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# A DUAL-CHANNEL SUPPLY CHAIN PROBLEM WITH RESOURCE-UTILIZATION PENALTY: WHO CAN BENEFIT FROM SALES EFFORT?

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(Communicated by Wenxun Xing)

ABSTRACT. As manufacturers may engage in both direct sale and wholesale, the channel conflict between manufacturer and retailer becomes inevitable. This paper considers a dual-channel supply chain in which a retailer sells the product through store channel with sales effort while the manufacturer holds a direct channel and may provide an incentive measure to share the cost of sales effort. To meet social responsibility, a penalty on the total resource consumed is imposed on the manufacturer. We present a manufacturer-led decentralized model in which both members maximize individual profit, and then derive the corresponding optimal direct/store price and wholesale price. The dualchannel supply chain model without sales effort policy is also considered so as to explain the effects of sales effort policy and sharing cost measure on both parties. Special properties are presented to show (i) the influence of retailer's sales effort and manufacturer's sharing cost on the optimal strategies; (ii) the resource-utilized penalty on the optimal decisions. Finally, numerical experiments are conducted to highlight the influence of various parameters on optimal solutions. We find that if the market response to retailer's sales effort is strong or the manufacturer's sharing portion of sales effort cost is increased, the retailer's profit and store selling price increase while the manufacturer's profit decreases and the direct sale and wholesale prices do not change. We also show that if the consumer's value on direct channel exceeds a threshold, the manufacturer's profit will be greater than that of the retailer. Moreover, if the market response to retailer's sales effort is strong, manufacturer's profit will be lesser than retailer's profit.

<sup>2020</sup> Mathematics Subject Classification. Primary: 90B06, 90B60; Secondary: 91B06.

 $Key\ words\ and\ phrases.$  Supply chain management, dual-channel, pricing strategy, sales effort, resource-utilization penalty.

This work is supported by National Natural Science Foundation of China (71502100, 71671125) and Humanities and Social Sciences Foundation of the Chinese Ministry of Education (20YJAZH135).

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1. Introduction. With the advancement of e-commerce and logistics technology, many manufacturers choose to sell their products to consumers directly using an internet online channel. This development results in a dual-channel supply chain for consumers to shop through either a retailer's store channel or a manufacturer's online channel. A number of papers have studied the dual-channel supply chain related problems. For a price-setting game model between a manufacturer and an independent retailer, Chiang et al. [9] show that the direct channel can increase the manufacturer's share of cooperative profits, while it may not always be detrimental to the retailer. Ding et al. [12] consider a hierarchical pricing decision process in a dual-channel problem with one manufacturer and one retailer. Matsui [21] investigates a different setting that a manufacturer manages the whole dual-channel supply chain consisting of a retail channel and a direct channel. Furthermore, Zhang et al. [32] investigate how the channel structure affects pricing decisions and what is the optimal channel structure for the retailer. Chen et al.<sup>[7]</sup> examine the impact of the supply chain power structure on the decisions of retailer and supplier when opening a direct channel. More related references can be found in Dan et al. [10], Xu et al. [29], Li et al. [19], Zhang and Wang [31], Niu et al. [22] and Chen and Chen **[6**].

The online channel may attract more consumers and get some market shares from the retailer's store channel owing to its competitive price and shopping convenience, which compels a retailer to exercise extra sales effort so as to hold or enlarge his/her market share. Value-added service such as extending the warranty, providing personal consultancy and giving out membership privilege in the marketing process can increase their consumer's purchasing inclination. Taylor [26] considers the effects of sales effort on channel rebates in supply chain coordination and designs proper target rebate and returns contract to achieve coordination. Xing and Liu [28] study sales effort coordination for a supply chain with one manufacturer and two retailers by designing a contract with price matching and selective compensation rebate. Considering customers' preference of retailing channel, Rodríguez and Aydın [25] utilize a nested-logit model to choose the channel for a supply chain with a buildto-order manufacturer selling through a dual channel. Ke and Liu [18] investigate a dual-channel supply chain in an uncertain environment and provide closed-form expressions for equilibria in centralized and decentralized cases. Dan et al. [11] study a dual-channel supply chain with a warranty service decision of the manufacturer and value-added service competition between the manufacturer and retailer.

Recently, with the increasing concern of environmental protection and public health, effective resource management become important. ERP (Extended Producer Responsibility) is a popular form of legislation to promote the total life cycle management of a product that mandates manufacturers to be physically and financially responsible for the used products through the end of life cycle (Brouillat et al.[5]; Bernard et al.[4]). Many scholars have focused on the producer's responsibility for the end-of-life products. Atasu et al.[1] provide a critical review of analytic research on product reuse economics in a closed-loop supply chain inspired by industrial practice. Atasu and Subramanian [3] investigate the implications of collective and individual producer responsibility models of product take-back laws for e-waste on manufacturers' design for product recovery choices and profits. Atasu and Souza [2] further point out that product take-back legislation can lead to a higher quality choice as opposed to voluntary take-back. Considering producers should have the responsibility of collecting backwards, Wang et al.[27] investigate the effect of a

reward-penalty mechanism on pricing decision and collective quantity in a closedloop supply chain with asymmetric information. Essenduran et al.[13] study the effects of regulations on remanufacturing level, consumer surplus, and the OEM profit by using a stylized model with an OEM facing competition from an independent remanufacturer. However, the implications of producer's responsibility on the dual-channel supply chain management are unclear, especially under the condition of retailer's sales effort.

As dual-channel studies in supply chain management have attracted much research attention, according to Taylor [26], quality, price and sales effort are the key dimensions for retailer's and manufacturer's marketing activities. Studies on pricing and sales effort can be referred to Chernong et al.[8]), Yan and Pei [30], Gao et al.[15] and Pu et al.[24]. These papers only consider the marketing behavior through pricing or sales effort while they seldom consider the excessive consumption of the non-renewable resources. However, since the irreversibility of natural resources and the urgency of environmental protection, it is necessary that manufacturer and retailer should be responsible for the the efficiency of resource utilization. In practice, many legislations about extended producer responsibility (EPR) system have been formulated and implemented in many countries. Therefore, it is an important factor in studying supply chain management and it should not be neglected. In this paper, we study a resource-utilization penalty dual-channel supply chain model with retailer's sales effort and manufacturer's sharing of the cost, and aim to answer the following questions:

i) How does the sales effort affect both of the retail channel and direct channel?

ii) How will the cost sharing provided by the manufacturer impact each member's profit?

iii) Can members benefit from sales effort under a resource-utilization penalty?

The remainder of the paper is organized as follows. We formulate the considered problem as a Stackelberg game model and analyze the dual-channel model with/without retailer's sales effort in Section 2. Section 3 discusses the impact of retailer's sales effort and manufacturer's incentive on the optimal decisions . In Section 4, a numerical study is conducted to explore the optimal strategies of retailer's sales effort and manufacturer's sharing portion cost. Conclusions and future research directions are provided in Section 5. For easy reference, all notations used in this paper are summarized in Table 1.

