On Supplier Encroachment with Retailer's Fairness Concerns

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Abstract:

With the development of e-commerce, many wholesale suppliers establish direct channels competing with their retailers. Such competition is often referred to as supplier encroachment. Previous studies assume the perfect rationality of retailers. However, supplier encroachment may trigger the fairness concerns of the retailers as a supplier is also a competitor of its retailer if the supplier encroaches. Thus, we introduce retailer's fairness concerns into the encroachment problem and explore its impact. It is shown that encroachment may be detrimental to the supplier when the retailer has strong fairness concerns and a significant marketing advantage. If the retailer has a significant marketing advantage, retailer's profit may decrease as her fairness concerns become much stronger. Numerical illustrations demonstrate that, when the retailer is fairness concerned, the supplier has more flexibility to encroach and the retailer has more possibility to benefit from encroachment in most cases. Moreover, retailer's fairness concerns can bring a remarkable improvement to the system profit.

Keywords: Supplier encroachment; Fairness concern; Direct channel; Game theory

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1. Introduction

Nowadays, with the development of e-commerce, other than a single channel (through retailers) to sell products, wholesale suppliers have an opportunity to establish a direct (self-owned) marketing channel. This may cause competition between the two channels which is often referred to as "encroachment" (Arya et al., 2007). The consequence of encroachment is twofold. On one hand, the suppliers may encroach on the retailers' profit (Hendershott and Zhang, 2006; Liu and Zhang, 2006), causing the dissatisfaction of the retailers. A letter sent by Home Depot to more than 1000 of its suppliers

states that, if those suppliers add direct channels, Home Depot has "the right to be selective in regard to the vendors we select ··· a company may be hesitant to do business with its competitors" (Brooker, 1999). On the other hand, the retailer may benefit from encroachment due to the lower wholesale price brought by encroachment (Arya et al., 2007; Tsay and Agrawal, 2004; Chiang et al., 2003)).

Although existing studies show the possible advantage of encroachment, it is noticed that all these papers assume the perfect rationality of retailers. However, if a supplier encroaches, the supplier is also a competitor of its retailer, which may trigger the fairness concerns of the retailer, as stated by Arya et al. (2007): "Dissent often is expressed as outrage that mercenary suppliers, bent on becoming vertical behemoths, are viciously exploiting their faithful retailers". Many papers in economics have indicated that fairness concerns have a significant impact on decision making (Rabin, 1993; Fehr and Schmidt, 1999; Ho and Su, 2009). In reality, "there is a significant incidence of cases in which firms, like individuals, are motivated by concerns of fairness" in business relationships, including channel relationships (Kahneman et al., 1986). Fairness plays an important role in developing and maintaining relationship between suppliers and retailers (Kaufmann and Stern, 1988; Anderson and Weitz, 1992; Corsten and Kumar, 2003, 2005). Therefore, to develop good descriptive models, fairness concerns are a factor that analytical modelers may not want to ignore (Cui et al., 2007).

The motivation of this paper is to examine the impact of retailer's fairness concerns on supplier's encroachment decision and on retailer's profit. We examine a situation which is often observed in reality where a supplier wholesales products to many identical retailers in independent markets while the retailer only sells the products of the supplier. As the supplier wholesales products to many retailers, the supplier will not compare his monetary payoff with the retailer's, thus does not care about fairness. About the retailer, she does not care about fairness when the supplier does not encroach because she does not have equal status as the supplier. However, if the supplier encroaches, the supplier is also a competitor of the retailer, which triggers the fairness concerns of the retailer. To our knowledge, this paper is the first to introduce fairness concerns into the encroachment problem. We find that encroachment is detrimental to the supplier when the retailer has strong fairness concerns and a significant marketing advantage. When the retailer has a significant marketing advantage, her profit may decrease as her fairness concerns become much stronger. Numerical illustrations demonstrate that,

when the retailer is fairness concerned, the supplier has more flexibility to encroach and the retailer has more possibility to benefit from encroachment in most cases. Moreover, the retailer's fairness concerns can bring a remarkable improvement to the systemwide profit.

The remainder of this paper is organized as follows. Section 2 provides reviews of the related literature. Section 3 describes the key elements of the model and introduces notation. Section 4 outlines the models in two settings–the no-encroachment setting and the encroachment setting. Section 5 numerically examines the impact of the retailer's fairness concerns on the supplier's encroachment decision and on the retailer's profit. Section 6 concludes the paper. The proofs of the propositions and corollaries are collected in Appendix.

2. Literature Review

Our research is related to the large and growing body of work on channel conflict and management (Chiang et al., 2003; Kumar and Ruan, 2006; Arya et al., 2007). Within this body of work, research that analyzes the strategic interactions between the supplier and retailer when the supplier serves the consumers using a direct channel, which competes with the traditional retail channel, is perhaps the most relevant. Hendershott and Zhang (2006) examined a setting in which an upstream firm can sell products to heterogeneous consumers engaging in time-consuming search through direct channel and intermediaries. They showed that encroachment by the upstream firm increases consumer surplus at the expense of intermediaries. Liu and Zhang (2006) found that a downstream retailer is worse off when an upstream supplier enters the market, but the retailer can deter the supplier from entering the market by acquiring personalized pricing.

While Hendershott and Zhang (2006) and Liu and Zhang (2006) showed that encroachment is detrimental to retailers, there are also papers demonstrating that encroachment may be beneficial to retailers. Chiang et al. (2003) showed that direct marketing may benefit the retailer as direct marketing may be accompanied by a wholesale price reduction. Moreover, direct marketing increases the flow of profit through the retail channel and improves overall profitability by reducing the marginalization. Tsay and Agrawal (2004) showed that the addition of a direct channel is not necessarily detrimental to the retailer, given the associated adjustment in the supplier's pricing. They also examined ways to adjust the supplier-retailer

relationship. In order to investigate the product-market characteristics that influence the optimality of adding a direct online channel, Kumar and Ruan (2006) contemplated a market with a single strategic supplier (focal supplier) selling products through a single strategic retailer. The retailer carries products of both the focal supplier and an exogenous supplier, and provides retail supports for the products which impact the demand of the two suppliers' products. Arya et al. (2007) demonstrated that the retailer can benefit from encroachment even when encroachment admits no synergies and does not facilitate product differentiation or price discrimination. Yan and Pei (2009) focused on the strategic role played by the retail services in a dual-channel competitive market. The supplier uses a direct channel as an effective tool to motivate the retailer to improve its retail services. Their results suggest that the improved retail services effectively alleviate the channel conflict and improve the supply chain performance in a competitive market. Li et al. (2013) extended the investigation of supplier encroachment to the environment with information asymmetry where the retailer is better informed of the market size than the supplier. They found that supplier encroachment can result in costly signaling behavior of the retailer, in which the retailer reduces his order quantity when the market size is small. Such a downward order distortion can amplify double marginalization. Li et al. (2015) studied supplier encroachment in competitive supply chains and showed that there may exist the prisoner's dilemma phenomenon for the suppliers. Furthermore, encroachment may lead to the "lose-lose" outcome for the suppliers and the retailers.

Beyond the above, extensive papers study the dual channel management problem (Geng and Mallik, 2007; Chen et al., 2008; Huang et al., 2012; Lu and Liu, 2013). Huang et al. (2012) developed a two-period pricing and production decision model in a dual-channel supply chain that experiences a demand disruption during the planning horizon. Lu and Liu (2013) examined how the pricing mode, game schemes, and efficiency of e-channels impact the wholesale prices, selling prices, and profits of both the supplier and retailer in a dual-channel supply chain system. They analyzed three types of pricing games: the Stackelberg game with uniform pricing, the Stackelberg game with differential pricing, and the Nash game with uniform pricing. All the above papers assume the perfect rationality of retailers. However, supplier encroachment may trigger the fairness concerns of the retailers. In this paper, we take into account the retailer's fairness concerns and examine its impact on the encroachment decisions of the supplier and the profit of the retailer.

Another stream of literature is relevant to our research, i.e., the fairness concerns problem. There is a long literature documenting the importance of fairness (Güth et al., 1982; Kahneman et al., 1986; Anderson and Simester, 2010; Camerer, 2011). It has been shown that fairness concerns have a significant impact on decision making. Rabin (1993) introduced the concept of fairness into game theory and explained the fact that people like to help those who are helping them and to hurt those who are hurting them. Fehr and Schmidt (1999) proposed an "inequality-aversion" model to characterize the fairness concerns. There is also empirical evidence indicating that fairness plays an important role in certain business contexts (Kumar et al., 1995; Olmstead and Rhode, 1985; Scheer et al., 2003; Liu et al., 2012). Through a survey of 216 paired suppliers and distributors in China, Liu et al. (2012) presented an analysis exploring how four types of fairness (distributive, procedural, interpersonal, and informational) influence dyadic relationship performance in the buyer–supplier context.

Furthermore, many papers study fairness concerns in supply chain management context. Cui et al. (2007) incorporated the concept of fairness in a dyadic channel and found that when channel members are concerned about fairness the supplier can use a simple wholesale price to coordinate the channel. Yang et al. (2009) took an initial step to incorporate fairness concerns of channel members into the study of co-operative advertising in a distribution channel consisting of a single supplier and a single retailer. They showed that when the retailer has fairness concerns, the channel can be coordinated by co-operative advertising under certain conditions. Fehr et al. (2007) conducted experiments to show that fairness concerns may have a decisive impact on designing contracts in a moral-hazard context. They also showed that the experimental result is consistent with the inequity aversion model in Fehr and Schmidt (1999). Katok and Pavlov (2013) reported a sequence of laboratory experiments designed to separate possible causes of channel inefficiency under contracts which coordinate the supply chain in the standard theory. They found that inequality aversion is the most explanatory power regarding retailers' behavior. Although these papers examined fairness concerns in the supply chain context, none of them consider fairness concerns in the encroachment problem. In this paper, we examine the impact of the retailer's fairness concerns on the encroachment decision of the supplier and on the profit of the retailer.

