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Asymmetric product distribution between symmetric manufacturers using dual-channel supply chains*

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Abstract

This paper investigates the optimal product distribution strategy for a manufacturer that uses dual-channel supply chains. We assume that two symmetric manufacturers facing price competition distribute products through (1) a retail channel only, (2) a direct channel only, or (3) both retail and direct channels. Our most notable result is that even though the two manufacturers are symmetric, a subgame perfect equilibrium always arises, including an asymmetric distribution policy, where one manufacturer distributes products only through the direct channel, while the other manufacturer distributes through both the direct channel and the retail channel. A practical implication of this result is that a symmetric distribution policy is not necessarily optimal for a manufacturer encountering price competition. In particular, when another competing manufacturer distributes products through its dual channels, a manufacturer should not similarly adopt a dual-channel distribution strategy just to counter the rival's dual-channel strategy. Such a symmetric dual-channel distribution strategy would trigger the most intense inter-brand competition, eroding not only the rival's profit, but also its own profit.

Keywords: Economics, Supply chain management, Distribution channels, Direct channel, Game theory

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1. Introduction

The rapid growth of the Internet has made it attractive and much easier for manufacturers that traditionally sold their products indirectly through retailers to engage in direct sales. Thanks to the development of e-commerce technologies and third-party logistics enterprises such as Federal Express and UPS, an increasing number of manufacturers in a variety of industries have established sales channels to sell to customers directly. In fact, many prominent manufacturers, such as Hewlett–Packard, IBM, Cisco System, Pioneer Electronics, Eastman Kodak, Nike, Sony, Panasonic, Mattel, Estee Lauder, Lenovo, and Apple, among others, have begun to use online channels to sell their products directly to consumers (Tsay and Agrawal, 2004a, 2004b). Online direct selling is beneficial to the manufacturer to save costs, increase sales revenues, and attract different customer segments to create manufacturer loyalty.

Because direct channels compete against, substitute, or complement conventional retail channels, finding the best way to utilize them in conjunction with the retail channel continues to be a challenge for many manufacturers. Nowadays, manufacturers often face a distribution policy problem regarding whether to add a new distribution channel in addition to their existing channels. When a manufacturer sells through a traditional retailer, and also has a direct channel to consumers, such a distribution system is usually called a "dual-channel" distribution system. Because a manufacturer and its retailer sell essentially the same products in a dual-channel distribution system, the retailer may feel excluded, giving rise to "channel conflict". In general, channel conflict can undermine attempts to develop cooperative relationships in the intermediated channel, which may have an effect of lowering the profits for all parties.

To cope with the channel management problem, different manufacturers adopt a variety of channel strategies. For example, Dell, which is arguably the most successful Internet marketer in the personal computer market, continuously explores desirable distribution channels for the company. Dell has opened kiosk locations in shopping malls across the US since 2002 and full-scale manufacturer-owned stores since the second half of 2006; Dell opened a retail store in Dallas and another one in New York in 2006. More recently, Dell expanded into retail stores such as Wal-Mart and Best Buy while it has shut down all its kiosks in the US in 2008.

In contrast to manufacturers supplying industrial products such as electric appliances, a large portion of leading manufacturers remain adamant about selling through retail channels although they are apparently capable of operating their own direct channels. For example, manufacturers of daily necessities or processed foods appear to distribute products through direct channels less frequently. Given the present channel environments that manufacturers encounter, this paper investigates the optimal product distribution strategy for a manufacturer that uses dual-channel supply chains: a traditional retail channel and a direct channel. We assume that two symmetric manufacturers facing price competition determine their product distribution strategy from three choices: the manufacturer distributes products through (1) the retail channel only, (2) the direct channel only, or (3) both the retail and direct channels. Moreover, another particularly important assumption underlying our model is that the two

manufacturers are perfectly symmetric in that they both have dual distribution channels and an identical cost structure. Our most notable result based on these settings is that even though the two manufacturers are symmetric, there always arises a subgame perfect equilibrium (SPE) that includes an asymmetric distribution policy, where one manufacturer distributes products only through the direct channel, while the other manufacturer distributes through both the direct channel and the retail channel. This is a unique implication of our results, because even when the manufacturers are symmetric, the product distribution policies that always arise in equilibrium are asymmetric between them. In addition to this main result, we point to the possibility that this asymmetric product distribution strategy may not be Pareto optimal for the two manufacturers, because the asymmetric strategy earns both manufacturers lower profits than other symmetric distribution strategies.

The mechanisms that drive the equilibrium asymmetric distribution strategies are described as follows. One merit of using a direct channel, instead of a retail channel, for a manufacturer is to avoid the "double marginalization" problem, which means that both the manufacturer and the retailer extract a margin from the product. Double marginalization causes the retail price to exceed the optimal level for the whole supply chain and the transaction quantity to be below the optimal level for the manufacturer in the supply chain.¹ As we will show later, if the distribution policy of two manufacturers is asymmetric, the timing for them to gain margin is not simultaneous but sequential. The game-theoretic literature has demonstrated that if price competition arises, the firm that sets its price at a later period earns higher profit than the firm that sets its price in an earlier move (e.g., Gal-or, 1985). This advantage of a later move has been called the "second-mover advantage." To obtain the second-mover advantage, each manufacturer wishes to set the price at a later period. This behavior leads to sequential price setting by the manufacturers, but not simultaneous setting, because each manufacturer delays their pricing decision, and simultaneous price setting thus becomes infeasible. Moreover, the literature has further demonstrated that both firms have higher profits under duopolistic price competition when choosing price sequentially rather than simultaneously.² As a result, there is an incentive for manufacturers to choose the asymmetric distribution strategy to gain margins at different timings. This is the rationale for why the asymmetric distribution strategy, not the symmetric one, always constitutes the equilibrium.

The remainder of the paper is structured as follows. Section 2 provides a review of the literature relating to dual-channel supply-chain management from a game-theoretic perspective. Section 3 delineates the basic settings of the model and formulates our model to derive the SPE that identifies the optimal distribution strategy for the manufacturers. In Section 4, we generalize the model so that it describes more realistic business environments. The final section provides concluding remarks.

¹ Note that the optimal level of price and quantity discussed here represents that for a firm, but not for consumers or for society. See Spengler (1950) for details on how double marginalization adversely affects optimality for the firm.

² See van Damme and Hurkens (2004, p. 405) who prove this fact.

2. Literature review

To date, there have been numerous operational research and management science (OR/MS) studies that explore channel coordination mechanisms (e.g., Jeuland and Shugan, 1983; McGuire and Staelin, 1983; Tsay and Agrawal, 2004b; Parlar and Weng, 2006; Anderson and Bao, 2010; Atkins and Liang, 2010; Matsui, 2012; Matsushima and Mizuno, 2013; Kumoi and Matsubayashi, 2014; Karaer and Erhun, 2015). Moreover, a number of studies appear to focus on coordination and conflict between direct marketers and conventional intermediaries such as retailers, typically analyzing the economic impacts of the introduction of the direct Internet channel (e.g., Balasubramanian, 1998; Chiang et al., 2003; Tsay and Agrawal, 2004a; Yao and Liu, 2003, 2005; Chiang and Monahan, 2005; Yao et al., 2005, 2009; Cattani et al., 2006; Liu et al., 2006; Kurata et al., 2007; Bernstein et al., 2008; Dumrongsiri et al., 2008; Huang and Swaminathan, 2009; Chiang, 2010; Hua et al., 2010; Khouja and Wang, 2010; Chen et al., 2013; Hsiao and Chen, 2013; Carrillo et al., 2014; Xiao et al., 2014; Khouja and Zhou, 2015; Li et al., 2015; Rodríguez and Aydın, 2015; Yan et al., 2015).

Balasubramanian (1998) investigates the competition between direct marketers and conventional retailers by considering the adaptability of products to the direct sales channel and the product information revealed to customers. He shows that when the product is not well adapted to the direct channel, the direct marketer must ideally lower the market information level about the direct channel because the lower information level mitigates competition between the direct marketer and conventional retailers. Chiang et al. (2003) analyze a manufacturer's decision to sell direct over the Internet, exclusively through a retailer or through a hybrid of both approaches. They demonstrate that a direct channel helps the manufacturer improve overall profitability by reducing the degree of inefficient price double marginalization. Liu et al. (2006) show that in the markets where retail price consistency across channels is mandatory, an incumbent traditional brick-and-mortar retailer can deter the entry of a pure-play online retailer by strategically refraining from entering online. By contrast, in the markets where price consistency is not a constraint, the incumbent can deter the entry of a pure-play online retailer only if it enters online. In the latter case, the incumbent is willing to cannibalize its own brick-and-mortar business by charging a low online price. Dumrongsiri et al. (2008) investigate a dual-channel supply chain in which a manufacturer sells to a retailer as well as to consumers directly. They show that the difference in marginal costs of the two channels and demand variability have a major influence on the manufacturer's motivation for opening a direct channel. Huang and Swaminathan (2009) study the optimal pricing strategies when a product is sold on two channels such as the Internet and a traditional channel. They construct a deterministic demand model where the demand on a channel depends on prices, degree of substitution across channels and the overall market potential, examining several prevalent pricing strategies which differ in the degree of autonomy for the Internet channel. Chen et al. (2013) consider pricing policies in a supply chain with one manufacturer, who sells a product to an independent retailer and

