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Enhancing Corporate Social Responsibility: Contract Design under Information Asymmetry

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Abstract

We consider a two-stage supply chain in which a contract manufacturer (CM) sells products through a brand name retailer. The contract manufacturer can invest in corporate social responsibility (CSR) activities to improve customer perception about the firm and increase demand, while the retailer can influence the demand by exerting marketing efforts. We design optimal contracts for such a supply chain, which faces information asymmetry. The wholesale price contract was developed as the base model to derive insight into the value of information sharing. We examine the impact of CSR cost on CSR commitment and profits. We find that CM's CSR cost impacts the manufacturer's and the retailer's profits differently. Under certain conditions, the CM's profit will increase with cost, while that of the retailer is uncertain. We also propose two-part tariff contracts for both the symmetric and asymmetric cases with the aim of maximizing the retailer's profit and improving CM's commitment to CSR. Finally, numerical experiments are conducted to illustrate and validate the proposed models and provide managerial insights.

Keywords: Supply chain management; CSR efforts; Marketing efforts; Asymmetric information; Game theory.

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1. Introduction

In this research, we focus on contract design under information asymmetry. This research was motivated by the need to enhance the corporate social responsibility (CSR) of a supply chain (SC). We investigate a brand-name firm that offers high-tech products (smartphones and computers) to consumers. Its supplier is a large manufacturer of computer, communication and consumer electronics. The firm believes that it can boost demand by engaging in advertising campaigns and enhancing its brand reputation through commitment to CSR. This is the case observed in the relationship between Apple Inc. and Foxconn, which is Apple's contract manufacturer (CM) in China. Foxconn is the world's largest electronics contract manufacturer. Tragedies occurred at Foxconn's Chinese facilities, where 18 employees of various plants attempted to take their own lives in 2010. Most of the workers committed suicide because they were unable to bear the stress, alienation and humiliation they experienced daily. These tragic events indicated that Foxconn had not met its social responsibility. Suicides among Foxconn workers have attracted much media attention. In 2012, Terry Gou, founder and chairman of Foxconn, announced that Foxconn and Apple would jointly share the cost of improving working conditions in Chinese factories. This research aims to design contracts by considering CSR efforts in a two-stage supply chain with one dominant retailer (Apple) and the contract manufacturer (Foxconn). Our models can be generalized to similar business settings.

Other examples of CSR can be found in Whole Foods Market and JiaDuoBao

Group. Whole Foods Market (WFM) is the world's largest retail chain of natural and organic foods. With a strong brand image and growing market presence, WFM operates more than 400 stores in the US, Canada and the U.K. WFM decides on its CSR activity with input from stakeholders (employees, investors, customers, suppliers and communities) [1]. It raises the bar in CSR by asking suppliers and manufacturers to grow green, taking a stand on GMOs, upcycling, exploring energy savings, investing in suppliers, encouraging diversity, urging transparency, caring for employees, supporting local communities, and giving back to the global community [2]. It has enjoyed customer loyalty and satisfaction, and many customers are willing to pay more for WFM's corporate**,** environmental, and ethical conscience**.** The JiaDuoBao Group (JDB), a foreign-funded enterprise in the British Virgin Islands that produces and sells drinks and mineral water, donates 1 million and 1.1 million to WenChuan Earthquake and the YuShu Earthquake, respectively [3]. The sales volume of JDB was 50 million in 2007, rose to 120 million in 2008, and reached 150 million in 2010 [4]. JDB's attention to vulnerable people and social welfare (CSR efforts) has helped enhance consumers' perceptions of brand equity, which in turn could boost demand. Moreover, Chinese businesses paid much more attention to CSR and to serving society properly in recent years. For example, 24 chemical companies pledged to share social responsibility in 2008 [5], while more than one thousand firms in Shanghai did so in 2011 [6]. Moreover, Shenzhen took the lead in launching the local standard of CSR in 2015, which encourages and incentivizes firms to exert CSR efforts [7]. With the increasing emphasis on CSR in contemporary society, our research provides a well-timed discussion and guidelines for businesses to expand and improve their CSR engagement.

Social responsibility comes at a cost and is fundamentally grounded in humanitarian obligations to employees, consumers, and others. This is a principle that Apple Inc. has publicly acknowledged. However, Apple does not have direct control over Foxconn's operations and does not know how much CSR effort should be invested to improve the working conditions in Chinese factories. How could Apple motivate Foxconn to engage in CSR and improve its performance in employee welfare, ecological footprint and production safety?

We design collaboration mechanisms in a two-stage supply chain with one dominant retailer (i.e., Apple) and a contract manufacturer (i.e., Foxconn). To address the CSR concern, we develop wholesale price and two-part tariff contracts under asymmetric information:

(1) We examine the wholesale price contract and derive the optimal decisions for both the symmetric and asymmetric cases (§3.1 and §3.2). From the differences between the two cases, we first investigate the value of information and establish the impact of the CSR cost coefficient on SC performance (§3.3.1 and §3.3.2). We subsequently investigate the interplay between the retailer's marketing efforts and the manufacturer's CSR efforts (§3.3.3).

(2) Next, we design a two-part tariff contract for the retailer to incentivize the CM to improve its CSR efforts under information symmetry and information asymmetry (§4).

(3) Finally, we extend the wholesale price contract and the two-part tariff contract to address the multi-CMs scenario when the SC faces two competing CMs (see Appendices D and E).

The contribution of this research is that we address an important supply-chain management (SCM) issue and design optimal contracts to motivate suppliers to improve their CSR commitment under asymmetric cost information, a topic that has not been studied in literature. Lou and Bhattacharya [8] have empirically shown that CSR may significantly influence customer satisfaction and corporate performance. To improve CSR performance, firms must commit and make extra efforts to invest in CSR activities.

The paper is organized as follows. Section 2 discusses the related literature. In Section 3, we formalize the problem, develop base models under both the symmetric and asymmetric information cases, and provide propositions for the wholesale price contract. Section 4 designs the two-part tariff contract under both the symmetric and asymmetric cases. Finally, we offer managerial implications and conclude this research in Section 5.

2. Related literature

A few researchers in the supply chain management area have studied CSR. Goering [9] proposes a marketing chain for CSR coordination. Barcos et al. [10] examine the influence of CSR on firms' inventory policy, while Ranangen and Zobel [11] study CSR in the extractive industries and forestry. Hsueh and Chang [12] and Cruz [13, 14] focus on CSR in supply chain networks. Servaes and Tamayo [15] show that CSR and firm value are positively related for firms with high customer awareness.

In contrast, Ni et al. [16] and Ni and Li [17] study the impact of exogenous factors on CSR commitment, while Hsueh [18] embeds CSR to coordinate a two-stage supply chain. Panda [19] uses a revenue-sharing contract to coordinate the CSR manufacturer-retailer chain. Unlike the above literature, we employ different decision structures to design the contracts for an asymmetric supply chain. In particular, we focus on designing the best contract from the perspective of a brand name retailer (e.g., Apple), with the aim of improving its CM's CSR efforts. Our paper differs considerably from the literature. The main differences between our model and those in the literature are summarized in Table 1a. In addition to CSR activities, our emphasis is on information asymmetry. Thus, we will focus on the discussion of information asymmetry in the following subsections.

Table 1a. Our Paper vs. the Literature

	Ni et al. [16]	Ni and Li [17]	Hsueh [18]	Panda [19]	Our Paper
Information	Symmetry	Symmetry	Symmetry	Symmetry	**Asymmetry**
Contracts	Wholesale Price Contract (WP)	WP	Revenue-Sharing Contract	Revenue-Sharing Contract	**WP & Two-part tariff contract**
CSR Activities	Supplier	Supplier & Downstream firm	Manufacturer	Manufacturer or retailer	**Contract Manufacturer**
Demand Functions Depend on:	Retail price & CSR	Price & CSR of the supplier and the firm	Follow a normal distribution	Retail	**Price, CSR & level of marketing efforts**
CM Competition	NO	NO	NO	No	**Yes (Appendix D)**

Table 1b. Our Paper vs. the Literature

Authors	Information asymmetry types		CSR activity	Focus
	Cost	Demand		
Corbett et al. [20]	√			Designing supply contracts
Liu and Cetinkaya [21]	√			Designing supply contracts
Cachon and Zhang [22]	√			Designing procurement mechanism
Mukhopadhyay et al. [23]	√			Information sharing
Yao et al. [24]	√			Vertical cost information sharing
Mukhopadhyay et al. [25, 26]	√			Contract design
Kaya and Ozer [27]	√			Quality risk in outsourcing
Ozer and Raz [28]	√			Supply chain sourcing
Xu et al. [29]	√			Sourcing and contracting strategies
Kim and Netessine [30]	√			Procurement contracting strategies
Yue et al. [31]	√			Optimal strategies
Yue et al. [32]	√			Impacts of the full returns policy
Mishra et al. [33]		√		Incentives for information distortion
Gal-Or et al. [34]		√		Investigate the nature of information-sharing arrangements
He et al. [35]		√		Value of information sharing
Gan et al. [36]		√		Investigate commitment-penalty contracts
Babich et al. [37]		√		Contract design
Li and Zhang [38]		√		Investigate ex ante information sharing
Our paper	√		√	Investigate the value of information sharing; contract design

2.1 Cost information asymmetry

Corbett et al. [20] examine the value of attaining better information on buyers' cost structure, while Liu and Cetinkaya [21] consider a buyer-driven supply chain. Cachon and Zhang [22] develop a queuing model to select a single supplier whose costs are private information. Mukhopadhyay et al. [23] investigate channel coordination under both the complete and asymmetric information cases. By extending the result of [23], Yao et al. [24] consider a supply chain with two value-adding heterogeneous retailers. Similarly, Mukhopadhyay et al. [25, 26] develop optimal contracts for mixed channels under asymmetric cost information.

Kaya and Ozer [27] investigate two quality risk factors: (i) no contract on quality and (ii) no information about the CM's quality cost. Ozer and Raz [28] study the effect of smaller suppliers' production costs on profits and contracting decisions. Meanwhile, Xu et al. [29] consider a leading supplier with price-setting power and an urgent supplier with private cost information. Finally, Kim and Netessine [30] investigate the impact of information asymmetry and procurement contracts on SC members' incentives to collaborate.

2.2 Demand information asymmetry

Researchers have also studied information asymmetry on demand. For example, Yue et al. [31, 32] investigate complementary bundled goods and return policies on SC with information asymmetry. Mishra et al. [33] study a make-to-order SC where members set prices based on their private demand forecasts. Alternatively, Gal-Or et al. [34] examine the information-sharing arrangements in a distribution channel when retailers are asymmetrically informed. Similarly, He et al. [35] examine the potential benefits of sharing information and contracts that facilitate such cooperation with asymmetric information about the demand volatility. Gan et al. [36] show that the supplier can offer a menu of commitment-penalty contracts such that the retailer will truthfully reveal its demand information under asymmetric demand information. Then again, Babich et al. [37] design a contract for a retailer that contains private information about the demand distribution. Finally, Li and Zhang [38] investigate ex ante information sharing in a supply chain between a make-to-stock manufacturer and a retailer. To summarize the differences between our model and the literature, we include Table 1b. In short, our paper differs from the literature in two main aspects:

(i) Most of the existing literature assumes that the supplier has imperfect information about the retailer, e.g., the retailer does not share inventory/sales information with the supplier. They even distort sales information to secure better contract terms from suppliers. Conversely, the problem that we face is that the retailer has asymmetric information about the CM, e.g., Apple does not have perfect information about Foxconn's CSR costs.

(ii) We develop a two-part tariff contract (TPT) to motivate the CM to improve CSR efforts. Practicable contracts are proposed for SC members to collaborate with each other when facing information asymmetry. This scenario is commonly observed in the real world but has not been studied to date. The main focus of our research is on incentivizing the CM to commit more effort to CSR activities and to maximize the retailer's profit.

3. The base model

We face a two-stage SC with a CM and a brand name retailer, which is the

Stackelberg leader. We assume that the demand is a function of retail price, the retailer's marketing efforts and the contract manufacturer's CSR efforts:

$$D = a - bp + \gamma e + \lambda y \, , \tag{1}$$

where a is the base market size, b is the price-sensitive parameter, p is the retail price, γ measures the influence of the retailer's marketing efforts (e) on demand, and λ measures the effect of the CM's CSR efforts (y) on demand. Eq. (1) implies that demand decreases with retail price but increases with marketing and CSR efforts.

We assume a quadratic cost function for the marketing efforts. Specifically, we use the function form $\frac{\eta e^2}{2}$ for the marketing efforts cost where the convex cost function is commonly adopted in the literature to imply increasing marginal cost (Bhaskaran and Krishnan [39]; Zhao and Wei [40]), and η is the marketing efforts cost coefficient. Similarly, the cost of the CSR efforts is assumed to be quadratic and has the function form $\frac{\xi y^2}{2}$, and ξ is the CSR efforts cost coefficient.

