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Highlights

- We investigate the influence of the manufacturer's overconfidence on supplier innovation and supply chain profits under the wholesale price contract and the cost-sharing contract settings.
- We define the impact of innovation on market demand with a continuous random variable to characterize the uncertainty with regard to technology performance and market acceptance.
- While the overconfidence is detrimental to the supplier's innovation under a wholesale price contract, it is beneficial to the supplier's innovation under a cost-sharing contract, and even more than in the centralized case.
- Under a wholesale price contract the manufacturer's profit can be higher than under a cost-sharing contract when the level of overconfidence exceeds a certain threshold.
- The supplier's unawareness of overconfidence benefits both biased supply chain members under a wholesale price contract but shows the opposite effect for a cost-sharing contract.

The upstream innovation with an overconfident manufacturer in a supply chain

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Abstract: Overconfidence is a common, pervasive cognitive bias that is of great practical importance in decision-making and widely recognized as an influential factor to consider in operations management. In this paper, we consider overconfidence bias in a supply chain innovation scenario, which consists of an innovative upstream supplier and an overconfident downstream manufacturer overestimating the impact of innovation to enhance demand. We investigate the influence of the manufacturer's overconfidence on supplier innovation and supply chain profits under the wholesale price contract and the cost-sharing contract settings. Our results suggest that while the overconfidence is detrimental to the supplier's innovation under a wholesale price contract, it is beneficial to the supplier's innovation under a cost-sharing contract, and even more beneficial than in the centralized case. We also find that, under a wholesale price contract the manufacturer's profit can be higher than under a cost-sharing contract when the level of overconfidence exceeds a certain threshold. Interestingly, we further find that the supplier's unawareness of overconfidence benefits both biased supply chain members under a wholesale price contract but shows the opposite effect for a cost-sharing contract. Our results offer insights into overconfidence bias in operations management and provide practical decision-making advice for supply chain members.

Keywords: overconfidence; overestimation; upstream innovation; cost-sharing contract; wholesale price contract

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1. Introduction

Innovation, which is sometimes also defined as quality improvement (Banker et al., 1998; Chakraborty et al., 2019; De Giovanni and Zaccour, 2019), is essential for firms to enhance market demand, improve performance, and achieve sustainable competitive advantages in the current, rapidly changing business environment (Barreto, 2010; Fawcett et al., 2012; Wang and Shin, 2015; Yenipazarli, 2017; Song et al., 2021). However, when located in turbulent technology and market conditions, firms often suffer from insufficient R&D resources, making a continuous flow of innovation difficult to achieve. To overcome this difficulty, firms are typically encouraged to collaborate with supply chain partners, particularly the supplier, during the innovation process. Successful management of supplier-enabled innovation has the potential to leverage the innovation power of the supply base, through, for instance, fresh ideas, shorter time-to-market, and higher margins, all of which help firms increase innovation performance and profitable growth (Eizenberg, 2014; Nouri et al., 2018). For example, the involvement of Leica Camera in product development helped Huawei create a fresh new selling point (i.e. the quad-camera) in the smartphone market, and even set off the photography use patterns of the smartphone. In yet another example, the launch of the external partnership program, Connect + Develop, empowered Procter & Gamble purple to expand its R&D department, attracting innovative suppliers from around the world, generating billions of dollars in new product sales[1].

Aware of the potential benefits of supplier innovation, firms initiate collaborations with suppliers to unlock additional value and expand the value chain that resides outside their walls. For instance, similar to other large companies, Apple has started a $5 billion U.S. manufacturing fund to subsidize individual app development projects on its IOS platform[2]. Despite the potential benefits, involving suppliers in the innovation process remains a challenge, particularly because firms may lack both a clear view of end-market needs and an appropriate level of confidence about potential benefits, which in turn could result in

[1] https://us.pg.com/innovation/

[2] https://www.apple.com/newsroom/2018/01/apple-accelerates-us-investment-and-job-creation/

an internal unwillingness to engage in innovation collaboration(Wagner and Bode, 2014). In order to tackle this problem, in this study, we consider the role of cognitive bias, a widespread irrational factor affecting decision-making that has been explored in both psychology and operations management fields (Xie et al., 2011; Du et al., 2019). Specifically, we focus on the most consistent and influential decision-maker' bias, overconfidence. One of the most consistent and influential decision-makers' biases, overconfidence is described as the tendency for individuals to be more confident in their opinions, actual abilities or performance than they ought to be (Moore and Healy, 2008; Gino and Pisano, 2008). In the case of managers, Phua et al. (2018) note that Jack Welch of General Electric and Steve Jobs of Apple Inc. both showed managerial overconfidence as CEOs, which in general can significantly affect the business activities and results of enterprises. Indeed as Plous (1993) points out, nothing is more potentially catastrophic than overconfidence in judgment and decision-making. Take, for instance, a manufacturer of touchscreen sensors responding to anticipated high demand for innovative products, leading to a decline in profits[3]. Despite the common perception that overconfidence is harmful, some scholars suggest that it does not necessarily damage supply chain performance (Kirshner and Shao, 2019; Li, 2019), arguing instead that in a competitive setting, a more overconfident buyer is not always destined to have a smaller expected profit than its less biased competitor (Li et al., 2016).