2. Model framework. Consider a dual-channel supply chain with one manufacturer and one retailer in which the manufacturer wholesales a product to an independent retailer and directly sells the product through an online channel. Consumers can buy the product either from online channel or from the retailer's store. The manufacturer supplies the retailer at a wholesale price w and sells the product online at a price  $p_d$ . The retailer decides the order quantity and resells the product at a retail price  $p_r$  to the consumers with a cost of c. For simple exposition, we assume that the operating cost of the manufacturer is normalized to zero which dose not affect the basic results.

The retailer exercises a sales effort to encourage consumers to buy products from the retail store with a cost of  $c(s) = \frac{1}{2}s^2$ , where s represents the sales effort. Such a quadratic cost function is widely used in the literature (e.g., Taylor [26], Martín and Sigué [20], Ghosh and Shah [16]). It means that the marginal cost of providing sales effort is increasing in s. The manufacturer may share a portion of the sales effort cost of  $\frac{1-\lambda}{2}s^2$ .

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Notation	Description		
Parameters			
$\theta$	Willing-to-pay of the consumer for retailer channel, $0 \le \theta \le 1$ .		
δ	Consumer's preference to select direct channel, $0 \le \delta < 1$ .		
c	Marginal costs incurred by the retailer for the product sold through the store channel, $0 \le c < 1$ .		
$\beta$	The coefficient of resource-utilization penalty, $\beta \ge 0$ .		
a	Market response to retailer's sales effort, $0 \le a \le 1$ .		
$\lambda$	Retailer's cost-sharing proportion for sales effort , $0 \le \lambda \le 1$ .		
NS/S	Without/with retailer's sales effort.		
$q_r, q_r^i$	Market demand for the retailer, $i \in \{NS, S\}$ .		
$q_d, q_d^i$	Market demand for the manufacturer, $i \in \{NS, S\}$ .		
$\Pi_r^i/\Pi_d^i$	Retailer's/Manufacturer's profit, $i \in \{NS, S\}$ .		
$CS^i$	Consumer surplus, $i \in \{NS, S\}$ .		
Superscript *	The optimal value of each decision variable.		
Decision variables			
$p_r, p_r^i$	Retail price at the retail store channel, $i \in \{NS, S\}$ .		
$p_d, p_d^i$	Retail price at the manufacturer's online channel, $i \in \{NS, S\}$ .		
8	Sales effort level provided by the retailer.		
$w, w^i$	Manufacturer's wholesale price to retailer, $i \in \{NS, S\}$ .		

For resource management and recycling responsibility, the manufacturer is requested to collect the used products from consumers or pay a fee for disposing the produced products with the cost of  $\frac{\beta}{2}(q_r+q_d)^2$ , where  $\beta$  denotes a positive constant, and  $q_r, q_d$  denote the sold quantity through the retail and online channel, respectively. This cost feature can be referred to the closed-loop supply chain literature (Ferguson and Toktay [14], Ovchinnkov [23], Atasu and Souza [2]). It means that product lifecycle oriented environmental management requires additional disposing cost which is an increasing and convex function of total quantities.

2.1. **Demand functions.** We start with the consumer's demand function in different channels. The consumer's consumption value  $\theta$  is uniformly distributed in [0, 1], while the retailer incurs a sales effort s to increase the consumption value. Since the product is sold through an online direct channel at price  $p_d$  and through a retail store channel at price  $p_r$ , the consumer utility through the retail store channel is  $u_r = \theta - p_r + as$ . The consumption value of consumers, if the products are purchased through an online channel, would be less than  $\theta$  which is empirically showed for most products in [17]. We capture the decrease in value of the parameter  $\delta$  and the consumer utility through online direct channel is  $u_d = \delta\theta - p_d$ .

The consumer's decision about which channel to choose revolves around the comparison of consumer utility on each channel. In other words, they make decisions according to  $max\{u_d, u_r, 0\}$ . If (i)  $u_r \ge max\{u_d, 0\}$ , the consumer buys the product from the store when  $\theta \in (\frac{p_r - p_d - as}{1 - \delta}, 1]$ ; (ii)  $u_d \ge max\{u_r, 0\}$ , the consumer buys the product online when  $\theta \in [\frac{p_d}{\delta}, \frac{p_r - p_d - as}{1 - \delta}]$ ; (iii)  $u_r, u_d \le 0$ , the consumer buys nothing from both channels when  $\theta \in [0, \frac{p_d}{\delta})$ . Therefore, the demand function becomes

$$(q_r, q_d) = \begin{cases} (1 - p_r + as, 0), & \text{if } p_r \leq \frac{p_d + \delta as}{\delta}; \\ (1 - \frac{p_r - p_d - as}{1 - \delta}, \frac{\delta p_r - p_d - \delta as}{\delta(1 - \delta)}), & \text{if } \frac{p_d + \delta as}{\delta} < p_r < p_d + as + (1 - \delta); \\ (0, 1 - \frac{p_d}{\delta}), & \text{if } p_r \geq p_d + as + (1 - \delta). \end{cases}$$
(1)

From above demand function, we find that when  $p_r \leq \frac{p_d + \delta as}{\delta}$  and  $p_r \geq p_d + as + (1 - \delta)$ , all consumers only purchase from one of the traditional channel and direct channel. That is, the manufacturer would not like to open a direct channel if  $p_r \leq \frac{p_d + \delta as}{\delta}$ , and the retailer would not like to open traditional channel if  $p_r \geq \frac{p_d + \delta as}{\delta}$ .

 $p_d + as + (1 - \delta)$ . Therefore, in this paper, we only focus on the analysis of dualchannel co-exist supply chain when  $\frac{p_d + \delta as}{\delta} < p_r < p_d + as + (1 - \delta)$ . To rule out the trivial cases of single-channel, we assume  $\delta < 1 - c$  and  $\beta < \frac{a^2 \delta - 2c \delta \lambda}{c \lambda + \delta \lambda - \lambda}$  so as to guarantee that the demand of both store channel and direct channel are greater than zero. Since the manufacturer owns more channel power, we also assume that the manufacturer is the leader and the retailer is the follower.

2.2. Model with no retailer's sales effort. We then consider the case of a dualchannel supply chain model without retailer's sales effort. Thus, the consumer's demands from the different channels are degenerated as  $q_r^{NS} = 1 - \frac{p_r^{NS} - p_d^{NS}}{1 - \delta}$  and  $q_d^{NS} = \frac{\delta p_r^{NS} - p_d^{NS}}{\delta(1 - \delta)}$ , respectively.

