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RESEARCH ARTICLE

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Who will undertake corporate social responsibility in supply chain encroachment? Manufacturer or retailer

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Abstract

As the sustainable economy has become more of a consensus, supply chain members, both manufacturer (e.g., Apple, Huawei, Xiaomi, Nike, and P&G) and retailer (e.g., Uniqlo, Walmart, and Bravo), are concentrated on corporate social responsibility (CSR). The literature in this area has investigated the role of CSR, but the optimal preference for CSR concern of supply chain members is not well understood, especially when manufacturer sells directly by implementing encroachment. This paper studies the optimal preference for CSR concern of supply chain members with considering manufacturer encroachment. We develop the supply chain with a manufacturer (M) and a retailer (R), where the manufacturer sells products via a retail channel which in turn sells them to the final consumers. The manufacturer can also implement encroachment to meet consumers directly. Meanwhile, by considering the manufacturer or retailer may have CSR concern, we explore four scenarios using a game-theoretic framework. Several interesting findings are as follows. First, for the sake of profits, retailer CSR should be encouraged, which may achieve Pareto improvement under certain conditions. Notably, manufacturer encroachment may narrow the "win–win" situation. While for the sake of environmental protection and consumer well-being, manufacturer CSR should be encouraged. Second, manufacturer implementing encroachment may not be blind, because it may be worse for itself when retailer has CSR concern. Third, manufacturer CSR may aggravate the cannibalization effect of encroaching, while retailer CSR may relieve it.

1 | INTRODUCTION

Corporate social responsibility (CSR), as a concept in which firms consider the profits of stakeholders, has already been accepted as a corporate behavioral code and may help firms gain more advantage (Kumar et al., 2021). As the globalization activities have expanded over the past few decades, the integration of CSR into supply chain management has begun to gain attention (Ni et al., 2010; Panda, 2014; Panda et al., 2017). As of 2022, 95% and 65% of N100 companies in the United Kingdom and Australia have declared CSR reports (KPMG, 2022).

In reality, CSR not only helps firms develop better relationships with stakeholders but also lowers the risks of business operations and increases corporate value (Albuquerque et al., 2019; Modak et al., 2019). For the perspective of supply chain members, both manufacturer (e.g., Huawei, Apple, Xiaomi, Nike, and P&G) and retailer (e.g., Uniqlo, Walmart, and Bravo) are concentrated on CSR. For example, Hongxing Erke Industrial Co. Ltd. donated 50 million RMB to

flood relief in the Henan Province of China, which improved consumer awareness of the brand valuation, leading to greater revenue. In addition, since the outbreak of the COVID-19, manufacturers, like Huawei and Xiaomi, and retailers, such as Bravo, Walmart, RT-Mall, and Metro, have been at the forefront of securing supplies to help the public tide over the difficult time. In the 1970s, researchers had begun to recognize the importance of evaluating and diagnosing social issues in order to enhance corporate social performance (Carroll, 1979).

To further broaden the market, manufacturers have begun to implement encroachment, which has been quite common in recent years (Zhang et al., 2019). In addition to selling their products through retailers (e.g., Huawei, Apple, and Xiaomi through Suning, GOME, and Five Star and P&G and Unilever through Walmart), manufacturers are able to distribute their products via third-party retail stores as effectively as their own websites, e-commerce platforms like JD and T-mall, or brick and mortar stores (Zhang et al., 2023). The phenomenon of manufacturer encroachment exists for many industries and, in particular, for manufacturers of sophisticated electronic equipment (e.g., Huawei, Apple, and Xiaomi) and some fashion brands (e.g., Hongxing Erke, Coach, and Nike). For example, Huawei, Apple, and Xiaomi sell products both through physical stores and e-commerce platforms (e.g., JD, T-mall, and PDD). The manufacturer encroachment may result in competition with downstream retailer (Arya et al., 2007). It is commonly acknowledged that the involvement of a manufacturer in the retail space is a potentially severe threat to the incumbent retailer (Xia & Niu, 2020).

Despite a large amount of research exploring the CSR concern and manufacturer encroachment, respectively, fewer studies have explored the optimal preference for CSR concern of supply chain members considering manufacturer encroachment and no-encroachment. In reality, both manufacturer (e.g., P&G, Unilever, Adidas, Nike, Huawei, and Xiaomi) and retailer (e.g., Walmart, Suning, and GOME) have begun to focus on social responsibility. Meantime, manufacturer implementing encroachment, like Huawei, Apple, and Xiaomi, is commonly seen in practice. Inspired by real-world business observations and the research gap, we expand the previous research on CSR concern (He et al., 2019; Modak et al., 2014; Wang & Li, 2021; Ying et al., 2023) and manufacturer encroachment (Arya et al., 2007; Guan et al., 2020; Ha et al., 2016; Huang et al., 2018; Wang et al., 2021) to further reveal the effect of firms with CSR concern and manufacturer encroachment. We strive to address the following issues:

1. How does the CSR concern and manufacturer encroachment affect the equilibrium results?
2. Who (manufacturer or retailer) might benefit from undertaking CSR under the cases with and without encroachment? How does different CSR levels affect equilibrium results?
3. Which case should the manufacturer encroach? What is the impact of manufacturer encroachment on the environment and consumer surplus in cases of manufacturer CSR or retailer CSR?

To address these questions, we construct a supply chain comprising a manufacturer and a retailer. The manufacturer has the option to sell directly in addition to selling through the resale channel. Meanwhile, manufacturer or retailer may consider undertaking CSR. Here, four scenarios are be found: (a) manufacturer no-encroachment and manufacturer with CSR concern (NM), for example, A&T, a worldwide manufacturer in sanitary ware industry, resells its products to J.ZAO[1] and owns CSR concern[2]; (b) manufacturer no-encroachment and retailer with CSR concern (NR), for example, New ASIA, a well-known clothing production firm in China, resells its clothes to Uniqlo who owns CSR concern[3,4]; (c) manufacturer encroachment and manufacturer with CSR concern (EM), for example, Huawei not only resells its products to Five Star owning CSR concern[5] but also sells directly by its physical store and several e-commerce platforms[6]; and (d) manufacturer encroachment and retailer with CSR concern (ER), for example, Ikide, an innovative water purifier manufacturer, not only resells products to Sunning who owns CSR concern[7] but also sells directly by T-mall and JD.[8] Our analysis will be as follows. We first study equilibriums including wholesale price, sales quantity of direct and retail channels, the profits, consumer surplus, and total emissions under each scenario. Then, we discuss the impact of CSR level on equilibrium results. Finally, by comparing equilibriums under four scenarios, we derive the circumstances under which manufacturer or retailer should undertake CSR and manufacturer should implement encroachment. Based on that, we illuminate some enlightening aspects.

Our contributions to the literature and practice are threefold. First, although literatures to date have examined CSR concern and manufacturer encroachment independently, we both focus on these two topics. Second, this is the first study to investigate the questions that manufacturer or retailer who is better for undertaking CSR under the cases with and without encroachment and which case should the manufacturer encroach. Third, based on the reality of supply chain members undertake CSR and manufacturer encroachment, we introduce the CSR concern in supply chain encroachment to reveal a number of interesting new findings and managerial implications.

The remaining parts of this paper are arranged as follows. In the next section, we present a review of the relevant literature and underline our creative points. In Section 3, we provide a detailed description of the research questions, notations, and assumptions. In Section 4, we establish four scenarios to disuse the optimal preference for CSR concern of supply chain members considering manufacturer encroachment and no-encroachment. Then, we analyze the impacts of CSR level on the equilibrium results. We explore the effect of CSR concern and manufacturer encroachment in Section 5. Finally, we summarize the main results and provide some managerial insights in Section 6. All proofs can be found in the appendices.

2 | RELATED LITERATURE

This paper is associated with both streams of corporate social responsibility (CSR) and manufacturer encroachment literature. To highlight our contributions, Table 1 summarizes the main findings and highlights the linkages between our study and existing studies.

TABLE 1 Differences between the prior analytic studies and this paper.

Literature	CSR concern		Manufacturer encroachment	Consumer surplus	Environment impact
	Manufacturer CSR	Retailer CSR			
Arya et al. (2007)			√	√	
Modak et al. (2014)	√			√	
Panda (2014)		√		√	
Ha et al. (2016)			√	√	
Panda et al. (2017)	√			√	
Zheng et al. (2019)			√		√
Wang and Li (2021)		√	√	√	
Ma (2021)	√	√		√	
Ying et al. (2023)	√			√	
Zhang et al. (2023)			√	√	
This paper	√	√	√	√	√

2.1 | Corporate social responsibility (CSR)

Our research is related to the literature on the application of corporate social responsibility (CSR) in supply chain management. CSR literature has been growing with the growth of stakeholder concerns about the social performance of companies becoming increasingly popular. The entry of CSR may change the interaction of market players. For an earlier review of CSR conception, please refer to Frederick (1987). Most studies focus on the supply chain members' CSR strategy, that is, CSR concern (He et al., 2019; Liu & Xiao, 2019; Modak et al., 2014, 2019; Panda et al., 2015, 2017; Wang et al., 2021; Wang & Li, 2021; Ying et al., 2023), CSR investment (Arya & Mittendorf, 2015; Liu et al., 2019, 2021; Ma et al., 2017; Modak et al., 2019; Ni & Li, 2012; Wu et al., 2017, 2020; Yan et al., 2023), CSR sharing (Hsueh & Chang, 2008; Ni et al., 2010; Syed Asif Raza, 2018), and CSR affect (Nie et al., 2019; Yan et al., 2021). Our work uses consumer surplus to measure the CSR of manufacturer and retailer, corelated with the first issue. Previous literature on CSR concern mainly occurred in different aspects. Panda et al. (2015) consider a three-echelon supply chain with manufacturers undertaking CSR and propose a bargaining contract to solve channel conflicts. Modak et al. (2019) establish a closed-loop supply chain that includes third-party recyclers and examines the impact of manufacturer's corporate social responsibility concern on product recycling. Wang and Li (2021) build a supply chain consisting of an encroaching supplier and a dual-proposed retailer and study the feasibility of dual-proposed retailer as an anti-encroachment strategy. Ying et al. (2023) construct an infinitely repeated game with a penalty mechanism, focusing on the impact of retailers' CSR behaviors on supply chain cooperation.

Our paper is mainly expanded from the related literature of the first issue. Compared with that, they only try to discuss the effect of CSR on supply chain. Whereas considering the two cases of manufacturer encroachment and no-encroachment, manufacturer or retailer who is better for undertaking CSR might be a worthy issue to address.