directly to consumers through an Internet channel. They show that improving brand loyalty is profitable for both the manufacturer and retailer and that an increased service value may alleviate the threat of the Internet channel for the retailer and increase the manufacturer's profit. Hsiao and Chen (2013) investigate a channel selection problem between a direct channel and a retail channel for a manufacturer that incurs no production costs in a duopoly, showing that the equilibrium where one manufacturer distributes products in both of the channels while the other manufacturer distributes only in the direct channel never arises. Conversely, we demonstrate that the asymmetric equilibrium always arises where one manufacturer uses both channels and the other manufacturer uses only the direct channel, which is different from Hsiao and Chen (2013). Xiao et al. (2014) develop a retailer-Stackelberg pricing model to investigate the product variety and channel structure strategies of a manufacturer. They demonstrate that the manufacturer is more likely to use dual channels under the retailer-Stackelberg channel leadership scenario than under the manufacturer-Stackelberg scenario if offering a greater variety of products is sufficiently expensive. Li et al. (2015) applies a channel selection framework to the distribution of books, examining different pricing and launch strategies of electronic books (e-books) for a publisher under copyright arrangements, which are the royalty and buyout arrangements. They propose optimal launch strategies and pricing decisions for the e-book supply chain. Rodríguez and Aydın (2015) study the pricing and assortment decisions in dual-channel supply chains, where the retailer offers a subset of the assortment that the manufacturer offers through its direct channel. They highlight the possibility that the manufacturer's and retailer's assortment preferences are in conflict, where the manufacturer prefers the retailer to carry items with high demand variability while the retailer prefers items with low demand variability.

In addition to the OR/MS studies, there also appear industrial organization studies that examine vertical channel relationships from a game-theoretic point of view. After Gal-or (1985) finds a second-mover advantage in a price-setting game, industrial organization research develops price competition models where the order of moves of players is determined endogenously (e.g., Dowrick, 1986; Hamilton and Slutsky, 1990; Deneckere and Kovenock, 1992; van Damme and Hurkens, 1996, 1999, 2004; Amir and Grilo, 1999; Amir and Stepanova, 2006). Dowrick (1986) examines under what circumstances firms agree on the choice of roles of leader and follower in the Stackelberg duopoly model. He shows that each will prefer to be the leader if the firms have downward-sloping reaction functions, while each will prefer that the other be the leader if they have upward-sloping reaction functions. Hamilton and Slutsky (1990) establish the framework of the "timing game," where the order of moves chosen by players in a noncooperative game is endogenously determined in the game itself. Van Damme and Hurkens (1996, 1999, 2004) extend the timing game by considering various economic environments. Specifically, van Damme and Hurkens (2004) investigate a price-setting duopoly game under uncertainty and determine endogenously which of the players will lead and which will follow. While the follower role is attractive for each firm, they show that waiting is more risky for the low-cost firm and only the high-cost firm will choose to wait. Amir and Stepanova (2006) consider the issue of first- versus

second-mover advantage in a Bertrand duopoly with general demand and asymmetric linear costs. They show that sequential play with the low-cost firm as leader arises as the unique equilibrium outcome because a firm with a sufficiently large cost lead over its rival has a first-mover advantage. As recent supply-chain studies in the OR/MS field rely substantially on insights gained in the industrial organization literature, we will also use insights from the literature to provide the rationale behind our equilibrium outcome that involves an asymmetric distribution strategy.

3. Model

3.1 Assumptions

Table 1 lists the variables used in our model. Suppose that two existing manufacturers, denoted by Manufacturer 1 and Manufacturer 2, produce differentiated products and sell them to consumers. We define the product supplied by Manufacturer i (hereafter, $i = 1, 2$) as Brand i . Each of the two manufacturers produces a product at a variable cost of c per unit and no fixed cost, and sells the product through a traditional retailer, which we define as the retail channel, or through a direct distribution channel, which we define as the direct channel. If using a retail channel, Manufacturer i initially sells products to Retailer i , who subsequently resells the products to end consumers. Figure 1 describes the structure of the channel form.

[Table 1]

[Fig. 1]

Because both manufacturers use dual channels, each manufacturer can choose a distribution policy regarding which channel it uses from the following three strategies. Let "Strategy R" denote that the manufacturer distributes the product only through the traditional retail channel; "Strategy D" denotes that the manufacturer sells the product only through the direct channel; and "Strategy RD" denotes that the manufacturer distributes products in both retail and direct channels. If Manufacturer i chooses Strategy RD, Manufacturer i and Retailer i compete to sell the identical product, Brand i . This type of competition is usually called "intra-brand competition." Meanwhile, the competition where Manufacturers (or Retailers) 1 and 2 compete to sell different brands is called "inter-brand competition." Accordingly, we distinguish these two types of competition in our model.

We assume that the utility function of a representative consumer, U , is:³

$$U = a(Q_1 + Q_2) - (b(Q_1^2 + Q_2^2) + 2b\theta Q_1 Q_2)/2, \quad (1)$$

where Q_i ($i = 1, 2$) represents the quantity purchased from Manufacturer i . Additionally, let q_i^R denote the quantity sold by Retailer i and q_i^D denote that sold by Manufacturer i in its direct

³ A utility function that is concave with respect to each control variable describes risk-averse consumer behavior (see, e.g., Varian, 1992, p. 177). We determine that the utility function given by Equation (1) is for a risk-averse consumer because $\partial^2 U / Q_i^2 = -b < 0$ ($i = 1, 2$) holds and the function is thus concave with respect to both Q_1 and Q_2 .

channel. Because supply quantity by Manufacturer i comprises those handled by the retail and the direct channels, $Q_i \equiv q_i^R + q_i^D$ holds. Hence, Equation (1) implies that the consumer is indifferent between buying a given brand from a retailer versus a direct seller.⁴

Given Equation (1), consumer surplus denoted by S is expressed as:

$$S = U - (p_1 Q_1 + p_2 Q_2) = a(Q_1 + Q_2) - (b(Q_1^2 + Q_2^2) + 2b\theta Q_1 Q_2)/2 - p_1 Q_1 - p_2 Q_2, \quad (2)$$

where p_i represents the retail price of Manufacturer i 's product. The consumer maximizes Equation (2) by solving $\partial S/\partial Q_1 = \partial S/\partial Q_2 = 0$, yielding the following inverse demand functions.⁵

$$p_i = a - b(Q_i + \theta Q_j) \quad (i, j) = (1, 2) \text{ or } (2, 1) \quad (3)$$

Hereafter, (i, j) signifies either $(1, 2)$ or $(2, 1)$ when the two variables are simultaneously present, but not in isolation. The parameter $\theta \in (0, 1)$ represents the degree of substitution among products, and $a (> c)$ and b are positive constants. The products become differentiated as θ approaches zero, whereas they become similar as θ approaches one.

Next, profits for Manufacturer i , Π_i , that chooses Strategy R, Strategy D, and Strategy RD, respectively, are:

$$\Pi_i = (r_i - c)q_i^R, \quad (4)$$

$$\Pi_i = (p_i^D - c)q_i^D, \quad (5)$$

$$\Pi_i = (r_i - c)q_i^R + (p_i^D - c)q_i^D, \quad (6)$$

where r_i denotes the wholesale price of a unit of the product sold by Manufacturer i and p_i^D is the direct price of a product sold by Manufacturer i . Profit for Retailer i , π_i , is:

$$\pi_i = (p_i^R - r_i)q_i^R, \quad (7)$$

⁴ In reality, however, some customers would be willing to pay slightly more at a retailer because they can see and touch the actual product and not incur the risk that an online image does not fit what they actually get, whereas other customers may be willing to pay slightly more to have goods shipped straight to their houses, which reduces their costs of travelling to the retailer. We employ the assumption of indifference between the channels in order to highlight our main result that an asymmetric product distribution policy arises by dispensing with extraneous factors that are not related to the main result.

⁵ Previous OR/MS studies on supply chain management have usually employed the linear demand schedule (e.g., McGuire and Staelin, 1983; Cai, 2010). Because these works form the foundation for our model, we also use the linear demand schedule represented by Equation (3).

where p_i^R is the retail price of a product resold by Retailer i .⁶

Following the recent study by Cai (2010) that constructs a dual-channel supply-chain model, we assume the timeline of events illustrated in Figure 2. Initially, each of the two manufacturers simultaneously determines their product distribution strategy: i.e., Strategy R, D, or RD at Stage 1. Subsequently, a manufacturer that uses a retail channel determines the wholesale price and sells the product to a retailer at that price at Stage 2. Finally, price competition at the retail level arises at Stage 3; the retail price is chosen either by a manufacturer that uses a direct channel or by a retailer in a retail channel used by a manufacturer. Because our model builds on the framework of a dynamic game of complete information, we employ a SPE as the equilibrium concept.⁷ We solve the game by backward induction to identify the SPE.