As a Stackelberg leader in our model, the manufacturer determines the wholesale price  $w^{NS}$  and his direct channel price  $p_d^{NS}$ , while the retailer reacts by determining the retail price  $p_r^{NS}$ . Therefore, for any given  $w^{NS}$  and  $p_d^{NS}$ , the retailer makes decision to maximize his profit

$$\max_{p_r^{NS}} \Pi_r^{NS} = (p_r^{NS} - w^{NS} - c)q_r^{NS}$$
(2)

and the manufacturer's decision is based on

$$\max_{p_d^{NS}, w^{NS}} \Pi_d^{NS} = w^{NS} q_r^{NS} + p_d^{NS} q_d^{NS} - \frac{\beta}{2} (q_d^{NS} + q_r^{NS})^2$$
(3)

The following proposition characterizes the retailer and the manufacturer's decisions with respect to the setting in which the retailer does not exercise sales effort.

**Proposition 1.** For the dual-channel supply chain model without retailer's sales effort, we have (i) the retailer's profit function  $\Pi_r^{NS}$  is strictly concave in  $p_r^{NS}$ ; (ii) the manufacturer's profit function  $\Pi_d^{NS}$  is concave in  $p_d^{NS}$  and  $w^{NS}$ ; (iii) there exist optimal decisions as follows:  $p_d^{NS*} = \frac{\delta(\beta+\delta)}{\beta+2\delta}$ ,  $w^{NS*} = \frac{\delta(\beta+\delta)}{\beta+2\delta}$  and  $p_r^{NS*} = \frac{(\beta+2\delta)(1+c)+\beta\delta}{2(\beta+2\delta)}$ .

Proof. See Appendix.

Proposition 1 shows that both the retailer and manufacturer have a unique optimal decision to maximize their profits, and also implies that each member has the optimal strategy in response to the decision of the other member in competition. We also obtain the optimal prices and profits of members by substituting the values of  $p_r^{NS*}, p_d^{NS*}$  and  $w^{NS*}$  into responding equations, and the optimal results are given as  $q_r^{NS*} = \frac{1-c-\delta}{2(1-\delta)}, \ q_d^{NS*} = \frac{2c\delta-\beta(1-c-\delta)}{2(1-\delta)(\beta+2\delta)}, \ \Pi_r^{NS*} = \frac{(1-c-\delta)^2}{4(1-\delta)} \ \text{and} \ \Pi_d^{NS*} = \frac{\delta^2}{2(\beta+2\delta)}.$ 

2.3. Model with retailer's sales effort. In this subsection, we consider the dualchannel supply chain with retailer's sales effort, and focus on how the retailer's sales effort and manufacturer's incentive influence the dual-channel supply chain decision making. Since the retailer conducts sales effort and the manufacturer shares a portion of the cost, the retailer's profit function is reformulated as

$$\max_{p_r^S,s} \ \Pi_r^S = (p_r^S - w^S - c)q_r^S - \frac{\lambda}{2}s^2$$
(4)

and the manufacturer's profit function is

$$\max_{p_d^S, w^S} \Pi_d^S = w^S q_r^S + p_d^S q_d^S - \frac{\beta}{2} (q_r^S + q_d^S)^2 - \frac{1 - \lambda}{2} s^2.$$
(5)

The following proposition characterizes the retailer and the manufacturer's decisions with respect to the setting in which the retailer exercises sales effort.

**Proposition 2.** For the dual-channel supply chain with retailer's sales effort, we have (i) the retailer's profit is concave in  $p_r^S$  and s; (ii) the manufacturer's profit is concave in  $p_d^S$  and  $w^S$ ; and (iii)  $p_d^{S*} = \frac{\delta(\beta+\delta)}{\beta+2\delta}$ ,  $w^{S*} = \frac{\delta(\beta+\delta)}{\beta+2\delta}$ ,  $s^* = \frac{a(1-c-\delta)}{2\lambda(1-\delta)-a^2}$  and  $p_r^{S*} = \frac{a^2[\delta(\beta+\delta)+c(\beta+2\delta)]+\lambda(\delta-1)[(c+1)(\beta+2\delta)+\delta\beta]}{(\beta+2\delta)[a^2+2\lambda(\delta-1)]}$ , respectively.

*Proof.* See Appendix.

Proposition 2 shows that the members have optimal choices to maximize their profits, and also implies that each member has the optimal strategies in response to the other member's decision. We further have  $q_r^{S*} = \frac{\lambda(1-c-\delta)}{2\lambda(1-\delta)-a^2}, q_d^{S*} = \frac{\lambda[\beta(1-c-\delta)-2c\delta]-a^2\delta}{(\beta+2\delta)[2\lambda(1-\delta)-a^2]},$   $\Pi_r^{S*} = \frac{\lambda(1-c-\delta)^2}{2[2\lambda(1-\delta)-a^2]} \text{ and } \Pi_d^{S*} = \frac{\delta^2[2\lambda(1-\delta)-a^2]^2+a^2(\beta+2\delta)(\lambda-1)(1-c-\delta)^2}{2(\beta+2\delta)[2\lambda(1-\delta)-a^2]^2}.$ Combining with Propositions 1 and 2, we derive the equilibrium decisions of

decentralized strategy, as shown in Table 2.

Variables	i = NS	i = S
$p_r^i$	$\frac{(\beta+2\delta)(1+c)+\beta\delta}{2(\beta+2\delta)}$	$\frac{\lambda(1-\delta)[(\beta+2\delta)(c+1)+\delta\beta]-a^2[\delta(\beta+\delta)+c(\beta+2\delta)]}{(\beta+2\delta)[2\lambda(1-\delta)-a^2]}$
$p_d^i$	$\frac{\delta(\beta+\delta)}{\beta+2\delta}$	$rac{\delta(eta+\delta)}{eta+2\delta}$
$w^i$	$rac{\delta(eta+\delta)}{eta+2\delta}$	$rac{\delta(eta+\delta)}{eta+2\delta}$
$s_i$	N/A	$rac{a(1-c-\delta)}{2\lambda(1-\delta)-a^2}$
$q_r^i$	$\frac{1-c-\delta}{2(1-\delta)}$	$rac{\lambda(1-c-\delta)}{2\lambda(1-\delta)-a^2}$
$q_d^i$	$\frac{2c\delta - \beta(1-c-\delta)}{2(1-\delta)(\beta+2\delta)}$	$\frac{\lambda[2c\delta - \beta(1-c-\delta)] - a^2\delta}{(\beta+2\delta)[2\lambda(1-\delta) - a^2]}$
$\Pi^i_r$	$\frac{(1-c-\delta)^2}{4(1-\delta)}$	$rac{\lambda(1-c-\delta)^2}{2[2\lambda(1-\delta)-a^2]}$
$\Pi_d^i$	$\frac{\delta^2}{2(\beta+2\delta)}$	$\frac{\delta^2 [2\dot{\lambda}(1-\dot{\delta}) - a^2]^2 + a^2(\beta + 2\delta)(\lambda - 1)(1 - c - \delta)^2}{2(\beta + 2\delta)[2\lambda(1 - \delta) - a^2]^2}$
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TABLE 2. Equilibrium decisions under different strategies.