We define Π_R and Π_{CM} as the profits of the retailer and the CM, respectively, and use the subscripts "W*" and "TPT*" to denote the optimal decisions under the wholesale price contract and the two-part tariff contract. The superscripts "asy*" and "sym*" signify the optimal decisions under asymmetric and symmetric (full) information cases, respectively. If the CM's wholesale price is w, then the retail price p set by the retailer will satisfy $m = p - w$, where m is the sales margin. Let c be the CM's unit production cost. We can then express the profits of the retailer and the CM as:

$$\Pi_R = (p-w)(a-bp+\gamma e+\lambda y)-\frac{\eta e^2}{2} = m(a-bm-bw+\gamma e+\lambda y)-\frac{\eta e^2}{2}, \quad (2)$$

$$\Pi_{CM} = (w-c)(a-bp+\gamma e+\lambda y)-\frac{\xi y^2}{2} = (w-c)(a-bm-bw+\gamma e+\lambda y)-\frac{\xi y^2}{2}. \quad (3)$$

In the following, we discuss two basic models that adopt the wholesale price contract under information symmetry and asymmetry, respectively. The CM's profits provide the basis for comparison with other models that we proposed in Section 4. If the profit from the proposed TPT model is greater than that from the base model derived in this section, then the CM will be motivated to work with the retailer and accept the TPT contract proposed in Section 4.

3.1 Wholesale price contract under information symmetry

We now identify the optimal decisions and the resulting profits when SC members have full information about each other's cost and price. In this model, the retailer is the Stackelberg leader that first sets a profit-maximizing sales margin (m) and marketing effort (e), based on which the CM determines its profit-maximizing wholesale price (w) and CSR efforts (y). To obtain the equilibrium solutions between the SC members, we derive the retailer's best response functions with respect to the values of m and e by setting $\partial\Pi_{CM}/\partial w = 0$ and $\partial\Pi_{CM}/\partial y = 0$ and solving for $w(m,e)$ and $y(m,e)$ as follows:

$$w(m,e) = \frac{\xi(a-bm+\gamma e-bc)}{2b\xi-\lambda^2}+c, \quad (4)$$

$$y(m,e) = \frac{\lambda(a-bm+\gamma e-bc)}{2b\xi-\lambda^2}. \quad (5)$$

Substitute Eqs. (4) and (5) into the retailer's profit function Eq. (2), and derive the first-order conditions on m and e. We find that the retailer's sales margin (m) and marketing efforts (e) at equilibrium are:

$$m^* = \frac{(2b\eta\xi - \lambda^2\eta)(a-bc)}{b(4b\eta\xi - 2\lambda^2\eta - \gamma^2\xi)}, \tag{6}$$

$$e^* = \frac{\gamma\xi(a-bc)}{4b\eta\xi - 2\lambda^2\eta - \gamma^2\xi}. \tag{7}$$

After substituting Eqs. (6)-(7) into Eqs. (4)-(5), we have

$$w_W^{sym*} = \frac{\eta\xi(a-bc)}{4b\eta\xi - 2\lambda^2\eta - \gamma^2\xi} + c, \tag{8}$$

$$y_W^{sym*} = \frac{\lambda\eta(a-bc)}{4b\eta\xi - 2\lambda^2\eta - \gamma^2\xi}. \tag{9}$$

After substituting Eqs. (6)-(9) into Eqs. (2)-(3), we have

$$(\Pi_R)_W^{sym*} = \frac{\eta\xi(a-bc)^2}{2(4b\eta\xi - 2\lambda^2\eta - \gamma^2\xi)}, \tag{10}$$

$$(\Pi_{CM})_W^{sym*} = \frac{\eta^2\xi(2b\eta - \lambda^2)(a-bc)^2}{2(4b\eta\xi - 2\lambda^2\eta - \gamma^2\xi)^2}. \tag{11}$$

The resulting CM's profit serves as a basis for our model comparisons. Only when the newly proposed TPT contract (§4) can derive higher profits than Eq. (11) will the CM be enticed to accept the TPT contract and invest in CSR efforts. Given any reasonable CSR effort level, the retailer will share the corresponding CSR efforts cost information through wholesale price and transfer fee to the CM.

3.2 Wholesale price contract under information asymmetry

The retailer in this case lacks full information about the CM's CSR costs. We assume that the cost parameter ξ is uniformly distributed, with probability density function $g(\xi)$ and cumulative distribution function $G(\xi)$. That is, $\xi \sim U[\bar{\xi} - \varepsilon, \bar{\xi} + \varepsilon]$,

$g(\xi)=\frac{1}{2\varepsilon}$, $0<\varepsilon<\bar{\xi}$, and ε is the half range of the CSR costs. The larger the value of ε is, the less certain the retailer will be of the CM's CSR costs. As the Stackelberg leader, the retailer will anticipate the CM's reaction and then decide on the sales margin and the marketing efforts. We now adapt the solution approach for the symmetric information case to address the asymmetric information scenario. Recall that in the symmetric information case, the CM's reaction can be expressed as Eqs. (4)-(5), which can be substituted into Eq. (2) to obtain

$$\Pi_R=\frac{b\xi m(a-bm+\gamma e-bc)}{2b\xi-\lambda^2}-\frac{\eta e^2}{2}. \tag{12}$$

Based on Eq. (12), we find that

$$E[\Pi_R]=\int_{\bar{\xi}-\varepsilon}^{\bar{\xi}+\varepsilon}[\frac{b\xi m(a-bm+\gamma e-bc)}{2b\xi-\lambda^2}-\frac{\eta e^2}{2}]g(\xi)d\xi,$$

$$=[\frac{1}{2}+\frac{\lambda^2}{8b\varepsilon}\ln\frac{2b(\bar{\xi}+\varepsilon)-\lambda^2}{2b(\bar{\xi}-\varepsilon)-\lambda^2}]m(a-bm+\gamma e-bc)-\frac{\eta e^2}{2}. \tag{13}$$

Let $h(\varepsilon)=\frac{1}{2}+\frac{\lambda^2}{8b\varepsilon}\ln\frac{2b(\bar{\xi}+\varepsilon)-\lambda^2}{2b(\bar{\xi}-\varepsilon)-\lambda^2}$. From the first-order condition of $E[\Pi_R]$ with respect to m and e, we find that

$$m_W^{asy*}=\frac{(a-bc)\eta}{2b\eta-\gamma^2h(\varepsilon)}, \tag{14}$$

$$e_W^{asy*}=\frac{\gamma h(\varepsilon)(a-bc)}{2b\eta-\gamma^2h(\varepsilon)}. \tag{15}$$

After substituting Eqs. (14)-(15) into Eqs. (4)-(5), we find that

$$w_W^{asy*}=\frac{\xi}{2b\xi-\lambda^2}\cdot\frac{b(a-bc)\eta}{2b\eta-\gamma^2h(\varepsilon)}+c, \tag{16}$$

$$y_W^{asy*}=\frac{\lambda}{2b\xi-\lambda^2}\cdot\frac{b(a-bc)\eta}{2b\eta-\gamma^2h(\varepsilon)}, \tag{17}$$

After substituting Eqs. (14)-(17) into Eqs. (2)-(3), we have

$$E[\Pi_R]_W^{asy*} = \frac{h(\varepsilon)[2b^2\eta^2\xi - (2b\xi - \lambda^2)\gamma^2\eta h(\varepsilon)](a-bc)^2}{2(2b\xi - \lambda^2)[2b\eta - \gamma^2 h(\varepsilon)]^2}, \qquad (18)$$

$$E[\Pi_{CM}]_W^{asy*} = \frac{b^2(a-bc)^2\eta^2\xi}{2(2b\xi - \lambda^2)[2b\eta - \gamma^2 h(\varepsilon)]^2}. \qquad (19)$$

Eq. (14) gives the retailer's optimal sales margin and subsequently the retail price, while Eq. (15) shows the retailer's optimal marketing efforts. Likewise, Eq. (16) determines the CM's optimal wholesale price, while Eq. (17) identifies the CM's optimal CSR effort level. Finally, Eqs. (18)-(19) present the retailer's and the CM's optimal profits, respectively.

3.3 Model comparisons and impacts of CSR cost and volatility on performance

For ease of analysis, we summarize the optimal decisions derived above in Table 2.

Table 2. Optimal decisions under information symmetry vs. information asymmetry

Values	Information Symmetry (§3.1)	Information Asymmetry (§3.2)
Sales Margin (m)	$\frac{(2b\eta\xi - \lambda^2\eta)(a-bc)}{b(4b\eta\xi - 2\lambda^2\eta - \gamma^2\xi)}$	$\frac{(a-bc)\eta}{2b\eta - \gamma^2 h(\varepsilon)}$
Marketing Effort (e)	$\frac{\gamma\xi(a-bc)}{4b\eta\xi - 2\lambda^2\eta - \gamma^2\xi}$	$\frac{\gamma h(\varepsilon)(a-bc)}{2b\eta - \gamma^2 h(\varepsilon)}$
Retailer's Profit (Π_R)	$\frac{\eta\xi(a-bc)^2}{2(4b\eta\xi - 2\lambda^2\eta - \gamma^2\xi)}$	$\frac{h(\varepsilon)[2b^2\eta^2\xi - (2b\xi - \lambda^2)\gamma^2\eta h(\varepsilon)](a-bc)^2}{2(2b\xi - \lambda^2)[2b\eta - \gamma^2 h(\varepsilon)]^2}$
Wholesale price (w)	$\frac{\eta\xi(a-bc)}{4b\eta\xi - 2\lambda^2\eta - \gamma^2\xi} + c$	$\frac{\xi}{2b\xi - \lambda^2}\cdot\frac{b(a-bc)\eta}{2b\eta - \gamma^2 h(\varepsilon)} + c$
CSR efforts level (y)	$\frac{\lambda\eta(a-bc)}{4b\eta\xi - 2\lambda^2\eta - \gamma^2\xi}$	$\frac{\lambda}{2b\xi - \lambda^2}\cdot\frac{b(a-bc)\eta}{2b\eta - \gamma^2 h(\varepsilon)}$
CM's Profit (Π_{CM})	$\frac{\eta^2\xi(2b\xi - \lambda^2)(a-bc)^2}{2(4b\eta\xi - 2\lambda^2\eta - \gamma^2\xi)^2}$	$\frac{b^2(a-bc)^2\eta^2\xi}{2(2b\xi - \lambda^2)[2b\eta - \gamma^2 h(\varepsilon)]^2}$

We now examine how the CM's and retailer's profits differ between full (symmetric) information and asymmetric information and offer Propositions 1 and 2.

3.3.1 Value of information sharing (from the symmetric to the asymmetric case)

To examine the difference between the information symmetry and information asymmetry cases, we assume that profits and efforts are positive and consequently that $h(\varepsilon)$ must satisfy the condition that $h(\varepsilon) < \frac{2b\eta}{\gamma^2}$. We also know that $h(\varepsilon) = \frac{1}{2} + \frac{\lambda^2}{8b\varepsilon} \ln \frac{2b(\bar{\xi}+\varepsilon)-\lambda^2}{2b(\bar{\xi}-\varepsilon)-\lambda^2} > \frac{1}{2}$ for all $0 < \varepsilon < \bar{\xi}$; therefore, $\frac{1}{2} < h(\varepsilon) < \frac{2b\eta}{\gamma^2}$. We compare the optimal profits of the retailer and the CM under information symmetry and asymmetry in Table 2 and derive the following proposition.

Proposition 1.

If $\frac{1}{2} < h(\varepsilon) < \min\{\frac{2b^2\eta\xi}{\gamma^2(3b\xi - 2\lambda^2)}, \frac{2b\eta}{\gamma^2}\}$, then

(1) The retailer's profit increases with the CM's cost variation (ε);

(2) The higher the degree of the CM's cost variation (large ε) is, the smaller the difference between the retailer's profits under information symmetry and asymmetry is.

However, if $\frac{2b^2\eta\xi}{\gamma^2(3b\xi - 2\lambda^2)} < h(\varepsilon) < \frac{2b\eta}{\gamma^2}$, then

(3) The retailer's profit decreases with the CM's cost variation (ε);

(4) The higher the degree of the CM's cost variation (large ε) is, the greater the difference between the retailer's profit under information symmetry and that under information asymmetry is.

Proof. See Appendix A.

Proposition 2.

If $\frac{1}{2} < h(\varepsilon) < \frac{2b\eta}{\gamma^2}$, then

(1) The CM's profit increases with the CM's cost variation (ε);

(2) The higher the degree of the CM's cost variation (large ε) is, the greater the difference between the CM's profits under information symmetry and asymmetry is.

Proof. See Appendix B.