[Fig. 2]

Note that an important assumption in our model is that the two manufacturers are perfectly symmetric; they have an identical cost structure and similarly, have two distribution channels. We will show that even under this setting, the product distribution policies that always arise in equilibrium are asymmetric between the two manufacturers.

3.2 Results

Following the above arrangements, we derive payoffs for each manufacturer by the combination of distribution strategies, as summarized in the following lemma. (All proofs are provided in the Appendix.)

Lemma 1. Equilibrium payoffs for each manufacturer by the combination of distribution strategies are described in Table 2.

[Table 2]

From Lemma 1, we identify equilibrium distribution strategies, as the next proposition shows.

⁶ Equations (4)–(7) imply that we assume no transportation costs for either the retail or direct sales strategies. In practice, shipping large quantities to a retailer may be cheaper than shipping many single units directly to customers. We do not consider such cost factors to highlight our main result, similar to the reason shown in Footnote 4.

⁷ Our model is classified as a dynamic game, because the game is comprised of three stages, in which each player makes a decision, as Fig. 2 illustrates. Besides, our model is also classified as a complete information game, because the model includes no random variable and each firm thus knows perfectly the form of the payoff functions of all the other firms. These two facts ensure that the model in this paper is classified as a dynamic game of complete information. For more details, see Gibbons (1992) who classifies various types of noncooperative games. In particular, chapter 2, "Dynamic Games of Complete Information" in Gibbons (1992), documents that the SPE is usually used as the solution concept of a dynamic game of complete information.

Proposition 1. The combinations of distribution strategies that always arise in the SPE regardless of the values of the exogenous parameters are strategies (D, RD) and (RD, D).

Proposition 1 suggests that the distribution strategy that always arises in equilibrium is asymmetric between the two manufacturers. Because of this asymmetry, it is worth examining which of the equilibrium strategies, (D, RD) or (RD, D), earns a larger profit for a manufacturer. The next corollary immediately follows from Lemma 1.

Corollary 1. In the asymmetric equilibrium of either Strategy (D, RD) or (RD, D), the profit for the manufacturer that chooses Strategy D is greater than that for the manufacturer that chooses Strategy RD.

Corollary 1 indicates that it is more advantageous for a manufacturer to choose Strategy D than RD in the asymmetric equilibrium. Although our result does not determine which of the two manufacturers chooses Strategy D or RD, the strategy to distribute products only in the direct channel earns a manufacturer a higher profit than the strategy to distribute products in the dual channels. In this respect, these asymmetric equilibria are a typical result of a "chicken game," which has been examined extensively in the noncooperative game theory literature.⁸

3.3 Rationale

Proposition 1 suggests that the combinations of the symmetric strategies (RD, RD) and (D, D), which yield the same payoffs as shown in Table 2, do not constitute an SPE. We provide the rationale behind this outcome in the following. If the manufacturers choose Strategy (RD, RD), intra-brand competition within the two channels used by each manufacturer occurs at the retail level. Because the two channels sell an identical brand, the intra-brand competition prevents both Retailer i and Manufacturer i from boosting p_i^R and p_i^D above the wholesale price, r_i , indicating that they earn no margin at the retail level. At the wholesale level, however, Manufacturer i earns a margin by setting the wholesale price, r_i , above c .⁹ Therefore, both manufacturers' channels extract margins not twice but only once at the wholesale level. Meanwhile, if the manufacturers choose Strategy (D, D), both manufacturers can boost the direct price, p_i^D , above c , meaning that they also only have one margin, in this case at the retail level. In summary, both strategies (RD, RD) and (D, D) allow the two manufacturers to extract margins only once in the simultaneous price-setting game, thereby leading to the same profits.

Based on the interpretation of these symmetric distribution strategies, we next explore the reason why asymmetric strategies (D, RD) and (RD, D) arise in equilibrium. Suppose that Manufacturer i chooses Strategy D while Manufacturer j chooses Strategy RD. Then,

⁸ Several previous OR studies apply the chicken game framework to supply chain management problems (e.g., Groznik and Heese, 2010; Zhou and Cao, 2013).

⁹ See Case (9) of Proof of Lemma 1 in Appendix to confirm these facts.

Manufacturer i obtains a margin once only at the retail level through the direct channel. On the other hand, Manufacturer j also obtains a margin once only at the wholesale level, because the intra-brand competition forces Manufacturer j and Retailer j to set p_j^D and p_j^R equal to r_j at the retail level, as discussed earlier. As a result, the timing to obtain a margin is later for Manufacturer i than for Manufacturer j ; namely, the former gains a margin at Stage 3 while the latter at Stage 2. In this sense, the manufacturer choosing Strategy D becomes the second mover while the manufacturer choosing Strategy RD becomes the first mover in the sequential price-setting game.

Note here that the game-theoretic literature has demonstrated that if price competition arises, the firm that sets its selling price in a later move earns a higher profit than the firm that sets its price in an earlier move (e.g., Gal-or, 1985). This advantage stemming from the later move has been called the second-mover advantage. Because each competing firm delays its pricing decision to obtain this second-mover advantage, simultaneous price setting by the two firms becomes unstable and sequential price setting by the manufacturers thus occurs in equilibrium.¹⁰ If we apply this insight from game theory to our model, an incentive arises for the manufacturers to choose asymmetric distribution strategies to gain margins at different timings. Consequently, the manufacturer choosing Strategy D exploits the second-mover advantage in the price competition, collecting higher profit than the other manufacturer choosing Strategy RD, because the former becomes the second mover while the latter becomes the first mover, as explained above. In summary, the second-mover advantage of price competition is the source of the higher payoff for the manufacturer choosing Strategy D than for the manufacturer choosing RD in the asymmetric equilibria, which is shown in Corollary 1, and is thus the reason why the asymmetric distribution strategy, and not the symmetric one, always constitutes the equilibrium.

3.4 Optimality

Next, we check whether the derived equilibria are optimal for both manufacturers by comparing nine combinations of the payoffs shown in Table 2. We use the concept of "Pareto optimality" as the criterion for this examination; Pareto optimality is a state of allocation of resources in which it is impossible to make any one individual better off without making at least one other individual worse off.¹¹ In the context of our model, if the payoff for at least one manufacturer decreases when the combinations of distribution strategies change from equilibrium, the equilibrium is Pareto optimal. Hence, note that the Pareto optimality here represents the state defined above for manufacturers, but neither for a consumer nor for the society. The following proposition summarizes the optimality.

Proposition 2. If $0 < \theta < 0.7188$, both of the asymmetric equilibria of strategies (RD, D)

¹⁰ Note that the game theory literature demonstrates that both competing firms in duopoly have higher profits when choosing their prices sequentially rather than simultaneously (e.g., van Damme and Hurkens, 2004).

¹¹ See, for example, Mas-Colell et al. (1995, p. 307) for a definition of Pareto optimality.

and (D, RD) are Pareto optimal. Meanwhile, if $0.7808 < \theta < 1$, both of the asymmetric equilibria of strategies (RD, D) and (D, RD) are not Pareto optimal; the profits for both manufacturers are higher in strategies (R, R) than those in the two asymmetric strategies.

If the products are not substantially differentiated so that $0.7808 < \theta < 1$, asymmetric equilibrium distribution policies (D, RD) and (RD, D) do not provide each manufacturer with the highest profit. Specifically, both of their profits improve if they move to another combination of strategies: Strategy (R, R). This means that both manufacturers are trapped in a prisoner's dilemma in the noncooperative game in that the equilibrium asymmetric distribution strategies are unfavorable to both of them. However, the manufacturers can escape from the state of this prisoner's dilemma resulting in the one-shot channel selection game if the manufacturers play the game an infinite number of times.¹² More specifically, by using trigger-type punishment strategies, implicit coordination between the manufacturers arises that enables them to achieve the state of Strategy (R, R).

4. Generalization

In this section, we generalize our model constructed in the previous section so that the model can describe more realistic business environments. Specifically, we pursue generalizations in the following two directions: (1) general cost and demand functions, and (2) different cost structures.