NS=No sales effort. S=Sales effort

3. Comparative analysis. In order to obtain managerial insights of the optimal results derived in previous section, we will compare the optimal decisions and profits of decentralized strategy between two cases. Based on the equilibrium values of the considered problem, we have the following propositions to make the effect of sales effort, the manufacture's cost sharing and the resource-utilization penalty on optimal decisions be well understood.

**Proposition 3.** For the retailer, we have  $p_r^{S*} > p_r^{NS*}, q_r^{S*} > q_r^{NS*}$  and  $\Pi_r^{S*} >$  $\Pi_r^{N\bar{S*}}$ .

*Proof.* See Appendix.

In a dual-channel supply chain competitive environment, the retailer's sales effort can increase his selling price, sale volume and profit comparing to the case without sales effort. The reason is that sales effort can make consumers raise the perception of the product and increase their utility thereby stimulating more buying. Therefore, the retailer is apt to exercise sales effort in a fiercely competitive environment.

**Proposition 4.** For the manufacturer, we have  $p_d^{NS*} = p_d^{S*}, q_d^{NS*} > q_d^{S*}$  and  $\Pi_d^{NS*} < \Pi_d^{S*}$ .

Proof. See Appendix.

Proposition 4 means that the manufacturer always benefits from retailer's sales effort by sharing a portion of the sales effort cost. The retailer's sales effort increases the direct sale volume and manufacturer's profit even if the price on the manufacturer's direct channel does not depend the sales effort. Therefore, the manufacturer can encourage the retailer to make sales effort by sharing a portion of cost so as to increase his profit.

**Proposition 5.** In the dual-channel supply chain model with retailer's sales effort, we have (i)  $s^*, p_r^{S*}, q_r^{S*}$  and  $\Pi_r^{S*}$  increase in a; (ii)  $\Pi_d^{S*}$  and  $q_d^{S*}$  decrease in a, while  $p_d^{S*}$  and  $w^{S*}$  are independent on a.

## Proof. See Appendix.

Market response to retailer's sales effort (a) always has positive influence on the retailer's selling price, sales effort level, sales volume and profit. However, it has negative effect on the manufacturer's sale volume and profit, and has no effect on direct selling price and wholesale price. Therefore, when a is high, the retailer tends to adopt sales effort policy, while the manufacturer tends not to participate if he may suffer a profit loss.

**Proposition 6.** In the dual-channel supply chain model with retailer's sales effort,  $p_r^{S*}, s^*$  and  $\Pi_r^{S*}$  decrease in  $\lambda$ , and  $\Pi_d^{S*}$  increases in  $\lambda$ , while  $p_d^{S*}$  and  $w^{S*}$  are independent on  $\lambda$ .

Proof. See Appendix.

Proposition 6 means the increase in manufacturer's cost-sharing proportion of sales effort can stimulate retailer to adopt a higher sales effort level although it may reduce the manufacturer's profit, in addition, direct selling price and wholesale price are not affected by cost-sharing proportion.

**Proposition 7.** For both models, we have (i)  $p_r^{S*}/p_r^{NS*}, p_d^{S*}/p_d^{NS*}$  and  $w^{S*}/w^{NS*}$  increase in  $\beta$ ,  $\Pi_d^{S*}/\Pi_d^{NS*}$  decreases in  $\beta$ , while  $s^*, \Pi_r^{S*}/\Pi_r^{NS*}$  do not depend on  $\beta$ ; (ii) Consumer surplus is a decreasing and convex function of  $\beta$ .

*Proof.* See Appendix.

Proposition 7 implies the impact of the resource-utilization penalty on the price, quantity, profit and consumer surplus are the same for both models with and without retailer's sales effort. The greater the resource utilization penalty is, the lower the manufacturer's profit is, and the higher the wholesale price and the selling price of each channel are. In addition, the retailer's profit and the sales effort level are not affected by the resource-utilization penalty. However, the increase in selling prices can be interpreted as a negative impact of resource-utilization penalty on consumers, although the resource-utilization penalty is beneficial for the environment, it is disadvantageous for consumers due to the reduction of total consumer surplus.

4. Numerical experiments. In this section, we will examine the impact of the coefficients  $\lambda$ , a,  $\delta$  and  $\beta$  on the optimal performance. The standard setting for the parameters in the numerical experiment is given in Figure 1-4. Since the demand of each channel must be nonnegative, parameters need to satisfy  $\delta < 1 - c$  and  $\beta < \frac{a^2\delta - 2c\delta\lambda}{c\lambda + \delta\lambda - \lambda}$ . The sensitivity analysis is processed under the condition that one parameter varies from its standard setting to reveal its impact on the profit while other parameters keep to be fixed, and then several managerial insights are proposed.



FIGURE 1. Variation of profits with the change of  $\delta$  for  $c=0.20, \lambda=0.75, \beta=0.15, a=0.35$ 



FIGURE 2. Variation of profits with the change of a for  $c = 0.25, \lambda = 0.75, \beta = 0.08, \delta = 0.50$ 

Figure 1 shows that both the retailer and the manufacturer benefit from retailer's sales effort policy and the manufacturer can obtain more profit than the retailer when  $\delta$  is relatively large. The manufacturer's profit increases in  $\delta$ , while the retailer's profit decreases in a dual-channel supply chain with/without retailer's sales effort. The increasing of  $\delta$  means that the direct channel has more and more attraction for consumers. From Figure 1, we find that if  $\delta < 0.4719$ , the retailer obtains more profit than that of the manufacturer in a dual-channel supply chain without retailer's sales effort, and if  $\delta < 0.3938$ , the retailer obtains more profit than that of the manufacturer in a dual-channel supply chain with retailer's sales effort. In addition, we find that the profit gap between manufacturer and retailer increases as  $\delta$  increases due to consumers' inclination to buy online. As shown in Figure 2, the profit of the retailer increases in a, while the manufacturer's profit decreases in a, and his profit is greater than that of the model without retailer's sales effort when a is relatively small. The retailer benefits from the retailer's sales effort policy, while the manufacturer only benefits from the retailer's sales effort if a < 0.4877, the manufacturer thereby encourage the retailer to exercise sales effort. If a > 0.4877, the manufacturer obtains less profit in the model with retailer's sales effort than that of the model without retailer's sales effort, the manufacturer may not encourage the retailer to exercise sales effort. If a > 0.5189, the retailer's profit exceeds manufacturer's profit, the reason is when the efficiency of sales effort is too high, the store channel will attract more consumers to buy and the manufacturer will suffer a great profit loss.