3. Model

Our model is the same as that in Arya et al. (2007) except that we introduce retailer's fairness concerns. Consider a standard model of a vertical supply chain in which a supplier (referred to as "he") wholesales products to a retailer (referred to as "she") which in turn sells the products to final consumers. In addition, the supplier can sell the products directly to consumers, perhaps by establishing a direct online store. Market demand is represented by a linear and downward sloping (inverse) function $p = a - Q$, where a is a strictly positive constant which represents the potential market demand, Q is the total quantity of the products in the retail market and p is the retail price. Without loss of generality, normalize the unit production cost of the supplier to zero. The supplier and the retailer incur marketing cost related to marketing operations in the direct channel and in the retail channel, respectively. Also, without loss of generality, normalize the unit marketing cost of the retailer to zero, and assume the unit marketing cost of the supplier to be $c \in (0, a]$, which implies that the retailer has a marketing advantage compared to the supplier. The marketing advantage of the retailer comes from the superior knowledge of the customer preferences, closed relationship with consumers or economies of scope with retailing activities, etc.

As mentioned in Section 1, we examine the situation where only the retailer cares about fairness. This applies in the case that the supplier wholesales products to many identical retailers in independent markets while the retailer only sells the products of the supplier. Therefore, the supplier will not compare his monetary payoff with the retailer's, thus does not care about fairness. About the retailer, she does not care about fairness either when the supplier does not encroach because she does not have equal status as the supplier. However, if the supplier encroaches, the supplier is also a competitor of the retailer, which triggers the fairness concerns of the retailer.

If the supplier does not encroach, the supplier and the retailer play a standard two-stage Stackelberg game. If the supplier encroaches, the retailer maximizes her utility accounting for her monetary payoff and her concerns for fairness. Denote Π_R and Π_S as the monetary payoffs of the retailer and the supplier, respectively. Let $\Pi_C = \Pi_R + \Pi_S$ denote the systemwide payoff. To evaluate retailer's fairness concerns, assume that the retailer's equitable outcome is γ times the supplier's payoff (Fehr and Schmidt, 1999), i.e., $\gamma\Pi_S$. If the retailer's monetary payoff Π_R is lower than $\gamma\Pi_S$, a disadvantageous inequality occurs, which results in a disutility for the retailer in the amount

of α per unit difference between the two payoffs. In specific, the retailer's utility function is expressed as follows:

$$U_R = \Pi_R - \alpha(\gamma\Pi_S - \Pi_R)^+, \tag{1}$$

where $\alpha > 0$, $\gamma > 0$. We call α as the disadvantageous-inequality aversion factor. It reflects the disadvantageous-inequality aversion degree of the retailer. In order to simplify analysis and avoid tedious mathematic complications, we intend not to incorporate the advantageous inequity in this utility function. This allows us to obtain relatively succinct results, focusing on the most important aspect related to fairness concerns. As pointed by Fehr and Schmidt (1999), people suffer more from inequity that is to their monetary disadvantage than from inequity that is to their monetary advantage. Moreover, people in some culture do not care about advantageous inequity. Scheer et al. (2003) surveyed 417 American auto dealers and 289 Dutch auto dealers, and found that while Dutch dealers reacting to both disadvantageous and advantageous inequity, American dealers react only to disadvantageous inequity. Cui and Mallucci (2012) showed that the players in the experiment display a greater aversion for disadvantageous inequity than for advantageous inequity.

The timing in the model is as follows. First of all, the supplier decides whether to encroach or not. Then the supplier and the retailer play the following game. In the first stage, the supplier determines the wholesale prices w. In the second stage, the retailer chooses the order quantity q_R. If the supplier encroaches, in the third stage, he determines the quantity q_S to sell through the direct channel. Hereafter, denote superscripts "N" and "E" as the no-encroachment and encroachment settings, respectively.

For ease of exposition, we summarize the notation used throughout the paper in Table 1.

(Insert Table 1 about here)

Table 1: Notation

4. Model Analysis

4.1. The No-Encroachment Setting

In the no-encroachment setting, the supplier and the retailer play a standard two-stage Stackelberg game. In the first stage, the supplier sets the

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wholesale price w^N. In the second stage, the retailer chooses the order quantity q_R^N to maximize her profit. The equilibrium outcome is given in Proposition 1.

Proposition 1. *In the no-encroachment setting, the equilibrium outcome is as follows:* $w^N = \frac{a}{2}$, $q_R^N = \frac{a}{4}$, $\Pi_S^N = \frac{a^2}{8}$, $\Pi_R^N = \frac{a^2}{16}$.

PROOF. We use backward induction to solve the game. In the second stage, given a wholesale price w of the supplier, the retailer chooses the order quantity q_R^N to maximize her profit:

$$\max_{q_R^N} \Pi_R^N = (a - q_R^N)q_R^N - wq_R^N. \tag{2}$$

Performing the optimization in (2) provides q_R^N as below:

$$q_R^N(w) = \frac{a - w}{2}. \tag{3}$$

In the first stage of the game, the supplier sets the wholesale price w^N to maximize his profit in anticipation of the retailer's reaction through $q_R^N(w)$ given in Equation (3):

$$\max_{w^N} \Pi_S^N = w^N q_R^N(w^N). \tag{4}$$

Substituting Equation (3) into (4) and performing the optimization in (4), the optimal wholesale price is given below:

$$w^N = \frac{a}{2}. \tag{5}$$

Substituting (5) into (3), we obtain that $q_R^N = a/4$. It is straightforward to calculate the retailer's and the supplier's profits: $\Pi_S^N = \frac{a^2}{8}$, $\Pi_R^N = \frac{a^2}{16}$. □

4.2. The Encroachment Setting

In this subsection, we consider the encroachment setting, in which the supplier can sell products to the consumers through his direct channel directly together with the retailer. The supplier and the retailer play a three-stage game. In the first stage, the supplier sets the wholesale price w^E. In the second stage, the retailer chooses the utility-maximizing order quantity q_R^E. In the third stage, the supplier chooses the optimal quantity q_S^E to sell through his direct channel. Backward induction is used to solve the game.

4.2.1. The Third-Stage Problem

In the third stage of the game, given a wholesale price w and the retailer's order quantity q_R, the supplier chooses the quantity q_S^E to sell through his direct channel:

$$\max_{q_S^E} \Pi_S^E = (a - q_R - q_S^E)q_S^E + wq_R - cq_S^E. \tag{6}$$

The first item in (6) is the supplier's revenue from the direct channel. The second item in (6) is the revenue from wholesaling to the retailer, and the third item is the marketing cost in the direct channel. Performing the optimization in (6) provides q_S^E as below:

$$q_S^E(q_R) = \frac{a - c - q_R}{2}. \tag{7}$$

Substituting Equation (7) into (6), the profit of the supplier can be expressed as a function of w and q_R:

$$\Pi_S^E = \frac{q_R^2}{4} + (w - \frac{a - c}{2})q_R + \frac{(a - c)^2}{4}. \tag{8}$$

As the supplier always encroaches when $a/c > 1 + 2\sqrt{(\gamma + 2)/\gamma}$ (See Part (2) of Proposition 4), we focus on the case where $a/c \leq 1 + 2\sqrt{(\gamma + 2)/\gamma}$ in the subsequent analysis unless specified. a/c stands for the retailer's relative marketing advantage. The smaller the value of a/c, the more the supplier relies on the retailer to obtain profit.

4.2.2. The Second-Stage Problem

In the second stage of the game, given the wholesale price w and anticipating the supplier's quantity to sell through his direct channel $q_S^E(q_R)$ in Equation (7), the retailer chooses her order quantity q_R^E to maximize her utility:

$$\max_{q_R^E} U_R^E = \Pi_R^E - \alpha(\gamma \Pi_S^E - \Pi_R^E)^+, \tag{9}$$

where

$$\Pi_R^E = \left[a - q_R^E - q_S^E(q_R^E)\right] q_R^E - wq_R^E. \tag{10}$$

Denote the following notation:

$$\begin{aligned}
y &= (\gamma + 2)\alpha + 2, \\
\Lambda &= [(\gamma + 1)(a - 2w) - (\gamma - 1)c]^2 - \gamma(\gamma + 2)(a - c)^2, \\
K_1 &= \gamma(\gamma + 2)[(\gamma + 1)^2 y^2 - \gamma^2](a - c)^2 + 4\gamma^2(\gamma + 2)^2 c^2, \\
K_2 &= \gamma(\gamma + 2)[4(\gamma + 1)^2 - \gamma^2](a - c)^2 + 4\gamma^2(\gamma + 2)^2 c^2,
\end{aligned} \tag{11}$$

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in which y is a strictly increasing function of α. Thus, the higher y is, the more averse the supplier is to the disadvantageous-inequality.