4.1 General functional form

While we assume the linear form demand and cost structures following the literature in the previous section, the functions do not necessarily take such concise forms in practice. Hence, suppose in this subsection that each firm faces the general demand functional form represented by $Q_i = Q(p_i, p_j, \theta)$ ($(i, j) = (1, 2)$ or $(2, 1)$), instead of Equation (3), and the general cost functional form denoted by $c_i = c(Q_i)$. We will prove that even if we employ such general functional forms, our main result regarding the equilibrium asymmetric distribution strategies still holds. The key logic in deriving this result is that the choice of distribution strategy for a manufacturer is essentially the same as the choice between the first move or the second move, as explained in Subsection 3.3. Specifically, remember that the manufacturer choosing Strategy RD in the asymmetric equilibrium makes the first move to earn its margin, whereas the manufacturer choosing Strategy D makes the second move. Because each manufacturer delays its pricing decision to exploit the second-mover advantage arising in the sequential price setting, simultaneous moves by the two manufacturers become unstable and thus unrealized. As a result, the manufacturers choose asymmetric distribution strategies that

¹² This fact is known as the Folk theorem in repeated game theory (Gibbons, 1992, p. 89). Research that adopts the repeated game framework to investigate supply chain management problems appears in the earlier OR literature (e.g., Huang and Sošić, 2010; Sun and Debo, 2014).

lead to sequential moves in equilibrium. Because this logic suggests that the second-mover advantage must arise so that asymmetric distribution strategies result in equilibrium, we first identify a sufficient condition for the emergence of the second-mover advantage using insights gained in Gal-or (1985).¹³

Similar to Subsection 3.3, we assume that Manufacturer i chooses Strategy D while Manufacturer j chooses Strategy RD in equilibrium. Then, profits for Manufacturers i and j and Retailer j with the general cost function are:

$$\Pi_i = (p_i^D - c(q_i^D))q_i^D \quad (8)$$

$$\Pi_j = (r_j - c(q_j^R))q_j^R + (p_j^D - c(q_j^D))q_j^D \quad (9)$$

$$\pi_j = (p_j^R - r_j)q_j^R. \quad (10)$$

With these settings, both of the retail prices of the product supplied by the manufacturer with Strategy RD, i.e., p_j^R and p_j^D , fall to r_j because of Bertrand competition. As a result, Manufacturer i sets p_i^D in the latter move (Stage 3) while Manufacturer j sets r_j in the earlier move (Stage 2) to earn margins, respectively, as shown in Subsection 3.3. Accordingly, we restate the profits of Equations (8) and (9) as the following payoff functions in the sequential price setting by using $Q_i = Q(p_i, p_j, \theta)$ ($(i, j) = (1, 2), (2, 1)$).

$$\Pi_i(p_i^D, r_j) = (p_i^D - c(Q(p_i^D, r_j, \theta)))Q(p_i^D, r_j, \theta), \quad (11)$$

$$\Pi_j(r_j, p_i^D) = (r_j - c(Q(r_j, p_i^D, \theta)))Q(r_j, p_i^D, \theta). \quad (12)$$

The first argument of the payoff function of a manufacturer, $\Pi_i(\cdot, \cdot)$, corresponds to his own strategy choice and the second argument corresponds to the other manufacturer's strategy choice. In this game, the pair (p_i^{D*}, r_j^*) constitutes the SPE based on strategies (D, RD) if: $p_i^{D*} \equiv g(r_j^*) = \arg \max_{p_i} \Pi_i(p_i, r_j^*)$ and $r_j^* = \arg \max_r \Pi_j(r, g(r))$, where the function $g(\cdot)$ is defined as the reaction function of Manufacturer i . If an interior equilibrium satisfying this condition exists, then the following first-order necessary conditions hold.

$$\begin{aligned} G_i(r_j^*, p_i^{D*}) &\equiv \Pi_i^1(p_i^{D*}, r_j^*) = 0 \\ G_j(r_j^*, p_i^{D*}) &\equiv \Pi_j^1(r_j^*, p_i^{D*}) - \Pi_j^2(r_j^*, p_i^{D*}) \Pi_i^{12}(p_i^{D*}, r_j^*) / \Pi_i^{11}(p_i^{D*}, r_j^*) = 0, \end{aligned} \quad (13)$$

where $G_i(\cdot, \cdot)$ ($i = 1, 2$) denotes the first-order derivative of Manufacturer i 's payoff and

¹³ Notations in this subsection follow Gal-or (1985).

superscripts 1 and 2 respectively denote the partial derivatives with respect to the first argument and the second argument. The second order condition is:

$$G_i^2(r_j^*, p_i^{D*}) < 0$$

$$G_j^1(r_j^*, p_i^{D*}) - G_j^2(r_j^*, p_i^{D*})\Pi_i^{12}(p_i^{D*}, r_j^*)/\Pi_i^{11}(p_i^{D*}, r_j^*) < 0. \quad (14)$$

If inequality (14) holds globally, the equilibrium is unique. Notice that the sign of the slope of the reaction function of manufacturer i is determined by the sign of Π_i^{12} ; namely, the cross partial derivative of the payoff function. Bulow et al. (1985) show that because the strategy choice of the follower is positively related to the strategy choice of the Stackelberg leader in price competition, Π_i^{12} is positive. Based on this insight, Gal-or (1985) proves that second-mover advantage arises in price competition as long as Inequality (14) is met. Consequently, Inequality (14) is a sufficient condition that the asymmetric distribution strategies (D, RD) and (RD, D), with which the two manufacturers extract margins at different time periods, constitute the SPE under the general cost and demand functions.¹⁴

Next, note that under the strategies of (D, RD) or (RD, D), the manufacturer that uses only the direct channel has no incentive to also distribute products through the retail channel, because such behavior changes the competition mode from sequential move to simultaneous move, which reduces the profit for the manufacturer. For the same reason, the other manufacturer that uses both channels has no incentive to stop distributing its products through its retail channel. That is, neither manufacturer has an incentive to deviate from the state resulting from strategies (D, RD) or (RD, D), which proves that the two asymmetric distribution strategies are sustained as equilibria under the general functional forms as long as Inequality (14) is satisfied.

Because the asymmetric distribution strategies arise even with the general functional forms, it seems favorable to assume the general functions from the beginning of model construction in this paper. However, we should note that there is one disadvantage of using such general functional forms; that is, we become unable to measure the magnitude of the effect of the product substitutability parameter, θ , on the equilibrium payoffs when using general functions. Stated differently, the major reason why we employed the linear form demand and cost functions in the previous section as the benchmark was to examine the quantitative effect of θ on the equilibrium payoffs and to compare the payoffs between the combinations of distribution strategies analytically. Indeed, the present model with general functional forms prevents us from calculating the thresholds of θ that identify the Pareto optimality of equilibrium such as Proposition 2. At least, however, we prove in this section that our central result shown in the previous section continues to hold even if we do not

¹⁴ It should be noted that as Gal-or (1985, p. 650) suggests, even if a priori we restrict ourselves to concave profit functions, Inequality (14) does not necessarily follow. Therefore, it follows that the concavity of the profit functions is not a sufficient condition that second-mover advantage arises.

restrict the demand and cost functions to take linear forms.

4.2 Asymmetric cost structure

While our focus in this paper is on the asymmetric distribution strategies chosen by symmetric manufacturers, the underlying assumption of the same marginal cost between the two manufacturers might be too strict, in that such a case is rare in real business environments. Accordingly, we allow marginal cost to differ between the two manufacturers in this subsection. Let c_1 and c_2 respectively denote the marginal cost of Manufacturers 1 and 2.

Given the cost difference, we should pay attention to the case where the difference between c_1 and c_2 is excessively large, because there occurs the possibility that one of the two manufacturers monopolizes the entire market in such a case. Because we consistently concentrate on the duopoly case throughout this paper, we henceforth exclude the monopoly case by assuming that the following inequality regarding the exogenous parameters holds.

$$a > \frac{(2 - \theta^2)c_i - \theta c_j}{(1 - \theta)(2 + \theta)} \quad (i, j) = (1, 2) \text{ or } (2, 1) \quad (15)$$

If Inequality (15) is met, all sales quantities, Q_i ($i = 1, 2$), supplied by both the manufacturers resulting from possible combinations of distribution strategies are positive, implying that monopoly never occurs. The following lemma holds given the assumption of Inequality (15).

Lemma 2. Equilibrium payoffs by the combination of distribution strategies are summarized in the following, where $\Pi_i^{(S_i, S_j)}$ denotes the profit for Manufacturer i when Manufacturers i and j respectively choose S_i and S_j as their distribution strategies.

$$\Pi_i^{(R,R)} = \frac{(2 - \theta^2)((1 - \theta)(2 + \theta)(4 + \theta - 2\theta^2)a - (8 - 9\theta^2 + 2\theta^4)c_i + \theta(2 - \theta^2)c_j)^2}{b(2 - \theta)(1 - \theta)(1 + \theta)(2 + \theta)(4 + \theta - 2\theta^2)^2(4 - \theta - 2\theta^2)^2}$$

$$\Pi_i^{(R,D)} = \frac{((2 - \theta - \theta^2)a - (2 - \theta^2)c_i + \theta c_j)^2}{4b(2 - \theta^2)(4 - 5\theta^2 + \theta^4)}$$

$$\Pi_i^{(D,R)} = \frac{((1 - \theta)(2 + \theta)(4 + \theta - 2\theta^2)a - (8 - 9\theta^2 + 2\theta^4)c_i + \theta(2 - \theta^2)c_j)^2}{4b(1 - \theta^2)(8 - 6\theta^2 + \theta^4)^2}$$

$$\Pi_i^{(R, RD)} = \frac{((4 - 2\theta - 3\theta^2 + \theta^3)a - (4 - 3\theta^2)c_i + \theta(2 - \theta^2)c_j)^2}{2b(1 - \theta)(1 + \theta)(8 - 5\theta^2)^2}$$

$$\Pi_i^{(RD, R)} = \frac{(2 - \theta^2)((4 - \theta - 3\theta^2)a - (4 - 3\theta^2)c_i + \theta c_j)^2}{2b(1 - \theta)(1 + \theta)(8 - 5\theta^2)^2}$$

$$\Pi_i^{(D,D)} = \frac{((2-\theta-\theta^2)a - (2-\theta^2)c_i + \theta c_j)^2}{b(2-\theta)^2(1-\theta)(1+\theta)(2+\theta)^2}$$

$$\Pi_i^{(D,RD)} = \frac{((4-2\theta-3\theta^2+\theta^3)a - (4-3\theta^2)c_i + \theta(2-\theta^2)c_j)^2}{16b(1-\theta)(1+\theta)(2-\theta^2)^2}$$

$$\Pi_i^{(RD,D)} = \frac{((2-\theta-\theta^2)a - (2-\theta^2)c_i + \theta c_j)^2}{8b(1-\theta)(1+\theta)(2-\theta^2)}$$

$$\Pi_i^{(RD,RD)} = \frac{((2-\theta-\theta^2)a - (2-\theta^2)c_i + \theta c_j)^2}{b(2-\theta)^2(1-\theta)(1+\theta)(2+\theta)^2}$$

The next proposition follows from the payoff values in Lemma 2.