2.2 | Manufacturer encroachment

Our research is also related to the literature on supply chain encroachment. Nowadays, to gain access to more customers, many manufacturers use several channels of distribution, including direct channel. However, direct selling complicates the relationship between manufacturer and retailer (Guan et al., 2019; Li & Jiang, 2019; Yao et al., 2022; Zheng et al., 2019). Some researchers show that supplier encroachment is always worse for the retailer. In particular, Ha et al. (2016) show that the effect on the retailer may always be adverse if defining quality as an endogenous variable. Liu and Zhang (2006) suggest that manufacturers will benefit from encroachment strategies at the expense of retailers, while Yang et al. (2018) explore the simple supply chain consisting of a supplier and a retailer. The results of their study suggest that the retailer is consistently harmed by the encroachment capability of their suppliers, even after the introduction of an inactive direct channel. On the other hand, some studies show that encroachment may benefit the retailer (Bell et al., 2003; Blair & Lafontaine, 2005; Sun et al., 2019; Tsay & Agrawal, 2004; Xia & Niu, 2019; Yoon, 2016; Zhang et al., 2020). For example, Yoon (2016) examines channel encroachment by manufacturers when there is an investment spillover. He alleges that channel encroachment by manufacturers might advantage retailers because their cost-cutting investment could overflow to the retailer, resulting in cheaper wholesale prices. Zhang et al. (2022) demonstrate that retailer can share information to achieve "win–win" situation when facing the manufacturer encroachment. Others show that encroachment may result in different conclusions. For the supply chain with one manufacturer and one retailer, Chiang et al. (2003), Tsay and Agrawal (2004), Cattani et al. (2006), and Arya et al. (2007) indicate that the strategy of manufacturer encroachment may profit each supply chain member. Zhang et al. (2019) state that while it is always the manufacturer who gains from encroachment, the retailer also has an advantage from encroachment at an intermediate direct cost to the manufacturer because it can prevent the manufacturer from reaching the consumer directly and averts channel competition. Li et al. (2014)

show that encroachment may not only result in "win–win" and "win–lose" outcomes for the manufacturer and retailer but can also result in "lose–lose" and "lose–win" outcomes. Tian et al. (2023) demonstrate that supply encroachment can achieve all-win situation.

With this in mind, the current paper innovatively investigates the supply chain encroachment literature by revealing how the upstream manufacturer's encroachment strategy can influence the supply chain. However, with the growth of society and the spread of CSR concern, CSR is highly valued. Moreover, the manufacturer or retailer with CSR concerns may relive the negative effect from encroaching and switch to the different strategies, which may be expected to achieve the win–win situation. Hence, it may be a vital issue that firms must face.

3 | MODEL SETUP

Consider a vertical supply chain composed of one manufacturer and one retailer. The manufacturer wholesales products to the retailer, who in turn sells the products to the terminal consumer. In addition, the manufacturer may sell products directly to consumers. Meantime, the manufacturer or retailer may undertake corporate social responsibility (CSR), which is reflected in the decision that manufacturer and retailer who not only pursue their own profits but also the consumer surplus. To capture such variations, four scenarios are considered and Stackelberg game models are constructed, that is, NM (no-encroachment and manufacturer CSR), NR (no-encroachment and retailer CSR), EM (encroachment and manufacturer CSR), and ER (encroachment and retailer CSR). Four possible scenarios are illustrated in Figure 1.

Assuming the possibility of manufacturer encroachment, the demand function is separated by the retail and direct channels. Specifically, the consumer demand of retailing channel is defined as a linear and inverse function $P = a - bq_r$, while the direct channel is defined as a nonlinear and inverse function $P = a - bq_r - bq_m$ (Arya et al., 2007; Wang et al., 2021). Specially, a and b are both strictly positive. P is denoted as the market-clearing price. q_r and q_m are denoted as the sales quantity of retail channel and direct channel. Similar to Arya et al. (2007), Li et al. (2014), and Wang et al. (2021), we normalize the marginal cost to the manufacturer for producing and the unit cost to the retailer for selling to zero. We refer to c as the direct selling cost. To ensure the manufacturer is incentivized to encroach, the parameters are assumed to satisfy $c \in (0, 3a(2-\beta)/(10-3\beta))$. Specifically, β means the CSR level of manufacturer or retailer, where $\beta \in (0,1)$ (Li et al., 2014; Wang et al., 2021). A larger β represents the manufacturer or retailer that cares more about consumer surplus.

Following the extant encroachment and CSR literature of Arya et al. (2007), Panda (2014), and Wang et al. (2021), we have consumer surplus $CS = q_r^2/2b$ in the no-encroachment setting (i.e., NM and NR scenarios) and $CS = (q_r + q_m)^2/2b$ in the encroachment setting (i.e., NM and NR scenarios). With the manufacturer or retailer undertakes CSR, he will get the socially responsible profit (βCS) as the consumer surplus in its profit (Modak et al., 2014, 2019; Panda, 2014; Panda et al., 2015, 2017; Wang et al., 2021). To express the impact on the environment, we denote e as the unit carbon emission of product. Hence, the total emission is $E = eq_r$ in the no-encroachment setting (i.e., NM and NR scenarios) and $E = e(q_r + q_m)$ in the encroachment setting (i.e., NM and NR scenarios). The relevant parameters are shown in Table 2 and thresholds are shown in Table 3.

4 | EQUILIBRIUM SOLUTIONS

4.1 | NM scenario

In this scenario, the manufacturer, who with CSR concern, only can access consumers via the retail channel. The timing of the NM scenario is that the manufacturer first sets the wholesale price of the retail channel, and then, the retailer determines the retail price. The profit functions of the manufacturer and retailer are as follows:

$$V_m^{NM} = wq_r + \frac{\beta b}{2} q_r^2, \tag{1}$$

$$\pi_r^{NM} = (a - bq_r - w)q_r. \tag{2}$$

The equilibrium outcomes are summarized in Lemma 1 solving by backward induction.

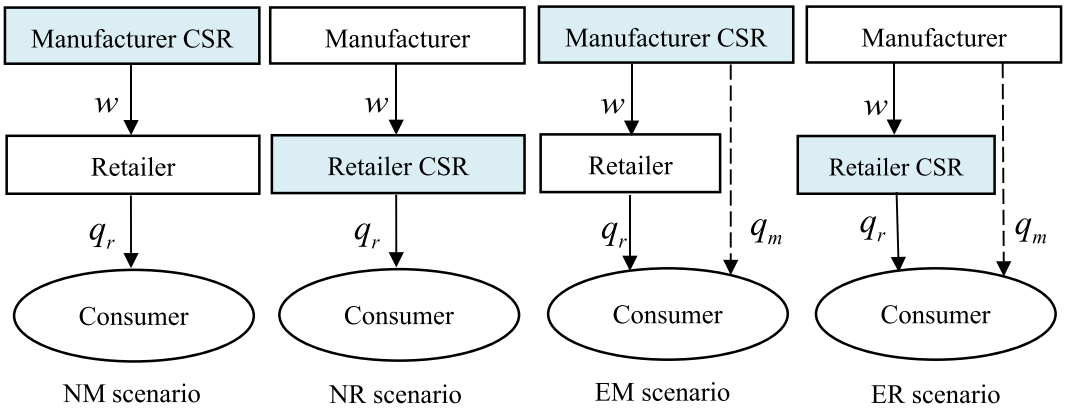

FIGURE 1 Four scenarios.

TABLE 2 Notation.

Nomenclature	
Symbol	**Definition**
r	Retail channel
m	Direct channel
Parameters	
c	The unit cost of manufacturer encroachment
e	The unit carbon emission of products in production stage
β	The CSR level of manufacturer or retailer
Decision variables	
w	The wholesale prices of products
q_r/q_m	The sales quantities of retail and direct channels
Other notations	
π_m/π_r	The pure profit of manufacturer and retailer
V_m/V_r	The total profit of manufacturer and retailer
CS	The consumer surplus
E	The total emission
Superscript	
NM, NR, EM, ER	NM, NR, EM, and ER scenarios
*	The optimal solutions

Lemma 1. In the NM scenario, the optimal equilibriums are given by $w^{NM*}=a(2-\beta)/(4-\beta)$, $q_r^{NM*}=a/b(4-\beta)$, $V_m^{NM*}=a^2/2b(4-\beta)$, $\pi_r^{NM*}=a^2/b(4-\beta)^2$, $CS^{NM*}=a^2/2b(4-\beta)^2$, and $E^{NM*}=ae/b(4-\beta)$.

(See proof in Appendix A.)

4.2 | NR scenario

In this scenario, the manufacturer only can access consumers via the retail channel and the retailer with CSR concern. According to the timing of the NR scenario, the manufacturer first determines the wholesale price of the retail channel, and then, the retailer sets the retail price to the terminal consumers. The profit functions of the manufacturer and retailer are as follows:

$$\pi_m^{NR}=wq_r, \tag{3}$$

$$V_r^{NR}=(a-bq_r-w)q_r+\frac{\beta b}{2}q_r^2. \tag{4}$$

The equilibrium outcomes are summarized in Lemma 2 solving by backward induction.

Lemma 2. In the NR scenario, the optimal equilibriums are given by $w^{NR*}=a/2$, $q_r^{NR*}=a/2b(2-\beta)$, $\pi_m^{NR*}=a^2/4b(2-\beta)$, $V_r^{NR*}=a^2/8b(2-\beta)$, $CS^{NR*}=a^2/8b(2-\beta)^2$, and $E^{NR*}=ae/2b(2-\beta)$.

(See proof in Appendix A.)

4.3 | EM scenario

In this scenario, the manufacturer, who with CSR concern, can reach consumers both through the retail channel and direct channel. The manufacturer first determines the wholesale price of the retail channel, and then, the retailer sets the retail price to the end consumers. Lastly, the manufacturer sets the retail price of the direct channel. The profit functions of the manufacturer and retailer are as follows:

$$V_m^{EM}=wq_r+(a-bq_r-bq_m-c)q_m+\frac{\beta b}{2}(q_r+q_m)^2, \tag{5}$$

$$\pi_r^{EM}=(a-bq_r-bq_m-w)q_r. \tag{6}$$

The equilibrium outcomes are summarized in Lemma 3 solving by backward induction.

Lemma 3. In the EM scenario, the optimal equilibriums are given by $w^{EM^*}=(3a(1-\beta)-c(1-2\beta))/3(2-\beta)$, $q_m^{EM*}=(3a-c(5-(3-\beta)\beta))/3b(2-\beta)$, $q_r^{EM*}=c(2-\beta)/3b$, $V_m^{EM*}=\left(3a^2-6ac+c^2(7-(4-\beta)\beta)\right)/6b(2-\beta)$, $\pi_r^{EM*}=c^2(2-\beta)/9b$, $CS^{EM*}=(3a-c-c\beta)^2/18b(2-\beta)^2$, and $E^{EM*}=e(3a-c-c\beta)/3b(2-\beta)$.