Proposition 2. *When $a/c \leq 1 + 2\sqrt{(\gamma+2)/\gamma}$, the retailer's best response function is given by:*

$$q_R^E(w) = \begin{cases} \frac{c+a-2w}{2} & \text{if } w \leq w_3 \text{ or } w \geq w_4 \\ \frac{[(\gamma+1)\alpha+1](a-2w)-[(\gamma-1)\alpha-1]c}{y} & \text{if } w_1 \leq w \leq w_2 \\ \frac{(\gamma+1)(a-2w)-(\gamma-1)c+\sqrt{\Lambda}}{\gamma+2} & \text{if } w_3 \leq w \leq w_1 \text{ or } w_2 \leq w \leq w_4, \end{cases} \quad (12)$$

where

$$w_1 = \frac{a}{2} + \frac{[3\gamma^2 - (\gamma^2 - 1)y^2]c - y\sqrt{K_1}}{2[(\gamma+1)^2 y^2 - \gamma^2]},$$

$$w_2 = \frac{a}{2} + \frac{[3\gamma^2 - (\gamma^2 - 1)y^2]c + y\sqrt{K_1}}{2[(\gamma+1)^2 y^2 - \gamma^2]},$$

$$w_3 = \frac{a}{2} + \frac{(-\gamma^2 + 4)c - 2\sqrt{K_2}}{2(\gamma+2)(3\gamma+2)},$$

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Corollary 1 indicates that the retailer's order quantity decreases in the wholesale price and also in her disadvantageous-inequality aversion degree.

Corollary 1. *$q_R^E(w)$ decreases in w. Moreover, $q_R^E(w)$ decreases in α.*

The formulation of $q_R^E(w)$ in Equation (12) is very complex. To give an intuitive impression, Figure 1 shows how $q_R^E(w)$ varies with w and α, and Figure 2 shows how $q_R^E(w)$ varies with α for some values of w.

(Insert Figure 1 about here)

Figure 1: The impact of w and α on $q_R^E(w)$, where $a/c = 5$ and $\gamma = 0.5$

(Insert Figure 2 about here)

Figure 2: The impact of α on $q_R^E(w)$ for some values of w, where $a/c = 5$ and $\gamma = 0.5$

4.2.3. The First-Stage Problem

In the first stage of the game, the supplier sets the wholesale price w to maximize his profit in anticipation of the retailer's reactions through $q_R^E(w)$ given in Equation (12). Proposition 3 presents the optimal wholesale price of the supplier and shows that there are five possible equilibrium outcomes. The explicit expressions of the five equilibrium outcomes are as follows.

The first equilibrium outcome:

$$w^{1E} = \frac{a}{2} + \frac{[3\gamma(\gamma + 2y) - y^2(\gamma^2 + 4\gamma + 1)]c}{2[(\gamma + 3)y + \gamma][(\gamma + 1)y - \gamma]},$$

$$q_R^{1E} = \frac{2(\gamma + y)c}{(\gamma + 3)y + \gamma},$$

$$q_S^{1E} = \frac{[(\gamma + 3)y + \gamma]a - (3\gamma + 5y + \gamma y)c}{(\gamma + 3)y + \gamma}, \tag{13}$$

$$\Pi_S^{1E} = \frac{(\gamma + y)^2 c^2}{[(\gamma + 3)y + \gamma][(\gamma + 1)y - \gamma]} + \frac{(a - c)^2}{4},$$

$$\Pi_R^{1E} = \frac{2(\gamma + y)[(\gamma^2 + 3\gamma + 1)y - \gamma(\gamma + 4)y - \gamma^2]c^2}{[(\gamma + 3)y + \gamma]^2[(\gamma + 1)y - \gamma]}.$$

The second equilibrium outcome:

$$w^{2E} = \frac{a}{2} + \frac{(-\gamma^2 + 4)c - 2\sqrt{K_2}}{2(\gamma + 2)(3\gamma + 2)},$$

$$q_R^{2E} = \frac{2\gamma(\gamma + 2)c + \sqrt{K_2}}{(\gamma + 2)(3\gamma + 2)},$$

$$q_S^{2E} = \frac{a}{2} - \frac{c}{2} - \frac{2\gamma(\gamma + 2)c + \sqrt{K_2}}{(\gamma + 2)(3\gamma + 2)}, \tag{14}$$

$$\Pi_S^{2E} = \frac{(\gamma + 2)(3\gamma + 2)(a - c)^2 + 4c\sqrt{K_2} + 8\gamma(\gamma + 2)c^2}{2(\gamma + 2)(3\gamma + 2)^2},$$

$$\Pi_R^{2E} = \gamma \Pi_S^{2E}.$$

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The third equilibrium outcome:

$$w^{3E} = \frac{a}{2} + \frac{[3\gamma^2 - (\gamma^2 - 1)y^2]c - y\sqrt{K_1}}{2[(\gamma + 1)^2 y^2 - \gamma^2]},$$

$$q_R^{3E} = \frac{2\gamma(\gamma + 2)c + \sqrt{K_1}}{(\gamma + 2)[(\gamma + 1)y + \gamma]},$$

$$q_S^{3E} = \frac{a}{2} - \frac{c}{2} - \frac{2\gamma(\gamma + 2)c + \sqrt{K_1}}{2(\gamma + 2)[(\gamma + 1)y + \gamma]}, \tag{15}$$

$$\Pi_S^{3E} = \frac{(\gamma + y)[(\gamma + 1)y + \gamma](a - c)^2 + 2yc\sqrt{K_1} + 4\gamma(\gamma + 2)yc^2}{2(\gamma + 2)[(\gamma + 1)y + \gamma]^2},$$

$$\Pi_R^{3E} = \gamma \Pi_S^{3E}.$$

The fourth equilibrium outcome:

$$w^{4E} = \frac{a}{2} - \frac{c}{6}, \; q_R^{4E} = \frac{2c}{3}, \; q_S^{4E} = \frac{3a - 5c}{6}, \; \Pi_S^{4E} = \frac{3a^2 - 6ac + 7c^2}{12}, \; \Pi_R^{4E} = \frac{2c^2}{9}. \tag{16}$$

The fifth equilibrium outcome:

$$w^{5E} = w^{1N}, \; q_R^{5E} = q_R^{1N}, \; q_S^{5E} = 0, \; \Pi_S^{5E} = \Pi_S^{1N}, \; \Pi_R^{5E} = \Pi_S^{1N}. \tag{17}$$

For fixed (α, γ), suppose $\frac{a}{c} = f(\alpha, \gamma)$ to be the root of $\Pi_S^{1E} = \Pi_S^{2E}$. Denote the following regions:

$$\Phi = \left\{ (\alpha, \gamma, \frac{a}{c}) : \frac{a}{c} < 1 + 2\sqrt{\frac{\gamma + 2}{\gamma}} \right\},$$

$$\Phi_1 = \left\{ (\alpha, \gamma, \frac{a}{c}) : \frac{a}{c} \geq \max \left\{ f(\alpha, \gamma), \frac{(\gamma + 5)y + 3\gamma}{(\gamma + 3)y + \gamma} \right\} \right\},$$

$$\Phi_2 = \left\{ (\alpha, \gamma, \frac{a}{c}) : \text{if } \gamma < \frac{1}{2}, \ 1 + \frac{2}{3}\sqrt{\frac{2 - 3\gamma}{\gamma}} \leq \frac{a}{c} \leq \max \left\{ f(\alpha, \gamma), \frac{(\gamma + 5)y + 3\gamma}{(\gamma + 3)y + \gamma} \right\} ; \right.$$

$$\left. \text{if } \gamma \geq \frac{1}{2}, \ \frac{3\gamma + 1}{\gamma + 1} \leq \frac{a}{c} \leq \max \left\{ f(\alpha, \gamma), \frac{(\gamma + 5)y + 3\gamma}{(\gamma + 3)y + \gamma} \right\} \right\},$$

$$\Phi_3 = \left\{ (\alpha, \gamma, \frac{a}{c}) : \text{if } \gamma < \frac{1}{2}, \ \frac{(\gamma + 1)y + \gamma(3\gamma + 5)}{(\gamma + 1)(\gamma + y)} < \frac{a}{c} < 1 + \frac{2}{3}\sqrt{\frac{2 - 3\gamma}{\gamma}} \text{ and } \Pi_S^{3E} \geq \Pi_S^{4E} ; \right.$$

$$\left. \text{if } \gamma \geq \frac{1}{2}, \ \frac{(\gamma + 1)y + \gamma(3\gamma + 5)}{(\gamma + 1)(\gamma + y)} < \frac{a}{c} < \frac{3\gamma + 1}{\gamma + 1} \right\},$$

$$\Phi_4 = \left\{ (\alpha, \gamma, \frac{a}{c}) : \gamma < \frac{1}{2}, \ \frac{5}{3} < \frac{a}{c} < 1 + \frac{2}{3}\sqrt{\frac{2 - 3\gamma}{\gamma}} \text{ and } \Pi_S^{4E} \geq \Pi_S^{3E} \right\},$$

$$\Phi_5 = \Phi - \Phi_1 - \Phi_2 - \Phi_3 - \Phi_4.$$

Notice that Region Φ_4 does not exist when $\gamma \geq 1/2$.