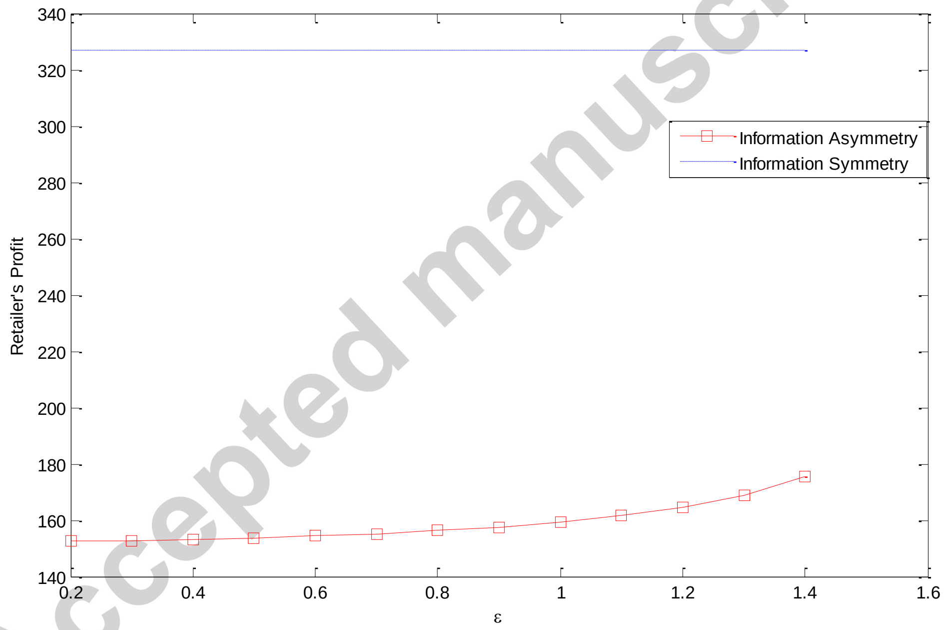

Fig. 1. Comparison of retailer's profits: information symmetry vs. asymmetry

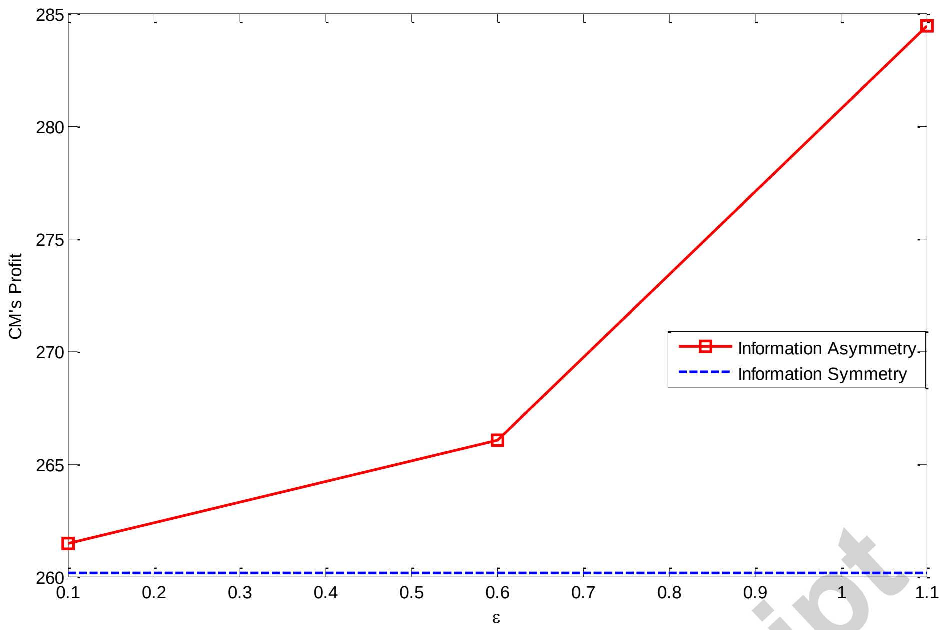

Fig. 2. Comparison of CM's profit: information symmetry vs. asymmetry

Propositions 1 and 2 imply that information asymmetry benefits CM but that the retailer may be worse off without the CM's full cost information. Therefore, the retailer is always motivated to entice the CM to disclose his CSR cost information. Based on the results in Table 2, we conduct a numerical study by assuming that $a=40$, $b=1$, $c=5$, $\gamma=1.5$, $\lambda=1$, $\eta=\xi=2$ and $\bar{\xi}=2$. For example, when $\varepsilon=1.2$, we have $\frac{2b^2\eta\xi}{\gamma^2(3b\xi-2\lambda^2)}=\frac{8}{9}$, $h(1.2)\approx 0.728$, and $\frac{2b\eta}{\gamma^2}=\frac{16}{9}$; i.e., $h(1.2)$ satisfies $\frac{1}{2}<h(1.2)<\min\{\frac{2b^2\eta\xi}{\gamma^2(3b\xi-2\lambda^2)},\frac{2b\eta}{\gamma^2}\}$ in Proposition 1 and $\frac{1}{2}<h(1.2)<\frac{2b\eta}{\gamma^2}$ in Proposition 2. Figs. 1 and 2 visually depict the impact of parameter ε on the retailer and the CM under both the information asymmetry and symmetry cases. The results validate Propositions 1 and 2.

3.3.2 Impact of ξ on the CM's performance

Will the CM derive more profit when she shares her CSR cost information with the retailer? How much profit will the CM gain if she moves from the asymmetric case to the symmetric case? It is important to discern the condition under which information sharing will benefit the CM so that she has an incentive to share cost information with the retailer.

The difference between the CM's profits under information asymmetry and those under information symmetry can be expressed as:

$$E[\Pi_{CM}]_W^{sym*} - E[\Pi_{CM}]_W^{asy*} = \frac{\eta^2\xi(2b\xi-\lambda^2)(a-bc)^2}{2(4b\eta\xi-2\lambda^2\eta-\gamma^2\xi)^2} - \frac{b^2(a-bc)^2\eta^2\xi}{2(2b\xi-\lambda^2)[2b\eta-\gamma^2h(\varepsilon)]^2},$$

$$= \frac{1}{2(4b\eta\xi-2\lambda^2\eta-\gamma^2\xi)^2(2b\xi-\lambda^2)\{2b\eta-\gamma^2h(\varepsilon)\}^2}\{[-16b^3\gamma^2\eta h(\varepsilon)+4b^2\gamma^4h^2(\varepsilon)+8b^3\eta\gamma^2$$

$$-b^2\gamma^4]\xi^2+(16\lambda^2b^2\gamma^2\eta h(\varepsilon)-4\lambda^2\gamma^4bh^2(\varepsilon)-4b^2\lambda^2\gamma^2\eta)\xi-4b\gamma^2\lambda^4\eta h(\varepsilon)+\lambda^4\gamma^4h^2(\varepsilon)\}.$$

Let $E[\Pi_{CM}]_W^{sym*} - E[\Pi_{CM}]_W^{asy*} = 0$ and

$$J(\xi) = [-16b^3\gamma^2\eta h(\varepsilon)+4b^2\gamma^4h^2(\varepsilon)+8b^3\eta\gamma^2-b^2\gamma^4]\xi^2$$

$$+(16\lambda^2b^2\gamma^2\eta h(\varepsilon)-4\lambda^2\gamma^4bh^2(\varepsilon)-4b^2\lambda^2\gamma^2\eta)\xi$$

$$-4b\gamma^2\lambda^4\eta h(\varepsilon)+\lambda^4\gamma^4h^2(\varepsilon)=0.$$

The discriminant of $J(\xi)=0$ is $\Delta = 4b^2\lambda^4\gamma^4[2b\eta-\gamma^2h(\varepsilon)]^2 > 0$. Thus, we can obtain two roots of the function when $J(\xi)=0$ as follows:

$$\xi_1 = \frac{2\lambda^2\gamma^4bh^2(\varepsilon)+4b^2\lambda^2\gamma^2\eta-8\lambda^2b^2\gamma^2\eta h(\varepsilon)-b\lambda^2\gamma^4h(\varepsilon)}{-16b^3\gamma^2\eta h(\varepsilon)+4b^2\gamma^4h^2(\varepsilon)+8b^3\eta\gamma^2-b^2\gamma^4}, \text{ and}$$

$$\xi_2 = \frac{2\lambda^2\gamma^4bh^2(\varepsilon)-8\lambda^2b^2\gamma^2\eta h(\varepsilon)+b\lambda^2\gamma^4h(\varepsilon)}{-16b^3\gamma^2\eta h(\varepsilon)+4b^2\gamma^4h^2(\varepsilon)+8b^3\eta\gamma^2-b^2\gamma^4}.$$

From $\Delta > 0$, we know that $J(\xi)=0$ will always have two different roots, i.e.,

$\xi_1 \neq \xi_2$.

Recall that $h(\varepsilon) = \frac{1}{2} + \frac{\lambda^2}{8b\varepsilon} \ln \frac{2b(\bar{\xi} + \varepsilon) - \lambda^2}{2b(\bar{\xi} - \varepsilon) - \lambda^2} > \frac{1}{2}$. It is easy to show that

$$-16b^3\gamma^2\eta h(\varepsilon) + 4b^2\gamma^4 h^2(\varepsilon) + 8b^3\eta\gamma^2 - b^2\gamma^4 = -2h(\varepsilon)b^2\gamma^2[8b\eta - 2\gamma^2 h(\varepsilon)] + b^2\gamma^2[8b\eta - \gamma^2]$$

$$< -2h(\varepsilon)b^2\gamma^2(8b\eta - \gamma^2) + b^2\gamma^2(8b\eta - \gamma^2)$$

$$= (-2h(\varepsilon)b^2\gamma^2 + b^2\gamma^2)(8b\eta - \gamma^2) < 0.$$

Moreover, we find that

$$2\lambda^2\gamma^4 b h^2(\varepsilon) + 4b^2\lambda^2\gamma^2\eta - 8\lambda^2 b^2\gamma^2\eta h(\varepsilon) - b\lambda^2\gamma^4 h(\varepsilon) = b\lambda^2\gamma^2[4b\eta - \gamma^2 h(\varepsilon)][1 - 2h(\varepsilon)] < 0.$$

Assuming that the values in Table 2 are positive, then ε must satisfy $h(\varepsilon) < \min\{\frac{2b\eta}{\gamma^2}, \frac{2b^2\eta\xi}{(2b\xi - \lambda^2)\gamma^2}\}$. For any given ε such that $h(\varepsilon) < \min\{\frac{2b\eta}{\gamma^2}, \frac{2b^2\eta\xi}{(2b\xi - \lambda^2)\gamma^2}\}$, it is clear that $\xi_1 > 0$. Similarly, we find that $\xi_2 > 0$.

Based on the discussion above, we derive the following proposition.

Proposition 3. (1) If $0 < \xi < \xi_1$ or $\xi > \xi_2$, then $E[\Pi_{CM}]_W^{sym*} > E[\Pi_{CM}]_W^{asy*}$, i.e., sharing CSR cost information will increase the CM's profit;

(2) If $\xi = \xi_1$ or $\xi = \xi_2$, then we have $E[\Pi_{CM}]_W^{sym*} = E[\Pi_{CM}]_W^{asy*}$; and

(3) If $\xi_1 < \xi < \xi_2$, then we have $E[\Pi_{CM}]_W^{sym*} < E[\Pi_{CM}]_W^{asy*}$, i.e., sharing CSR cost information will decrease the CM's profit.

Proposition 3 shows that when the CSR cost coefficient is very small or very large, the CM will benefit from sharing the cost information with the retailer. Because the wholesale price contract models in this section provide only one variable, *w*, for negotiation, they are less adaptable. In the following, we propose a more flexible model by considering a TPT contract. The TPT contract, including a fixed payment and unit cost, provides a better mechanism to motivate CSR effort provisions. In addition to the wholesale price, the retailer will also pay a lump-sum transfer fee to the CM according to the CM's CSR effort level. The CM is allowed to choose among various CSR effort levels.

3.3.3 Interplay between y and e

Both the CSR efforts y and marketing efforts e affect demand (Eq. (1)). We now investigate the interplay between the two decisions. Recall that η is the marketing efforts cost coefficient and ξ is the CSR efforts cost coefficient. Given the wholesale price contract under information symmetry, we first study the impact of ξ on marketing efforts e and then investigate the influence of η on CSR efforts y. From the results in Table 2, we take the first derivative of e_w^{sym*} with respect to ξ and obtain

$\frac{\partial e_w^{sym*}}{\partial \xi} = \frac{-2\lambda^2\eta\gamma(a-bc)}{(4b\eta\xi - 2\lambda^2\eta - \gamma^2\xi)} < 0$. This shows that marketing efforts will decrease with the CSR efforts cost coefficient.

Similarly, we study the impact of parameter η on y, and find

$\frac{\partial y_w^{sym*}}{\partial \eta} = \frac{-\gamma^2\xi\lambda(a-bc)}{(4b\eta\xi - 2\lambda^2\eta - \gamma^2\xi)} < 0$. This indicates that CSR efforts will decrease with the marketing effort cost coefficient.

For the wholesale price contract with information asymmetry, because the CSR efforts cost coefficient ξ is a function of ε (Section 3.2, $g(\xi) = \frac{1}{2\varepsilon}$), we examine the impact of ε on marketing efforts e first and then investigate the influence of η on CSR efforts y.

In the following, we take the first derivative of e_w^{asy*} with respect to ε and that of y_w^{asy*} pertaining to η:

$\frac{\partial e_w^{asy*}}{\partial \varepsilon} = \frac{2b\eta\gamma h'(\varepsilon)(a-bc)}{[2b\eta - \gamma^2 h(\varepsilon)]^2} > 0$ when $0 < \varepsilon < \bar{\xi}$. This result shows that marketing efforts will increase with the CSR cost variation. We also find that

$\frac{\partial y_w^{asy*}}{\partial \eta} = \frac{\lambda b(a-bc)}{2b\xi - \lambda^2} . \frac{-\gamma^2 h(\varepsilon)}{[2b\eta - \gamma^2 h(\varepsilon)]^2} < 0$. This indicates that CSR efforts will decrease with the marketing efforts cost coefficient.