(See proof in Appendix A.)

4.4 | ER scenario

In this scenario, the manufacturer can reach consumers through both the retail channel and direct channel and the retailer with CSR concern. The manufacturer first determines the wholesale price of the retail channel, and then, the retailer sets the retail price to the end consumers. Lastly, the manufacturer sets the retail price of the direct channel. The profit functions of the manufacturer and retailer are as follows:

$$\pi_m^{ER}=wq_r+(a-bq_r-bq_m-c)q_m, \tag{7}$$

$$V_r^{ER}=(a-bq_r-bq_m-w)q_r+\frac{\beta b}{2}(q_r+q_m)^2. \tag{8}$$

The equilibrium outcomes are summarized in Lemma 4 solving by backward induction.

Lemma 4. In the EM scenario, the optimal equilibriums are given by $w^{ER*}=(a(12-\beta(2+\beta))-c(4+(2-\beta)\beta))/8(3-\beta)$, $q_m^{ER*}=(3a(2-\beta)-c(10-3\beta))/4b(3-\beta)$, $\pi_m^{ER*}=(a^2(12-(4-\beta)\beta)-2ac(6-\beta)(2-\beta)+c^2(28-(12-\beta)\beta))/16b(3-\beta)$, $V_r^{ER*}=(a^2\beta(36-\beta(20-3\beta))-2ac(2-\beta)\beta(10-3\beta)+c^2(64-3\beta(4+(4-\beta)\beta)))/32b(3-$

TABLE 3 The closed-form expressions of the thresholds.

Threshold	Expression
$c_{\max}(\beta)$	$\frac{3(2-\beta)}{10-3\beta}$
$c_1(\beta)$	$\frac{a\left(6-6\beta+\beta^2\right)}{10-6\beta+\beta^2}$
$c_2(\beta)$	$\frac{a\left(\sqrt{3}\sqrt{4-4\beta+\beta^2}-3\right)}{1-4\beta+\beta^2}$
$c_3(\beta)$	$\frac{3\beta-12+\sqrt{3}\sqrt{-8+22\beta-13\beta^2+2\beta^3}}{23\beta-8\beta^2+\beta^3-28}$
$c_4(\beta)$	$\frac{3a}{\sqrt{32-32\beta+10\beta^2-\beta^3}}$
$c_5(\beta)$	$\frac{a\left(28\beta-10\beta^2+\beta^3-24+2\sqrt{-24+44\beta-18\beta^2-\beta^3+\beta^4}\right)}{52\beta-14\beta^2+\beta^3-56}$
$c_6(\beta)$	$\frac{a\left(28\beta-10\beta^2+\beta^3-24-2\sqrt{-24+44\beta-18\beta^2-\beta^3+\beta^4}\right)}{52\beta-14\beta^2+\beta^3-56}$
$c_7(\beta)$	$\frac{a\left(+52\beta^2-22\beta^3+3\beta^4-40\beta+2\sqrt{1152-3864\beta+4964\beta^2-3182\beta^3+1085\beta^4-188\beta^5+13\beta^6}\right)}{88\beta+12\beta^2-18\beta^3+3\beta^4-128}$
$c_8(\beta)$	$\frac{a\left(+52\beta^2-22\beta^3+3\beta^4-40\beta-2\sqrt{1152-3864\beta+4964\beta^2-3182\beta^3+1085\beta^4-188\beta^5+13\beta^6}\right)}{88\beta+12\beta^2-18\beta^3+3\beta^4-128}$
$c_9(\beta)$	$\frac{a\left(60-30\beta+3\beta^2-2\sqrt{6}\sqrt{144-168\beta+70\beta^2-13\beta^3+\beta^4}\right)}{4+14\beta-5\beta^2}$
β_1	$\frac{13}{6}-\frac{1}{6}\sqrt{9+\left(4184-72\sqrt{1641}\right)^{1/3}+2\left(523+9\sqrt{1641}\right)^{1/3}}$ $-\frac{1}{2}\sqrt{2-\frac{1}{9}\left(4184-72\sqrt{1641}\right)^{1/3}-\frac{2}{9}\left(523+9\sqrt{1641}\right)^{1/3}+\frac{118}{9\sqrt{9+\left(4184-72\sqrt{1641}\right)^{1/3}+2\left(523+9\sqrt{1641}\right)^{1/3}}}}$

$\beta)^2$, $CS^{ER*} = (a(6-\beta)+c(2-\beta))^2/32b(3-\beta)^2$, and $E^{ER*} = e(a(6-\beta)-c(2-\beta))/4b(3-\beta)$.

(See proof in Appendix A.)

4.5 | CSR impact

In this section, we study the impact of CSR level on the equilibrium results in four scenarios. Considering manufacturer or retailer with CSR concern, we propose the following corollaries and figures. For more details, please see Appendix B.

Corollary 1. Considering the wholesale price:

i. With manufacturer CSR, $\frac{\partial w_r^{NM*}}{\partial \beta} < 0$; $\frac{\partial w_r^{EM*}}{\partial \beta} < 0$.
ii. With retailer CSR, $\frac{\partial w_r^{NR*}}{\partial \beta} = 0$; $\frac{\partial w_r^{ER*}}{\partial \beta} > 0$, when $0 < c < c_1$ and $\frac{\partial w_r^{ER*}}{\partial \beta} < 0$, when $c_1 < c < c_{\max}$.

(See proof in Appendix B.)

Part (i) of Corollary 1 shows that, with manufacturer CSR, whether there is manufacturer encroachment or not, the higher the CSR level, the lower wholesale price will be set at. Previous studies have obtained similar conclusions, for example, Yan et al. (2021). The reason might be that as the manufacturer becomes more aware of its CSR behavior, it will take the initiative to reduce wholesale prices in the retail channel to better benefit stakeholder, thus maximizing social welfare (Corollary 3 also suggests that manufacturer's social welfare maximization goal is positively related to its awareness of CSR behavior).

Interestingly, with retailer CSR, wholesale price may be affected by the CSR level depending on the encroachment strategy. Specifically, on the one hand, when the manufacturer no-encroachment, the retailer with more CSR may not get the lower wholesale price. On the other hand, when the manufacturer encroachment, retailer with more CSR will get a higher wholesale price when the cost of encroachment is lower, but lower when it is higher.

In summary, combining Corollary 1(i) with (ii), as manufacturer or retailer with more CSR concern, the strategy of encroaching by manufacturer may alter the setting of wholesale price. Resorting to numerical study shown in Figure 2, the above result still holds. The parameters for Figure 2 are $a = 1$, $b = 1$, and $c = 0.35$.

Corollary 2. Considering the sales quantity of direct and retail channels:

i. With manufacturer CSR, $\frac{\partial q_r^{NM*}}{\partial \beta} > 0$, $\frac{\partial q_r^{EM*}}{\partial \beta} < 0$; $\frac{\partial q_m^{EM*}}{\partial \beta} > 0$.
ii. With retailer CSR, $\frac{\partial q_r^{NR*}}{\partial \beta} > 0$, $\frac{\partial q_r^{ER*}}{\partial \beta} > 0$; $\frac{\partial q_m^{ER*}}{\partial \beta} < 0$.

(See proof in Appendix B.)

As Corollary 2 shows, when the manufacturer with more CSR, the sales quantity of the retail channel will increase when the

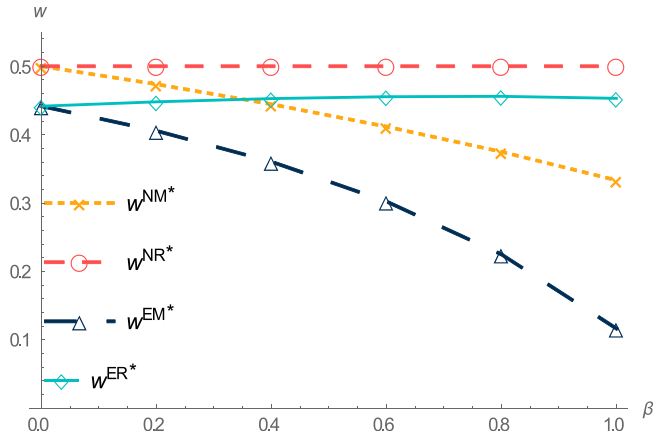

FIGURE 2 The wholesale price under four scenarios.

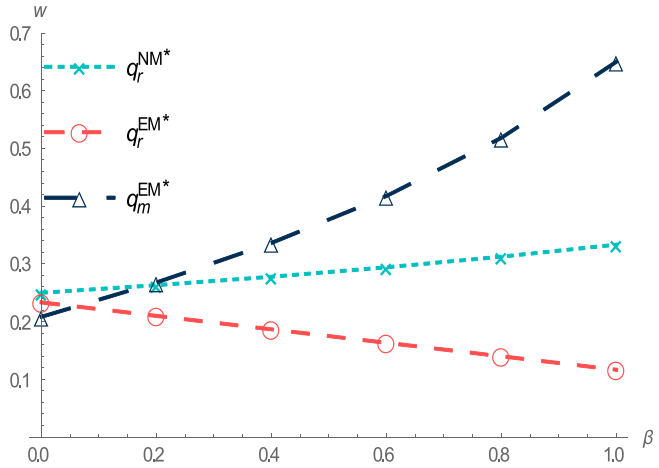

FIGURE 3 The sales quantity when manufacturer CSR.

manufacturer no-encroachment, but decrease with encroaching, while the sales quantity of direct channels will increase with manufacturer undertakes more CSR when manufacturer implements encroachment. As the retailer with more CSR concern, the sales quantity of the retailing channel will always increase no matter whether there is manufacturer encroachment or not, but the sales quantity of direct channel may decrease, which differs from the manufacturer CSR.

The conventional wisdom shows that manufacturer implementing encroachment may be worse for the retailer, because it may cause the fierce competition between the direct channel and the retail channel, inducing the cannibalization effect (Arya et al., 2007; Zhang et al., 2020). However, the result may not be immutable and frozen with considering CSR. On the one hand, manufacturer undertaking more CSR may aggravate the cannibalization effect from direct channel to retail channel. Interestingly, on the other hand, retailer undertaking more CSR may relieve or even offset the negative effect of manufacturer encroachment.