Proposition 3. *When $a/c \leq 1 + 2\sqrt{(\gamma + 2)/\gamma}$, if $(\alpha, \gamma, a/c)$ falls into Region Φ_i ($i = 1, ..., 5$), then the supplier sets $w^E = w^{iE}$, and the equilibrium outcome is $w^E = w^{iE}, q_S^E = q_S^{iE}, q_R^E = q_R^{iE}, \Pi_S^E = \Pi_S^{iE}, \Pi_R^E = \Pi_R^{iE}$ ($i = 1, ..., 5$). Moreover, $\Pi_R^{2E} = \gamma \Pi_S^{2E}, \Pi_R^{3E} = \gamma \Pi_S^{3E}$ and $w^{5E} = w^N, q_R^{5E} = q_R^N, q_S^{5E} = 0, \Pi_S^{5E} = \Pi_S^N, \Pi_R^{5E} = \Pi_R^N$.*

When $a/c \leq 1 + 2\sqrt{(\gamma + 2)/\gamma}$, for all combinations of parameters $(\alpha, \gamma, a/c)$, there are at most five different equilibrium outcomes, and if $\gamma \geq 1/2$, no more than four equilibrium outcomes exist. Hereafter, we refer to $(w^{iE}, q_S^{iE}, q_R^{iE}, \Pi_S^{iE}, \Pi_R^{iE})$ as the ith equilibrium outcome and the ith equilibrium for short. Among the five equilibria, the fifth one is the same as that in the no-encroachment setting except $q_S^{5E} = 0$. In the other four equilibria, q_S^{iE}'s are all larger than zero. Note that in the second and the third equilibria, the retailer's profit is γ times the supplier's profit, i.e., the retailer's incentive and the supplier's incentive are aligned.

Corollary 2 indicates that Region Φ_1 corresponds to larger levels of a/c than Φ_2 and Region Φ_2 corresponds to larger levels of a/c than Φ_3.

Corollary 2. *For fixed α and γ, $\min\{\frac{a}{c}|(\alpha, \gamma, \frac{a}{c}) \in \Phi_1\} \geq \max\{\frac{a}{c}|(\alpha, \gamma, \frac{a}{c}) \in \Phi_2\}$ and $\min\{\frac{a}{c}|(\alpha, \gamma, \frac{a}{c}) \in \Phi_2\} \geq \max\{\frac{a}{c}|(\alpha, \gamma, \frac{a}{c}) \in \Phi_3\}$.*

Corollary 2 is straightforward from the expression of Φ_1, Φ_2 and Φ_3. In order to give an intuitive impression of the equilibrium outcomes in the encroachment setting, we plot the regions corresponding to different equilibria when γ equals to $1/2$ in Figure 3. There is no Region Φ_4 in Figure 3 because the fourth equilibrium may exist only when $\gamma < 1/2$. Moreover, we observe that Φ_1 lies above Φ_2 and Φ_2 lies above Φ_3, which are consistent with Corollary 2. More discussions about Figure 3 are given in Section 5.

(Insert Figure 3 about here)

Figure 3: Equilibria in the encroachment-setting when $\gamma = 1/2$

4.2.4. Properties of the Equilibria

In this subsection, we present some properties of the equilibria in the encroachment setting.

Corollary 3. *(1) w^{1E}, Π_S^{1E} and Π_C^{1E} decease in α, while Π_R^{1E} increases in α;*
(2) w^{iE}, Π_S^{iE}, Π_C^{iE} and Π_R^{iE} ($i = 2, 4, 5$) are independent of α;
(3) w^{3E} increases in α, while Π_S^{3E}, Π_C^{3E} and Π_R^{3E} decrease in α.

Corollary 3 summarizes the impact of the retailer's fairness concerns on the wholesale price and on the profits of both parties in the five equilibria. The retailer's profit does not always increase in her fairness concerns degree α. In the third equilibrium, the retailer's profit decreases in α. Thus, referring to Corollary 2, when the retailer has a significant marketing advantage (i.e., a/c being small), the retailer's profit may decrease as her fairness concerns become much stronger.

Corollary 4. *If $(\alpha, \gamma, \frac{a}{c})$ falls into regions Φ_1 or Φ_3, $\frac{\partial q_R^E(w)}{\partial w}$ increases in α.*

If $(\alpha, \gamma, a/c)$ falls into regions Φ_1 or Φ_3, the retailer's best response function is $q_R^E(w) = \{[1 - \alpha(\gamma - 1)]c + [1 + \alpha(\gamma + 1)](a - 2w)\}/y$. Therefore, $\partial q_R^E(w)/\partial w = -2[1 + \alpha(\gamma + 1)]/[(\gamma + 2)\alpha + 2]$, which indicates that, if w is increased by one unit, the retailer's order quantity q_R will decrease $2[1 + \alpha(\gamma + 1)]/[(\gamma + 2)\alpha + 2]$ units which is increasing with α. This implies that, in the region corresponding to the first or the third equilibrium, the retailer's order quantity is more sensitive to w as α increases.

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Corollary 5. *(1) When $(\alpha, \gamma, \frac{a}{c}) \in \Phi_3$, $\frac{\partial w^{3E}}{\partial c} \leq 0$ and $\frac{\partial q_R^{3E}}{\partial c} \geq 0$.*
(2) When $(\alpha, \gamma, \frac{a}{c}) \in \Phi_3$, if $\gamma \leq 1$, or $\gamma > 1$ and $\alpha \leq \frac{1}{\gamma - 1}$, then $(\frac{\partial q_R^{3E}}{\partial c})/(\frac{\partial w^{3E}}{\partial c})$ increases in c.

Part (1) of Corollary 5 is intuitive. As the retailer's marketing advantage becomes more significant (i.e., c increases), the wholesale price is lower and the retailer's order quantity is higher. Part (2) indicates that, as c decreases, the increment rate of w^E is faster than the decrement rate of q_R^E. Thus, the wholesale profit (profit from wholesaling to the retailer) of the supplier diminishes as c decreases.

5. Managerial Implications

Comparing the equilibrium outcome in the no-encroachment setting with that in the encroachment setting, the supplier determines whether or not to encroach. The supplier encroaches if and only if encroachment benefits himself. The encroachment decision of the supplier is characterized by Proposition 4.

Proposition 4. *(1) For $\frac{a}{c} \leq 1 + 2\sqrt{\frac{\gamma+2}{\gamma}}$, if $(\alpha, \gamma, \frac{a}{c})$ falls into Region Φ_i and $\Pi_S^{iE} > \Pi_S^N$ ($i = 1, ..., 4$), then the supplier encroaches and the equilibrium outcome is $w^E = w^{iE}, q_S^E = q_S^{iE}, q_R^E = q_R^{iE}, \Pi_S^E = \Pi_S^{iE}, \Pi_R^E = \Pi_R^{iE}$ ($i = 1, ..., 4$); otherwise, if $(\alpha, \gamma, \frac{a}{c})$ falls into Region Φ_i and $\Pi_S^{iE} \leq \Pi_S^N$ ($i = 1, ..., 4$), or $(\alpha, \gamma, \frac{a}{c})$ falls into Region Φ_5, the supplier does not encroach and the equilibrium outcome is $(w^N, q_R^N, \Pi_S^N, \Pi_R^N)$.*
(2) For $\frac{a}{c} > 1 + 2\sqrt{\frac{\gamma+2}{\gamma}}$, the supplier always encroaches.

Part (2) of Proposition 4 shows that when $a/c > 1 + 2\sqrt{(\gamma+2)/\gamma}$, the supplier always encroaches. In fact, when a/c is large enough, the supplier encroaches and only sells through his direct channel. Consider an extreme case where c equals to zero. The supplier will only sell through his direct channel. In this case, the supplier is a monopolist in both the supply side and the retail side. We are not interested in the case where the supplier always encroaches. Therefore, we focus our attention on the case where $a/c \leq 1 + 2\sqrt{(\gamma+2)/\gamma}$ in the subsequent analysis.

In the following, we illustrate the supplier's encroachment decision and the impact of encroachment on the retailer's profit as well as on the system

profit numerically for $\gamma = 1/2$. Cui and Mallucci (2012) support our choice of γ to a certain extent. They proposed the sequence-aligned fairness ideal, according to which the sequence of moving determines the formation of equitable payoff for players. The sequence-aligned fairness ideal significantly outperforms other fairness ideals, and reflects the concept that the equitable payoff for the retailer is consonant with the ratio of players' profits in the standard Stackelberg game. In our model, the supplier is the leader of the game and the retailer is the follower, so choosing γ to be $1/2$ is reasonable. The managerial insights are similar for other γ values.

5.1. When Will The Supplier Encroach

Figure 4 shows the region where the supplier encroaches when $\gamma = 1/2$. The supplier encroaches if and only if $(\alpha, a/c)$ falls into the upper left side of the solid curve. Roughly speaking, the supplier does not encroach when the retailer has a significant marketing advantage (i.e., a/c being small) or strong fairness concerns (i.e., α being large). The parameter region where the supplier encroaches can be divided into three parts, i.e., Regions Φ_1, Φ_2 and Ω_3. Region Ω_3 corresponds to the third equilibrium, which is a part of Φ_3. Comparing Figure 4 with Figure 3, we know that encroachment may be detrimental to the supplier. In Region Φ_5 of Figure 3, the supplier is indifferent between encroachment and no-encroachment (as $q_S^{5E} = 0$). In Region Φ_3 of Figure 3, encroachment may be detrimental to the supplier. In short, when the retailer has a significant marketing advantage and strong fairness concerns, encroachment may be detrimental to the supplier.

(Insert Figure 4 about here)

Figure 4: Region where the supplier encroaches when $\gamma = 1/2$

This is different from the result in Arya et al. (2007) that encroachment does not harm the supplier's interest. In Figure 4, notice that the vertical coordinate of the intersection of the solid curve and the vertical axis is $5/3$. In Arya et al. (2007), the supplier encroaches if and only if $a/c > 5/3$. However, we observe from Figure 4 that, when the retailer fairness is concerned, the supplier may encroach even if $a/c \leq 5/3$. As α increases, the range of a/c at which the supplier encroaches enlarges first and then diminishes and eventually becomes stable.