4. Two-part tariff (TPT) contract

4.1 With symmetric information

Under a TPT contract, the retailer offers a per-unit payment *w* and a lump-sum transfer payment *F*. Fig. 3 summarizes the sequence of events in the TPT model. The CM can accept or reject the terms offered in the contract. The retailer aims to maximize his profit subject to the CM's acceptance, while the CM will accept a contract only if her expected profit is greater than her reservation profit $\bar{\Pi}_{CM}^{sym}$, i.e., the optimal profit in the base model given in Eq. (11).

In the TPT, using backward induction, we can first solve the retailer's problem of establishing the optimal retail price (*p*) and the marketing efforts (*e*) as a function of the CSR efforts (y). Next, the CM will determine the optimal CSR efforts, according to the retailer's reaction function and the anticipated results *p* and *e*. Finally, the retailer will determine the optimal *w* and *F*, according to the CM's optimal CSR efforts level *y*.

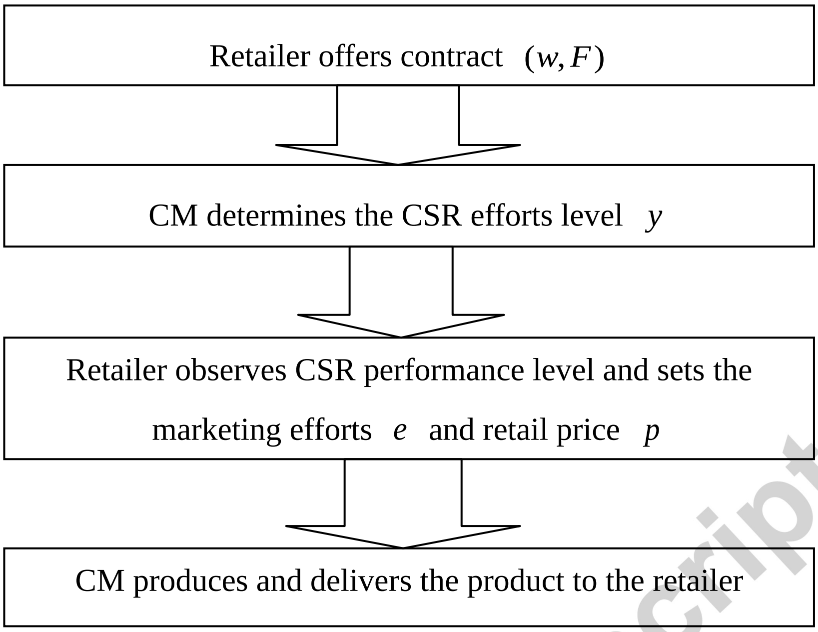

Fig. 3. Decision flow of the two-part tariff contract

The profits of the retailer and the CM are similar to those in Eqs. (2)-(3), except for the term “F”:

$$\Pi_R = (p - w)(a - bp + \gamma e + \lambda y) - \frac{\eta e^2}{2} + \quad , \tag{20}$$

$$\Pi_{CM} = (w - c)(a - bp + \gamma e + \lambda y) - \frac{\xi y^2}{2} - F . \tag{21}$$

The following proposition characterizes the optimal terms of the TPT contract.

Proposition 4. Facing symmetric information, the retailer’s optimal TPT contract (w, F) can be described as

$$w_{TPT}^{sym*} = \frac{a\lambda^2\eta(2b\eta\xi - \gamma^2\xi) + bc(2b\eta\xi - \gamma^2\xi + \lambda^2\eta)(2b\eta\xi - \gamma^2\xi - \lambda^2\eta)}{(2b\eta\xi - \gamma^2\xi)(4b^2\eta\xi - 2b\gamma^2\xi - b\lambda^2\eta) - b(2b\eta\xi - \lambda^2\eta - \gamma^2\xi)^2},$$

$$F_{TPT}^{sym*} = \frac{b\eta}{2b\eta-\gamma^2}(w_{TPT}^{sym*}-c)[a-bw_{TPT}^{sym*}+\frac{b\lambda^2\eta(w_{TPT}^{sym*}-c)}{2(2b\eta\xi-\gamma^2\xi)}]-\bar{\Pi}_{CM}^{sym}.$$

Proof. See Appendix C.

4.2 With asymmetric information

We now consider the contract design when ξ is unknown to the retailer. The retailer only has prior knowledge that ξ is in the range of $[\bar{\xi}-\varepsilon,\bar{\xi}+\varepsilon]$. We define ξ as a uniform distribution, i.e., $\xi \sim U[\bar{\xi}-\varepsilon,\bar{\xi}+\varepsilon]$, $g(\xi)=\frac{1}{2\varepsilon}$, $0<\varepsilon<\bar{\xi}$. Because the retailer does not know the exact value of ξ, he cannot determine the optimal value of w and F.

The retailer faces the following objective and constraint:

$$\max_{<(w,F)>} E[\Pi_R] = \int_{\bar{\xi}-\varepsilon}^{\bar{\xi}+\varepsilon}[\frac{\eta}{2(2b\eta-\gamma^2)}[a-bw+\frac{b\lambda^2\eta(w-c)}{2b\eta\xi-\gamma^2\xi}]^2+F]g(\xi)d\xi, \tag{22}$$

$$\text{s.t } \Pi_{CM} = \frac{b\eta}{2b\eta-\gamma^2}(w-c)[a-bw+\frac{b\lambda^2\eta(w-c)}{2(2b\eta\xi-\gamma^2\xi)}]-F \ge \bar{\Pi}_{CM}^{asy}. \tag{23}$$

The constraint ensures that the expected profit received by the CM is no less than her reservation profit, defined as the CM's optimal profit with a wholesale price contract under information asymmetry (Table 2). The following proposition offers the optimal contract parameters when facing asymmetric information.

Proposition 5. Under asymmetric information, the retailer's optimal TPT contract (w,F) is given by

$$w_{TPT}^{asy*} = \frac{(a+bc)2\varepsilon + a[\frac{\lambda^2\eta}{2b\eta-\gamma^2}\ln\frac{\bar{\xi}+\varepsilon}{\bar{\xi}-\varepsilon}-2\varepsilon]-\frac{2\lambda^4\eta^2bc\varepsilon}{(2b\eta-\gamma^2)(\bar{\xi}-\varepsilon)(\bar{\xi}+\varepsilon)}}{2b+b[\frac{\lambda^2\eta}{2b\eta-\gamma^2}\ln\frac{\bar{\xi}+\varepsilon}{\bar{\xi}-\varepsilon}-2\varepsilon]-\frac{2\lambda^4\eta^2b\varepsilon}{(2b\eta-\gamma^2)(\bar{\xi}-\varepsilon)(\bar{\xi}+\varepsilon)}},$$

$$F_{TPT}^{asy*} = \frac{b\eta}{2b\eta - \gamma^2}(w_{TPT}^{asy*} - c)[a - bw_{TPT}^{asy*} + \frac{b\lambda^2\eta(w_{TPT}^{asy*} - c)}{4(2b\eta - \gamma^2)\varepsilon}\ln\frac{\bar{\xi} + \varepsilon}{\bar{\xi} - \varepsilon}] - \bar{\Pi}_{CM}^{asy}.$$

Proof. The proof is similar to Proposition 4 and is thus omitted here.

4.3 Numerical example

4.3.1 TPT model vs. wholesale price contract (information symmetry)

To compare the CSR effort levels under different effort costs, we assume that the parameters are: $a = 40$, $b = 1$, $c = 5$, $\gamma = 1.5$, $\lambda = 1$ and $\eta = 2$. From Fig. 4, we find that the CM will exert greater CSR efforts in the TPT model if $\xi < 1.9384$. The CSR efforts are greater in the wholesale price contract than in the TPT model when the parameter ξ passes a certain threshold. This is because when the parameter ξ is large, the CSR effort cost is too high, deterring the CM from making the CSR efforts.

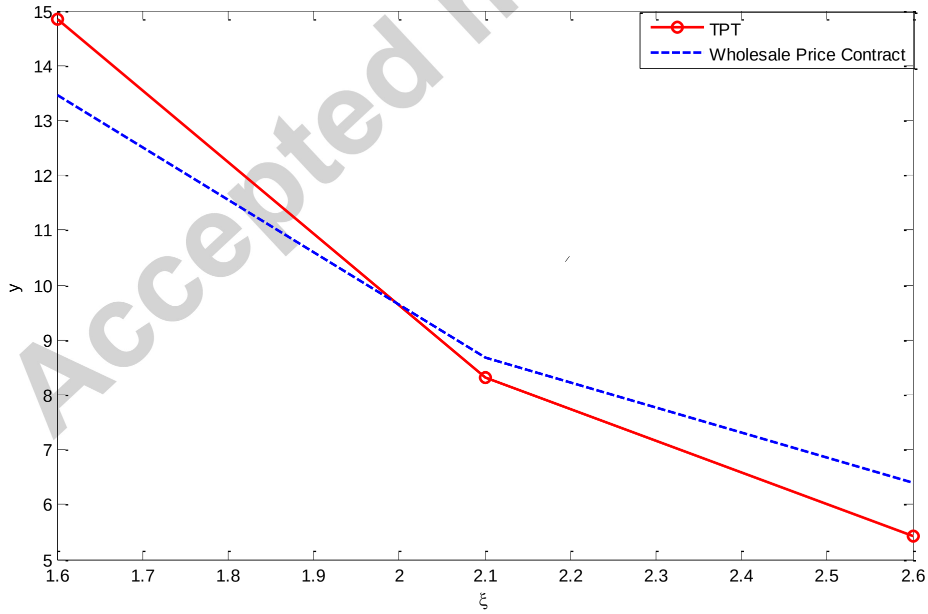

Fig. 4. CSR effort levels under the wholesale price contract and TPT

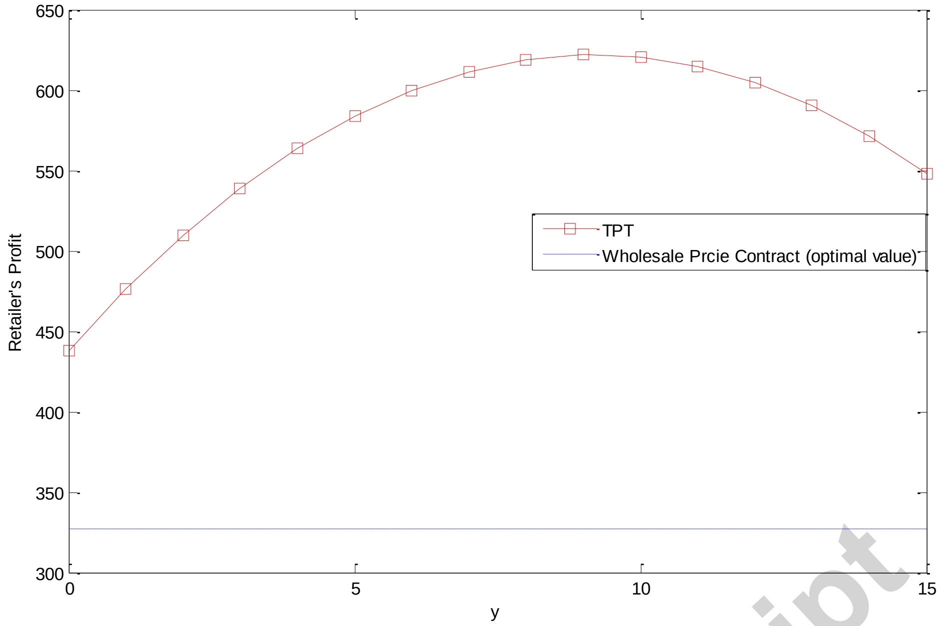

Fig. 5. Retailer's profit changes with CSR effort level

In Fig. 5, we assume that the parameters are: $a=40$, $b=1$, $c=5$, $\gamma=1.5$, $\lambda=1$, $\eta=2$ and $\xi=2$. We find that in the TPT: (1) the retailer's profit first increases with the CSR effort level and then decreases with CSR efforts when it passes a certain threshold; and (2) the retailer can derive more profit in the TPT model than in the wholesale price contract model. Thus, the TPT contract is preferred by the retailer.

We assume that the parameters are: $a=40$, $b=1$, $c=5$, $\gamma=1.5$, $\lambda=1$ and $\eta=2$ in Fig. 6, which contrasts the retailer's profits between the two contracts. We find that the TPT contract outperforms the wholesale price contract. The retailer's profit decreases with effort cost (ξ) significantly when ξ is relatively small. However, the retailer's profit remains stable when ξ becomes larger.