To further confirm the conclusion, we depict Figures 3 and 4 with the same parameters as Figure 2. Figure 3 shows clearly that when manufacturer without CSR concern, namely, $\beta = 0$, there may be a

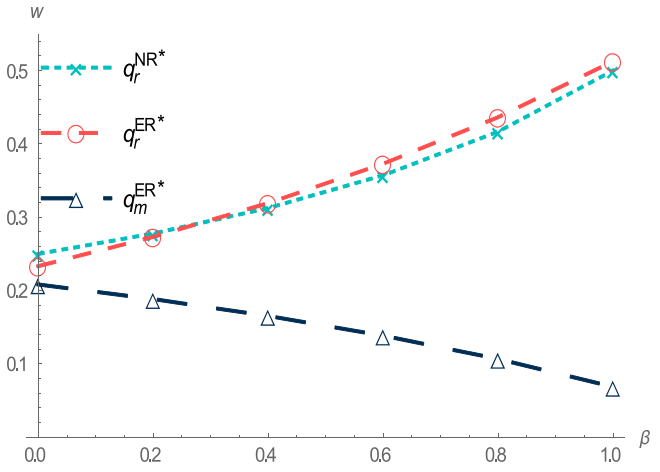

FIGURE 4 The sales quantity when retailer CSR.

widening gap between the sales quantity of the retail channel before and after the manufacturer encroachment. As the manufacturer's CSR level rises, the cannibalization effect may be more pronounced. Intuitively, the gap between before and after manufacturer encroachment in the retail channel's sales quantity may get bigger and bigger. However, Figure 4 shows surprisingly, although the cannibalization effect will still occur, with continuous improvement of the retailer's CSR level, the sales quantity of the retail channel may not be encroached by manufacturer, but even get higher.

Corollary 3. Considering the profits of manufacturer and retailer:

i. With manufacturer CSR, $\frac{\partial V_m^{NM*}}{\partial \beta} > 0$; $\frac{\partial \pi_r^{NM*}}{\partial \beta} > 0$; $\frac{\partial V_m^{EM*}}{\partial \beta} > 0$, when $\beta \in \left[0, 2-\sqrt{3}\right) \cup c \in (0, c_2)$ and $\beta \in \left(2-\sqrt{3}, 1\right]$, $\frac{\partial V_m^{EM*}}{\partial \beta} < 0$, when $\beta \in \left[0, 2-\sqrt{3}\right) \cup c \in (c_2, c_{\max})$; $\frac{\partial \pi_r^{EM*}}{\partial \beta} < 0$.

ii. With retailer CSR, $\frac{\partial \pi_m^{NR*}}{\partial \beta} > 0$; $\frac{\partial V_r^{NR*}}{\partial \beta} > 0$; $\frac{\partial \pi_m^{ER*}}{\partial \beta} > 0$; $\frac{\partial V_r^{ER*}}{\partial \beta} > 0$.

(See proof in Appendix B.)

As part (i) of Corollary 3 shows, without manufacturer encroachment, the profits of the manufacturer and retailer will both be increased by the higher CSR level undertaken by manufacturer. It confirmed that CSR as a positive concept let us believe that greater CSR level will bring better performance for those undertaking it. However, with manufacturer encroachment, as the CSR level of the manufacturer increases, the profits of the manufacturer may decrease first and then increase when the cost is higher. Moreover, the more CSR manufacturers take on, the more retailers lose out. As part (ii) of Corollary 3 shows, retailer undertaking more CSR can benefit both manufacturer and retailer no matter the manufacturer encroachment. Figures 5 and 6 further confirm the conclusion with the same parameters as the aforementioned.

Combining Parts (i) and (ii), the profits of the manufacturer and the retailer are often related to the encroachment with the

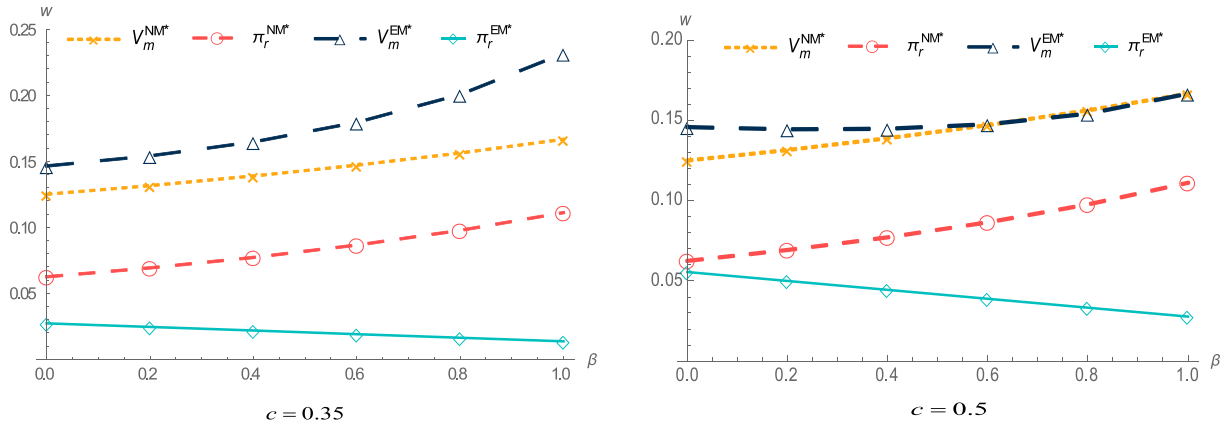

FIGURE 5 The profits of manufacturer and retailer when manufacturer CSR.

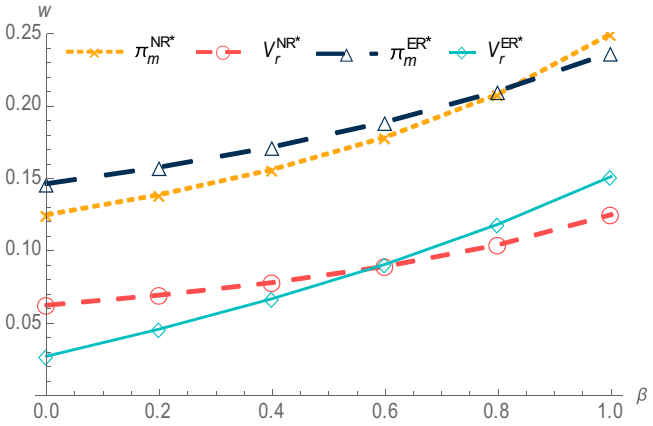

FIGURE 6 The profits of manufacturer and retailer when retailer CSR.

consideration of the factor of CSR. The reason may be clear. With manufacturer CSR, for one thing, although manufacturer encroachment and improved CSR level are both positive factors on its profits, the manufacturer may get worse when the encroachment cost is too high and initial CSR level is too low. Thus, manufacturer with high-level CSR blindly may not get the desired result. On the other hand, although the wholesale price may decrease as the manufacturer with more CSR concern, the cannibalization effect of encroachment may worsen the sales quantity of the retail channel, as shown in Corollary 2 (i). Thus, the profits of the retailer will further decrease. However, retailer with more CSR may both benefit for manufacturer and itself. Hence, it should be encouraged.

Corollary 4. Considering the consumer surplus and total emission:

i. With manufacturer CSR, $\frac{\partial CS^{NM*}}{\partial \beta} > 0$; $\frac{\partial CS^{EM*}}{\partial \beta} > 0$; $\frac{\partial E^{NM*}}{\partial \beta} > 0$; $\frac{\partial E^{EM*}}{\partial \beta} > 0$.
ii. With retailer CSR, $\frac{\partial CS^{NR*}}{\partial \beta} > 0$; $\frac{\partial CS^{ER*}}{\partial \beta} > 0$; $\frac{\partial E^{NR*}}{\partial \beta} > 0$; $\frac{\partial E^{ER*}}{\partial \beta} > 0$.

(See proof in Appendix B.)

Corollary 4 states that no matter who undertakes CSR and no matter if there is manufacturer encroachment, manufacturer or retailer with more CSR concern may always be advantage to consumer but harm to the environment. In other words, although increasing CSR level can benefit the consumer, manufacturer or retailer with good social responsibility may fail to achieve better corporate environmental performance, which may have something to do with the insufficient understanding of social responsibility. We further depict Figures 7 and 8 to illustrate these conclusions, in which the parameters are $a = 1$, $b = 1$, $c = 0.35$, and $e = 0.1$.

5 | COMPARISON

In this section, we compare equilibrium solutions between four scenarios (including NM vs. NR, NM vs. EM, NR vs. ER, and EM vs. ER) and sum up propositions as follows. For more details, please see Appendix C.

5.1 | NM versus EM

Proposition 1. With manufacturer CSR,

i. Encroachment may be worse for the manufacturer when $\{\beta, c\} \subset \{[0.54, 0.71) \cup [0, c_3]\}$.
ii. Encroachment may be better for the retailer when $\{\beta, c\} \subset \{[0, 0.17) \cup [c_4, c_{max}]\}$.

(See proof in Appendix C.)

As Proposition 1 shows, we find that with manufacturer CSR, encroachment may not always get better for the manufacturer and not always get worse for the retailer. Generally speaking, the strategy of encroachment is to the detriment of the retailer and to the advantage of the manufacturer (Arya et al., 2007). But the reality may change with considering CSR concern. By comparison, we find that

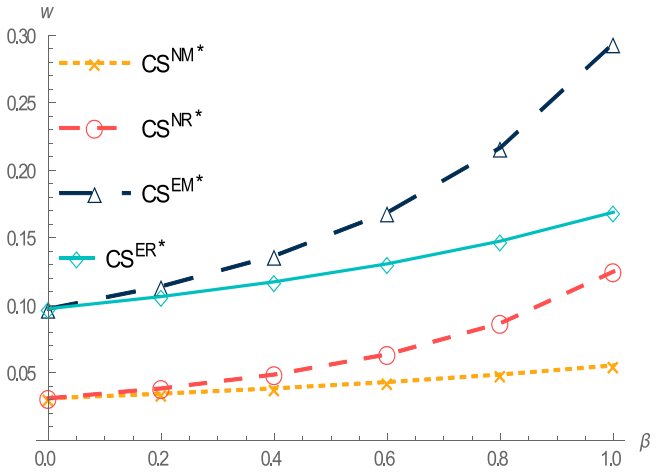

FIGURE 7 The consumer surplus under four scenarios.

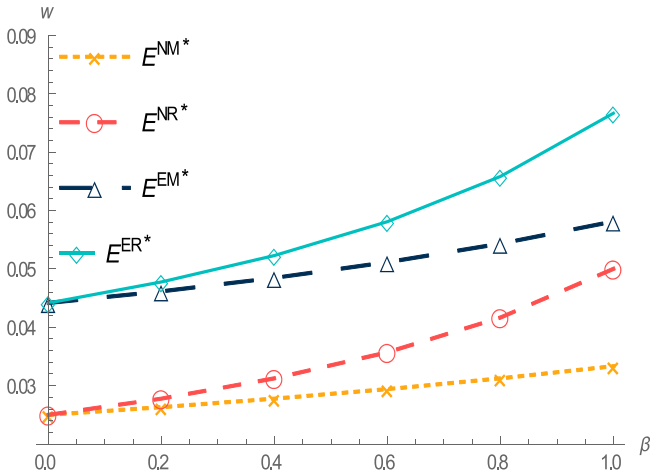

FIGURE 8 The total emission under four scenarios.

with manufacturer CSR, manufacturer encroachment may not always earn more profits for itself when the encroachment cost is relatively lower and the CSR level is intermediate. More surprisingly, encroachment also can bring more profits for retailers when the CSR level is relatively lower and the cost of encroachment relatively higher. Some previous papers can be identified, such as Arya et al. (2007) and Wang et al. (2021). Thus, manufacturer encroachment with CSR concern needs both concentrate on the cost of encroachment and the CSR level.