Proposition 3. The combinations of distribution strategies that always arise in SPE regardless of the values of the exogenous parameters are strategies (D, RD) and (RD, D).

Note that Proposition 3 is identical to Proposition 1 derived under symmetric marginal cost. Proposition 3 suggests that even if we incorporate different cost structures into our model, the asymmetric distribution strategy that one manufacturer uses only the direct channel while the other manufacturer uses both the direct and retail channels arises in equilibrium. Because cost structures are likely to vary more or less between firms in the real business environment, the generalized model reinforces that our central message from the present study is robust.

5. Conclusions and implications

This paper investigates the optimal product distribution strategy for manufacturers that use dual-channel supply chains. Even though the two manufacturers are assumed to be symmetric, an equilibrium always arises that includes an asymmetric distribution policy, where one manufacturer distributes products only in the direct channel while the other distributes products in both channels. However, if product differentiation between manufacturers is insufficient, both manufacturers can be trapped in the prisoner's dilemma because the asymmetric distribution policy earns both of them lower profits than a symmetric one. Finally, we generalize our benchmark model by introducing general cost and demand functional forms and different cost structures between manufacturers. As a consequence, our central result that the asymmetric distribution strategies constitute the SPE holds under more practical environments.

Note that our model is a variation of the typical Stackelberg duopoly. Similar to the setting in the Stackelberg duopoly, our model also involves sequential price setting, where a manufacturer first sets the wholesale price and a retailer subsequently sets the retail price. Meanwhile, there is also a difference between our model and the Stackelberg duopoly. In the

Stackelberg duopoly, sequential price setting occurs, but not simultaneous price setting. By contrast, simultaneous price setting as well as sequential price setting can occur in our model. For example, if both manufacturers use only the direct channel to distribute products (i.e., Strategy (D, D)) in our model, they set the direct price simultaneously. This difference between our model and the Stackelberg duopoly comes from the nature of the relationship between the firms; namely, competition between two firms having a horizontal relationship is considered in the Stackelberg duopoly, whereas competition between firms in a vertical relationship as well as in a horizontal relationship is considered in our model. More specifically, in the Stackelberg duopoly, one of the two firms first sets the selling price of a product and the other firm then sets the price of the product. By contrast, while one firm (i.e., a retailer) sets the retail price of a product sold to end consumers, another firm (i.e., a manufacturer) sets not only the direct price but also the wholesale price of a product sold to a retailer in our model. In this respect, our model is clearly distinct from the Stackelberg duopoly.

Finally, we document the practical implications of our study that can be used as decision support. The most notable implication relates to the optimal distribution policy that manufacturers should implement; that is, a symmetric distribution policy is not necessarily optimal for a manufacturer encountering price competition. In particular, when another competing manufacturer distributes products through its dual channels, a manufacturer should not also adopt a dual-channel distribution strategy without careful consideration, only to counter its rival's dual-channel strategy. At first glance, it seems advantageous for a manufacturer to distribute products through both direct and retail channels if a rival also distributes products through dual channels, because dual channels are expected to broaden the market. However, our model suggests the contrary; when products are not differentiated between the channels managed by the same manufacturer, as considered in our model, the dual-channel distribution policy causes serious channel conflict between the channels. As a result, such a dual-channel distribution strategy against the rival triggers the most intense inter-brand competition between the manufacturers. To avoid this destructive competition, the manufacturer should instead use only the direct channel in this case. This single-channel strategy enables the manufacturer to delay the timing of the setting of the direct price and to select the price more flexibly after observing the wholesale price set by its rival with dual channels, thereby exploiting the second-mover advantage. Indeed, the wholesale price is expected to be set before the retail price is set in a traditional retail channel in a real business environment.

Notice that the above counterintuitive implication has been derived precisely because we apply the rigorous game theory framework that describes strategic behavior of firms as the theoretical foundation to a dual-channel supply-chain management problem. Specifically, the desirable distribution policy corresponds to the best response of a manufacturer and constitutes the Nash equilibrium in the noncooperative game. In this respect, our unique implication is robust and thus serves as a guideline for decision-making about distribution-channel strategy for manufacturers managing multiple supply chains.

Appendix

In the below proofs, we use the following four inverse demand functions, which are derived by substituting $Q_i = q_i^R + q_i^D$ ($i = 1, 2$) into Equation (3).

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

Proof of Lemma 1.

We derive an SPE that specifies optimal pricing strategy at Stages 2 and 3 under each of the nine combinations of distribution strategies chosen by the two manufacturers at Stage 1. The first letter contained in the parentheses below represents the strategy chosen by Manufacturer 1, whereas the latter represents that chosen by Manufacturer 2. For example, (R, RD) means that Manufacturer 1 distributes products only in the retail channel while Manufacturer 2 distributes products in both the retail and direct channels.

Case (1): Strategy (R, R)

We replace q_1^D and q_2^D in Equations (A1) and (A3) with zero. Then, we solve the two equations for q_1^R and q_2^R to derive the demands:

$$q_1^R = ((1-\theta)a - p_1^R + \theta p_2^R)/(b(1-\theta^2)), \quad q_2^R = ((1-\theta)a - p_2^R + \theta p_1^R)/(b(1-\theta^2)). \quad (A5)$$

With the use of Equation (A5), profits for the retailers at Stage 3 are as follows:

$$\pi_1 = (p_1^R - r_1)q_1^R = (p_1^R - r_1)((1-\theta)a - p_1^R + \theta p_2^R)/(b(1-\theta^2)), \quad (A6)$$

$$\pi_2 = (p_2^R - r_2)q_2^R = (p_2^R - r_2)((1-\theta)a - p_2^R + \theta p_1^R)/(b(1-\theta^2)). \quad (A7)$$

Solving $\partial\pi_1/\partial p_1^R = \partial\pi_2/\partial p_2^R = 0$ yields the following prices:

$$p_1^R = \frac{a(1-\theta)(2+\theta) + 2r_1 + \theta r_2}{(2-\theta)(2+\theta)}, \quad p_2^R = \frac{a(1-\theta)(2+\theta) + 2r_2 + \theta r_1}{(2-\theta)(2+\theta)}. \quad (A8)$$

Note that second-order conditions for all maximization problems in this appendix are satisfied because all profit functions are concave and quadratic with respect to strategic variable (price). Because one may confirm the concavity, we henceforth omit writing the second-order conditions. Substituting Equation (A5) into Equation (4), we restate profits for the two manufacturers as:

$$\Pi_1 = (r_1 - c)q_1^R = (r_1 - c)((1-\theta)a - p_1^R + \theta p_2^R)/(b(1-\theta^2)), \quad (A9)$$

$$\Pi_2 = (r_2 - c)q_2^R = (r_2 - c)((1-\theta)a - p_2^R + \theta p_1^R)/(b(1-\theta^2)). \quad (A10)$$

Substituting Equation (A8) into Equations (A9) and (A10) and maximizing them with respect to each wholesale price by solving $\partial\Pi_1/\partial r_1 = \partial\Pi_2/\partial r_2 = 0$ at Stage 2 yields:

$$r_1 = r_2 = ((2 - \theta - \theta^2)a + (2 - \theta^2)c) / (4 - \theta - 2\theta^2). \quad (\text{A11})$$

Re-evaluating Equations (A9) and (A10) by using Equations (A8) and (A11) yields equilibrium profits in this case.