FIGURE 3. Variation of profits with the change of  $\lambda$  for  $c=0.15,\beta=0.20,\delta=0.55,a=0.35$ 



FIGURE 4. Variation of profits with the change of  $\beta$  for  $c=0.25, \lambda=0.70, \delta=0.55, a=0.30$ 

Figure 3 shows that the retailer's profit decreases in  $\lambda$  and the manufacturer's profit increases in  $\lambda$ , and manufacturer's profit is more sensitive to changes in  $\lambda$ . We find that when the retailer adopts sales effort policy and the manufacturer shares a portion of sales effort cost, their profits are higher than that of the model without sales effort. Because the manufacturer also benefits from retailers' sales effort policy, he has the incentive to encourage the retailer to adopt sales effort policy by sharing the cost incurred.

Figure 4 shows that if the resource-utilization penalty coefficient  $\beta$  increases, the manufacturer's profit decreases in dual-channel supply chain model with/without retailer's sales effort, while the retailer's profit does not depend on the change of  $\beta$ . We find that the retailer's sales effort brings the manufacturer more profit than the case of without sales effort, and the manufacturer's profit decline slows down as  $\beta$  becomes larger.

5. Concluding remarks. For environmental protection, manufacturers have to face a resource-utilization penalty. In this paper, we propose a dual-channel supply chain model with a retailer's sales effort and a manufacturer's sharing cost of sales effort under the resource-utilized penalty. As a comparison, we also present a baseline model without retailer's sales effort under the resource-utilized penalty. Closed-form optimal solutions are derived for both models, by analyzing and comparing the solutions, we examine the impact of sales effort and sharing cost on decision-making, and find that adopting sales effort policy can efficiently improve members' profits and retail price, while the sales effort has no influence on direct selling price and wholesale price.

Furthermore, we conduct sensitivity analysis of the important parameters such as market response (a), retailer's cost-sharing proportion for sales effort ( $\lambda$ ), consumer's preference to select direct channel ( $\delta$ ) and resource-utilized penalty ( $\beta$ ). The analysis shows that i) the sales effort level increases in a and decreases in  $\lambda$ ; ii) the retailer's retailing price and profit increase in a and decrease in  $\lambda$ , respectively, and the retailer's profit is not affected by  $\beta$ , while the manufacturer's profit decreases in a as well as  $\beta$  and increases in  $\lambda$ , in addition, the direct selling price and wholesale price do not depend on a as well as  $\lambda$ ; iii) the retailer's retailing price increases in  $\beta$ , but his profit does not depend on  $\beta$ , while the direct selling price and the wholesale price increase in  $\beta$ , respectively. Through a number of numerical experiments, we find that (i) the manufacturer obtains more profit in the model with retailer's sales effort than that of the model without retailer's sales effort if adoes not exceed a threshold, which drives the manufacturer to encourage the retailer to exercise sales effort; (ii) the retailer obtains less profit than that of the manufacturer in a dual-channel supply chain without/without retailer's sales effort when  $\delta$  is relatively large, and the profit gap between manufacturer and retailer increases as  $\delta$  increases due to consumers' inclination to buy online. Our analysis and findings provide some economic and managerial insights for supply chain members and policy makers.

This study can be extended in several ways. First, the model studied in this paper can be extended to one with multiple manufacturers and retailers. Second, this study focuses on the case of deterministic demand, a future study can examine uncertain demands in a dual-channel supply chain.

Acknowledgments. The authors would like to thank the Editor, Associate Editor and anonymous referees for their most valuable critiques and suggestions.

# Appendix.

**Proof of Proposition 1.** (i) Since the second derivative of  $\Pi_r^{NS}$  with respect to  $p_r^{NS}$  is  $\frac{\partial^2 \Pi_r^{NS}}{\partial p_r^{NS^2}} = -\frac{2}{1-\delta} < 0$ ,  $\Pi_r^{NS}$  is concave in  $p_r^{NS}$ .

(ii) From (2), we have  $p_r^{NS} = \frac{1}{2}(c - \delta + p_d + w + 1)$  and substituting it into (3). Taking the second-order partial derivatives of  $\Pi_d^{NS}$  with respect to  $p_d^{NS}$  and  $w^{NS}$ , we have

$$\frac{\partial^2 \Pi_d^{NS}}{\partial p_d^{NS^2}} = -\frac{(\beta + \delta)(1 - \delta) + \delta}{(1 - \delta)\delta^2}, \ \frac{\partial^2 \Pi_d^{NS}}{\partial w^{NS^2}} = -\frac{1}{1 - \delta}$$

and

$$\frac{\partial^2 \Pi_d^{NS}}{\partial p_d^{NS} \partial w^{NS}} = \frac{\partial^2 \Pi_d^{NS}}{\partial w^{NS} \partial p_d^{NS}} = \frac{1}{1-\delta}.$$

The Hessian matrix of  $\Pi_d^{NS}$  is

$$H_d^{NS} = \begin{bmatrix} -\frac{(\beta+\delta)(1-\delta)+\delta}{(1-\delta)\delta^2} & \frac{1}{1-\delta} \\ \frac{1}{1-\delta} & -\frac{1}{1-\delta} \end{bmatrix}.$$

It is clear that  $H_d^{NS}$  is negative definite, and hence  $\Pi_d^{NS}$  is jointly concave with respect to  $p_d^{NS}$  and  $w^{NS}$ .

(iii) In the Stackelberg game, the retailer responds to the manufacturer's strategy by solving the reaction function of the retailer. From (2), we have

$$\frac{\partial \Pi_r^{NS}}{\partial p_r^{NS}} = \frac{1 - \delta + c + p_d^{NS} - 2p_r^{NS} + w^{NS}}{1 - \delta} = 0$$
(6)

then, the retailer's best response is

$$p_r^{NS} = \frac{1}{2}(1 - \delta + c + p_d^{NS} + w^{NS}).$$
(7)

Substituting (7) into (3), then by the differential of  $\Pi_d^{NS}$  on  $p_d^{NS}$  and  $w^{NS}$ , respectively, and letting  $\frac{\partial \Pi_d^{NS}}{\partial p_d^{NS}} = 0$  and  $\frac{\partial \Pi_d^{NS}}{\partial w^{NS}} = 0$ , we have  $p_d^{NS} = \frac{\delta(\beta+\delta)}{\beta+2\delta}$  and  $w^{NS} = \frac{(1-c)(\beta+2\delta)+\delta\beta}{2(\beta+2\delta)}$ .

By using the assumption  $\delta < 1 - c$ , we have  $p_d^{NS} - w^{NS} = \frac{\delta + c - 1}{2} < 0$ , which conflicts to the constraint  $p_d^{NS} \ge w^{NS}$ . Therefore, we obtain the optimal direct selling price and the optimal wholesale price as

$$p_d^{NS*} = w^{NS*} = \frac{\delta(\beta + \delta)}{\beta + 2\delta} \tag{8}$$

Substituting  $p_d^{NS*}$  and  $w^{NS*}$  into (7), we have the optimal retailer's retailing price  $p_r^{NS*} = \frac{(\beta+2\delta)(1+c)+\beta\delta}{2(\beta+2\delta)}$ . From the assumptions  $\delta < 1-c$  and  $\beta < \frac{a^2\delta-2c\delta\lambda}{c\lambda+\delta\lambda-\lambda}$ , we have  $\frac{\beta(1-c)}{\beta+2c} < \delta$ , then  $\delta p_r^{NS*} - p_d^{NS*} = \frac{2c\delta-\beta(1-c-\delta)}{2(\beta+2\delta)} > 0$  and  $1-\delta + p_d^{NS*} - p_r^{NS*} = \frac{1-c-\delta}{2} > 0$  which guarantee that the demand of direct channel and store channel are positive.