Remark 1. Under the scenario that manufacturer undertakes CSR and implements encroachment, the "win–win" situation for manufacturer and retailer can be achieved when manufacturer CSR level is lower and encroachment cost is higher, that is, $\{\beta,c\} \subset \{[0,0.17) \cup [c_4,c_{\max}]\}$.

As Remark 1 shows, when the CSR level of manufacturer is lower and the cost of encroachment is higher, a "win–win" situation for each supply chain members can be achieved. Understandably, a manufacturer possessing a consciousness about CSR may prefer to focus on stakeholders' benefit instead of pursuing pure profit. The

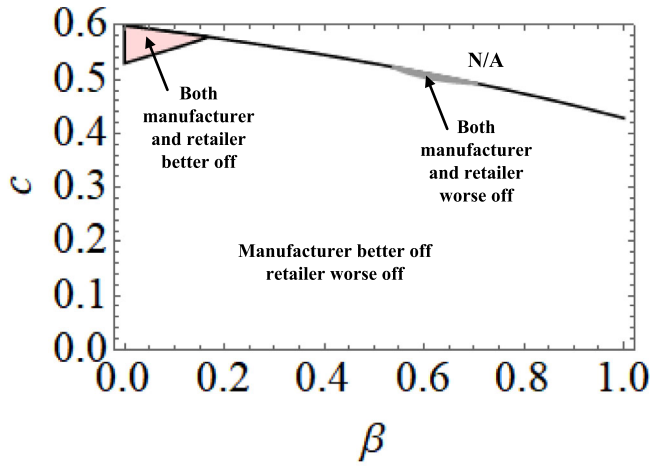

FIGURE 9 The impact of encroachment when manufacturer CSR.

manufacturer's higher level of corporate social responsibility may result in higher costs. However, it could also result in losses. Furthermore, the higher cost of encroachment may also encourage the manufacturer to sell its products through retail channels rather than direct channels. The influence of encroachment with manufacturer CSR is depicted in Figure 9. Interestingly, when the CSR level is intermediate and the encroachment cost is relatively high, manufacturer encroachment may lead to a "lose–lose" situation. The possible explanation for this discrepancy might be that high cost makes the manufacturer lose the advantage of encroaching; meantime, the medium-level CSR may not make the manufacturer profitable. Meanwhile, for the retailer, although manufacturer with more CSR concern may benefit for it, the cost of encroachment is lower than "win–win" situation, driving manufacturers to prefer selling through direct channel.

Proposition 2. With manufacturer CSR, no-encroachment may be better for both consumer and the environment, that is, $CS^{NM*} > CS^{EM*}$ and $E^{NM*} < E^{EM*}$.

(See proof in Appendix C.)

As Proposition 2 shows, if a manufacturer is not a pure profit maximizer, adopting an encroachment strategy may result in lower consumer surplus and higher total emissions, which is unfavorable for both the consumer and the environment. Consequently, for the sake of consumer and environmental protection, it is better for the manufacturer to choose the strategy of no-encroachment strategy than the encroachment strategy.

5.2 | NR versus ER

Proposition 3. With retailer CSR,

i. Encroachment may be worse for the manufacturer when $\{\beta,c\} \subset \left\{\left[2\left(\sqrt{2}-1\right),2(9-4\sqrt{2})/7\right) \cup [c_5,c_6), \left[2\left(9-4\sqrt{2}\right)/7,1\right] \cup [0,c_5)\right\}$.

ii. Encroachment may be better for the retailer when $\{\beta,c\}\subset\{[0,\beta_1)\cup[c_8,c_{\max}],[\beta_1,0.77)\cup[0,c_7],[0.77,1)\cup[0,c_{\max}]\}$.

(See proof in Appendix C.)

As Proposition 3 shows, with retailer CSR, the similar conclusions can be drawn in Proposition 1. Compared with it, although manufacturer encroachment may be a positive factor for manufacturer's profit, manufacturer encroaching with retailer CSR may both have the positive and negative effects on supply chain members. Specifically, when both CSR level of retailer and the cost of encroachment are intermediate or the level is relatively higher and the cost is relatively lower, manufacturer encroachment may cause damage to itself, otherwise, may benefit itself. On the other hand, when both CSR level and encroachment cost meet the certain conditions revealed in Proposition 3(ii), encroachment may also benefit to the retailer; otherwise, retailer may be lost. Interestingly, manufacturer encroachment may be even worse for itself no matter manufacturer CSR or retailer CSR.

Remark 2. Under the scenario that both the manufacturer encroachment and retailer CSR makes the "win–win" situation for manufacturer and retailer be achieved when $\{\beta,c\}\subset\Omega$, where $\Omega=\{\varphi_1,\varphi_2,\varphi_3,\varphi_4,\varphi_5\}$, $\varphi_1=\beta\in(0,\beta_1)\cup c\in(c_7,c_{\max})$, $\varphi_2=\beta\in(\beta_1,0.77)\cup c\in(0,c_6)\cup(c_7,c_{\max})$, $\varphi_3=\beta\in\left(0.77,2\left(\sqrt{2}-1\right)\right)\cup c\in(0,c_{\max})$, $\varphi_4=\beta\in\left(2\left(\sqrt{2}-1\right),2\left(9-4\sqrt{2}\right)/7\right)\cup c\in(0,c_4)\cup(c_5,c_{\max})$, and $\varphi_5=\beta\in\left(2\left(9-4\sqrt{2}\right)/7,1\right)\cup c\in(c_4,c_{\max})$.

As Remark 2 shows, manufacturer encroaching with retailer CSR may be conductive to the "win–win" situation. Specifically, five regions depicted in Figure 10 show that encroaching with retailer CSR can both benefit to manufacturer and retailer. Understandably, the retailer with CSR concern may obtain an extra profit from consumer and be conducive to manufacturer; meantime, the higher cost of encroachment may also let the manufacturer sell its products by retail channel making more profits for retailer. Hence, retailer CSR can deter the manufacturer from encroachment and lead to the "win–win" situation.

Proposition 4. With retailer CSR, consumer may better from the manufacturer encroachment, while environment may be better for no-encroachment, that is, $CS^{NR*}<CS^{ER*}$ and $E^{NR*}>E^{ER*}$.

(See proof in Appendix C.)

According to Proposition 4, when a retailer undertakes CSR, manufacturer encroachment strategy may lead to higher consumer surplus and total emissions. This suggests that manufacturer encroachment with retailer CSR may bring about a rise in consumer surplus, but also brings damage to the environment. Compared with Proposition 2, manufacturer with no-encroachment may be more environmentally friendly in a socially responsible supply chain.

5.3 | NM versus NR

Proposition 5. Without manufacturer encroachment, the retailer CSR may be more beneficial than the manufacturer CSR for the sake of their profits, that is, $V_m^{NM*}<\pi_m^{NR*}$ and $\pi_r^{NM*}<V_r^{NR*}$.

(See proof in Appendix C.)

Proposition 5 shows that both manufacturer and retailer may be better off through the retailer CSR if the manufacturer has not implemented direct sales channels. Understandably, retailer CSR may bring more benefits to manufacturer. Thus, manufacturer is more likely to prefer to retailer CSR rather than undertaking CSR by itself. Meanwhile, although retailer CSR may result in a loss of pure profit, it may be offset by an increase in consumer surplus. Consequently, compared with manufacturer CSR, retailer CSR when manufacturer no-encroachment is the dominant strategy.

Remark 3. Without encroachment, both manufacturer and retailer can be better off with retailer CSR.

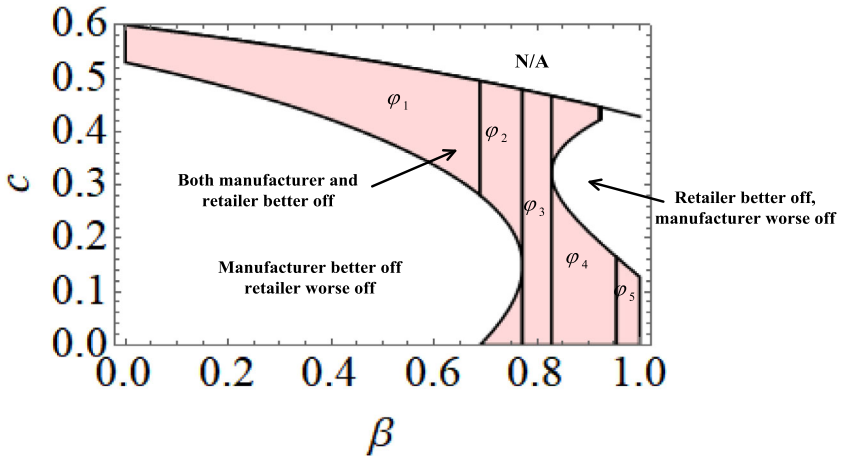

FIGURE 10 The impact of encroachment when retailer CSR.

Remark 3 shows that both manufacturer and retailer can be better off with retailer CSR if the manufacturer has not implemented encroachment, leading to a "win–win" situation. In other words, although with CSR concern can obtain a fraction of consumer surplus which can bring some profits, we may not advise the manufacturer CSR when manufacturer no-encroachment. This conclusion is depicted in Figure 11 with the parameters of $a = 1$ and $b = 1$.

Proposition 6. Without manufacturer encroachment, the manufacturer CSR may benefit both consumer surplus and environmental protection, that is, $CS^{NM*} > CS^{NR*}$ and $E^{NM*} < E^{NR*}$.

(See proof in Appendix C.)

As Proposition 6 shows, in the absence of direct channel, manufacturer CSR, compared retailer CSR, may bring higher consumer surplus and lower total emissions. That is to say, the manufacturer with CSR concern will not only be beneficial to consumer but also be conducive to environmental protection under the no-encroachment scenario. Thus, for the sake of consumers and the environment, manufacturer CSR should be advocated in this scenario.

5.4 | EM versus ER

Proposition 7. Retailer CSR can relieve the cannibalization effect of manufacturer encroachment, that is, $q_m^{EM*} > q_m^{ER*}$ and $q_r^{EM*} < q_r^{ER*}$.

(See proof in Appendix C.)