Case (2): Strategy (R, D)

We replace q_1^D and q_2^R in Equations (A1) and (A4) with zero. Then, we solve them for q_1^R and q_2^D to derive the demands:

$$q_1^R = ((1 - \theta)a - p_1^R + \theta p_2^D) / ((1 - \theta^2)b), \quad q_2^D = ((1 - \theta)a - p_2^D + \theta p_1^R) / ((1 - \theta^2)b). \quad (\text{A12})$$

Profits for Retailer 1 and Manufacturer 2 with these demands are:

$$\pi_1 = (p_1^R - r_1)q_1^R = (p_1^R - r_1)((1 - \theta)a - p_1^R + \theta p_2^D) / ((1 - \theta^2)b), \quad (\text{A13})$$

$$\Pi_2 = (p_2^D - c)q_2^D = (p_2^D - c)((1 - \theta)a - p_2^D + \theta p_1^R) / ((1 - \theta^2)b). \quad (\text{A14})$$

Solving $\partial \pi_1 / \partial p_1^R = \partial \Pi_2 / \partial p_2^D = 0$ at Stage 3 yields the following prices:

$$p_1^R = ((1 - \theta)(2 + \theta)a + \theta c + 2r_1) / ((2 - \theta)(2 + \theta)), \quad (\text{A15})$$

$$p_2^D = ((1 - \theta)(2 + \theta)a + 2c + \theta r_1) / ((2 - \theta)(2 + \theta)).$$

Profit for Manufacturer 1 is:

$$\Pi_1 = (r_1 - c)q_1^R. \quad (\text{A16})$$

Substituting Equations (A12) and (A15) into Equation (A16) and solving $\partial \Pi_1 / \partial r_1 = 0$ at Stage 2 gives:

$$r_1 = ((1 - \theta)(2 + \theta)a + (2 - \theta)(1 + \theta)c) / (2(2 - \theta^2)). \quad (\text{A17})$$

Lastly, substituting Equations (A15) and (A17) into Equations (A14) and (A16) gives equilibrium profits in this case.

Case (3): Strategy (R, RD)

Profits for the manufacturers and retailers are as follows:

$$\Pi_1 = (r_1 - c)q_1^R, \quad (\text{A18})$$

$$\Pi_2 = (r_2 - c)q_2^R + (p_2^D - c)q_2^D, \quad (\text{A19})$$

$$\pi_1 = (p_1^R - r_1)q_1^R, \quad (\text{A20})$$

$$\pi_2 = (p_2^R - r_2)q_2^R. \quad (\text{A21})$$

At Stage 3, Manufacturer 2 determines p_2^D , while Retailer i ($i = 1, 2$) determines p_i^R . Note that products supplied by Manufacturer 2 through both channels, i.e., q_2^R and q_2^D , are identical. Hence, due to Bertrand competition, the unique combination of p_2^R and p_2^D that

constitutes the Nash equilibrium at this stage in the case of Strategy (R, RD) is $p_2^R = p_2^D = r_2$. We initially prove that only these retail prices constitute the equilibrium.

First, we prove that Manufacturer 2 has to set its direct price as $p_2^D = p_2^R$ in the case of strategy (R, RD). If Manufacturer 2 sets the direct price below p_2^R so that $p_2^D < p_2^R$ holds, the manufacturer collects all demands in its direct channel and Retailer 2 faces no demand, meaning that the manufacturer does not distribute products through the retail channel anymore. Because this corresponds to another case of Strategy (R, D), we need not examine the situation of $p_2^D < p_2^R$ in this case. Conversely, if Manufacturer 2 sets the direct price so that $p_2^D > p_2^R$ holds, Retailer 2 collects all demands and the direct channel faces no demand, meaning that the manufacturer no longer sells products through the direct channel. Because this corresponds to another case of Strategy (R, R), we also need not examine the situation of $p_2^D > p_2^R$ in this case. Consequently, Manufacturer 2 has no choice but to set its direct price as $p_2^D = p_2^R$ in the case of Strategy (R, RD).

Secondly, we prove that Retailer 2 necessarily sets the retail price as $p_2^R = r_2$ by examining each of the following three cases: $p_2^D > r_2$, $p_2^D < r_2$, or $p_2^D = r_2$. First, when Manufacturer 2 sets the direct price at the level of $p_2^D > r_2$, the optimal response price for Retailer 2 is $p_2^D - \varepsilon$, where ε is a positive minimal value, because this price enables the retailer to collect all demands at the possible highest price that brings the largest profit to the retailer. Hence, Bertrand-Nash equilibrium does not exist when $p_2^D > r_2$. Second, suppose that Manufacturer 2 sets p_2^D as $p_2^D < r_2$. Note that Retailer 2 has to set the price, p_2^R , greater than r_2 to earn a nonnegative profit. However, if Retailer 2 actually sets the retail price as $p_2^R > r_2$ in this case, demand for the retailer falls to 0 because $p_2^D < r_2 < p_2^R$ holds, which corresponds to the case of Strategy (R, D). Therefore, we also need not consider the case of $p_2^D < r_2$. Third, when Manufacturer 2 sets $p_2^D = r_2$, the optimal response price for Retailer 2 is $p_2^R = r_2$ due to the following two facts. If Retailer 2 raises the price from this level so that $p_2^R > r_2$ holds, the demand for the retailer falls to 0, which prevents the retailer from earning profits. Conversely, if Retailer 2 reduces the price so that $p_2^R < r_2$, the margin for the retailer becomes negative. Therefore, the only optimal sales price for Retailer 2 is r_2 . As a consequence, $p_2^R = p_2^D = r_2$ is the unique combination of prices that constitutes the Bertrand-Nash equilibrium at Stage 3 in the case of Strategy (R, RD).

At Stage 3, Retailer 1 also maximizes its profit. Replacing p_2^R in Equation (A3) with r_2 and q_1^D with 0, the equation is solved for $q_2^R + q_2^D$ and yields $q_2^R + q_2^D = (a - r_2 - b\theta q_1^R)/b$. Substituting this and $q_1^D = 0$ into Equation (A1) solves it for q_1^R as it gives $q_1^R = ((1-\theta)a - p_1^R + \theta r_2)/(b(1-\theta^2))$. Substituting this into Equation (A20) and solving $\partial \pi_1 / \partial p_1^R = 0$ for p_1^R yields the following price:

$$p_1^R = ((1-\theta)a + r_1 + \theta r_2) / 2. \quad (\text{A22})$$

At stage 2, we substitute $p_2^R = p_2^D = r_2$, $q_2^R + q_2^D = (a - r_2 - b\theta q_1^R)/b$, $q_1^R = ((1-\theta)a - p_1^R + \theta r_2)/(b(1-\theta^2))$, and Equation (A22) into Equations (A18) and (A19) and maximize them by solving $\partial \Pi_1 / \partial r_1 = \partial \Pi_2 / \partial r_2 = 0$ at Stage 2. Then, we yield:

$$r_1 = \frac{(1-\theta)(4+2\theta-\theta^2)a + (2+\theta)(2-\theta^2)c}{8-5\theta^2}, \quad r_2 = \frac{(1-\theta)(4+3\theta)a + (4+\theta-2\theta^2)c}{8-5\theta^2}. \quad (\text{A23})$$

Re-evaluating Equations (A18) and (A19) by using $q_2^R + q_2^D = (a - r_2 - b\theta q_1^R)/b$, $q_1^R = ((1-\theta)a - p_1^R + \theta r_2)/(b(1-\theta^2))$, $p_2^R = p_2^D = r_2$, and Equations (A22) and (A23) gives equilibrium profits in this case.

Case (4): Strategy (D, R)

Because this case is the symmetric opposite of that of Case (2) (R, D) with respect to the firms' strategies, equilibrium profits are given simply by interchanging the profits between Manufacturer 1 and Manufacturer 2 from that for Case (2).

Case (5): Strategy (D, D)

We replace q_1^R and q_2^R in Equations (A2) and (A4) with zero. Then, we solve them for q_1^D and q_2^D to derive the demands:

$$q_1^D = ((1-\theta)a - p_1^D + \theta p_2^D)/((1-\theta^2)b), \quad q_2^D = ((1-\theta)a - p_2^D + \theta p_1^D)/((1-\theta^2)b). \quad (A24)$$

Profits for the manufacturers with these demands are:

$$\Pi_1 = (p_1^D - c)q_1^D = (p_1^D - c)((1-\theta)a - p_1^D + \theta p_2^D)/((1-\theta^2)b), \quad (A25)$$

$$\Pi_2 = (p_2^D - c)q_2^D = (p_2^D - c)((1-\theta)a - p_2^D + \theta p_1^D)/((1-\theta^2)b). \quad (A26)$$

Solving $\partial \Pi_1 / \partial p_1^D = \partial \Pi_2 / \partial p_2^D = 0$ at Stage 3 yields the following prices:

$$p_1^D = p_2^D = ((1-\theta)a + c)/(2-\theta). \quad (A27)$$

Substituting Equations (A24) and (A27) into Equations (A25) and (A26) gives equilibrium profits in this case.

Case (6): Strategy (D, RD)

Profits for Manufacturers 1 and 2 and Retailer 2, respectively, are:

$$\Pi_1 = (p_1^D - c)q_1^D, \quad (A28)$$

$$\Pi_2 = (r_2 - c)q_2^R + (p_2^D - c)q_2^D, \quad (A29)$$

$$\pi_2 = (p_2^R - r_2)q_2^R. \quad (A30)$$

At Stage 3, Retailer 2 determines p_2^R and Manufacturer i ($i = 1, 2$) determines p_i^D . Due to Bertrand competition, the unique combination of p_2^R and p_2^D that constitutes the Nash equilibrium at this stage is $p_2^R = p_2^D = r_2$. We have already proven in Case (3): Strategy (R, RD) that only these retail prices constitute the equilibrium when Manufacturer 2 uses both the retail and the direct channels.