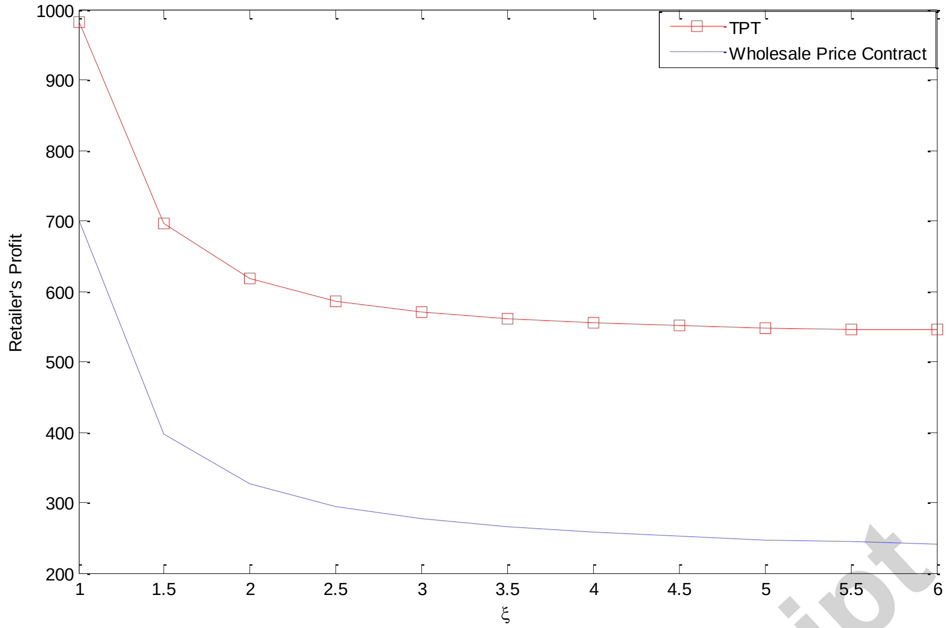

Fig. 6. Retailer's profit changes with parameter ξ

4.3.2 Retailer's profits under TPT: Information Symmetry vs. Asymmetry Cases

As in §3.3.1, we assume that $a=40$, $b=1$, $c=5$, $\gamma=1.5$, $\lambda=1$, $\eta=\xi=2$ and $\bar{\xi}=2$. Fig. 7 shows the impact of parameter ε on the retailer under both the information asymmetry and information symmetry cases in the TPT. Under information asymmetry, the retailer's profit increases with ε when ε is small. However, the retailer's profit declines rapidly when ε becomes larger.

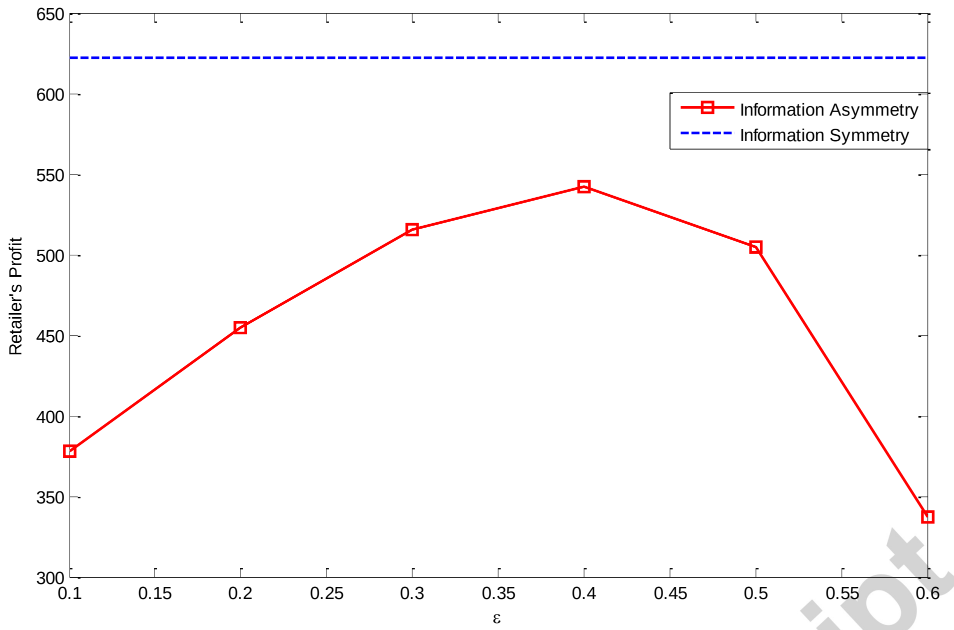

Fig. 7. Comparison of retailer's profits: two-part tariff contract case

4.3.3 TPT vs. wholesale price contract under asymmetric information

The effects of ε on the optimal wholesale price under the TPT and under the wholesale price contract model are examined. Fig. 8 shows that ε has a greater effect on the wholesale price under the TPT than under the wholesale price contract.

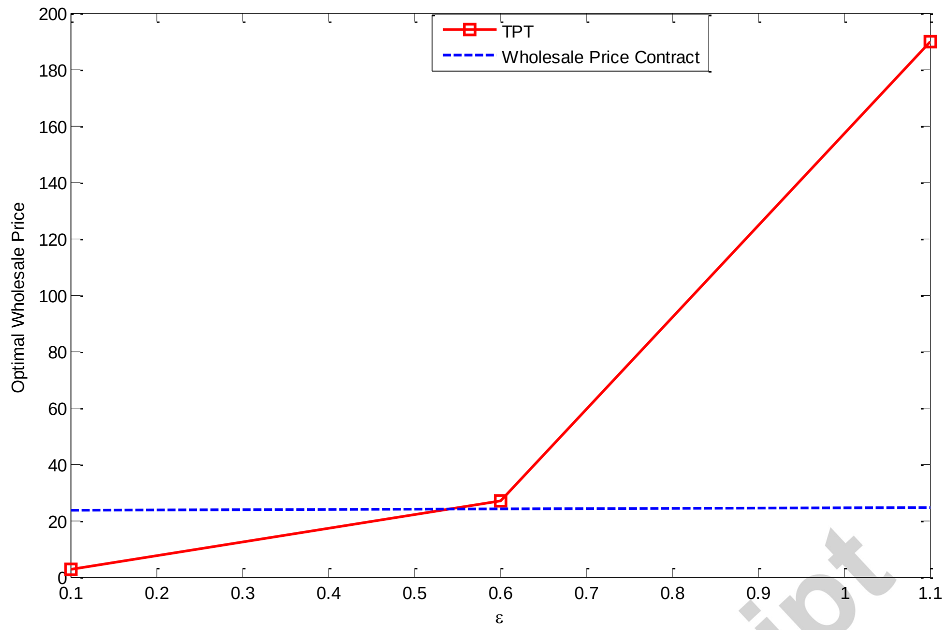

Fig. 8. Wholesale price vs. ε

5. Conclusions

Information asymmetry in a SC has drawn much attention recently. However, no researchers have studied the SC in which the cost of CSR efforts is the private information of CMs (suppliers). We address the contract design under asymmetric information between the CM and the retailer where market demand is influenced by the CM's CSR efforts and the retailer's marketing efforts. Under the wholesale price contract, the CM must decide on the CSR effort level and the wholesale price, while the retailer must determine the marketing effort level and the sales margin. Alternatively, in the TPT contract, the CM decides only on the CSR effort level.

Using the wholesale price contract, we first derive the optimal decisions for the CM and the retailer under both symmetric and asymmetric information. We then study the value of the CM’s information sharing with the retailer and the impact of the

CSR cost coefficient on the supply chain members' profits. Finally, we investigate the interplay between the CSR efforts and the marketing efforts.

We find that the retailer's profit may increase or decrease with the increase in cost variation (ε), depending on the value of $h(\varepsilon)$ as described in Proposition 1. However, the CM's profit will always increase with cost variation. Depending on the CSR cost variation ε, the difference between the retailer's profits under information symmetry and asymmetry may vary significantly. However, when $h(\varepsilon)$ satisfies certain conditions, the greater the CSR cost variation ε is, the greater the difference between the CM's profits under information symmetry and asymmetry is. Subsequently, we employ the two-part tariff contract approach to maximize the retailer's performance under both the symmetric and asymmetric cases and identify the optimal contract parameters for both cases.

This paper helps retailers design SC contracts under information asymmetry, with the aim of motivating the CM to enhance CSR effort levels. In the future, we may simultaneously consider the supply chain's CSR efforts from both the supplier and the retailer's perspectives, e.g., how to coordinate CSR efforts. Finally, one can also examine the quality effort and other investments in supply and how they influence the supply chain dynamics.

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References

[1] http://panmore.com/whole-foods-market-stakeholders-csr-analysis.

[2] http://www.buzzbinpadillacrt.com/10-ways-whole-foods-is-raising-the-bar-in-csr/.

[3] http://news.xinhuanet.com/fortune/2010-04/21/c_1246524.htm.

[4] http://news.xixik.com/zt/wanglaoji-jiaduobao/.

[5] http://news.cnpc.com.cn/system/2008/06/06/001182015.shtml.

[6] http://www.shzgh.org/renda/node5902/node6520/node6522/u1a1581012.html.

[7] http://www.sznews.com/zhuanti/content/2015-04/17/content_11475388.htm.

[8] Lou X, Bhattacharya CB. Corporate social responsibility, customer satisfaction, and market value. Journal of Marketing 2006; 70(4): 1-18.

[9] Goering GE. Corporate social responsibility and marketing channel coordination. Research in Economics 2012; 66(2): 142-148.

[10] Barcos L, Barroso A, Surroca J, Tribo JA. Corporate social responsibility and inventory policy. International Journal of Production Economics 2013; 143(2): 580-588.

[11] Ranangen H, Zobel T. Revisiting the 'how' of corporate social responsibility in extractive industries and forestry. Journal of Cleaner Production 2014; 84: 299-312.

[12] Hsueh CF, Chang MS. Equilibrium analysis and corporate social responsibility for supply chain integration. European Journal of Operational Research 2008; 190(1): 116-129.

[13] Cruz JM. Dynamics of supply chain networks with corporate social responsibility through integrated environmental decision-making. European Journal of Operational Research 2008; 184(3): 1005-1031.

[14] Cruz JM. The impact of corporate social responsibility in supply chain management: Multicriteria decision-making approach. Decision Support Systems 2009; 48(1): 224-236.

[15] Servaes H, Tamayo A. The impact of corporate social responsibility on firm value: the role of customer awareness. 2013; 59(5): 1045-1061.

[16] Ni D, Li KW, Tang X. Social responsibility allocation in two-echelon supply chains: Insights from wholesale price contracts. European Journal of Operational Research 2010; 207(3): 1269-1279.

[17] Ni D, Li KW. A game-theoretic analysis of social responsibility conduct in two-echelon supply chains. International Journal of Production Economics 2012; 138(2): 303-313.

[18] Hsueh CF. Improving corporate social responsibility in a supply chain through a new revenue sharing contract. International Journal of Production Economics 2014; 151(2): 214-222.

[19] Panda S. Coordination of a socially responsible supply chain using revenue sharing contract. Transportation Research Part E 2014; 67:92-104.

[20] Corbett CJ, Zhou D, Tang CS. Designing supply contracts: contract type and information asymmetry. Management Science 2004; 50(4): 550-559.

[21] Liu X, Cetinkaya S. Designing supply contracts in supplier vs. buyer-driven channels: The impact of leadership, contract flexibility and information asymmetry. IIE Transactions 2009; 41(8): 687-701.

[22] Cachon GP, Zhang F. Procuring fast delivery: sole sourcing with information asymmetry. Management Science 2006; 52(6): 881-896.

[23] Mukhopadhyay SK, Yao DQ, Yue X. Information sharing of value-adding

retailer in a mixed channel hi-tech supply chain. Journal of Business Research 2008; 61(9): 950-958.

[24] Yao D, Yue X, Liu J. Vertical cost information sharing in a supply chain with value-adding retailers. Omega 2008; 36(5): 838-851.

[25] Mukhopadhyay SK, Zhu X, Yue X. Optimal contract design for mixed channels under information asymmetry. Production and Operations Management 2008; 17(6): 641-650.

[26] Mukhopadhyay SK, Su X, Ghose S. Motivating retail marketing effort: optimal contract design. Production and Operations Management 2009; 18(2): 197-211.

[27] Kaya O, Ozer O. Quality risk in outsourcing: non contractible product quality and private quality cost information. Naval Research Logistics 2009; 56 (7): 669-685.

[28] Ozer O, Raz G. Supply chain sourcing under asymmetric information. Production and Operations Management 2011; 20(1): 92-115.

[29] Xu H, Yao N, Tong S. Sourcing under cost information asymmetry when facing time-sensitive customers. International Journal of Production Economics 2013; 144(2): 599-609.

[30] Kim SH, Netessine S. Collaborative cost reduction and component procurement under information asymmetry. Management Science 2013; 59(1):189-206.

[31] Yue X, Mukhopadhyay SK, Zhu X. A Bertrand model of pricing of complementary goods under information asymmetry. Journal of Business Research 2006; 59(10-11): 1182-1192.

[32] Yue X, Raghunathan S. The impacts of the full returns policy on a supply chain with information asymmetry. European Journal of Operational Research 2007; 180(2): 630-647.

[33] Mishra BK, Raghunathan S, Yue X. Information sharing in supply chains: Incentives for information distortion. IIE Transactions 2007; 39(9): 863-877.

[34] Gal-Or E, Geylani T, Dukes AJ. Information sharing in a channel with partially informed retailers. Marketing Science 2008; 27(4): 642-658.

[35] He C, Marklund J, Vossen T. Research note-vertical information sharing in a

volatile market. Marketing Science 2008; 27(3): 513-530.

[36] Gan X, Sethi SP, Zhou J. Commitment-penalty contracts in drop-shipping supply chains with asymmetric demand information. European Journal of Operational Research 2010; 204(3): 449-462.

[37] Babich V, Li H, Ritchken P, Wang Y. Contracting with asymmetric demand information in supply chains. European Journal of Operational Research 2012; 217(2): 313-341.