Proposition 7 shows that, compared with manufacturer CSR, the retailer CSR may lead to more sales quantity via retail channels and protect the sales quantity of direct channels from decreasing under the scenario of manufacturer encroachment, which may relieve the cannibalization effect of encroaching. Intuitively, when manufacturer encroachment with undertaking CSR, the channel competition will be further intensified. However, manufacturer encroachment with retailer CSR may lead to the competition between channels becoming less fierce, and hence, the cannibalization effect becomes less pronounced.

Proposition 8. With manufacturer encroachment,

i. For the profits of the manufacturer, the manufacturer CSR may be better (worse) off than the retailer CSR when encroachment cost is lower (higher).
ii. For the profits of the retailer, the retailer CSR may be better off than the manufacturer CSR.

(See proof in Appendix C.)

Part (i) of Proposition 8 shows that the cost of encroachment may alter the manufacturer CSR strategy. Specifically, when encroachment cost is lower (specifically, $c \in [0, c_9)$), manufacturer may have more motivation to undertake CSR. Otherwise, it may lose the motivation. As part (ii) of Proposition 8 shows, for the retailer's profits, it may always own the motivation to undertake CSR under the scenario of encroaching.

Combined with the phenomenon that manufacturer CSR may aggravate the cannibalization effect, while retailer CSR can relieve it, the results might be explained. On the one hand, when encroachment cost is lower, the manufacturer will prefer to sell products via direct channels. Thus, manufacturer CSR will further promote the sales quantity of direct channels, thus obtaining more profits, while when encroachment cost is higher, the manufacturer will prefer to sell

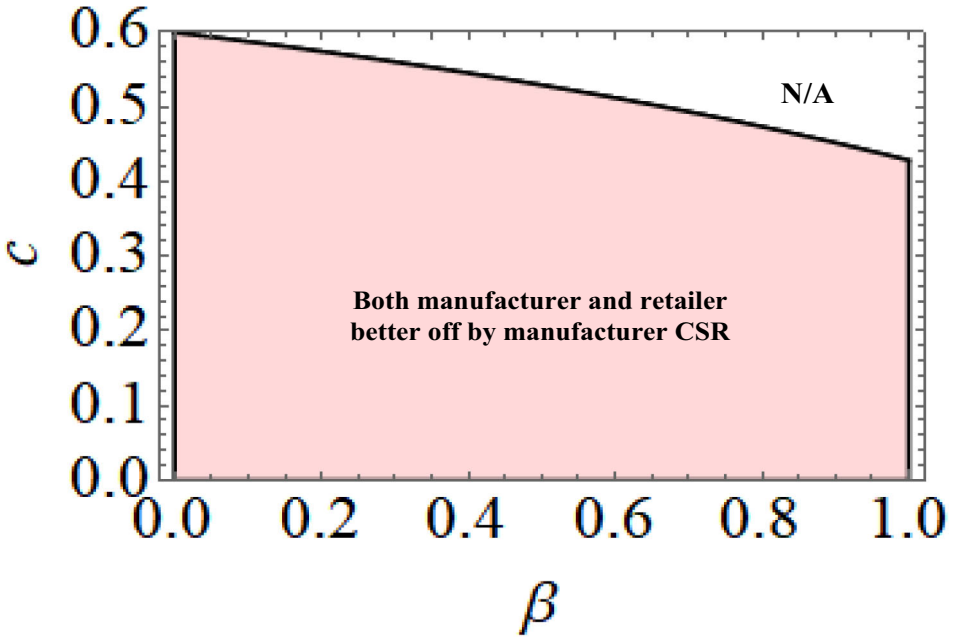

FIGURE 11 The "win–win" situation for both manufacturer and retailer without encroachment.

products via retail channels. Thus, retailer CSR will further promote the sales quantity of retail channels, which also be more profitable for the manufacturer. On the other hand, from the perspective of retailer, the retail channel is consistently disadvantageous from the manufacturer with CSR concern under the scenario of manufacturer encroachment, resulting in a reduction in the retailer's profits. Therefore, retailer CSR becomes a dominant strategy to counteract the encroachment from manufacturer.

Remark 4. With manufacturer encroachment, both manufacturer and retailer can be better off when the retailer has CSR concerns and the cost of encroachment is relatively higher, that is, $c \in [c_9, c_{\max})$.

Remark 4 reveals that both manufacturer and retailer can achieve a "win–win" situation with retailer CSR and manufacturer encroachment when the cost of encroachment is relatively higher. Similar to Remark 3, although manufacturer CSR can obtain more profits from consumer surplus, for the sake of a "win–win" situation, the manufacturer CSR with encroachment may not be advisable. This conclusion is depicted in Figure 12 with the same parameters as Figure 11.

Proposition 9. With manufacturer encroachment, the manufacturer CSR will benefit both consumer surplus and environmental protection, that is, $CS^{EM*} > CS^{ER*}$ and $E^{EM*} < E^{ER*}$.

(See proof in Appendix C.)

As Proposition 9 shows, compared with retailer CSR, manufacturer CSR with encroaching can bring the higher consumer surplus and the lower total emissions. In other words, manufacturer with CSR concern may both benefit for consumer surplus and environmental protection if the manufacturer implements encroachment. Thus, for the sake of consumers and the environment, we advocate manufacturer CSR with encroachment. Interestingly, compared with

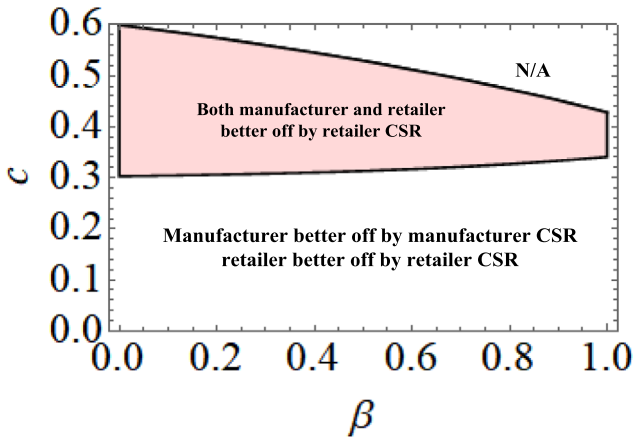

FIGURE 12 The "win–win" situation for both manufacturer and retailer with encroachment.

Proposition 7, manufacturer CSR may always be beneficial to consumer and environment whether there is manufacturer encroachment or not. Consequently, for the sake of consumers and the environment, manufacturer CSR should be encouraged.

6 | CONCLUSION

As CSR is a key driver for sustainable business development, both manufacturers like Huawei, Apple, and Xiaomi and retailers like Uniqlo, Walmart, and Bravo are concentrated on CSR. Meantime, integrating the direct channel into the supply chain has become a tool for manufacturers to maximize profits. Motivated by the real business problems, this paper studies the impact of members' CSR preference on decisions, consumer, and environment with considering manufacturer no-encroachment and encroachment. We reconstruct the supply chain and place the manufacturer encroachment in it to analyze the dominant strategy when manufacturer or retailer may own CSR concern. Four scenarios have been developed to investigate the better CSR preference of manufacturer or retailer under the scenarios of manufacturer no-encroachment and encroachment: manufacturer no-encroachment and manufacturer CSR (NM scenario), manufacturer no-encroachment and retailer CSR (NR scenario), manufacturer encroachment and manufacturer CSR (EM scenario), and manufacturer encroachment and retailer CSR (ER scenario). In each scenario, we investigate the impacts of CSR level on wholesale price, sales quantity of direct and retail channels, of manufacturer and retailer, consumer surplus, and total emissions. By comparing the equilibrium outcomes of the four scenarios in pairs, we offer some high theoretical and practical managerial insights.

First, the cannibalization effect of manufacturer encroachment is conspicuous if the manufacturer with more CSR concern, but the effect is inconspicuous and even disappears if the retailer with more CSR. It is interesting that manufacturer encroachment may be self-defeating, confirmed by the previous research (e.g., Wang et al., 2021). Hence, the manufacturer implementing encroachment blindly is not advisable, especially when there is retailer CSR. However, retailer can deter fierce competition of the cannibalization effect from direct channel by undertaking CSR initiatives.

Second, manufacturer encroachment can always achieve Pareto improvement for supply chain members under certain conditions. Hence, the retailer should not always deter manufacturer encroachment. Specifically, compared with manufacturer CSR, manufacturer encroachment with retailer CSR is more likely to achieve a "win–win" situation. Besides, retailer CSR should be encouraged, which is more conducive to supply chain members.

Third, manufacturer CSR should be encouraged. That is because that it is relatively superior to retailer CSR for both environmental protection and consumer surplus improvement no matter the presence of encroachment. Moreover, we also find that with manufacturer CSR, no-encroachment may both benefit for consumer and environment, while with retailer CSR, no-encroachment may benefit for environment but worse for consumer.

We believe these findings may assist manufacturer and retailer in determining the optimal strategy of CSR and encroachment. Furthermore, our paper could be expanded in the following aspects. First, this research mainly centers on deterministic demand. Therefore, taking uncertain or stochastic demand into account could be a future research direction. Second, in this study, we supposed that the supply chain members have complete information. Yet, some information may be private. Therefore, an alternative future research direction might be to investigate the impact of demand information asymmetry. Last, we could further examine the effect of encroachment and CSR undertaking decision-making among supply chains with different power structures.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request. His email is yonghongch1228@163.com.

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ENDNOTES

[1] https://ds.fanyaozu.com/86608.html

[2] https://baijiahao.baidu.com/s?id=1744741942298794378&wfr=spider&for=pc

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APPENDIX A

A.1 | Proof for Lemma 1

As $\partial^2\pi_r^{NM}/\partial\left(q_r^{NM}\right)^2=-2b<0$, there is a unique optimal solution q_r^{NM}. By solving equation $\partial\pi_r^{NM}/\partial q_r^{NM}=0$, we obtain q_r^{NM} optimal function, namely, $q_r^{NM}=\left(a-w^{NM}\right)/2b$. Substituting q_r^{NM} into V_m^{NM}, then we get $V_m^{NM}=\left(a-w^{NM}\right)\left(w^{NM}(4-\beta)+a\beta\right)/8b$. As $\partial^2V_m^{NM}/\partial\left(w^{NM}\right)^2=-(4-\beta)/4b<0$, there is a unique optimal solution w^{NM}. By solving equation $\partial V_m^{NM}/\partial w^{NM}=0$, we obtain w^{NM} optimal solution $w^{NM*}=a(2-\beta)/(4-\beta)$. Substituting w^{NM*} into q_r^{NM}, so we obtain q_r^{NM} optimal solution $q_r^{NM*}=a/b(4-\beta)$. Substituting w^{NM*} and q_r^{NM*} into the function of total carbon emission, the profits of manufacturer, the profits of retailer, and consumer surplus, we obtain all optimal solutions.