**Proof of Proposition 2.** (i) Taking the second-order partial derivatives of  $\Pi_r^S$  with respect to  $p_r^S$  and s, we have

$$\frac{\partial^2 \Pi_r^S}{\partial p_r^{S^2}} = -\frac{2}{1-\delta}, \ \frac{\partial^2 \Pi_r^S}{\partial s^2} = -\lambda,$$

$$\frac{\partial^2 \Pi_r^S}{\partial p_r^S \partial s} = \frac{\partial^2 \Pi_r^S}{\partial p_r^S \partial s} = \frac{a}{1-\delta}$$

The Hessian matrix of  $\Pi_r^S$  becomes

$$H_r^S = \begin{bmatrix} -\frac{2}{1-\delta} & \frac{a}{1-\delta} \\ \frac{a}{1-\delta} & -\lambda \end{bmatrix}.$$

From assumptions  $\delta < 1 - c$  and  $\beta < \frac{a^2 \delta - 2c \delta \lambda}{c \lambda + \delta \lambda - \lambda}$ , we can deduce  $a^2 - 2\lambda c < 0$ , then we have that  $H_r^S$  is negative definite. Thus  $\Pi_r^S$  is concave in  $p_r^S$  and s.

(ii) From (4), we get the retailer's best response function to manufacturer's decision,  $s = \frac{a(1-c-\delta+p_d^S-w^S)}{2\lambda(1-\delta)-a^2}$  and  $p_r^S = \frac{\lambda(1-\delta)(1-\delta+p_d^S+w^S+c)-a^2(c+w^S)}{2\lambda(1-\delta)-a^2}$ . Substituting them into (5) and taking the second-order partial derivatives of  $\Pi_d^S$  with respect to  $p_d^S$  and  $w^S$ , we have

$$\frac{\partial^2 \Pi_d^S}{\partial p_d^{S^2}} = -\frac{(\beta + 2\delta)[2\lambda(1-\delta) - a^2]^2 + \delta^2[a^2(1-3\lambda) - 4\lambda^2(\delta-1)]}{\delta^2[2\lambda(1-\delta) - a^2]^2}$$

$$\frac{\partial^2 \Pi_d^S}{\partial p_d^S \partial w^S} = \frac{a^2(1-3\lambda) - 4\lambda^2(\delta-1)}{[2\lambda(1-\delta) - a^2]^2}$$

and

$$\frac{\partial^2 \Pi_d^S}{\partial w^{S^2}} = \frac{a^2(3\lambda - 1) + 4\lambda^2(\delta - 1)}{[2\lambda(1 - \delta) - a^2]^2}$$

The Hessian matrix of  $\Pi_d^S$  is

$$H_d^S = \begin{bmatrix} -\frac{(\beta+2\delta)[2\lambda(1-\delta)-a^2]^2 + \delta^2[a^2(1-3\lambda)-4^2\lambda^2(\delta-1)]}{\delta^2[2\lambda(1-\delta)-a^2]^2} & \frac{a^2(1-3\lambda)-4\lambda^2(\delta-1)}{[2\lambda(1-\delta)-a^2]^2} \\ \frac{a^2(1-3\lambda)-4\lambda^2(\delta-1)}{[2\lambda(1-\delta)-a^2]^2} & \frac{a^2(3\lambda-1)+4\lambda^2(\delta-1)}{[2\lambda(1-\delta)-a^2]^2} \end{bmatrix}$$

From assumption  $\delta < 1 - c$  and  $\beta < \frac{a^2 \delta - 2c \delta \lambda}{c\lambda + \delta \lambda - \lambda}$ , we have  $a^2(3\lambda - 1) + 4\lambda^2(\delta - 1) < 0$ . Thus,  $\frac{\partial^2 \Pi_d^S}{\partial w^{S^2}} = \frac{a^2(3\lambda - 1) + 4\lambda^2(\delta - 1)}{[2\lambda(1 - \delta) - a^2]^2} < 0$  and  $Det(H_d^S) = -\frac{(\beta + 2\delta)[a^2(3\lambda - 1) + 4\lambda^2(\delta - 1)]}{\delta^2[2\lambda(1 - \delta) - a^2]^2} > 0$ , which means that  $H_d^S$  is negative definite and  $\Pi_d^S$  is concave in  $p_d^S$  and  $w^S$ .

(iii) Since the manufacturer is the leader, from (5), the retailer's best response function to manufacturer's decision is given by

$$\frac{\partial \Pi_r^S}{\partial p_r^S} = \frac{as + p_d^S - 2p_r^S + w^S + c + (1 - \delta)}{1 - \delta} = 0$$
(9)

$$\frac{\partial \Pi_r^S}{\partial s} = \frac{a(p_r^S - w^S - c) - s\lambda(1 - \delta)}{1 - \delta} = 0 \tag{10}$$

Consequently, the optimal response price and sales effort of the retailer is

$$p_r^S = \frac{(w^S + c)[(1 - \delta)\lambda - a^2] + \lambda(1 - \delta)(1 - \delta + p_d^S)}{2\lambda(1 - \delta) - a^2},$$
(11)

$$s = \frac{a(1 - c - \delta + p_d^S - w^S)}{2\lambda(1 - \delta) - a^2}.$$
(12)

Substituting the retailer's response function into (5), then by the differential of  $\Pi_d^S$  on  $p_d^S$  and  $w^S$ , respectively, and letting  $\frac{\partial \Pi_d^S}{\partial p_d^S} = 0$  and  $\frac{\partial \Pi_d^S}{\partial w^{NS}} = 0$ , we have

$$\begin{split} p_d^S &= \frac{\delta(\beta+\delta)}{\beta+2\delta}, \\ w^S \\ &= \frac{a^2\delta^2(1-\lambda)+\lambda\beta\delta[a^2+2\lambda(\delta-1)]+(\beta+2\delta)(1-c)[a^2(2\lambda-1)+2\lambda^2(\delta-1)]}{(\beta+2\delta)[a^2(3\lambda-1)+4\lambda^2(\delta-1)]}. \end{split}$$