[38] Li T, Zhang H. Information sharing in a supply chain with a make-to-stock manufacturer. Omega 2015; 50: 115-125.

[39] Bhaskaran SR, Krishnan V. Effort, revenue, and cost sharing mechanisms for collaborative new product development. Management Science 2009; 55(7):1152-1169.

[40] Zhao J, Wei J. The coordinating contracts for a fuzzy supply chain with effort and price dependent demand. Applied Mathematical Modelling 2014; 38: 2476-2489.

Appendix A. Proof of Proposition 1

Recall that $h(\varepsilon)=\frac{1}{2}+\frac{\lambda^2}{8b\varepsilon}\ln\frac{2b(\bar{\xi}+\varepsilon)-\lambda^2}{2b(\bar{\xi}-\varepsilon)-\lambda^2}$, and after taking the first derivative of $E[\Pi_R]_W^{asy*}$ with respect to ε, we find that

$$\frac{\partial E[\Pi_R]_W^{asy*}}{\partial\varepsilon}=\frac{b\eta h'(\varepsilon)[2b^2\eta^2\xi+\gamma^2\eta(2\lambda^2-3b\xi)h(\varepsilon)](a-bc)^2}{(2b\xi-\lambda^2)[2b\eta-\gamma^2h(\varepsilon)]^3}$$

where

$$h'(\varepsilon)=\frac{\lambda^2}{8b\varepsilon^2}\{\frac{4b(2b\bar{\xi}-\lambda^2)\varepsilon}{[2b(\bar{\xi}+\varepsilon)-\lambda^2][2b(\bar{\xi}-\varepsilon)-\lambda^2]}-\ln\frac{2b(\bar{\xi}+\varepsilon)-\lambda^2}{2b(\bar{\xi}-\varepsilon)-\lambda^2}\}.$$

Let $k(\varepsilon)=\frac{4b(2b\bar{\xi}-\lambda^2)\varepsilon}{[2b(\bar{\xi}+\varepsilon)-\lambda^2][2b(\bar{\xi}-\varepsilon)-\lambda^2]}-\ln\frac{2b(\bar{\xi}+\varepsilon)-\lambda^2}{2b(\bar{\xi}-\varepsilon)-\lambda^2}$, then we have

$k(0)=0$ and $k'(\varepsilon)=\dfrac{32b^3(2b\bar{\xi}-\lambda^2)\varepsilon^2}{[2b(\bar{\xi}+\varepsilon)-\lambda^2]^2[2b(\bar{\xi}-\varepsilon)-\lambda^2]^2}>0$. Thus, $k(\varepsilon)>0$ if $0<\varepsilon<\bar{\xi}$. Then, we have $h'(\varepsilon)>0$ if $0<\varepsilon<\bar{\xi}$. Recall that $\dfrac{1}{2}<h(\varepsilon)<\dfrac{2b\eta}{\gamma^2}$; hence we find that $\dfrac{\partial E[\Pi_R]_W^{asy*}}{\partial\varepsilon}>0$ if $2b^2\eta^2\xi+\gamma^2\eta(2\lambda^2-3b\xi)h(\varepsilon)>0$. We therefore find that $\dfrac{1}{2}<h(\varepsilon)<\min\{\dfrac{2b^2\eta\xi}{\gamma^2(3b\xi-2\lambda^2)},\dfrac{2b\eta}{\gamma^2}\}$. Similarly, we find that $\dfrac{\partial E[\Pi_R]_W^{asy*}}{\partial\varepsilon}<0$ if $\dfrac{2b^2\eta\xi}{\gamma^2(3b\xi-2\lambda^2)}<h(\varepsilon)<\dfrac{2b\eta}{\gamma^2}$.

To find the difference between $E[\Pi_R]_W^{sym*}$ and $E[\Pi_R]_W^{asy*}$, we have

$$\Delta E[\Pi_R]=E[\Pi_R]_W^{sym*}-E[\Pi_R]_W^{asy*}$$

$$=\frac{\eta\xi(a-bc)^2}{2(4b\eta\xi-2\lambda^2\eta-\gamma^2\xi)}-\frac{k(\varepsilon)\{2b^2\eta^2\xi-(2b\xi-\lambda^2)\gamma^2\eta h(\varepsilon)\}(a-bc)^2}{2(2b\xi-\lambda^2)\{2b\eta-\gamma^2h(\varepsilon)\}^2},$$

After taking the first derivative of $\Delta E[\Pi_R]$ with respect to ε, we find that

$$\frac{\partial\Delta E[\Pi_R]}{\partial\varepsilon}=-\frac{b\eta h'(\varepsilon)[2b^2\eta^2\xi+\gamma^2\eta(2\lambda^2-3b\xi)h(\varepsilon)](a-bc)^2}{(2b\xi-\lambda^2)[2b\eta-\gamma^2h(\varepsilon)]^3}.$$

Recall that $\dfrac{1}{2}<h(\varepsilon)<\dfrac{2b\eta}{\gamma^2}$. Therefore, $\dfrac{\partial\Delta E[\Pi_R]}{\partial\varepsilon}<0$ is true. $h(\varepsilon)$ must satisfy $2b^2\eta^2\xi+\gamma^2\eta(2\lambda^2-3b\xi)h(\varepsilon)>0$ and $2b\eta-\gamma^2h(\varepsilon)>0$. Thus, we find that $\dfrac{1}{2}<h(\varepsilon)<\min\{\dfrac{2b^2\eta\xi}{\gamma^2(3b\xi-2\lambda^2)},\dfrac{2b\eta}{\gamma^2}\}$. Similarly, $\dfrac{\partial\Delta E[\Pi_R]}{\partial\varepsilon}>0$ if $\dfrac{2b^2\eta\xi}{\gamma^2(3b\xi-2\lambda^2)}<h(\varepsilon)<\dfrac{2b\eta}{\gamma^2}$. After combining the above results, we complete the proof of Proposition 1.■

Appendix B. Proof of Proposition 2

Recall that $h(\varepsilon)=\frac{1}{2}+\frac{\lambda^2}{8b\varepsilon}\ln\frac{2b(\bar{\xi}+\varepsilon)-\lambda^2}{2b(\bar{\xi}-\varepsilon)-\lambda^2}$, and after taking the first derivative of $E[\Pi_{CM}]_W^{asy*}$ with respect to ε, we find that

$$\frac{\partial E[\Pi_{CM}]_W^{asy*}}{\partial\varepsilon}=\frac{b^2(a-bc)^2\gamma^2\eta^2\xi h'(\varepsilon)}{(2b\xi-\lambda^2)[2b\eta-\gamma^2h(\varepsilon)]^3}>0 \text{ if } \frac{1}{2}<h(\varepsilon)<\frac{2b\eta}{\gamma^2}.$$

Then, we compare the values $E[\Pi_{CM}]_W^{sym*}$ and $E[\Pi_{CM}]_W^{asy*}$, producing

$$\Delta E[\Pi_{CM}]=E[\Pi_{CM}]_W^{asy*}-E[\Pi_{CM}]_W^{sym*},$$

$$=\frac{b^2(a-bc)^2\eta^2\xi}{2(2b\xi-\lambda^2)\{2b\eta-\gamma^2h(\varepsilon)\}^2}-\frac{\eta^2\xi(2b\xi-\lambda^2)(a-bc)^2}{2(4b\eta\xi-2\lambda^2\eta-\gamma^2\xi)^2}.$$

After taking the first derivative of $\Delta E[\Pi_{CM}]$ with respect to ε, we have $\frac{\partial\Delta E[\Pi_{CM}]}{\partial\varepsilon}=\frac{b^2(a-bc)^2\gamma^2\eta^2\xi h'(\varepsilon)}{(2b\xi-\lambda^2)[2b\eta-\gamma^2h(\varepsilon)]^3}>0$ if $\frac{1}{2}<h(\varepsilon)<\frac{2b\eta}{\gamma^2}$. ■

Appendix C. Proof of Proposition 4

After taking the first derivative of Eq. (20) with respect to p and e, we have

$$\frac{\partial\Pi_R}{\partial p}=a-2bp+\gamma e+\lambda y+bw=0, \tag{C.1}$$

$$\frac{\partial\Pi_R}{\partial e}=\gamma(p-w)-\eta e=0. \tag{C.2}$$

From Eqs. (C.1)-(C.2), we find that

$$p=w+\frac{\eta(a+\lambda y-bw)}{2b\eta-\gamma^2},\quad e=\frac{\gamma(a+\lambda y-bw)}{2b\eta-\gamma^2}. \tag{C.3}$$

After substituting Eq. (C.3) into Eq. (21), we have

$$\Pi_{CM}=(w-c)\frac{b\eta(a+\lambda y-bw)}{2b\eta-\gamma^2}-\frac{\xi y^2}{2}-F. \tag{C.4}$$

Taking the first derivative of Eq. (C.4) with respect to y, we obtain

$$\frac{\partial \Pi_{CM}}{\partial y} = \frac{\lambda b\eta}{2b\eta-\gamma^2}(w-c) - \xi y = 0, \tag{C.5}$$

Solving Eq. (C.5), we find that

$$y = \frac{\lambda b\eta (w-c)}{2b\eta\xi - \gamma^2\xi}. \tag{C.6}$$

Then, the retailer's problem becomes

$$\max_{w,F} \Pi_R = \frac{\eta}{2(2b\eta-\gamma^2)}[a-bw+\frac{b\lambda^2\eta(w-c)}{2b\eta\xi-\gamma^2\xi}]^2 + F, \tag{C.7}$$

Subject to

$$\Pi_{CM} = \frac{b\eta}{2b\eta-\gamma^2}(w-c)[a-bw+\frac{b\lambda^2\eta(w-c)}{2(2b\eta\xi-\gamma^2\xi)}] - F \geq \bar{\Pi}_{CM}^{sym},$$

where $\bar{\Pi}_{CM}^{sym} = \dfrac{\eta^2\xi(2b\xi-\lambda^2)(a-bc)^2}{2(4b\eta\xi-2\lambda^2\eta-\gamma^2\xi)^2}$ (Table 2).

The CM will accept the contract only if her profit exceeds her reservation profit, normalized to zero. Therefore, we find that

$$F = \frac{b\eta}{2b\eta-\gamma^2}(w-c)[a-bw+\frac{b\lambda^2\eta(w-c)}{2(2b\eta\xi-\gamma^2\xi)}] - \bar{\Pi}_{CM}^{sym}. \tag{C.8}$$

After substituting F into Eq. (C.7), the retailer's objective function becomes

$$\Pi_R = \frac{\eta}{2(2b\eta-\gamma^2)}[a-bw+\frac{b\lambda^2\eta(w-c)}{2b\eta\xi-\gamma^2\xi}]^2$$

$$+\frac{b\eta}{2b\eta-\gamma^2}(w-c)[a-bw+\frac{b\lambda^2\eta(w-c)}{2(2b\eta\xi-\gamma^2\xi)}] - \bar{\Pi}_{CM}^{sym}. \tag{C.9}$$

After taking the first and second derivatives of Eq. (C.9) with respect to *w*, we find that

$$\frac{\partial \Pi_R}{\partial w} = \frac{b\eta(\lambda^2\eta+\gamma^2\xi-2b\eta\xi)}{(2b\eta-\gamma^2)(2b\eta\xi-\gamma^2\xi)}.[a-bw+\frac{b\lambda^2\eta(w-c)}{2b\eta\xi-\gamma^2\xi}]$$

$$+\frac{b\eta}{2b\eta-\gamma^2}[a-bw+\frac{b\lambda^2\eta(w-c)}{2(2b\eta\xi-\gamma^2\xi)}]+\frac{b\eta}{2b\eta-\gamma^2}(w-c).[-b+\frac{b\lambda^2\eta}{2(2b\eta\xi-\gamma^2\xi)}],$$

(C.10)

$$\frac{\partial^2\Pi_R}{\partial w^2}=\frac{b^2\eta(2b\eta\xi-\lambda^2\eta-\gamma^2\xi)\xi}{(2b\eta-\gamma^2)(2b\eta\xi-\gamma^2\xi)^2}+\frac{2b\eta}{2b\eta-\gamma^2}[-b+\frac{b\lambda^2\eta}{2(2b\eta\xi-\gamma^2\xi)}]<0 \tag{C.11}$$

If $\frac{\partial^2\Pi_R}{\partial w^2}<0 \Leftrightarrow 4b^2\eta^2\xi^2+2b\lambda^2\eta^2\xi-4b\gamma^2\eta\xi^2-\lambda^4\eta^2+\gamma^4\xi^2-\lambda^2\gamma^2\eta\xi>0$, then we can solve Eq. $\partial\Pi_R/\partial w=0$ and obtain

$$w_{TPT}^{sym*}=\frac{a\lambda^2\eta(2b\eta\xi-\gamma^2\xi)+bc(2b\eta\xi^2-\gamma^2\xi^2+\lambda^2\eta)(2b\eta-\eta^2\xi-\gamma^2)}{(2b\eta\xi-\gamma^2\xi)(4b^2\eta\xi-2b^2\gamma^2\xi-b^2\lambda^2\eta)+\eta b(2b\eta\xi^2-\lambda^2\eta)}, \tag{C.12}$$

$$F_{TPT}^{sym*}=\frac{b\eta}{2b\eta-\gamma^2}(w_{TPT}^{sym*}-c)[a-bw_{TPT}^{sym*}+\frac{b\lambda^2\eta(w_{TPT}^{sym*}-c)}{2(2b\eta\xi-\gamma^2\xi)}]-\bar{\Pi}_{CM}^{sym}. \tag{C.13}$$

We thus complete the proof of Proposition 4.■

Appendix D. Wholesale Price Contract under CM Competition

Define the demand function as:

$$D_i=a-\delta p_i+\beta p_j+\gamma e+y_i-\theta y_j \tag{D.1}$$

where $D_i\geq 0$, θ measures the competitive intensity of CSR efforts in the market and $\theta<1$. The parameter δ denotes the demand responsiveness to the firm's own price, while β denotes the demand responsiveness to the competitor's price and y_i is the CSR effort level of CM_i (i=1,2).