A.2 | Proof of Lemma 2

As $\partial^2V_r^{NR}/\partial\left(q_r^{NR}\right)^2=-b(2-\beta)<0$, there is a unique optimal solution q_r^{NR}. By solving equation $\partial V_r^{NR}/\partial q_r^{NR}=0$, we obtain q_r^{NR} optimal function, namely, $q_r^{NR}=\left(a-w^{NR}\right)/b(2-\beta)$. Substituting q_r^{NR} into π_m^{NR}, then we get $\pi_m^{NR}=w^{NR}\left(a-w^{NR}\right)/b(2-\beta)$. As $\partial^2\pi_m^{NR}/\partial\left(w^{NR}\right)^2=-2/b(2-\beta)<0$, there is a unique optimal solution w^{NR}. By solving equation $\partial V_m^{NR}/\partial w^{NR}=0$, we obtain w^{NR} optimal solution $w^{NR*}=a/2$. Substituting w^{NR*} into q_r^{NR}, so we obtain q_r^{NR} optimal solution $q_r^{NR*}=a/2b(2-\beta)$. Substituting w^{NR*} and q_r^{NR*} into the function of total carbon emission, the profits of manufacturer, the profits of retailer, and consumer surplus, we obtain all optimal solutions.

A.3 | Proof of Lemma 3

As $\partial^2V_m^{EM}/\partial\left(q_m^{EM}\right)^2=-b(2-\beta)<0$, there is a unique optimal solution. By solving equation $\partial V_m^{EM}/\partial q_m^{EM}=0$, we obtain q_m^{EM} optimal function, namely, $q_m^{EM}=\left(a-c-bq_r^{EM}(1-\beta)\right)/b(2-\beta)$. Substituting q_m^{EM} into π_r^{EM}, then we get $\pi_r^{EM}=q_r^{EM}\left(c-bq_r^{EM}+a(1-\beta)-w^{EM}(2-\beta)\right)/(2-\beta)$. As $\partial^2\pi_r^{EM}/\partial\left(q_r^{EM}\right)^2=-2b(2-\beta)<0$, there is a unique optimal solution q_r^{EM}. By solving equation $\partial\pi_r^{EM}/\partial q_r^{EM}=0$, we obtain q_r^{EM} optimal function $q_r^{EM}=\left(a+c-2w^{EM}-\left(a-w^{EM}\right)\beta\right)/2b$. Substituting q_r^{EM} into V_m^{EM}, then we get $V_m^{EM}=\left(2w^{EM}-(3-\beta)\left(c+w^{EM}\beta\right)+a(1+(2-\beta)\beta)\right)/\ 2b(2-\beta)$. By solving equation $\partial V_m^{EM}/\partial w^{EM}=0$, we obtain w^{EM} optimal solution $w^{EM*}=(3a-c-(3a-2c)\beta)/3(2-\beta)$. Substituting w^{EM*} into q_r^{EM}, so we obtain q_r^{EM} optimal solution $q_r^{EM*}=c(2-\beta)/3b$. Substituting w^{EM*} and q_r^{EM*} into q_m^{EM}, so we obtain q_m^{EM} optimal solution $q_m^{EM*}=(3a-c(5-(3-\beta)\beta))/3b(2-\beta)$. Substituting w^{EM*}, q_r^{EM*}, and q_m^{EM*} into the function of total carbon emission, the profits of manufacturer, the profits of retailer, and consumer surplus, we obtain all optimal solutions.

A.4 | Proof of Lemma 4

As $\partial^2\pi_m^{ER}/\partial\left(q_m^{ER}\right)^2=-2b<0$, there is a unique optimal solution q_m^{ER}. By solving equation $\partial\pi_m^{ER}/\partial q_m^{ER}=0$, we obtain q_m^{ER} optimal function, namely, $q_m^{ER}=\left(a-c-bq_r^{ER}\right)/2b$. Substituting q_m^{ER} into V_r^{ER}, then we get $V_r^{ER}=\left(4q_r^{ER}\left(a+c-bq_r^{ER}-2w^{ER}\right)+\left(a-c+bq_r^{ER}\right)^2\beta/b\right)/8$. As $\partial^2V_r^{ER}/\partial\left(q_r^{ER}\right)^2=-b(4-\beta)/4<0$, there is a unique optimal solution q_r^{ER}. By solving equation $\partial V_r^{ER}/\partial q_r^{ER}=0$, we obtain q_r^{ER} optimal function $q_r^{ER}=(2(a+c-2w)+(a-c)\beta)/b(4-\beta)$. Substituting q_r^{ER} into π_m^{ER}, then we can get the manufacturer's profit function containing only w^{ER}: $\pi_m^{ER}=-4w^{ER^2}(3-\beta)+c^2(3-\beta)^2+a^2(1-\beta)^2-cw^{ER^2}(4+(2-\beta)\beta)-a\left(2c(3-\beta)(1-\beta)-w^{ER^2}(12-\beta(2+\beta))\right)/b(4-\beta)^2$. By solving equation $\partial\pi_m^{ER}/\partial w^{ER}=0$, we obtain w^{ER} optimal solution $w^{ER*}=a(12-\beta(2+\beta))-c(4+(2-\beta)\beta)/8(3-\beta)$. Substituting w^{ER*} into q_r^{ER}, so we obtain q_r^{ER} optimal solution $q_m^{ER*}=(6a-10c-3\beta(a-c))/4b(3-\beta)$. Substituting w^{ER*} and q_m^{ER*} into q_r^{ER}, so we obtain q_r^{ER} optimal solution $q_r^{ER*}=(4c+(a-c)\beta)/2b(3-\beta)$. Substituting w^{ER*}, q_r^{ER*}, and q_m^{ER*} into the function of total carbon emission, the profits of manufacturer, the profits of retailer, and consumer surplus, we obtain all optimal solutions.

APPENDIX B

B.1 | Proof of Corollary 1

$\partial w^{NM*}/\partial\beta=-2a/(4-\beta)^2<0$; $\partial w^{NR*}/\partial\beta=0$; $\partial w^{EM*}/\partial\beta=-(a-c)/(2-\beta)^2<0$; $\partial w^{ER*}/\partial\beta=\left((a-c)(3-\beta)^2-(3a+c)\right)/8(3-\beta)^2$. Because of $8(3-\beta)^2>0$, we can obtain the threshold of c for giving $(a-c)(3-\beta)^2-(3a+c)=0$: $c_1=a\left(6-6\beta+\beta^2\right)/\left(10-6\beta+\beta^2\right)$, which $0<c_1<c_{max}$. So, we have $\partial w^{ER*}/\partial\beta>0$, when $0<c<c_1$ and $\partial w^{ER*}/\partial\beta<0$, $c_1<c<c_{max}$.

B.2 | Proof of Corollary 2

$\partial q_r^{NM*}/\partial\beta=a/b(4-\beta)^2>0$; $\partial q_m^{EM*}/\partial\beta=(3a+c(1-(4-\beta)\beta))/3b(2-\beta)^2>0$; $\partial q_r^{EM*}/\partial\beta=-c/3b<0$; $\partial q_r^{NR*}/\partial\beta=a/2b(2-\beta)^2>0$; $\partial q_m^{ER*}/\partial\beta=-(3a+c)/4b(3-\beta)^2<0$; $\partial q_r^{ER*}/\partial\beta=(3a+c)/2b(3-\beta)^2>0$.

B.3 | Proof of Corollary 3

$\partial V_m^{NM*}/\partial\beta = a^2/2b(4-\beta)^2 > 0$; $\partial \pi_r^{NM*}/\partial\beta = 2a^2/b(4-\beta)^3 > 0$; $\partial V_m^{EM*}/\partial\beta = \left(3a^2 - 6ac - c^2(1-(4-\beta)\beta)\right)/6b(2-\beta)^2$. By solving $\partial V_m^{EM*}/\partial\beta = 0$, we can obtain a threshold of c: $c_2 = \left(\sqrt{3}a\sqrt{4-4\beta+\beta^2} - 3a\right)/\left(1-4\beta+\beta^2\right)$, and two thresholds of β for giving $1-(4-\beta)\beta = 0$: $\beta = 2-\sqrt{3}$. Hence, we can get if $\beta \in \left(0, 2-\sqrt{3}\right)$, then $\partial V_m^{EM*}/\partial\beta > 0$, when $0 < c < c_2$ and $\partial V_m^{EM*}/\partial\beta < 0$ when $c_2 < c < c_{\max}$; if $\beta \in \left(2-\sqrt{3}, 1\right]$, then $\partial V_m^{EM*}/\partial\beta > 0$; $\partial \pi_r^{EM*}/\partial\beta = -c^2/9b < 0$; $\partial \pi_m^{NR*}/\partial\beta = a^2/4b(2-\beta)^2 > 0$; $\partial V_r^{NR*}/\partial\beta = a^2/8b(2-\beta)^2 > 0$; $\partial \pi_m^{ER*}/\partial\beta = (a(6-\beta) - c(2-\beta))(c(4-\beta)+a\beta)/16b(3-\beta)^2 > 0$; $\partial V_r^{ER*}/\partial\beta = 3a^2(36 - \beta(28-(9-\beta)\beta)) + c^2(92 - 3\beta(28-(9-\beta)\beta)) - 2ac(60 - \beta(76 - 3(9-\beta)\beta))/32b(3-\beta)^3 > 0$.

B.4 | Proof of Corollary 4

$\partial CS^{NM*}/\partial\beta = a^2/b(4-\beta)^3 > 0$; $\partial CS^{EM*}/\partial\beta = (a-c)(3a-c-c\beta)/3b(2-\beta)^3 > 0$; $\partial E^{NM*}/\partial\beta = ae/b(4-\beta)^2 > 0$; $\partial E^{EM*}/\partial\beta = (a-c)e/b(2-\beta)^2 > 0$; $\partial CS^{NR*}/\partial\beta = a^2/4b(2-\beta)^3 > 0$; $\partial CS^{ER*}/\partial\beta = (3a+c)(a(6-\beta) - c(2-\beta))/16b(3-\beta)^3 > 0$; $\partial E^{NR*}/\partial\beta = ae/2b(2-\beta)^2 > 0$; $\partial E^{ER*}/\partial\beta = e(a(6-\beta) - c(2-\beta))\beta/4b(3-\beta) > 0$.

