)^2(1+\tau)} \begin{bmatrix} -2 & \tau & -2(1-\tau) & \tau \\ \tau & -2 & \tau & -2(1-\tau) \\ -2(1-\tau) & \tau & -2 & \tau \\ \tau & -2(1-\tau) & \tau & -2 \end{bmatrix}.$$

It is easy to show that $H^{EE} + H^{EE^T}$ is negative definite. Therefore, there is a unique Nash equilibrium. Similarly, solving the first order conditions results in the overall channel profit in terms of η as follows:

$$\Pi_{1a}^{EE} = \Pi_1^{*EE} + \Pi_a^{*EE} = \frac{(1-\eta)(1-\tau)}{8(3-2\eta(1-\tau)-2\tau)^2(1+\tau)}.$$

Solving the first order condition yields the unique η in the feasible domain optimizing this exclusive channel profit as follows:

$$\eta^* = \frac{1-2\tau}{2-2\tau}.$$

Note the above η^* also optimizes the entire supply chain profit. Plugging the above η into the price and profit functions yields

$$\begin{aligned} p_1^{*EE} &= \frac{1}{16} + r_0 - \frac{r_0}{\tau}, \\ p_a^{*EE} &= \frac{1}{16} - r_0 + \frac{r_0}{\tau}, \\ \Pi_1^{*EE} &= \frac{1}{128+128\tau}, \\ \Pi_a^{*EE} &= \frac{1}{128+128\tau}. \end{aligned}$$

Immediately, we can obtain the equilibrium package price,

$$P_{1a}^{*EE} = \frac{1}{8},$$

and the optimal single channel profit,

$$\Pi_{1a}^{O} = \frac{1}{64+64\tau}.$$

The base revenue sharing rate r_0 does not affect the profit of any player. Due to the symmetry, we have $\Pi_{2b}^{O} = \Pi_{1a}^{O}$. □

Proof of Theorem 8: From the proof of Lemma 1,

$$\Pi_{1a}^{IO} = \Pi_1^{*EE} + \Pi_a^{*EE} = \frac{1-\tau}{8(3-2\tau)^2(1+\tau)}.$$

Comparing Π_{1a}^{IO} with Π_{1a}^{O} obtained in Lemma 5, we have

$$\Pi_{1a}^{O} - \Pi_{1a}^{IO} = \frac{(1-2\tau)^2}{64(3-2\tau)^2(1+\tau)} \geq 0.$$

Comparing Case CP with Case O results in

$$\Pi_{1a}^{O} - \Pi_{1a}^{CP} = \frac{1}{64 + 64\tau} - \frac{1 - \tau}{16(2 - \tau)^2(1 + \tau)} = \frac{\tau^2}{64(2 - \tau)^2(1 + \tau)} \geq 0.$$

Thus, Case O always outperforms Cases IO and CP for the entire supply chain. □

Proof of Corollary 1: Recall that $P_{1a}^{*EE} = 1/8$ in Case O from the proof of Lemma 5 and

$$P_{1a}^{*AA} = \frac{1 - \tau}{2(3 - \tau)}$$

from the proof of either Lemma 1 or Lemma 2. Thus,

$$P_{1a}^{*AA} - P_{1a}^{*EE} = \frac{1 - 3\tau}{24 - 8\tau}.$$

Given that $\tau < 1$, thus $24 - 8\tau > 0$, we find that if $\tau < 1/3$, $P_{1a}^{*EE} < P_{1a}^{*AA}$; otherwise, the reverse is true.□