To interpret the phenomenon, we first compare the wholesale prices in the no-encroachment and encroachment settings. Intuitively, one might expect that the supplier will increase the wholesale price to reduce the competition from the retailer in the retail market. However, it can be shown that the wholesale price in the encroachment setting is always lower than that in the no-encroachment setting (for $\gamma = 1/2$). If the supplier sets a higher wholesale price in the former case to weaken the retailer's competitive power so as to enforce his own competitive power in the retail market, the retailer will decrease her order quantity which declines even more due to her fairness concerns. This lowers down the wholesale profit (the profit from wholesaling to the retailer) of the supplier by a large amount. Thus, although lowering the wholesale price may decrease the retail profit (the profit from retailing through his direct channel) of the supplier, his wholesale profit is greatly improved. Hence the supplier still has incentive to lower the wholesale price.

The above observation helps us interpret why the range of a/c at which the supplier encroaches first enlarges as α increases. From Figure 4, it is known that when $a/c \leq 5/3$ and $\alpha < 1$, the value of a/c at which the supplier encroaches decreases as α increases. Note that $a/c \leq 5/3$ indicates that the retailer has a significant marketing advantage, so the supplier's main profit is the wholesale profit. From Corollary 4, the retailer's optimal order quantity is more sensitive to the wholesale price w as α increases. Thus, if $a/c \leq 5/3$, as α increases, the supplier is more likely to encroach at lower a/c levels and sets a lower wholesale price (compared to the no-encroachment setting) to induce the retailer to order more.

Next, we explain why the range of a/c at which the supplier encroaches narrows as α becomes much larger. To simplify the analysis, we fix a to a certain value. Referring to Corollary 5, if the supplier encroaches, as c decreases, the wholesale price w becomes higher and the retailer's order quantity q_R becomes lower. Besides, the increment rate of w is slower than the decrement rate of q_R. Thus, the wholesale profit of the supplier diminishes. When the retailer has a significant marketing advantage, the increment of the supplier's retail profit in the direct channel cannot offset the decrement of the supplier's wholesale profit. As a result, the supplier's profit decreases as c decreases. So when c becomes smaller, the supplier does not encroach. Moreover, from Part (3) of Corollary 3, Π_S^{3E} decreases in α. Thus, as α becomes larger, the supplier does not encroach either. Therefore, the range of a/c corresponding to the third equilibrium narrows as α becomes much larger.

In a word, when the retailer's fairness concerns are weak, the supplier

has more flexibility to encroach compared to the situation where the retailer has no fairness concerns; when the retailer's fairness concerns are strong, encroachment may be detrimental to the supplier. Therefore, the supplier should take the retailer's fairness concerns into account and make the encroachment decision carefully.

5.2. The Impact Of Encroachment On Retailer's Profit

(Insert Figure 5 about here)

Figure 5: Region where the retailer benefits from encroachment for $\gamma = 1/2$

(Insert Figure 6 about here)

Figure 6: Wholesale price when $\gamma = 1/2$ and $a/c = 2.5$

The reduction of the wholesale price in the encroachment setting implies that the retailer may benefit from encroachment. For $\gamma = 1/2$, Region Ω (i.e., the region between the two curves) in Figure 5 is the region where encroachment increases the retailer's profit, which is a part of Φ_1, Φ_2 and Ω_3. The region where encroachment increases the retailer's utility is almost the same as Region Ω in Figure 5. It is obvious that the profits of both the supplier and the retailer are improved by encroachment in Region Ω. In Region Ω, the width of the range of a/c largely increases as α increases. This width can increase as much as four times compared to that in the no fairness concerns case (i.e., $\alpha = 0$). The reason behind this phenomenon is the considerable reduction in the wholesale price as α increases. Figure 6 plots the wholesale price for $a/c = 2.5$, from which we observe that there is a great jump down of the wholesale price as α increases.

The managerial insight is that, compared to a retailer with no fairness concerns, a retailer with fairness concerns should embrace supplier encroachment more warmly when her marketing advantage is significant, as the supplier will take the retailer's fairness concerns into account when he decides whether or not to encroach. In general, the analysis in Sections 5.1 and 5.2 indicates that if the retailer is fairness concerned, the supplier has more flexibility to encroach and the retailer has more possibility to benefit from encroachment.

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5.3. The Impact Of Encroachment On System Profit

Figure 7 plots the region where encroachment increases the system profit, i.e., Ω_1, Φ_2 and Ω_3. $\Omega_i(i = 1, 3)$ corresponds to the ith equilibrium, which is a part of Φ_i. When $(\alpha, 1/2, a/c) \in \Phi_2$, the system profit increases as much as 15% compared to the no fairness concerns case (referring to Figure 8). When $(\alpha, 1/2, a/c) \in \Omega_3$, the calculation shows that the system profit increases as much as 25%. Consequently, the retailer's fairness concerns bring a remarkable improvement to the system profit when the retailer has a significant marketing advantage.

(Insert Figure 7 about here)

Figure 7: Region where encroachment increases system profit when $\gamma = 1/2$

(Insert Figure 8 about here)

Figure 8: System profit improvement ratio under the second equilibrium when $\gamma = 1/2$

6. Conclusion

In this paper, we consider the encroachment problem with retailer's fairness concerns. We show that the supplier may be worse off by encroachment when the retailer has strong fairness concerns and a significant marketing advantage. When the retailer has a significant marketing advantage, the retailer's profit may decrease as her fairness concerns become much stronger. If the retailer is fairness concerned, the supplier has more flexibility to encroach and the retailer has more possibility to benefit from encroachment in most cases. The retailer's fairness concerns can bring a remarkable improvement to the system profit when the retailer has a significant marketing advantage.

In the current paper, we implicitly assume the information to be complete. The supplier knows the exact values of the fairness related factors α and γ of the retailer. This assumption may seem to be strict, but it is possible for the supplier to infer them from the long history of transactions with the retailer.

There are several directions for future research. First, more general utility functions of the retailer can be considered, such as taking into account the advantageous inequity in the retailer's utility function. Second, fairness

concerns of the supplier can be incorporated into the model. Third, other behavioral factors, such as loss aversion and risk aversion, can be further considered in the encroachment problem. Fourth, we consider a supply chain composed of one supplier and one retailer. As we stated in Section 1, in reality, one supplier often wholesales products to many retailers in different retail markets. When the retail markets are independent, if the retailers are identical, or if the retailers are not identical but the supplier could charge different wholesale prices for the retailers due to their different order quantities, then the results in the current paper are still applicable; However, if the supplier is forbidden by law to charge different wholesale prices for the non-identical retailers, then the results in the current paper will no longer be applicable. Furthermore, if the retail markets are dependent, the results in the current paper will no longer be applicable either. All of these are interesting directions for future research.

Appendix A. Proof of Proposition 2

In the second stage of the game, given the wholesale price w and anticipating the supplier's quantity to sell through his direct channel $q_S^E(q_R)$ in Equation (7), the retailer chooses her order quantity q_R to maximize her utility:

$$\max_{q_R} U_R^E = \Pi_R^E - \alpha(\gamma\Pi_S^E - \Pi_R^E)^+. \tag{A.1}$$

Substituting (7) into (10), the profit of the retailer Π_R^E can be expressed as a function of q_R and w:

$$\Pi_R^E = -\frac{q_R^2}{2} + \frac{c+a-2w}{2}q_R. \tag{A.2}$$

Referring to Equation (8),

$$\Pi_S^E = \frac{q_R^2}{4} + (w - \frac{a-c}{2})q_R + \frac{(a-c)^2}{4}. \tag{A.3}$$

Substituting Equations (A.2) and (A.3) into (A.1), the retailer's optimization problem (A.1) can be written as:

$$\max_{q_R} U_R^E = -\frac{q_R^2}{2} + \frac{c+a-2w}{2}q_R - \alpha\left[\frac{\gamma+2}{4}q_R^2 + \frac{(\gamma-1)c-(\gamma+1)(a-2w)}{2}q_R + \frac{\gamma(a-c)^2}{4}\right]^+. \tag{A.4}$$

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Next, we solve the optimization problem (A.4) which can be discussed in the following two cases.

(1) When the retailer's monetary payoff is lower than her equitable payoff, i.e., $\gamma\Pi_S^E - \Pi_R^E \geq 0$, according to (A.4), the retailer's problem is as below:

$$\max_{q_R} U_{1R} = -\frac{(\gamma+2)\alpha+2}{4}q_R^2 + \frac{[1-\alpha(\gamma-1)]c + [1+\alpha(\gamma+1)](a-2w)}{2}q_R - \frac{\alpha\gamma(a-c)^2}{4}$$

$$s.t. \ \frac{\gamma+2}{4}q_R^2 + \frac{(\gamma-1)c - (\gamma+1)(a-2w)}{2}q_R + \frac{\gamma(a-c)^2}{4} \geq 0.$$

$$\text{(A.5)}$$

Denote the solution of the optimization problem (A.5) as q_{1R}. The objective function U_{1R} is a quadratic function of q_R, and the maximum point of U_{1R} is $q_1^* = \frac{[1-\alpha(\gamma-1)]c+[1+\alpha(\gamma+1)](a-2w)}{y}$. The constraint function of the optimization problem (A.5) is also a quadratic function of q_R, and the minimum point of the constraint function is $q_2^* = \frac{(\gamma+1)(a-2w)-(\gamma-1)c}{\gamma+2}$.