APPENDIX C

C.1 | Proof of Proposition 1

$V_m^{NM*} - V_m^{EM*} = \left(6ac(4-\beta) - c^2(4-\beta)(7-(4-\beta)\beta) - 6a^2\right)/6b(4-\beta)(2-\beta) < 0$. We can obtain the two thresholds of c for giving $V_m^{NM*} - V_m^{EM*} = 0$: $c_3 = \left(3\beta + \sqrt{3}\sqrt{-8+22\beta-13\beta^2+2\beta^3} - 12\right)/\left(23\beta - 8\beta^2 + \beta^3 - 28\right)$ and $c_3' = \left(3\beta - \sqrt{3}\sqrt{-8+22\beta-13\beta^2+2\beta^3} - 12\right)/\left(23\beta - 8\beta^2 + \beta^3 - 28\right)$. When $\beta \in [0, 0.54) \cup [0.71, 1)$, we have $c_{\max} < c_3 < c_3'$, and when $\beta \in [0.54, 0.71)$, we have $0 < c_3 < c_{\max} < c_3'$. So, if $\beta \in [0, 0.54) \cup [0.71, 1)$, we have $V_m^{NM*} < V_m^{EM*}$; if $\beta \in [0.54, 0.71)$, we have $V_m^{NM*} < V_m^{EM*}$ when $0 < c < c_3$ and $V_m^{NM*} > V_m^{EM*}$ when $c_3 < c < c_{\max}$.

$\pi_r^{NM*} - \pi_r^{EM*} = \left(9ba^2 - c^2(2-\beta)b(4-\beta)^2\right)/9b^2(4-\beta)^2$. We can obtain two thresholds of c for giving $\pi_r^{NM*} - V_r^{EM*} = 0$: $c_4 = 3a/\sqrt{32 - 32\beta + 10\beta^2 - \beta^3}$ and $c_4' = -3a/\sqrt{32 - 32\beta + 10\beta^2 - \beta^3}$. When $\beta \in [0, 0.17)$, we have $c_4' < 0 < c_4 < c_{\max}$, and when $\beta \in [0.17, 1]$, we have $c_4' < 0 < c_{\max} < c_4$. So, if $\beta \in [0, 0.17)$, we have $\pi_r^{NM*} > V_r^{EM*}$ when $0 < c < c_4$ and $\pi_r^{NM*} < V_r^{EM*}$ when $c_4 < c < c_{\max}$; if $\beta \in [0, 0.17)$, we have $\pi_r^{NM*} > V_r^{EM*}$.

C.2 | Proof of Proposition 2

$CS^{NM*} - CS^{EM*} = \left(9a^2(2-\beta)^2 + (4-\beta)^2(3a-c-c\beta)^2\right)/(4-\beta)^2(2-\beta)^2 > 0$; $E^{NM*} - E^{EM*} = e(c(4-\beta)(1+\beta) - 6a)/3b(4-\beta)(2-\beta) < 0$.

C.3 | Proof of Proposition 3

$\pi_m^{NR*} - \pi_m^{ER*} = \left(4a^2(3-\beta) + (2-\beta)2ac(6-\beta)(2-\beta) - c^2(28-(12-\beta)\beta) - a^2(12-(4-\beta)\beta)\right)/16b(2-\beta)(3-\beta)$. We can get two thresholds of c for giving $V_m^{NR*} - \pi_m^{ER*} = 0$: $c_5 = a\left(28\beta - 10\beta^2 + \beta^3 - 24 + 2\sqrt{44\beta - 18\beta^2 - \beta^3 + \beta^4 - 24}\right)/\left(52\beta - 14\beta^2 + \beta^3 - 56\right)$ and $c_6 = a(28\beta - 10\beta^2 + \beta^3 - 24 - 2\sqrt{44\beta - 18\beta^2 - \beta^3 + \beta^4 - 24})/(52\beta - 14\beta^2 + \beta^3 - 56)$. When $\beta \in \left[0, 2\left(\sqrt{2}-1\right)\right)$, c_5 and c_6 don't exist; when $\beta \in \left[2\left(\sqrt{2}-1\right), 2\left(9-4\sqrt{2}\right)/7\right)$, we have $0 < c_5 < c_6 < c_{\max}$ and $\beta \in \left[2\left(9-4\sqrt{2}\right)/7, 1\right]$; we have $0 < c_5 < c_{\max} < c_6$. So, if $\beta \in \left[0, 2\left(\sqrt{2}-1\right)\right)$, we have $V_m^{NR*} < \pi_m^{ER*}$; if $\beta \in \left[2\left(\sqrt{2}-1\right), 2\left(9-4\sqrt{2}\right)/7\right)$, we have $V_m^{NR*} < \pi_m^{ER*}$ when $0 < c < c_5$ and $c_6 < c < c_{\max}$, $V_m^{NR*} > \pi_m^{ER*}$ when $c_5 < c < c_6$, and if $\beta \in \left[2\left(9-4\sqrt{2}\right)/7, 1\right]$, we have $V_m^{NR*} > \pi_m^{ER*}$ when $0 < c < c_5$, $V_m^{NR*} < \pi_m^{ER*}$ when $c_5 < c < c_{\max}$.

$V_r^{NR*} - V_r^{ER*} = \left(4a^2(3-\beta)^2 + (2-\beta)\left(2ac(2-\beta)\beta(10-3\beta) - a^2\beta(36 - \beta(20-3\beta)) - c^2(64 - 3\beta(4 + (4-\beta)\beta))\right)\right)/32b(2-\beta)(3-\beta)^2$. We can get two thresholds of c for giving $\pi_r^{NR*} - V_r^{ER*} = 0$: $c_7 = a(52\beta^2 - 22\beta^3 + 3\beta^4 - 40\beta + 2\sqrt{1152 - 3864\beta + 4964\beta^2 - 3182\beta^3 + 1085\beta^4 - 188\beta^5 + 13\beta^6})/(88\beta + 12\beta^2 - 18\beta^3 + 3\beta^4 - 128)$ and $c_8 = a(52\beta^2 - 22\beta^3 + 3\beta^4 - 40\beta - 2\sqrt{1152 - 3864\beta + 4964\beta^2 - 3182\beta^3 + 1085\beta^4 - 188\beta^5 + 13\beta^6})/(88\beta + 12\beta^2 - 18\beta^3 + 3\beta^4 - 128)$. When $\beta \in [0, \beta_1)$, we have $c_7 < 0 < c_8 < c_{\max}$; when $\beta \in [\beta_1, 0.77)$, we have $0 < c_7 < c_8 < c_{\max}$; and when $\beta \in [0.77, 1]$, c_7 and c_8 don't exist. Among that, we can get β_1 by solving $c_7 = 0$:

$$\beta_1 = \frac{13}{6} - \frac{1}{6}\sqrt{9 + \left(4184 - 72\sqrt{1641}\right)^{1/3} + 2\left(523 + 9\sqrt{1641}\right)^{1/3}} - \frac{1}{2}\sqrt{2 - \frac{1}{9}\left(4184 - 72\sqrt{1641}\right)^{1/3} - \frac{2}{9}\left(523 + 9\sqrt{1641}\right)^{1/3} + \frac{118}{9\sqrt{9 + \left(4184 - 72\sqrt{1641}\right)^{1/3} + 2\left(523 + 9\sqrt{1641}\right)^{1/3}}}}.$$

So, if $\beta \in [0,\beta_1)$, we have $\pi_r^{NR*} > V_r^{ER*}$ when $0 < c < c_8$ and $\pi_r^{NR*} < V_r^{ER*}$ when $c_8 < c < c_{max}$; if $\beta \in [\beta_1, 0.77)$, we have $\pi_r^{NR*} < V_r^{ER*}$ when $0 < c < c_7$ and $c_7 < c < c_{max}$ and $\pi_r^{NR*} > V_r^{ER*}$ when $c_7 < c < c_8$; and if $\beta \in [0.77, 1]$, we have $\pi_r^{NR*} < V_r^{ER*}$.

C.4 | Proof of Proposition 4

$CS^{NR*} - CS^{ER*} = \left(4a^2(3-\beta)^2 - (2-\beta)^2\left(c(2-\beta) - a(6-\beta)^2\right)\right)/32b(2-\beta)^2(3-\beta)^2 < 0;$
$E^{NR*} - E^{ER*} = e\left(c(2-\beta)^2 - a(6-(6-\beta)\beta)\right)/4b(3-\beta)(2-\beta) < 0.$

C.5 | Proof of Proposition 5

$V_m^{NM*} - \pi_m^{NR*} = -a^2\beta/4b(8-6\beta+\beta^2) < 0$; $\pi_r^{NM*} - V_r^{NR*} = -a^2\beta^2/8b(4-\beta)^2(2-\beta) < 0.$

C.6 | Proof of Proposition 6

$CS^{NM*} - CS^{NR*} = a^2/2b(4-\beta)^2 > 0$; $E^{NM*} - E^{NR*} = -ae\beta/2b(8-6\beta+\beta^2) < 0.$

C.7 | Proof of Proposition 7

$q_m^{EM*} - q_m^{ER*} = \beta(a(24-9\beta)+c(8-\beta(15-4\beta)))/12b(3-\beta)(2-\beta) > 0$; $q_r^{EM*} - q_r^{ER*} = -(3a+c(7-2\beta))\beta/6b(3-\beta) < 0.$

C.8 | Proof of Proposition 8

$V_m^{EM*} - \pi_m^{ER*} = \beta\left(c^2(4+(14-5\beta)\beta) - 6ac(20-(10-\beta)\beta) + 3a^2(12-(6-\beta)\beta)\right)/48b(3-\beta)(2-\beta)$. We have two thresholds of c for giving $V_m^{EM*} - \pi_m^{ER*} = 0$: $c_9 = a\left(60-30\beta+3\beta^2-2\sqrt{6}\sqrt{144-168\beta+70\beta^2-13\beta^3+\beta^4}\right)/(4+14\beta-5\beta^2)$ and $c_9' = a\left(60-30\beta+3\beta^2+2\sqrt{6}\sqrt{144-168\beta+70\beta^2-13\beta^3+\beta^4}\right)/(4+14\beta-5\beta^2)$, which $0 < c_9 < c_{max} < c_9'$. So, we have $V_m^{EM*} > \pi_m^{ER*}$ when $0 < c < c_9$ and $V_m^{ME*} < \pi_m^{ER*}$ when $c_9 < c < c_{max}$; $\pi_r^{EM*} - V_r^{ER*} = \beta\left(18ac(2-\beta)(10-3\beta) - c^2(564-(364-59\beta)\beta) - 9a^2(36-\beta(20-3\beta))\right)/288b(3-\beta)^2 < 0.$

C.9 | Proof of Proposition 9

$CS^{EM*} - CS^{ER*} = \left(16(3a-c-c\beta)^2(3-\beta)^2 + 9(a(6-\beta)-c(2-\beta))^2(2-\beta)^2\right)/288b(2-\beta)^2(3-\beta)^2 > 0;$
$E^{EM*} - E^{ER*} = -e\beta(c(20-7\beta)-3a(4-\beta))/12b(3-\beta)(2-\beta) < 0.$