From Eq. (D.1), we have $D_1=a-\delta p_1+\beta p_2+\gamma e+y_1-\theta y_2$ and $D_2=a-\delta p_2+\beta p_1+\gamma e+y_2-\theta y_1$. Let c_i and w_i ($i=1,2$) be the CMi's unit production cost and wholesale price, respectively. The profits of CM1, CM2 and the retailer are as follows:

$$\Pi_{CM1} = (w_1 - c_1)(a - \delta p_1 + \beta p_2 + \gamma e + y_1 - \theta y_2) - \frac{\xi_1 y_1^2}{2}, \tag{D.2}$$

$$\Pi_{CM2} = (w_2 - c_2)(a - \delta p_2 + \beta p_1 + \gamma e + y_2 - \theta y_1) - \frac{\xi_2 y_2^2}{2}, \tag{D.3}$$

$$\begin{aligned} \Pi_R &= (p_1 - w_1)D_1 + (p_2 - w_2)D_2 - \frac{\eta e^2}{2}, \\ &= (p_1 - w_1)(a - \delta p_1 + \beta p_2 + \gamma e + y_1 - \theta y_2) \\ &\quad + (p_2 - w_2)(a - \delta p_2 + \beta p_1 + \gamma e + y_2 - \theta y_1) - \frac{\eta e^2}{2}. \end{aligned} \tag{D.4}$$

Using the same assumptions as in Sections E2 and E3 in Appendix E and the methods in Section 3, we can obtain the optimal parameters for the contract under the asymmetric information case (i.e., vertical information sharing between the CM and the retailer; no vertical information sharing between the CM and the retailer). Because our paper focuses on a dominant retailer (e.g., Apple) and a TPT contract, we investigate CM competition under the TPT contract in which the retailer is the leader of the SC. In other words, Appendix D is the extension of Section 3, and Appendix E is the extension of Section 4, while the main text focuses on the TPT contract.

Appendix E. TPT Contract under CM Competition

We now extend the model to address the competition case. We design a SC contract with two competing CMs exerting CSR efforts under the full and asymmetric information cases.

Similar to the earlier discussion, we assume that CM1 and CM2 are Stackelberg followers, while the retailer is the Stackelberg leader (Fig. E.1). Let Π_{CM1}, Π_{CM2} and Π_R be the profits of CM1, CM2, and the retailer, respectively. Because each CM may or may not be willing to reveal his cost information to the retailer, we face three scenarios:

(1) Both of the CMs will share information with the retailer;
(2) One of the CMs will share information with the retailer;
(3) Neither CM will share information with the retailer.

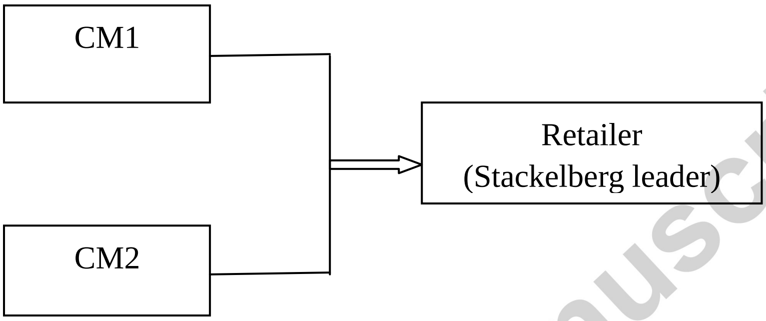

Fig. E.1. Model with two competitive CMs

E1. The case of vertical information sharing (symmetric)

We assume that the demand function is as follows:

$$D_i = a - bp + \gamma e + y_i - \theta y_j \,, \tag{E.1}$$

where $D_i \geq 0$ and θ measures the CSR effort competitive intensity in the market and $\theta < 1$; while y_i is the CSR effort level of CM_i (i=1,2).

From Eq. (E.1), we have $D_1 = a - bp + \gamma e + y_1 - \theta y_2$ and $D_2 = a - bp + \gamma e + y_2 - \theta y_1$. The profits of CM1, CM2 and the retailer are as follows:

$$\Pi_{CM1} = (w - c_1)(a - bp + \gamma e + y_1 - \theta y_2) - \frac{\xi_1 y_1^2}{2} - F_1, \tag{E.2}$$

$$\Pi_{CM2} = (w - c_2)(a - bp + \gamma e + y_2 - \theta y_1) - \frac{\xi_2 y_2^2}{2} - F_2, \quad \text{(E.3)}$$

$$\Pi_R = (p - w)(D_1 + D_2) - \frac{\eta e^2}{2} + F_1 + F_2,$$

$$= (p - w)[2(a - bp + \gamma e) + (1-\theta)(y_1 + y_2)] - \frac{\eta e^2}{2} + F_1 + F_2. \quad \text{(E.4)}$$

After taking the first derivative of Eq. (E.4) with respect to p and e, we find that

$$e^* = \frac{2\gamma(a - bw) + (1-\theta)\gamma(y_1 + y_2)}{2(b\eta - \gamma^2)}, \quad \text{(E.5)}$$

$$p^* = w + \frac{2\eta(a - bw) + (1-\theta)\eta(y_1 + y_2)}{4(b\eta - \gamma^2)}. \quad \text{(E.6)}$$

After substituting Eqs. (E.5)-(E.6) into Eq. (E.2), we have

$$\Pi_{CM1} = (w - c_1)[\frac{b\eta(a - bw)}{2(b\eta - \gamma^2)} + \frac{(1-\theta)(y_1 + y_2)(2\gamma^2 - b\eta)}{4(b\eta - \gamma^2)} + y_1 - \theta y_2] - \frac{\xi_1 y_1^2}{2} - F_1. \quad \text{(E.7)}$$

Taking the first derivative of Eq. (E.7) with respect to y_1 and assigning it to 0, we obtain

$$\frac{\partial \Pi_{CM1}}{\partial y_1} = [\frac{(1-\theta)(2\gamma^2 - b\eta)}{4(b\eta - \gamma^2)} + 1](w - c_1) - \xi_1 y_1 = 0, \quad \text{(E.8)}$$

Solving Eq. (E.8), we find

$$y_1^* = \frac{w - c_1}{\xi_1}[\frac{(1-\theta)(2\gamma^2 - b\eta)}{4(b\eta - \gamma^2)} + 1]. \quad \text{(E.9)}$$

Similarly, we find

$$y_2^* = \frac{w - c_2}{\xi_2}[\frac{(1-\theta)(2\gamma^2 - b\eta)}{4(b\eta - \gamma^2)} + 1]. \quad \text{(E.10)}$$

Denoting $\kappa_1 = \frac{(1-\theta)(2\gamma^2 - b\eta)}{4(b\eta - \gamma^2)} + 1$ and $\kappa_2 = \frac{(1-\theta)(2\gamma^2 - b\eta)}{4(b\eta - \gamma^2)} - \theta$. After substituting Eqs. (E.9)-(E.10) into Eqs. (E.2)-(E.3), we obtain

$$\Pi_{CM1} = (w-c_1)[\frac{b\eta(a-bw)}{2(b\eta-\gamma^2)} + \frac{\kappa_1^2(w-c_1)}{\xi_1} + \frac{\kappa_1\kappa_2(w-c_2)}{\xi_2}] - \frac{\kappa_1^2(w-c_1)^2}{2\xi_1} - F_1, \quad (E.11)$$

$$\Pi_{CM2} = (w-c_2)[\frac{b\eta(a-bw)}{2(b\eta-\gamma^2)} + \frac{\kappa_1^2(w-c_2)}{\xi_2} + \frac{\kappa_1\kappa_2(w-c_1)}{\xi_1}] - \frac{\kappa_1^2(w-c_2)^2}{2\xi_2} - F_2. \quad (E.12)$$

Let CM1 and CM2's reservation profits be $\bar{\Pi}_{CM1}$ and $\bar{\Pi}_{CM2}$, respectively. Assume that the CMs will accept the contract if their expected profits are greater than their respective reservation profits. Combining Eqs. (E.11) and (E.12), we find

$$F_1 = (w-c_1)[\frac{b\eta(a-bw)}{2(b\eta-\gamma^2)} + \frac{\kappa_1^2(w-c_1)}{\xi_1} + \frac{\kappa_1\kappa_2(w-c_2)}{\xi_2}] - \frac{\kappa_1^2(w-c_1)^2}{2\xi_1} - \bar{\Pi}_{CM1}, \quad (E.13)$$

$$F_2 = (w-c_2)[\frac{b\eta(a-bw)}{2(b\eta-\gamma^2)} + \frac{\kappa_1^2(w-c_2)}{\xi_2} + \frac{\kappa_1\kappa_2(w-c_1)}{\xi_1}] - \frac{\kappa_1^2(w-c_2)^2}{2\xi_2} - \bar{\Pi}_{CM2}. \quad (E.14)$$

After substituting Eqs. (E.13)-(E.14) into Eq. (E.4), we obtain

$$\Pi_R = \frac{2\eta(a-bw)+(1-\theta)\eta(y_1+y_2)}{4(b\eta-\gamma^2)}[\frac{b\eta(a-bw)}{b\eta-\gamma^2} + \frac{b\eta(1-\theta)}{2(b\eta-\gamma^2)}(y_1+y_2)]$$

$$-\frac{\eta}{2}\cdot\frac{[2\gamma(a-bw)+(1-\theta)\gamma(y_1+y_2)]^2}{4(b\eta-\gamma^2)^2} + F_1 + F_2 - \bar{\Pi}_{CM1} - \bar{\Pi}_{CM2}. \quad (E.15)$$

Let $\Delta(\xi_1,\xi_2) = \frac{\kappa_1}{\xi_1} + \frac{\kappa_1}{\xi_2}$. After taking the first derivative of Eq. (E.15) and assigning it to 0, we have

$$\frac{\partial \Pi_R}{\partial w} = \frac{-2b\eta+(1-\theta)\eta\Delta(\xi_1,\xi_2)}{4(b\eta-\gamma^2)}[\frac{b\eta(a-bw)}{b\eta-\gamma^2} + \frac{b\eta(1-\theta)}{2(b\eta-\gamma^2)}(y_1+y_2)]$$

$$+\frac{2\eta(a-bw)+(1-\theta)\eta(y_1+y_2)}{4(b\eta-\gamma^2)}[-\frac{b^2\eta}{b\eta-\gamma^2} + \frac{b\eta(1-\theta)\Delta(\xi_1,\xi_2)}{2(b\eta-\gamma^2)}]$$

$$-\frac{\eta[2\gamma(a-bw)+(1-\theta)\gamma(y_1+y_2)]}{4(b\eta-\gamma^2)^2}[-2\gamma b+(1-\theta)\gamma\Delta(\xi_1,\xi_2)]$$

$$+\frac{b\eta(a-bw)}{2(b\eta-\gamma^2)} + (w-c_1)[-\frac{b^2\eta}{2(b\eta-\gamma^2)} + \frac{\kappa_1^2}{\xi_1} + \frac{\kappa_1\kappa_2}{\xi_2}] + \frac{\kappa_1\kappa_2}{\xi_2}(w-c_2)$$

$$+\frac{b\eta(a-bw)}{2(b\eta-\gamma^2)} + (w-c_2)[-\frac{b^2\eta}{2(b\eta-\gamma^2)} + \frac{\kappa_1^2}{\xi_2} + \frac{\kappa_1\kappa_2}{\xi_1}] + \frac{\kappa_1\kappa_2}{\xi_1}(w-c_1) = 0. \quad (E.16)$$

We can rewrite Eq. (E.16) as follows:

$$\frac{\partial \Pi_R}{\partial w} = \frac{\eta(1-\theta)\Delta(\xi_1,\xi_2)}{2(b\eta-\gamma^2)}(a-bw)$$

$$+(w-c_1)[\frac{-b^2\eta}{2(b\eta-\gamma^2)} + \frac{\kappa_1\kappa_2}{\xi_2} + \frac{\kappa_1^2}{\xi_1} + \frac{\kappa_1\kappa_2}{\xi_1} - \frac{\kappa_1 b\eta(1-\theta)}{2(b\eta-\gamma^2)\xi_1} + \frac{\kappa_1\eta(1-\theta)^2\Delta(\xi_1,\xi_2)}{4(b\eta-\gamma^2)\xi_1}]$$

$$+(w-c_2)[\frac{-b^2\eta}{2(b\eta-\gamma^2)} + \frac{\kappa_1\kappa_2}{\xi_1} + \frac{\kappa_1^2}{\xi_2} + \frac{\kappa_1\kappa_2}{\xi_2} - \frac{\kappa_1 b\eta(1-\theta)}{2(b\eta-\gamma^2)\xi_2} + \frac{\kappa_1\eta(1-\theta)^2\Delta(\xi_1,\xi_2)}{4(b\eta-\gamma^2)\xi_2}] = 0.$$