Denote $(\frac{a}{2} - \frac{(\gamma-1)c+\sqrt{\gamma(\gamma+2)}(a-c)}{2(\gamma+1)}, \frac{a}{2} - \frac{(\gamma-1)c-\sqrt{\gamma(\gamma+2)}(a-c)}{2(\gamma+1)}) \triangleq (w_5, w_6)$. When $w \in (w_5, w_6)$, the constraint condition always holds. Thus, q_{1R} equals to q_1^*. When $w \leq w_5$ or $w \geq w_6$, the two roots of the constraint function in the optimization problem (A.5) are:

$$q_{1,2} = \frac{(\gamma+1)(a-2w)-(\gamma-1)c \mp \sqrt{[(\gamma+1)(a-2w)-(\gamma-1)c]^2 - \gamma(\gamma+2)(a-c)^2}}{\gamma+2}.$$

If $q_1^* \leq q_1$ or $q_1^* \geq q_2$, q_{1R} equals to q_1^*; otherwise, if $q_1^* \geq q_2^*$, i.e., $w \geq \frac{a-3c}{2}$, then q_{1R} equals to q_2; if $q_1^* \leq q_2^*$, i.e., $w \leq \frac{a-3c}{2}$, then q_{1R} equals to q_1.

The inequalities $q_1^* \leq q_1$ or $q_1^* \geq q_2$ are equivalent to the following inequality:

$$(q_1^* - q_1)^2 \geq (q_2^* - q_1)^2. \tag{A.6}$$

Substituting the formulations of q_1^*, q_2^* and q_1 into (A.6), (A.6) can be transformed into the following inequality:

$$[(\gamma+1)^2y^2 - \gamma^2](a-2w)^2 - 2c[(\gamma^2-1)y^2 - 3\gamma^2](a-2w)$$
$$+ [(\gamma-1)^2y^2 - 9\gamma^2]c^2 - \gamma(\gamma+2)y^2(a-c)^2 \leq 0. \tag{A.7}$$

The solution of Inequality (A.7) is

$$w \in \left[\frac{a}{2} + \frac{[3\gamma^2 - (\gamma^2 - 1)y^2]c - y\sqrt{K_1}}{2[(\gamma + 1)^2 y^2 - \gamma^2]}, \frac{a}{2} + \frac{[3\gamma^2 - (\gamma^2 - 1)y^2]c + y\sqrt{K_1}}{2[(\gamma + 1)^2 y^2 - \gamma^2]} \right]$$
$$\triangleq [w_1, w_2].$$

(A.8)

where $K_1 = \gamma(\gamma + 2)[(\gamma + 1)^2 y^2 - \gamma^2](a - c)^2 + 4\gamma^2(\gamma + 2)^2 c^2$.

It is easy to show that $[w_5, w_6] \subset [w_1, w_2]$. Thus, if $w \in [w_1, w_2]$, q_{1R} equals to q_1^*. We can also show that when $\frac{a}{c} \leq 1 + 2\sqrt{\frac{\gamma+2}{\gamma}}$, the inequality $\frac{a-3c}{2} \leq w_1$ holds. Thus, if $w \geq w_2$ or $\frac{a-3c}{2} \leq w \leq w_1$, q_{1R} equals to q_2. Otherwise, q_{1R} equals to q_1.

The retailer's optimal order quantity, conditional on disadvantageous inequity, is given as below:

$$q_{1R}(w) = \begin{cases} \frac{[1-\alpha(\gamma-1)]c+[1+\alpha(\gamma+1)](a-2w)}{y} & \text{if } w_1 \leq w \leq w_2 \\ \frac{(\gamma+1)(a-2w)-(\gamma-1)c+\sqrt{\Lambda}}{\gamma+2} & \text{if } \frac{a-3c}{2} \leq w \leq w_1 \text{ or } w \geq w_2 \\ \frac{(\gamma+1)(a-2w)-(\gamma-1)c-\sqrt{\Lambda}}{\gamma+2} & \text{otherwise,} \end{cases}$$

(A.9)

where $\Lambda = [(\gamma + 1)(a - 2w) - (\gamma - 1)c]^2 - \gamma(\gamma + 2)(a - c)^2$.

(2) When the retailer's monetary payoff is higher than her equitable payoff, i.e., $\gamma\Pi_S^E - \Pi_R^E \leq 0$, according to (A.4), the retailer's problem is:

$$\max_{q_R} U_{2R} = -\frac{q_R^2}{2} + \frac{c + a - 2w}{2} q_R$$
$$s.t. \; \frac{\gamma + 2}{4} q_R^2 + \frac{(\gamma - 1)c - (\gamma + 1)(a - 2w)}{2} q_R + \frac{\gamma(a - c)^2}{4} \leq 0.$$

(A.10)

Denote the solution of the optimization problem (A.10) as q_{2R}. Through similar analysis as the optimization problem (A.5), the retailer's optimal order quantity in the case of no-disadvantageous inequity is given by:

$$q_{2R}(w) = \begin{cases} \frac{c+a-2w}{2} & \text{if } w \leq w_3 \text{ or } w \geq w_4 \\ \frac{(\gamma+1)(a-2w)-(\gamma-1)c+\sqrt{\Lambda}}{\gamma+2} & \text{if } w_3 \leq w \leq w_5 \text{ or } w_6 \leq w \leq w_4, \end{cases}$$

(A.11)

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where,

$$w_3 = \frac{a}{2} + \frac{(-\gamma^2 + 4)c - 2\sqrt{K_2}}{2(\gamma + 2)(3\gamma + 2)},$$

$$w_4 = \frac{a}{2} + \frac{(-\gamma^2 + 4)c + 2\sqrt{K_2}}{2(\gamma + 2)(3\gamma + 2)},$$

$$K_2 = \gamma(\gamma + 2)[4(\gamma + 1)^2 - \gamma^2](a - c)^2 + 4\gamma^2(\gamma + 2)^2 c^2.$$

When $w \in (w_5, w_6)$, the optimization problem (A.10) has no feasible solution.

In the following, we show that $w_3 \le w_1 \le w_2 \le w_4$. Note that $w_3 = w_1|_{\alpha=0}$, $w_4 = w_2|_{\alpha=0}$. As $y = (\gamma + 2)\alpha + 2$ is an increasing function of α, we just need to show that w_1 increases in y and w_2 decreases in y.

$$w_2 = \frac{a}{2} + \frac{[3\gamma^2 - (\gamma^2 - 1)y^2]c + y\sqrt{K_1}}{2[(\gamma + 1)^2 y^2 - \gamma^2]}$$

$$= \frac{a}{2} + \frac{[3\gamma^2 - (\gamma^2 - 1)y^2]c}{2[(\gamma + 1)^2 y^2 - \gamma^2]} + \frac{1}{2}\sqrt{\frac{\gamma(\gamma + 2)(a - c)^2 y^2}{(\gamma + 1)^2 y^2 - \gamma^2} + \frac{4\gamma^2(\gamma + 2)^2 c^2 y^2}{[(\gamma + 1)^2 y^2 - \gamma^2]^2}},$$

in which, the second item and the third item both decrease in y. Thus, w_2 decreases in y.

Now, we verify that w_1 increases in y. By taking derivative of w_1 with respect to y, we obtain that:

$$\frac{\partial w_1}{\partial y} = \frac{\gamma^2 \left[\sqrt{K_1} - 2(\gamma + 1)(\gamma + 2)yc\right]^2}{[(\gamma + 1)^2 y^2 - \gamma^2]^2 \sqrt{K_1}} \ge 0. \tag{A.12}$$

Thus, w_1 increases in y. Therefore, the inequalities $w_3 \le w_1 \le w_2 \le w_4$ hold. And it is not difficult to show that when $\frac{a}{c} \le 1 + 2\sqrt{\frac{\gamma+2}{\gamma}}$, the inequality $\frac{a-3c}{2} \le w_3$ holds. According to (A.9) and (A.11), the retailer's optimal order quantity is determined by:

$$q_R^E(w) = \begin{cases} \frac{c + a - 2w}{2} & \text{if } w \le w_3 \text{ or } w \ge w_4 \\ \frac{[(\gamma+1)\alpha+1](a-2w) - [(\gamma-1)\alpha-1]c}{y} & \text{if } w_1 \le w \le w_2 \\ \frac{(\gamma+1)(a-2w) - (\gamma-1)c + \sqrt{\Lambda}}{\gamma+2} & \text{if } w_3 \le w \le w_1 \text{ or } w_2 \le w \le w_4. \end{cases}$$

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Appendix B. Proof of Proposition 3

We analyze the first stage problem of the game in the encroachment setting. In this stage, the supplier sets the wholesale price w to maximize his profit in anticipation of the retailer's reactions through $q_R^E(w)$ in Equation (12).