From the assumption  $\delta < 1-c$  and  $\beta < \frac{a^2\delta - 2c\delta\lambda}{c\lambda + \delta\lambda - \lambda}$ , we have  $a^2(2\lambda - 1) + 2\lambda^2(\delta - 1) < 0$  and  $a^2(3\lambda - 1) + 4\lambda^2(\delta - 1) < 0$ , then  $p_d^S - w^S = \frac{(c+\delta-1)[a^2(2\lambda - 1) + 2\lambda^2(\delta - 1)]}{a^2(3\lambda - 1) + 4\lambda^2(\delta - 1)} \leq 0$ , which conflicts to the constraint  $p_d^S \geq w^S$ . Therefore, we obtain the optimal wholesale price and direct selling price as

$$w^{S*} = p_d^{S*} = \frac{\delta(\beta + \delta)}{\beta + 2\delta}.$$
(13)

Substituting  $w^{S*}$  and  $p_d^{S*}$  into (11) and (12), we have the optimal retailer's selling price and sales effort

$$p_r^{S*} = \frac{\lambda(1-\delta)[(c+1)(\beta+2\delta)+\delta\beta] - a^2[\delta(\beta+\delta) + c(\beta+2\delta)]}{(\beta+2\delta)[2\lambda(1-\delta) - a^2]},$$
$$s^* = \frac{a(1-c-\delta)}{2\lambda(1-\delta) - a^2}.$$

From the assumptions  $\delta < 1-c$  and  $\beta < \frac{a^2\delta - 2c\delta\lambda}{c\lambda + \delta\lambda - \lambda}$ , we easily find  $\operatorname{that} p_r^{S*} - \frac{p_d^{S*} + \delta as^*}{\delta} = \frac{(1-\delta)[\lambda(2c\delta - \beta(1-c-\delta)) - a^2\delta]}{(\beta + 2\delta)[2\lambda(1-\delta) - a^2]} \ge 0$  and  $(1-\delta) + as^* + p_d^{S*} - p_r^{S*} = \frac{\lambda(1-\delta)(1-c-\delta)}{2\lambda(1-\delta) - a^2} \ge 0$ , which guarantee that the demand of direct channel and store channel are positive.  $\Box$ 

**Proof of Proposition 3.** From the assumptions  $\delta < 1 - c$  and  $\beta < \frac{a^2 \delta - 2c \delta \lambda}{c \lambda + \delta \lambda - \lambda}$ , we have  $a^2 + 2\lambda(\delta - 1) < 0$ . By using Propositions 1 and 2, we get

$$\begin{split} p_r^{NS*} - p_r^{S*} &= -\frac{a^2(1-c-\delta)}{2[2\lambda(1-\delta)-a^2]} < 0, \\ q_r^{NS*} - q_r^{S*} &= -\frac{a^2(1-c-\delta)}{2(1-\delta)[2\lambda(1-\delta)-a^2]} < 0. \end{split}$$

and

$$\begin{split} \Pi_r^{NS*} - \Pi_r^{S*} &= -\frac{a^2(1-c-\delta)^2}{4(1-\delta)[2\lambda(1-\delta)-a^2]} < 0. \end{split}$$
 Thus,  $p_r^{NS*} < p_r^{S*}, q_r^{NS*} < q_r^{S*}$  and  $\Pi_r^{NS*} < \Pi_r^{S*}$ .

**Proof of Proposition 4.** From the assumptions  $\delta < 1 - c$  and  $\beta < \frac{a^2 \delta - 2c \delta \lambda}{c \lambda + \delta \lambda - \lambda}$ , we obtain that

$$\begin{split} p_d^{NS*} - p_d^{S*} &= \frac{\delta(\beta+\delta)}{\beta+2\delta} - \frac{\delta(\beta+\delta)}{\beta+2\delta} = 0, \\ q_d^{NS*} - q_d^{S*} &= \frac{2\beta\lambda(\delta-1)^2 + a^2(\beta+2\delta)(1-c-\delta)}{2(1-\delta)(\beta+2\delta)[2\lambda(1-\delta)-a^2]} > 0, \end{split}$$

and

$$\Pi_d^{NS*} - \Pi_d^{S*} = -\frac{a^2(1-\lambda)(1-c-\delta)^2}{2[2\lambda(1-\delta)-a^2]^2} < 0.$$
  
Thus,  $p_d^{NS*} = p_d^{S*}, q_d^{NS*} > q_d^{S*}$  and  $\Pi_d^{NS*} < \Pi_d^{S*}$ .

**Proof of Proposition 5.** Taking the first partial derivatives of  $p_r^{S*}, q_r^{S*}, s^*$  and  $\Pi_r^{S*}$  with respect to a, and using the assumptions  $\delta < 1 - c$  and  $\beta < \frac{a^2 \delta - 2c \delta \lambda}{c \lambda + \delta \lambda - \lambda}$ , we have

$$\begin{split} \frac{\partial p_r^{S*}}{\partial a} &= \frac{2a\lambda(1-\delta)(1-c-\delta)}{[2\lambda(1-\delta)-a^2]^2} \ge 0,\\ \frac{\partial q_r^{S*}}{\partial a} &= \frac{2a\lambda(1-c-\delta)}{[2\lambda(1-\delta)-a^2]^2} \ge 0,\\ \frac{\partial s^*}{\partial a} &= \frac{(1-c-\delta)[2\lambda(1-\delta)+a^2]}{[2\lambda(1-\delta)-a^2]^2} \ge 0,\\ \frac{\partial \pi_r^{S*}}{\partial a} &= \frac{a\lambda(1-c-\delta)^2}{[2\lambda(1-\delta)-a^2]^2} \ge 0, \end{split}$$

which means that  $p_r^{S*},q_r^{S*},s^*$  and  $\Pi_r^{S*}$  increase in a. Similarly, for  $p_d^{S*},q_d^{S*}$  and  $\Pi_d^{S*}$ , we have

$$\begin{split} &\frac{\partial p_d^{S*}}{\partial a} = \frac{\partial w^{S*}}{\partial a} = 0,\\ &\frac{\partial q_d^{S*}}{\partial a} = \frac{2a\lambda(c+\delta-1)}{[2\lambda(1-\delta)-a^2]^2} \leq 0,\\ &\frac{\partial \pi_d^{S*}}{\partial a} = \frac{a(1-\lambda)(1-c-\delta)^2[2\lambda(1-\delta)-a^2]}{[2\lambda(1-\delta)-a^2]^3} \leq 0, \end{split}$$

which means that  $q_d^{S*}, \pi_d^{S*}$  are decrease in *a* while  $p_d^{S*}, w^{S*}$  are not affected by *a*.  $\Box$ 

**Proof of Proposition 6.** Taking the first partial derivatives of  $p_r^{S*}$  and  $w^{S*}, s^*$  with respect to  $\lambda$ , we have

$$\frac{\partial p_r^{S*}}{\partial \lambda} = -\frac{a^2(1-\delta)(1-c-\delta)}{[2\lambda(1-\delta)-a^2]^2}.$$

and

$$\frac{\partial s^*}{\partial \lambda} = -\frac{2a(1-\delta)(1-c-\delta)}{[2\lambda(1-\delta)-a^2]^2}$$