At Stage 3, Manufacturer 1 also maximizes its profit with respect to its direct price. Replacing p_2^R in Equations (A2) and (A3) with r_2 and q_1^R with 0 solves the equation for q_1^D and $q_2^R + q_2^D$ yields $q_1^D = ((1-\theta)a - p_1^D + \theta r_2)/(b(1-\theta^2))$ and $q_2^R + q_2^D = ((1-\theta)a - r_2 + \theta p_1^D)/(b(1-\theta^2))$. After substituting these quantities and $p_2^R = p_2^D = r_2$ into Equation (A28), we solve $\partial \Pi_1 / \partial p_1^D = 0$ to yield the following price:

$$p_1^D = ((1-\theta)a+c+\theta r_2)/2. \quad (A31)$$

At Stage 2, we substitute $q_1^D = ((1-\theta)a-p_1^D+\theta r_2)/(b(1-\theta^2))$, $q_2^R+q_2^D = ((1-\theta)a-r_2+\theta p_1^D)/(b(1-\theta^2))$, $p_2^R = p_2^D = r_2$, and Equation (A31) into Equation (A29) maximizes the profit of Manufacturer 2 by solving $\partial\Pi_2/\partial r_2 = 0$ yields:

$$r_2 = ((1-\theta)(2+\theta)a + (2-\theta)(1+\theta)c)/(2(2-\theta^2)). \quad (A32)$$

Finally, putting $q_1^D = ((1-\theta)a-p_1^D+\theta r_2)/(b(1-\theta^2))$, $q_2^R+q_2^D = ((1-\theta)a-r_2+\theta p_1^D)/(b(1-\theta^2))$, $p_2^R = p_2^D = r_2$, and Equations (A31) and (A32) into Equations (A28) and (A29) gives equilibrium profits in this case.

Case (7): Strategy (RD, R)

Because this case is the symmetric opposite of that of Case (3) (R, RD) with respect to the firms' strategies, equilibrium profits are given by interchanging the profits between Manufacturer 1 and Manufacturer 2 from that for Case (3).

Case (8): Strategy (RD, D)

Because this case is the symmetric opposite of that of Case (6) (D, RD) with respect to the firms' strategies, equilibrium profits are given by interchanging the profits between Manufacturer 1 and Manufacturer 2 from that for Case (6).

Case (9): Strategy (RD, RD)

Profits for Manufacturers 1 and 2 and Retailers 1 and 2 are as follows:

$$\Pi_1 = (r_1 - c)q_1^R + (p_1^D - c)q_1^D, \quad (A33)$$

$$\Pi_2 = (r_2 - c)q_2^R + (p_2^D - c)q_2^D, \quad (A34)$$

$$\pi_1 = (p_1^R - r_1)q_1^R, \quad (A35)$$

$$\pi_2 = (p_2^R - r_2)q_2^R. \quad (A36)$$

At Stage 3, Manufacturer i ($i = 1, 2$) determines p_i^D , while Retailer i determines p_i^R . We have already proven in Case (3): Strategy (R, RD) that the retail and direct prices of $p_i^R = p_i^D = r_i$ constitute the Bertrand-Nash equilibrium when Manufacturer i uses both the retail and the direct channels. Plugging $p_i^R = p_i^D = r_i$ into Equations (A1)–(A4) and solving them for $q_1^R+q_1^D$ and $q_2^R+q_2^D$ gives $q_1^R+q_1^D = ((1-\theta)a-r_1+\theta r_2)/(b(1-\theta^2))$, $q_2^R+q_2^D = ((1-\theta)a-r_2+\theta r_1)/(b(1-\theta^2))$.

At Stage 2, we substitute $p_1^R = p_1^D = r_1$, $p_2^R = p_2^D = r_2$, $q_1^R+q_1^D = ((1-\theta)a-r_1+\theta r_2)/(b(1-\theta^2))$, $q_2^R+q_2^D = ((1-\theta)a-r_2+\theta r_1)/(b(1-\theta^2))$ into Equations (A33) and (A34). Then, we maximize them by solving $\partial\Pi_1/\partial r_1 = \partial\Pi_2/\partial r_2 = 0$, yielding:

$$r_1 = r_2 = ((1-\theta)a+c)/(2-\theta). \quad (A37)$$

Re-evaluating Equations (A33) and (A34) by using $p_1^R = p_1^D = r_1$, $p_2^R = p_2^D = r_2$, $q_1^R+q_1^D = ((1-\theta)a-r_1+\theta r_2)/(b(1-\theta^2))$, $q_2^R+q_2^D = ((1-\theta)a-r_2+\theta r_1)/(b(1-\theta^2))$ and Equation (A37) gives equilibrium profits in this case. \square

Proof of Proposition 1.

Henceforth, let $\Pi_i^{(S_i, S_j)}$ denote the profit for Manufacturer i when Manufacturers i and j respectively choose S_i and S_j as their distribution strategies. Lemma 1 suggests that the following series of inequalities hold.

$$\Pi_i^{(RD, D)} - \Pi_i^{(D, D)} = \theta^4(1-\theta)(a-c)^2 / (8b(2-\theta)^2(1+\theta)(2-\theta^2)) > 0 \quad (\text{A38})$$

$$\Pi_i^{(RD, D)} - \Pi_i^{(R, D)} = (2-\theta-\theta^2)(a-c)^2 / (8b(2-\theta)(1+\theta)) > 0 \quad (\text{A39})$$

$$\Pi_i^{(D, RD)} - \Pi_i^{(R, RD)} = \frac{(1-\theta)(32-48\theta^2+17\theta^4)(4+2\theta-\theta^2)^2(a-c)^2}{16b(1+\theta)(8-5\theta^2)^2(2-\theta^2)^2} > 0 \quad (\text{A40})$$

$$\Pi_i^{(D, RD)} - \Pi_i^{(RD, RD)} = \theta^3(1-\theta)(16-8\theta^2+\theta^3)(a-c)^2 / (16b(2-\theta)^2(1+\theta)(2-\theta^2)^2) > 0 \quad (\text{A41})$$

First, Inequalities (A38) and (A39) show that if Manufacturer j undertakes Strategy D, Strategy RD is the optimal response for Manufacturer i . Second, Inequalities (A40) and (A41) show that if Manufacturer j undertakes Strategy RD, Strategy D is the optimal response for Manufacturer i . Therefore, Strategy RD is the optimal response for Manufacturer i if Manufacturer j undertakes Strategy D, while Strategy D is the optimal response for Manufacturer i if Manufacturer j undertakes Strategy RD. Consequently, strategies (D, RD) and (RD, D) always constitute the Nash equilibrium at Stage 1 and the SPE in the whole game. \square

Proof of Corollary 1.

From Table 2, the following inequality holds:

$$\Pi_i^{(D, RD)} - \Pi_i^{(RD, D)} = \theta^3(1-\theta)(4+3\theta)(a-c)^2 / (16b(1+\theta)(2-\theta^2)^2) > 0, \quad (\text{A42})$$

which proves this corollary. \square

Proof of Proposition 2.

Within the domain of the definition of $\theta \in (0, 1)$, the following value is positive if $0 < \theta < 0.7808$ and negative if $0.7808 < \theta < 1$.

$$\begin{aligned} & \Pi_i^{(D, RD)} - \Pi_i^{(R, R)} \\ &= \frac{(1-\theta)(2-\theta-2\theta^2)(128-176\theta^2+16\theta^3+76\theta^4-12\theta^5-11\theta^6+2\theta^7)(a-c)^2}{16b(2-\theta)(1+\theta)(2-\theta^2)^2(4-\theta-2\theta^2)^2} \end{aligned}$$

Meanwhile, the following value is positive if $0 < \theta < 0.7188$ and negative if $0.7188 < \theta < 1$.

$$\begin{aligned} & \Pi_i^{(RD,D)} - \Pi_i^{(R,R)} \\ &= \frac{(1-\theta)(2+\theta)(32-32\theta-44\theta^2+24\theta^3+23\theta^4-4\theta^5-4\theta^6)(a-c)^2}{8b(2-\theta)(1+\theta)(2-\theta^2)(4-\theta-2\theta^2)^2} \end{aligned} \quad \square$$

Proof of Lemma 2.

In the proof of Lemma 1 shown above, we change the marginal cost of Manufacturer i from c to c_i ($i = 1, 2$), and thus it can differ between the two manufacturers. Then, we can derive payoffs summarized in this lemma by tracking the same calculation processes shown in the proof of Lemma 1. We can also confirm that $Q_i > 0$ ($i = 1, 2$) is satisfied in all combinations of distribution strategies given the assumption of Inequality (15). \square

Proof of Proposition 3.