(1) If the supplier chooses a wholesale price from ranges $0 \leq w \leq w_3$ or $w \geq w_4$, his optimization problem is given by:

$$\max_w \Pi_{1S} = \frac{q_R^2}{4} + (w - \frac{a-c}{2})q_R + \frac{(a-c)^2}{4}$$
$$s.t. \begin{cases} q_R = \frac{c+a-2w}{2} \\ 0 \leq w \leq w_3 \text{ or } w \geq w_4. \end{cases} \quad \text{(B.1)}$$

Substituting the expression of q_R into Π_{1S}, the optimization problem (B.1) is transformed to the following one:

$$\max_w \Pi_{1S} = \frac{(c+a-2w)(5c-3a+6w)}{16} + \frac{(a-c)^2}{4} \quad \text{(B.2)}$$
$$s.t. \ 0 \leq w \leq w_3 \text{ or } w \geq w_4.$$

It is not difficult to show that the optimal wholesale price, quantity sold through the direct channel and the supplier's profit in equilibrium are as below:

(a) when $\gamma \geq \frac{1}{2}$, if $q_S^{2E} > 0$ (i.e., $\frac{a}{c} > \frac{3\gamma+1}{\gamma+1}$), then $w^E = w^{2E}$, $q_S^E = q_S^{2E}$, $\Pi_S^E = \Pi_S^{2E}$; otherwise, $w^E = w^{5E}$, $q_S^E = q_S^{5E}$, $\Pi_S^E = \Pi_S^{5E}$;

(b) when $\gamma < \frac{1}{2}$, if $\frac{a}{c} \geq 1 + \frac{2}{3}\sqrt{\frac{2-3\gamma}{\gamma}}$ and $q_S^{2E} > 0$ (i.e., $\frac{a}{c} > \frac{3\gamma+1}{\gamma+1}$), then $w^E = w^{2E}$, $q_S^E = q_S^{2E}$, $\Pi_S^E = \Pi_S^{2E}$; if $\frac{a}{c} < 1 + \frac{2}{3}\sqrt{\frac{2-3\gamma}{\gamma}}$ and $q_S^{4E} > 0$ (i.e., $\frac{a}{c} > \frac{5}{3}$), then $w^E = w^{4E}$, $q_S^E = q_S^{4E}$, $\Pi_S^E = \Pi_S^{4E}$; otherwise, $w^E = w^{5E}$, $q_S^E = q_S^{5E}$, $\Pi_S^E = \Pi_S^{5E}$.

(2) If the supplier chooses a wholesale price from the range $w_1 \leq w \leq w_2$, his optimization problem is as follows:

$$\max_w \Pi_{2S} = \frac{q_R^2}{4} + (w - \frac{a-c}{2})q_R + \frac{(a-c)^2}{4}$$
$$s.t. \begin{cases} q_R = \frac{[(\gamma+1)\alpha+1](a-2w)-[(\gamma-1)\alpha-1]c}{y} \\ w_1 \leq w \leq w_2. \end{cases} \quad \text{(B.3)}$$

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Substituting the expression of q_R into Π_{2S} and denoting $x = a - 2w$, the optimization problem (B.3) is transformed to the following one:

$$\max_x \Pi_{2S} = \frac{1}{4(\gamma+2)^2 y^2} \left\{ -[(\gamma+1)y - \gamma][(\gamma+3)y + \gamma]x^2 + 2[y^2(\gamma^2 + 4\gamma + 1) \right.$$
$$\left. - 3\gamma(\gamma + 2y)]cx - [(\gamma+5)y + 3\gamma][(\gamma-1)y - 3\gamma] \right\}$$
$$s.t.\ x \in \left[\frac{-[3\gamma^2 - (\gamma^2 - 1)y^2]c \mp y\sqrt{K_1}}{(\gamma+1)^2 y^2 - \gamma^2} \right].$$

Denote $g(\alpha, \gamma) = 1 + \frac{2}{\gamma + (\gamma+3)y} \sqrt{\frac{(\gamma+2)(\gamma+y)(y^2\gamma + y^2 - y\gamma^2 - 4y\gamma - \gamma^2)}{\gamma[(\gamma+1)y - \gamma]}}$ which is the root of $\Pi_S^{1E} = \Pi_S^{3E}$. It is not difficult to show that if $\frac{a}{c} \geq g(\alpha, \gamma)$ and $q_S^{1E} > 0$ (i.e., $\frac{a}{c} > \frac{(\gamma+5)y + 3\gamma}{(\gamma+3)y + \gamma}$), then $w^E = w^{1E}$, $q_S^E = q_S^{1E}$ and $\Pi_S^E = \Pi_S^{1E}$; if $\frac{a}{c} < g(\alpha, \gamma)$ and $q_S^{3E} > 0$ (i.e., $\frac{a}{c} > \frac{(\gamma+1)y + \gamma(3\gamma+5)}{(\gamma+1)(\gamma+y)}$), then $w^E = w^{3E}$, $q_S^E = q_S^{3E}$ and $\Pi_S^E = \Pi_S^{3E}$; otherwise, $w^E = w^{5E}$, $q_S^E = q_S^{5E}$ and $\Pi_S^E = \Pi_S^{5E}$.

(3) If the supplier chooses a wholesale price from ranges $w_3 \leq w \leq w_1$ or $w_2 \leq w \leq w_4$, his optimization problem is as follows:

$$\max_w \Pi_{3S} = \frac{q_R^2}{4} + (w - \frac{a-c}{2})q_R + \frac{(a-c)^2}{4}$$
$$s.t. \begin{cases} q_R = \frac{(\gamma+1)(a-2w) - (\gamma-1)c + \sqrt{\Lambda}}{\gamma+2} \\ w_3 \leq w \leq w_1 \text{ or } w_2 \leq w \leq w_4. \end{cases} \tag{B.4}$$

Substitute the expression of q_R into Π_{3S}. Denote

$$x = a - 2w,$$
$$[x_1, x_2] = \left[\frac{-[3\gamma^2 - (\gamma^2 - 1)y^2]c + \sqrt{K_1 y^2}}{(\gamma+1)^2 y^2 - \gamma^2}, \frac{-(-\gamma^2 + 4)c + \sqrt{4K_2}}{4(\gamma+1)^2 - \gamma^2} \right],$$
$$[x_3, x_4] = \left[\frac{-(-\gamma^2 + 4)c - \sqrt{4K_2}}{4(\gamma+1)^2 - \gamma^2}, \frac{-[3\gamma^2 - (\gamma^2 - 1)y^2]c - \sqrt{K_1 y^2}}{(\gamma+1)^2 y^2 - \gamma^2} \right], \tag{B.5}$$
$$G = [(\gamma+1)x - (\gamma-1)c]^2 - \gamma(\gamma+2)(a-c)^2,$$
$$K = \gamma(\gamma+2)[(\gamma+1)^2 t^2 - \gamma^2](a-c)^2 + 4\gamma^2(\gamma+2)^2 c^2, \quad t \in [-2, y].$$

If $x \in [x_1, x_2]$, x can be represented as $\frac{-[3\gamma^2 - (\gamma^2 - 1)t^2]c + \sqrt{Kt^2}}{(\gamma+1)^2 t^2 - \gamma^2}$, where $t \in [-2, y]$. If $x \in [x_3, x_4]$, x can be represented as $\frac{-[3\gamma^2 - (\gamma^2 - 1)t^2]c - \sqrt{Kt^2}}{(\gamma+1)^2 t^2 - \gamma^2}$, where $t \in [-2, y]$.

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The optimization problem (B.4) can be transformed to the following one:

$$\max_x \Pi_{3S} = \frac{(3c - x)[(\gamma + 1)x - (\gamma - 1)c + \sqrt{G}]}{2(\gamma + 2)^2} + \frac{(a - c)^2}{2(\gamma + 2)} \qquad \text{(B.6)}$$

$$s.t.\ x \in [x_1, x_2] \text{ or } [x_3, x_4].$$

First, we consider the case where $x \in [x_3, x_4]$. It can be easily shown that the inequality $(\gamma + 1)x - (\gamma - 1)c < 0$ holds. As $G = [(\gamma + 1)x - (\gamma - 1)c]^2 - \gamma(\gamma + 2)(a - c)^2$, the inequality $(\gamma + 1)x - (\gamma - 1)c + \sqrt{G} < 0$ holds. Besides, it is easy to show that the inequality $(3c - x) > 0$ holds. Thus, $(3c - x)[(\gamma + 1)x - (\gamma - 1)c + \sqrt{G}]$ is non-positive.

Next, we consider the case where $x \in [x_1, x_2]$. The inequality $3c - x \geq 0$ holds if and only if $\frac{a}{c} \leq 1 + 2\sqrt{\frac{\gamma + 2}{\gamma}}$. It is not difficult to show that the inequality $(\gamma + 1)x - (\gamma - 1)c + \sqrt{G} \geq 0$ holds. So the inequality $(\gamma + 1)x - (\gamma - 1)c + \sqrt{G} \geq 0$ holds. Thus, $(3c - x)[(\gamma + 1)x - (\gamma - 1)c + \sqrt{G}]$ is non-negative.

To sum up, the optimal x which maximizes Π_{3S} falls into the interval $[x_1, x_2]$. In the following, we only consider the case where $x \in [x_1, x_2]$ and show that Π_{3S} is increasing in $[x_1, x_2]$. We only need to show that $(3c - x)[(\gamma + 1)x - (\gamma - 1)c + \sqrt{G}]$ is increasing in $[x_1, x_2]$.

$$\frac{\partial\{(3c - x)[(\gamma + 1)x - (\gamma - 1)c + \sqrt{G}]\}}{\partial x}$$
$$= \frac{[(\gamma + 1)x - (\gamma - 1)c + \sqrt{G}][(\gamma + 1)(3c - x) - \sqrt{G}]}{\sqrt{G}},$$

in which, $(\gamma + 1)x - (\gamma - 1)c + \sqrt{G} \geq 0$ holds. It can be easily shown that $(\gamma + 1)(3c - x) - \sqrt{G} \geq 0$ is equivalent to $[\gamma(a - c)^2 + 4(2\gamma + 1)c^2]/[4(\gamma + 1)c] - x \geq 0$. To verify that Π_{3S} is increasing in $[x_1, x_2]$, we just need to show that the inequality $[\gamma(a - c)^2 + 4(2\gamma + 1)c^2]/[4(\gamma + 1)c] - x_2 \geq 0$ holds.