(E.17)

Let

$$A = \frac{\eta(1-\theta)\Delta(\xi_1,\xi_2)}{2(b\eta-\gamma^2)},$$

$$B = \frac{-b^2\eta}{2(b\eta-\gamma^2)} + \frac{\kappa_1\kappa_2}{\xi_2} + \frac{\kappa_1^2}{\xi_1} + \frac{\kappa_1\kappa_2}{\xi_1} - \frac{\kappa_1 b\eta(1-\theta)}{2(b\eta-\gamma^2)\xi_1} + \frac{\kappa_1\eta(1-\theta)^2\Delta(\xi_1,\xi_2)}{4(b\eta-\gamma^2)\xi_1},$$

$$C = \frac{-b^2\eta}{2(b\eta-\gamma^2)} + \frac{\kappa_1\kappa_2}{\xi_1} + \frac{\kappa_1^2}{\xi_2} + \frac{\kappa_1\kappa_2}{\xi_2} - \frac{\kappa_1 b\eta(1-\theta)}{2(b\eta-\gamma^2)\xi_2} + \frac{\kappa_1\eta(1-\theta)^2\Delta(\xi_1,\xi_2)}{4(b\eta-\gamma^2)\xi_2}.$$

From Eq. (E.17), we have

$$w^* = \frac{aA - c_1B - c_2C}{bA - B - C}.$$

In summary, we find that the contract parameters (w^*, F_1^*) and (w^*, F_2^*) under CSR competition are:

$$w^* = \frac{aA - c_1B - c_2C}{bA - B - C},$$

$$F_1 = (w^*-c_1)[\frac{b\eta(a-bw^*)}{2(b\eta-\gamma^2)} + \frac{\kappa_1^2(w^*-c_1)}{\xi_1} + \frac{\kappa_1\kappa_2(w^*-c_2)}{\xi_2}] - \frac{\kappa_1^2(w^*-c_1)^2}{2\xi_1} - \bar{\Pi}_{CM1},$$

$$F_2 = (w^*-c_2)[\frac{b\eta(a-bw^*)}{2(b\eta-\gamma^2)} + \frac{\kappa_1^2(w^*-c_2)}{\xi_2} + \frac{\kappa_1\kappa_2(w^*-c_1)}{\xi_1}] - \frac{\kappa_1^2(w^*-c_2)^2}{2\xi_2} - \bar{\Pi}_{CM2}.$$

E2. Vertical information sharing between one CM and the retailer

Without loss of generality, we assume that CM1 decides to share information with the retailer, i.e., the retailer has full knowledge of CM1's cost structure ξ_1. We assume that ξ_2 follows a uniform distribution, i.e., $\xi_2 \sim U[\bar{\xi}-\varepsilon_2, \bar{\xi}+\varepsilon_2]$, $g_2(\xi)=\frac{1}{2\varepsilon_2}$, $0<\varepsilon_2<\bar{\xi}$. Thus, the objective of the retailer is to find the optimal wholesale price to maximize his expected profit

$$\max_w E[\Pi_R]=\int_{\bar{\xi}_2-\varepsilon_2}^{\bar{\xi}_2+\varepsilon_2}\{\frac{2\eta(a-bw)+(1-\theta)\eta(y_1+y_2)}{4(b\eta-\gamma^2)}[\frac{b\eta(a-bw)}{b\eta-\gamma^2}+\frac{b\eta(1-\theta)}{2(b\eta-\gamma^2)}(y_1+y_2)]$$

$$-\frac{\eta}{2}.\frac{[2\gamma(a-bw)+(1-\theta)\gamma(y_1+y_2)]^2}{4(b\eta-\gamma^2)^2}+F_1+F_2\}f(\xi_2)d\xi_2. \quad \text{(E.18)}$$

Proposition E1. If CM1 discloses his cost information to the retailer, then the optimal TPT contract (w, F_1, F_2) is given as

$$w^*=\frac{aA_1-A_2c_1-A_3c_2}{bA_1-A_2-A_3},$$

$$E[F_1]=(w^*-c_1)[\frac{b\eta(a-bw^*)}{2(b\eta-\gamma^2)}+\frac{\kappa_1^2(w^*-c_1)}{\xi_1}+\kappa_1\kappa_2(w^*-c_2)\ln\frac{\bar{\xi}+\varepsilon_2}{\bar{\xi}-\varepsilon_2}]-\frac{\kappa_1^2(w^*-c_1)^2}{2\xi_1},$$

$$E[F_2]=(w^*-c_2)[\frac{b\eta(a-bw^*)}{2(b\eta-\gamma^2)}+\kappa_1^2(w^*-c_2)\ln\frac{\bar{\xi}+\varepsilon_2}{\bar{\xi}-\varepsilon_2}+\frac{\kappa_1\kappa_2(w^*-c_1)}{\xi_1}]$$

$$-\frac{\kappa_1^2(w^*-c_2)^2}{2}\ln\frac{\bar{\xi}+\varepsilon_2}{\bar{\xi}-\varepsilon_2},$$

where

$$A_1=\frac{\eta(1-\theta)}{2(b\eta-\gamma^2)}(\frac{\kappa_1}{\xi_1}+\kappa_1\ln\frac{\bar{\xi}+\varepsilon_2}{\bar{\xi}-\varepsilon_2}),$$

$$A_2=-\frac{b^2\eta}{2(b\eta-\gamma^2)}+\kappa_1\kappa_2\ln\frac{\bar{\xi}+\varepsilon_2}{\bar{\xi}-\varepsilon_2}+\frac{\kappa_1^2+\kappa_1\kappa_2}{\xi_1}-\frac{\kappa_1 b\eta(1-\theta)}{2(b\eta-\gamma^2)\xi_1}(\frac{\kappa_1}{\xi_1}+\kappa_1\ln\frac{\bar{\xi}+\varepsilon_2}{\bar{\xi}-\varepsilon_2}),$$

$$A_3=-\frac{b^2\eta}{2(b\eta-\gamma^2)}+\frac{\kappa_1\kappa_2}{\xi_1}+(\kappa_1\kappa_2+\kappa_1^2)\ln\frac{\bar{\xi}+\varepsilon_2}{\bar{\xi}-\varepsilon_2}-\frac{\kappa_1 b\eta(1-\theta)}{2(b\eta-\gamma^2)}\ln\frac{\bar{\xi}+\varepsilon_2}{\bar{\xi}-\varepsilon_2}$$

$$+\frac{\kappa_1\eta(1-\theta)^2}{4(b\eta-\gamma^2)}[\frac{\kappa_1}{\xi_1}\ln\frac{\bar{\xi}+\varepsilon_2}{\bar{\xi}-\varepsilon_2}+\kappa_1(-\frac{1}{\bar{\xi}+\varepsilon_2}+\frac{1}{\bar{\xi}-\varepsilon_2})].$$

Proof. This proof is similar to that of Proposition 4 and is thus omitted here.

E3. No Vertical information sharing between the CMs and the retailer

In this case, we assume that ξ_1 follows a uniform distribution. Suppose there is no information sharing between the retailer and any CM. The retailer's objective is to find the optimal contract parameters (w, F_1, F_2) that maximize his expected profit, i.e.,

$$\max_w E[\Pi_R] = \iint_{\substack{\xi_1 \in [\bar{\xi}-\varepsilon_1, \bar{\xi}+\varepsilon_1] \\ \xi_2 \in [\bar{\xi}-\varepsilon_2, \bar{\xi}+\varepsilon_2]}} \{ \frac{2\eta(a-bw)+(1-\theta)\eta(y_1+y_2)}{4(b\eta-\gamma^2)} [\frac{b\eta(a-bw)}{b\eta-\gamma^2} + \frac{b\eta(1-\theta)}{2(b\eta-\gamma^2)}(y_1+y_2)]$$

$$-\frac{\eta}{2} \cdot \frac{[2\gamma(a-bw)+(1-\theta)\gamma(y_1+y_2)]^2}{4(b\eta-\gamma^2)^2} + F_1 + F_2 \} f(\xi_1) f(\xi_2) d\xi_1 d\xi_2$$

Accordingly, we have Proposition E2 below.

Proposition E2. If neither CM1 nor CM2 discloses their cost information to the retailer, then the optimal TPT contract (w, F_1, F_2) is given as

$$w^* = \frac{aB_1 - B_2c_1 - B_3c_2}{bB_1 - B_2 - B_3},$$

$$E[F_1] = (w^* - c_1)[\frac{b\eta(a-bw^*)}{2(b\eta-\gamma^2)} + \kappa_1^2 (w^* - c_1) \ln\frac{\bar{\xi}+\varepsilon_1}{\bar{\xi}-\varepsilon_1} + \kappa_1\kappa_2 (w^* - c_2) \ln\frac{\bar{\xi}+\varepsilon_2}{\bar{\xi}-\varepsilon_2}]$$

$$-\frac{\kappa_1^2 (w^* - c_1)^2}{2} \ln\frac{\bar{\xi}+\varepsilon_1}{\bar{\xi}-\varepsilon_1},$$

$$E[F_2] = (w - c_2)[\frac{b\eta(a-bw)}{2(b\eta-\gamma^2)} + \kappa_1^2 (w - c_2) \ln\frac{\bar{\xi}+\varepsilon_2}{\bar{\xi}-\varepsilon_2} + \kappa_1\kappa_2 (w - c_1) \ln\frac{\bar{\xi}+\varepsilon_1}{\bar{\xi}-\varepsilon_1}]$$

$$-\frac{\kappa_1^2 (w - c_2)^2}{2} \ln\frac{\bar{\xi}+\varepsilon_2}{\bar{\xi}-\varepsilon_2},$$

where

$$B_1 = \frac{\eta(1-\theta)}{2(b\eta-\gamma^2)}(\kappa_1 \ln\frac{\bar{\xi}+\varepsilon_1}{\bar{\xi}-\varepsilon_1} + \kappa_1 \ln\frac{\bar{\xi}+\varepsilon_2}{\bar{\xi}-\varepsilon_2}),$$

$$B_2 = -\frac{b^2\eta}{2(b\eta-\gamma^2)} + \kappa_1\kappa_2 \ln\frac{\bar{\xi}+\varepsilon_2}{\bar{\xi}-\varepsilon_2} + (\kappa_1^2+\kappa_1\kappa_2)\ln\frac{\bar{\xi}+\varepsilon_1}{\bar{\xi}-\varepsilon_1} - \frac{\kappa_1 b\eta(1-\theta)}{2(b\eta-\gamma^2)}\ln\frac{\bar{\xi}+\varepsilon_1}{\bar{\xi}-\varepsilon_1}$$

$$+\frac{\kappa_1\eta(1-\theta)^2}{4(b\eta-\gamma^2)}(-\frac{\kappa_1}{\bar{\xi}+\varepsilon_1} + \frac{\kappa_1}{\bar{\xi}-\varepsilon_1} + \kappa_1 \ln\frac{\bar{\xi}+\varepsilon_1}{\bar{\xi}-\varepsilon_1}\ln\frac{\bar{\xi}+\varepsilon_2}{\bar{\xi}-\varepsilon_2}),$$

$$B_3 = -\frac{b^2\eta}{2(b\eta-\gamma^2)} + \kappa_1\kappa_2 \ln\frac{\bar{\xi}+\varepsilon_1}{\bar{\xi}-\varepsilon_1} + (\kappa_1\kappa_2+\kappa_1^2)\ln\frac{\bar{\xi}+\varepsilon_2}{\bar{\xi}-\varepsilon_2} - \frac{\kappa_1 b\eta(1-\theta)}{2(b\eta-\gamma^2)}\ln\frac{\bar{\xi}+\varepsilon_2}{\bar{\xi}-\varepsilon_2}$$

$$+\frac{\kappa_1\eta(1-\theta)^2}{4(b\eta-\gamma^2)}[\kappa_1 \ln\frac{\bar{\xi}+\varepsilon_1}{\bar{\xi}-\varepsilon_1}\ln\frac{\bar{\xi}+\varepsilon_2}{\bar{\xi}-\varepsilon_2} + \kappa_1(-\frac{1}{\bar{\xi}+\varepsilon_2} + \frac{1}{\bar{\xi}-\varepsilon_2})].$$

Proof. This proof is similar to that of Proposition 4 and is thus omitted here.

Proposition E2 gives the optimal contract parameters when no information is shared between the CMs and the retailer. The contract parameters w, F_1 and F_2 in Proposition E2 contain the random terms ε_1 and ε_2, which increase the complexity of the contract design. These terms show that without vertical information, collaboration between SC members is greatly compromised because the contract is complex and difficult to implement. It is therefore crucial that SC members share information, such as the proposals in §E1 and §E2.

Research Highlights

- Study corporate social responsibility and asymmetric cost information
- Design supply chain contract facing CSR-effort dependent demand
- Research the impact of CSR cost on SC members' effort-commitment and profits
- Examine the value of cost information sharing
- Motivate CMs to enhance CSR efforts