Using the equilibrium profits in Lemma 2, we obtain the next four inequalities.

$$\Pi_i^{(RD,D)} - \Pi_i^{(D,D)} = \frac{\theta^4((2-\theta-\theta^2)a - (2-\theta^2)c_i + \theta c_j)^2}{8b(1-\theta)(1+\theta)(4-\theta^2)^2(2-\theta^2)} > 0 \quad (\text{A43})$$

$$\Pi_i^{(RD,D)} - \Pi_i^{(R,D)} = \frac{((2-\theta-\theta^2)a - (2-\theta^2)c_i + \theta c_j)^2}{8b(4-5\theta^2+\theta^4)} > 0 \quad (\text{A44})$$

$$\Pi_i^{(D,RD)} - \Pi_i^{(R,RD)} = \frac{(32-48\theta^2+17\theta^4)((4-2\theta-3\theta^2+\theta^3)a - (4-3\theta^2)c_i + \theta(2-\theta^2)c_j)^2}{16b(1-\theta)(1+\theta)(8-5\theta^2)^2(2-\theta^2)^2} > 0 \quad (\text{A45})$$

$$\begin{aligned} \Pi_i^{(D,RD)} - \Pi_i^{(RD,RD)} &= \frac{\theta^3((2-\theta-\theta^2)a + \theta c_i - (2-\theta^2)c_j)}{16b(1-\theta)(1+\theta)(8-6\theta^2+\theta^4)^2} \\ &\times ((32-16\theta-32\theta^2+10\theta^3+7\theta^4-\theta^5)a - (32-32\theta^2+7\theta^4)c_i + \theta(16-10\theta^2+\theta^4)c_j) > 0 \end{aligned} \quad (\text{A46})$$

Note that Inequality (A46) holds because of the assumption of Inequality (15). Inequalities (A43) and (A44) show that if Manufacturer j undertakes Strategy D, Strategy RD is the optimal response for Manufacturer i . Inequalities (A45) and (A46) show that if Manufacturer j undertakes Strategy RD, Strategy D is the optimal response for Manufacturer i . These two results indicate that strategies (D, RD) and (RD, D) always constitute the SPE. \square

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Table 1. Notations

p	retail price
q	quantity
Q	quantity
r	wholesale price
c	marginal cost
a	positive constant greater than c
b	positive constant
θ	substitutability of products supplied by the two manufacturers ($0 < \theta < 1$) ($1-\theta$ is the degree of product differentiation between the manufacturers.)
i	subscript that indexes the manufacturer, retailer, or brand ($i = 1$ or 2)
j	subscript that indexes the manufacturer, retailer, or brand that is different from i
Π	profit for a manufacturer
π	profit for a retailer
R	strategy of distributing products only in the retail channel
D	strategy of distributing products only in the direct channel
RD	strategy of distributing products in both the retail and direct channels

Table 2. Payoff matrix for the two manufacturers

Manufacturer 2			
Manufacturer 1	distribution strategy	R	D
	R	$\left(\frac{(1-\theta)(2+\theta)(2-\theta^2)(a-c)^2}{b(2-\theta)(1+\theta)(4-\theta-2\theta^2)^2} \right)$ $\left(\frac{(1-\theta)(2+\theta)(2-\theta^2)(a-c)^2}{b(2-\theta)(1+\theta)(4-\theta-2\theta^2)^2} \right)$	$\left(\frac{(1-\theta)(2+\theta)(a-c)^2}{4b(2-\theta^2)(2-\theta)(1+\theta)} \right)$ $\left(\frac{(1-\theta)(4+\theta-2\theta^2)^2(a-c)^2}{4b(2-\theta)^2(1+\theta)(2-\theta^2)^2} \right)$
	RD	$\left(\frac{(4+3\theta)^2(1-\theta)(2-\theta^2)(a-c)^2}{2b(1+\theta)(8-5\theta^2)^2} \right)$ $\left(\frac{(1-\theta)(4+2\theta-2\theta^2)^2(a-c)^2}{2b(1+\theta)(8-5\theta^2)^2} \right)$	$\left(\frac{(1-\theta)(4+2\theta-2\theta^2)^2(a-c)^2}{16b(1+\theta)(2-\theta^2)^2} \right)$ $\left(\frac{(1-\theta)(2+\theta)^2(a-c)^2}{8b(1+\theta)(2-\theta^2)} \right)$
Manufacturer 2	distribution strategy	R	D
	R	$\left(\frac{(1-\theta)(4+\theta-2\theta^2)^2(a-c)^2}{4b(2-\theta)^2(1+\theta)(2-\theta^2)^2} \right)$ $\left(\frac{(1-\theta)(2+\theta)(a-c)^2}{4b(2-\theta^2)(2-\theta)(1+\theta)} \right)$	$\left(\frac{(1-\theta)(a-c)^2}{b(2-\theta)^2(1+\theta)} \right)$ $\left(\frac{(1-\theta)(a-c)^2}{b(2-\theta)^2(1+\theta)} \right)$
	RD	$\left(\frac{(4+3\theta)^2(1-\theta)(2-\theta^2)(a-c)^2}{2b(1+\theta)(8-5\theta^2)^2} \right)$ $\left(\frac{(1-\theta)(4+2\theta-2\theta^2)^2(a-c)^2}{2b(1+\theta)(8-5\theta^2)^2} \right)$	$\left(\frac{(1-\theta)(2+\theta)^2(a-c)^2}{8b(1+\theta)(2-\theta^2)} \right)$ $\left(\frac{(1-\theta)(4+2\theta-2\theta^2)^2(a-c)^2}{16b(1+\theta)(2-\theta^2)^2} \right)$

Note: The first value in each parenthesis represents the payoff for Manufacturer 1, while the second value is the payoff for Manufacturer 2. The circled payoffs represent the Nash equilibria that always arise.

Fig. 1. Description of firms and channels

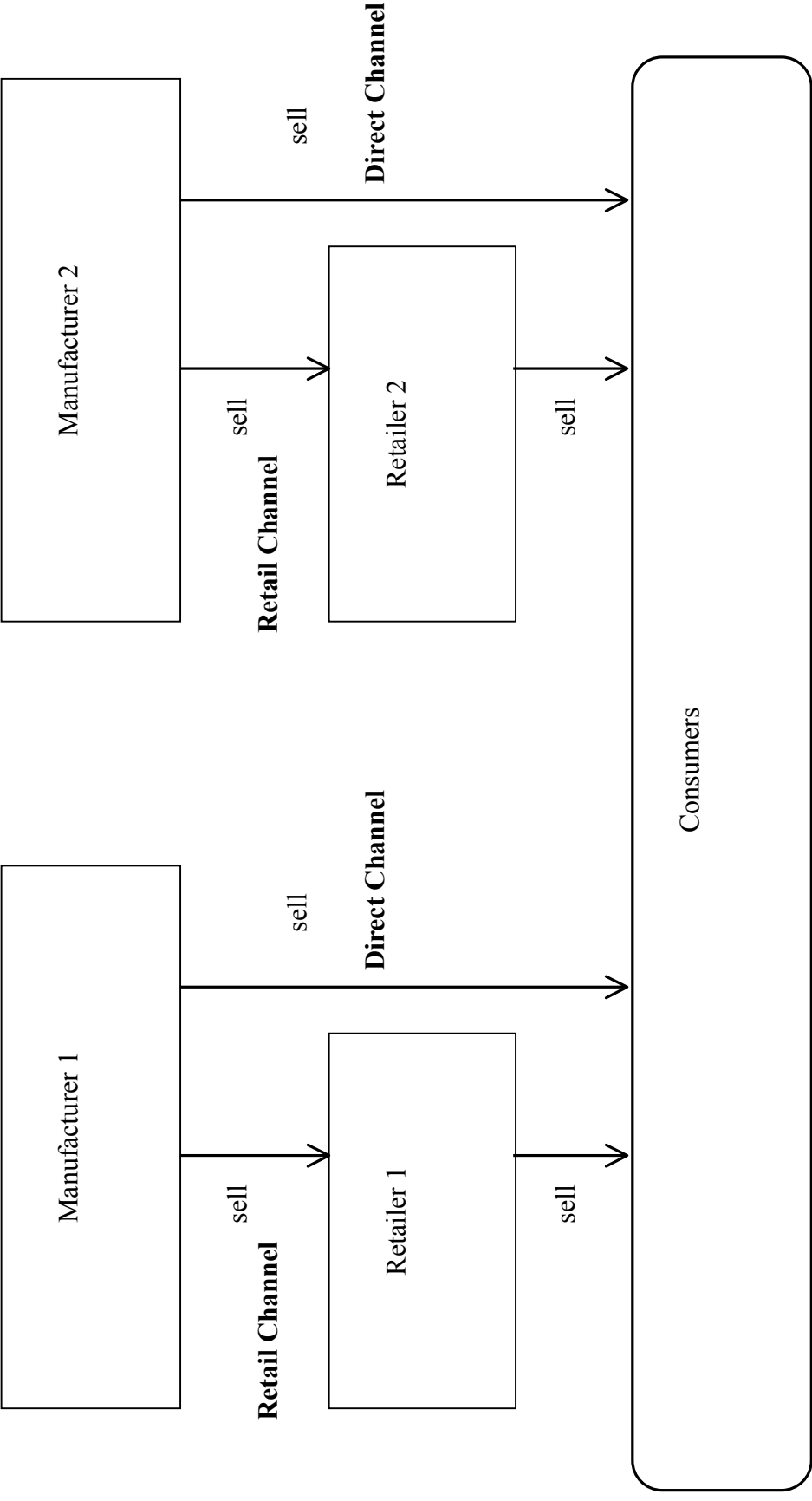


Fig. 2. Timeline of events