$$\frac{\gamma(a - c)^2 + 4(2\gamma + 1)c^2}{4(\gamma + 1)c} - x_2$$
$$= \frac{\gamma(a - c)^2 + 4(2\gamma + 1)c^2}{4(\gamma + 1)c} - \frac{-(-\gamma^2 + 4)c + \sqrt{4K_2}}{4(\gamma + 1)^2 - \gamma^2}$$
$$= \frac{\gamma[4(\gamma + 1)^2 - \gamma^2](a - c)^2 + 4(\gamma + 2)[4(\gamma + 1)^2 + \gamma^2]c^2 - 8(\gamma + 1)c\sqrt{K_2}}{4(\gamma + 1)[4(\gamma + 1)^2 - \gamma^2]c},$$

in which,

$$\left\{\gamma[4(\gamma+1)^2-\gamma^2](a-c)^2+4(\gamma+2)[4(\gamma+1)^2+\gamma^2]c^2\right\}^2-\left[8(\gamma+1)c\sqrt{K_2}\right]^2$$
$$=[4(\gamma+1)^2-\gamma^2]^2[\gamma(a-c)^2-4(\gamma+2)c^2]^2\geq 0.$$

Thus, Π_{3S} increases in the interval $[x_1, x_2]$. Therefore, if $q_S^{2E} > 0$ (i.e. $\frac{a}{c} > \frac{3\gamma+1}{\gamma+1}$), then $w^E = w^{2E}$, $q_S^E = q_S^{2E}$, $\Pi_S^E = \Pi_S^{2E}$; otherwise, $w^E = w^{5E}$, $q_S^E = q_S^{5E}$, $\Pi_S^E = \Pi_S^{5E}$.

To sum up, there are at most five equilibria as shown in (13) to (17). Note that $\Pi_S^{2E} \geq \Pi_S^{3E}$ always holds. In fact, it can be verified that $\Pi_S^{2E} = \Pi_S^{3E}|_{\alpha=0}$. From Corollary 3, Π_S^{3E} decreases in α. Therefore, the inequality $\Pi_S^{2E} \geq \Pi_S^{3E}$ holds. For fixed (α, γ), denote $\frac{a}{c} \geq f(\alpha, \gamma)$ as the solution of $\Pi_S^{1E} \geq \Pi_S^{2E}$. Recall that $\frac{a}{c} \geq g(\alpha, \gamma)$ is the solution of $\Pi_S^{1E} \geq \Pi_S^{3E}$. As $\Pi_S^{2E} \geq \Pi_S^{3E}$, the inequality $f(\alpha, \gamma) \geq g(\alpha, \gamma)$ always holds.

From the analysis above, it is not difficult to show that if $(\alpha, \gamma, \frac{a}{c})$ falls into Region Φ_i $(i = 1, ..., 5)$, the equilibrium outcome is the ith $(i = 1, ..., 5)$ one.

Appendix C. Proof of Corollary 5

Denote

$$B = 4\gamma^2(\gamma+2)^2 c - \gamma(\gamma+2)[(\gamma+1)^2 y^2 - \gamma^2](a-c),$$
$$C = \gamma(\gamma+2)[(\gamma+1)^2 y^2 - \gamma^2] + 4\gamma^2(\gamma+2)^2.$$

(1) Take derivative of q_R^{3E} with respect to c:

$$\frac{\partial q_R^{3E}}{\partial c} = \frac{2\gamma(\gamma+2) + BK_1^{-\frac{1}{2}}}{(\gamma+2)[(\gamma+1)y+\gamma]}. \tag{C.1}$$

It's not difficult to show that when $a/c \leq 1 + 2\sqrt{\frac{\gamma+2}{\gamma}}$, $B \geq 0$ holds. Thus, $\partial q_R^{3E}/\partial c \geq 0$. Furthermore, from Part (2) of the proof of Proposition 3, when $(\alpha, \gamma, \frac{a}{c}) \in \Phi_3$, $\partial q_R^E(w)/\partial w = -2[(\gamma+1)\alpha+1]/[(\gamma+2)\alpha+2] \leq 0$. Therefore, $\partial w^{3E}/\partial c \leq 0$.

(2) Take derivative of w^{3E} with respect to c:

$$\frac{\partial w^{3E}}{\partial c} = \frac{[3\gamma^2 - (\gamma^2-1)y^2] - yBK_1^{-\frac{1}{2}}}{2[(\gamma+1)^2 y^2 - \gamma^2]}. \tag{C.2}$$

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From (C.1) and (C.2), we have

$$\frac{\partial q_R^{3E}}{\partial c} \Big/ \frac{\partial w^{3E}}{\partial c} = \frac{2[(\gamma+1)y-\gamma]}{\gamma+2} \frac{2\gamma(\gamma+2)K_1^{\frac{1}{2}} + B}{[3\gamma^2 - (\gamma^2-1)y^2]K_1^{\frac{1}{2}} - yB}.$$

Denote

$$L = \frac{2\gamma(\gamma+2)K_1^{\frac{1}{2}} + B}{[3\gamma^2 - (\gamma^2-1)y^2]K_1^{\frac{1}{2}} - yB}.$$

Take derivative of L with respect to c:

$$\partial L/\partial c = \frac{[3\gamma + (1-\gamma)y][(\gamma+1)y+\gamma](K_1^{\frac{1}{2}}C - K_1^{-\frac{1}{2}}B^2)}{\{[3\gamma^2 - (\gamma^2-1)y^2]K_1^{\frac{1}{2}} - yB\}^2},$$

in which, if $\gamma \le 1$, or $\gamma > 1$ and $\alpha \le \frac{1}{\gamma-1}$, the inequality $[3\gamma + (1-\gamma)y] \ge 0$ holds. And the inequality $(K_1^{\frac{1}{2}}C - K_1^{-\frac{1}{2}}B^2) = K_1^{-\frac{1}{2}}(K_1C - B^2) = 4\gamma^3(\gamma+2)^3 K_1^{-\frac{1}{2}}a^2 \ge 0$ always holds. Therefore, when $\gamma \le 1$, or $\gamma > 1$ and $\alpha \le \frac{1}{\gamma-1}$, $\partial L/\partial c \ge 0$, i.e., $\frac{\partial q_R^{3E}}{\partial c} \Big/ \frac{\partial w^{3E}}{\partial c}$ increases in c.

Appendix D. Proof of Proposition 4

(1) It is straightforward from Proposition 3.

(2) From Part (2) in the proof of Proposition 3, when $\frac{a}{c} \ge g(\alpha, \gamma)$, the first equilibrium can be obtained, which means that $\Pi_S^E \ge \Pi_S^{1E}$. It is easy to show that when $\frac{a}{c} > 1 + 2\sqrt{\frac{\gamma+2}{\gamma}}$, the inequality $\frac{a}{c} \ge g(\alpha, \gamma)$ always holds. In the following, we just need to show that Π_S^{1E} is larger than Π_S^N when $\frac{a}{c} > 1 + 2\sqrt{\frac{\gamma+2}{\gamma}}$.

$$\Pi_S^{1E} - \Pi_S^N = \frac{(\gamma+y)^2c^2}{[(\gamma+3)y+\gamma][(\gamma+1)y-\gamma]} + \frac{(a-c)^2}{4} - \frac{a^2}{8}. \tag{D.1}$$

When $\frac{a}{c} \ge 2 + \sqrt{2}$, the inequality $\frac{(a-c)^2}{4} - \frac{a^2}{8} \ge 0$ always holds. Note that $2\sqrt{\frac{\gamma+2}{\gamma}}$ is a decreasing function of γ and the inequality $1 + 2\sqrt{\frac{\gamma+2}{\gamma}} \ge 2 + \sqrt{2}$ holds when $\gamma \le \frac{8(1+2\sqrt{2})}{7}$. Thus, when $\gamma \le \frac{8(1+2\sqrt{2})}{7}$, the inequality $\Pi_S^{1E} - \Pi_S^N \ge 0$ holds.

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In the following, we consider the case where $\gamma > \frac{8(1+2\sqrt{2})}{7}$. Denote $D = \frac{(\gamma+y)^2 c^2}{[(\gamma+3)y+\gamma][(\gamma+1)y-\gamma]}$. When $D \geq \frac{1}{4}$, $\Pi_S^{1E} - \Pi_S^N \geq 0$ always holds. When $D < \frac{1}{4}$, the two roots of $\Pi_S^{1E} - \Pi_S^N = 0$ are $2 \pm \sqrt{2-8D}$. It suffices to show that $1 + 2\sqrt{\frac{\gamma+2}{\gamma}} \geq 2 + \sqrt{2-8D}$ which always holds when $\gamma > \frac{8(1+2\sqrt{2})}{7}$.

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Acknowledgements

Table 1
Notation

Notation	Meaning
a	potential market demand
c	unit marketing cost of the supplier
p	retail price
Π_R	monetary payoff of the retailer
Π_S	monetary payoff of the supplier
Π_C	systemwide payoff of the supply chain
γ	the equitable outcome for the retailer is a fraction γ of the supplier's payoff
α	the disadvantageous-inequality aversion factor
U_R	utility of the retailer
w	wholesale price
q_R	retailer's order quantity
w^N	wholesale price in the no-encroachment setting
q_R^N	retailer's order quantity in the no-encroachment setting
Π_R^N	monetary payoff of the retailer in the no-encroachment setting
Π_S^N	monetary payoff of the supplier in the no-encroachment setting
w^E	wholesale price in the encroachment setting
q_R^E	retailer's order quantity in the encroachment setting
q_S^E	quantity the supplier sells through the direct channel
Π_R^E	monetary payoff of the retailer in the encroachment setting
Π_S^E	monetary payoff of the supplier in the encroachment setting
U_R^E	utility of the retailer in the encroachment setting