From the assumptions  $\delta < 1 - c$  and  $\beta < \frac{a^2 \delta - 2c \delta \lambda}{c \lambda + \delta \lambda - \lambda}$ , we have  $\frac{\partial p_r^{S*}}{\partial \lambda} < 0$  and  $\frac{\partial s^*}{\partial \lambda} < 0$ . For  $\Pi_r^{S*}$ , we have

$$\frac{\partial \Pi_r^{S*}}{\partial \lambda} = -\frac{a^2(1-c-\delta)^2}{2[2\lambda(1-\delta)-a^2]^2} < 0.$$

Therefore,  $p_r^{S*}, s^*$  and  $\Pi_r^{S*}$  decrease in  $\lambda$ . Similarly, for  $p_d^{S*}, w^{S*}, \Pi_d^{S*}$ , we have

$$\begin{split} &\frac{\partial p_d^{S*}}{\partial \lambda} = \frac{\partial w^{S*}}{\partial \lambda} = 0, \\ &\frac{\partial \Pi_d^{S*}}{\partial \lambda} = \frac{a^2 [a^2 + 2(2-\lambda)(\delta-1)](1-c-\delta)^2}{2[a^2 + 2\lambda(\delta-1)]^3} > 0 \end{split}$$

which means that  $p_d^{S*}, w^{S*}$  do not depend on  $\lambda$  and  $\Pi_d^{S*}$  increases in  $\lambda$ . 

**Proof of Proposition 7.** (i) Taking the first and second partial derivatives of  $p_r^{S*}/p_r^{NS*}$  with respect to  $\beta$ , we have

$$\frac{\partial p_r^{S*}}{\partial \beta} = \frac{\partial p_r^{NS*}}{\partial \beta} = \frac{\delta^2}{2(\beta + 2\delta)^2} > 0,$$
$$\frac{\partial^2 p_r^{S*}}{\partial \beta^2} = \frac{\partial^2 p_r^{NS*}}{\partial \beta^2} = -\frac{2\delta^2}{(\beta + 2\delta)^3} < 0.$$

For  $\Pi_r^{S*}/\Pi_r^{NS*}$  and  $s^*$ , we have

$$\begin{split} \frac{\partial \Pi_r^{S*}}{\partial \beta} &= \frac{\partial \Pi_r^{NS*}}{\partial \beta} = 0, \\ \frac{\partial s^*}{\partial \beta} &= 0. \end{split}$$

Therefore,  $p_r^{S*}/p_r^{NS*}$  is an increasing and concave function of  $\beta$ , and  $\Pi_r^{S*}/\Pi_r^{NS*}$ ,  $s^*$ do not depend on  $\beta$ . Similarly, for  $p_d^{S*}/p_d^{NS*}, w^{S*}/w^{NS*}, \Pi_d^{S*}/\Pi_d^{NS*}$ , we have

$$\begin{split} \frac{\partial p_d^{S*}}{\partial \beta} &= \frac{\partial p_d^{NS*}}{\partial \beta} = \frac{\partial w^{S*}}{\partial \beta} = \frac{\partial w^{NS*}}{\partial \beta} = \frac{\delta^2}{2(\beta + 2\delta)^2} > 0, \\ \frac{\partial^2 p_d^{S*}}{\partial \beta^2} &= \frac{\partial^2 p_d^{NS*}}{\partial \beta^2} = \frac{\partial^2 w^{S*}}{\partial \beta^2} = \frac{\partial^2 w^{NS*}}{\partial \beta^2} = -\frac{2\delta^2}{(\beta + 2\delta)^3} < 0, \\ \frac{\partial \Pi_d^{S*}}{\partial \beta} &= \frac{\partial \Pi_d^{NS*}}{\partial \beta} = -\frac{\delta^2}{2(\beta + 2\delta)^2} < 0, \\ \frac{\partial^2 \Pi_d^{S*}}{\partial \beta^2} &= \frac{\partial^2 \Pi_d^{NS*}}{\partial \beta^2} = \frac{\delta^2}{(\beta + 2\delta)^3} > 0. \end{split}$$

which means that  $p_d^{S*}/p_d^{NS*}, w^{S*}/w^{NS*}$  are increasing and concave functions of  $\beta$ , and  $\Pi_d^{S*}/\Pi_d^{NS*}$  is a decreasing and convex function of  $\beta$ . (ii)The consumer surplus  $CS^{S*}/CS^{NS*}$  is the surplus of consumers who buy on

both channels:

$$CS^{S*} = \int_{\frac{p_r^{S*} - p_d^{S*} - as^*}{1 - \delta}}^{1} (\theta - p_r^{S*} + as^*) d\theta + \int_{\frac{p_d^{S*}}{\delta}}^{\frac{p_r^{S*} - p_d^{S*} - as^*}{1 - \delta}} (\delta\theta - p_d^{S*}) d\theta$$

$$= \frac{1}{2(\beta + 2\delta)^2 (a^2 + 2(\delta - 1)\lambda)^2} [a^4 \delta^3 + 4a^2(\delta - 1)\delta^3 \lambda - (\delta - 1)\lambda^2 (\beta^2(c + \delta - 1)^2 + 4\beta\delta(c + \delta - 1)^2 + 4\delta^2 ((2c - 1)\delta + (c - 1)^2))]$$

$$CS^{NS*} = \int_{-1}^{1} (\theta - n^{NS*}) d\theta + \int_{-\frac{p_r^{S*} - p_d^{NS*}}{1 - \delta}}^{\frac{p_r^{S*} - p_d^{NS*}}{1 - \delta}} (\delta\theta - n^{NS*}) d\theta$$

$$CS^{NS*} = \int_{\frac{p_r^{NS*} - p_d^{NS*}}{1-\delta}} (\theta - p_r^{NS*}) d\theta + \int_{\frac{p_d^{NS*}}{\delta}} (\delta\theta - p_d^{NS*}) d\theta$$
$$= -\frac{4\delta^2 \left(c^2 + 2c(\delta - 1) - \delta + 1\right) + \beta^2 (c + \delta - 1)^2 + 4\beta\delta(c + \delta - 1)^2}{8(\delta - 1)(\beta + 2\delta)^2}.$$

Taking the first and second partial derivatives of  $CS^{S*}/CS^{NS*}$  with respect to  $\beta$ , respectively, we have

$$\frac{\partial CS^{S*}}{\partial \beta} = \frac{\partial CS^{NS*}}{\partial \beta} = -\frac{\delta^3}{(\beta + 2\delta)^3} < 0,$$

$$\frac{\partial^2 CS^{S*}}{\partial \beta^2} = \frac{\partial^2 CS^{NS*}}{\partial \beta^2} = \frac{3\delta^3}{(\beta + 2\delta)^4} > 0.$$

which means that  $CS^{S*}/CS^{NS*}$  is a decreasing and convex function of  $\beta$ .

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Received October 2019; revised February 2020.

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