As to the relation of overconfidence and innovation, empirical research shows that companies prefer to hire overconfident managers in their ambition for future growth, a preference which is more likely to lead to innovation projects during their tenure (Galasso and Simcoe, 2011; Hirshleifer et al., 2012). In the supply chain setting, previous researchers demonstrate overconfident enterprises can motivate the supplier's actions due to their ability to inform the supply chain about the business opportunities, build long-term "win-win" partnerships, and improve profits in the supply chain. Phua et al. (2018) find that overconfident managers can induce their upstream suppliers to enhance relationship-specific investments. There are also some empirical and theoretical studies that regard overconfidence as the tendency to overestimate performance (Galasso and Simcoe, 2011;

[3]https://www.redeye.se/research/506231/neonode-increases-its-airbar-capacity-due-anticipated-high-demand

Tang et al., 2015; Xiang and Xu, 2020; Xiao et al., 2020). Nelson and Schwartz (2020) find that suppliers are directly dependent on the operational decisions of overconfident manufacturer. More specifically, in their investigation of the overconfidence spillover effect in the supply chain they find that suppliers do not become overconfident in response to their downstream manufacturer's overconfidence.

Based on these empirical and theoretical studies, we employ a game-theoretic analysis to investigate the influence of overconfidence bias on the mechanism design of an upstream innovation supply chain where the manufacturer is overconfident who overestimates the impact of innovation on market demand and the supplier is not. We consider two types of contract to encourage innovation in the upstream. One is a wholesale price contract, a classic, typical incentive contract, in which a downstream manufacturer buys parts from a supplier at a fixed price (Gray et al., 2009; Wang and Shin, 2015; Shen et al., 2016). The other is a cost-sharing contract, a widely studied type of contract, designed to encourage upstream innovation through cost sharing (Bernstein and Kök, 2009; Ghosh and Shah, 2015). Many previous empirical studies have shown that cost-sharing is a widely employed R&D incentive (Merkle and Weber, 2011). For instance, in 2018, the technology giant Apple paid 60 billion US dollars to 9000 American suppliers to share in the cost of innovation [4]. We aim to address the following research questions:

- What is the influence of manufacturer overconfidence on upstream innovation and product pricing in a game-theoretic analysis?
- Does the manufacturer overconfidence affect the choice of incentive contract?

To answer these questions, we consider a supply chain with an overconfident manufacturer (he) and an upstream supplier (she). The supplier invests in innovation that is an upgrade of a component and is anticipated to increase the value of a product for consumers, enhancing market demand. The manufacturer incorporates the technology-laden component into the product, which is priced and then sold to consumers. Thus, in the supply chain, the supplier does not directly face the market and relies more on the manufacturer's operational decisions. We examine the effects of this overconfidence on

[4] https://www.apple.com/newsroom/2019/01/component-manufacturing-drives-apple-us-job-creation/

supplier innovation and the choice of either a wholesale price or cost-sharing contract. By determining and contrasting the equilibrium strategies for an overconfident manufacturer and a rational supplier under the two different contracts, we obtain the following insights: (i)If the overconfident manufacturer tries to encourage the rational supplier to invest in innovation, it is better for the manufacturer to enter into a cost-sharing contract. In this scenario the innovation effort is even higher than it is in the centralized case. Our research results provide an important theoretical explanation for innovation-seeking companies like Apple Inc. that provide financial support for parts enterprises to offset innovation costs; (ii) When the level of overconfidence of the manufacturer exceeds a certain threshold, his profit could be higher with a wholesale price contract than with a cost-sharing contract. This is because when the rate of cost-sharing increases in the manufacturer's overconfidence, leading him to bear a greater cost of innovation investment. In other words, when the manufacturer has a relatively high level of overconfidence, he would be better off using a wholesale price contract as an incentive mechanism. This study differs from prior studies that assume a cost-sharing contract is usually better than a wholesale price contract in terms of innovation and profits; (iii) If a manufacturer uses only a wholesale price contract to cooperate with the rational supplier, he is better off not disclosing his overconfidence to the supplier. This is because overconfidence without resource commits may cause the supplier to be more cautious when investing in innovation, which can ultimately decrease the profits of the supply chain members.

In addition, when the supplier is biased and unaware of the manufacturer's overconfidence, her unawareness shows diverse effects on different cooperative mechanisms. Under a wholesale price contract, the supplier's lack of awareness can benefit both biased members of the supply chain. However, it has the opposite effect under a cost-sharing contract.

Our study makes three contributions to the literature. First, we enrich the research on overconfidence in operations management. As one of the most widely recognized irrational behaviors, overconfidence can affect decision-making. Given the effects of overconfidence and the necessity of innovation for firms, we construct a game-theoretical model to include overconfidence in upstream innovation in the supply chain scenarios. Second, our study provides practical advice for mechanism design of upstream innovation in the supply chain. Previous studies have shown that a cost-sharing contract is superior to a wholesale price contract in terms of profits and innovation when members are rational. Our model results demonstrate that a cost-sharing contract can stimulate the supplier to invest more in innovation, but does not always increase profits for the manufacturer. When the level of manufacturer overconfidence is high, a wholesale price contract is more favorable to the manufacturer. That is, when the manufacturer pays more attention to supplier innovation, he would be better off choosing a cost-sharing contract as the incentive mechanism; and when he cares more about his own profit, he would like to choose a wholesale price contract. Third, we provide new insights into the operational strategy of supply chain members. In our exploration of how members make pricing decisions in a supply chain with an overconfidence bias, we find that the impact of overconfidence on pricing depends on the type of incentive contract, and that overconfidence does not necessarily damage the supply chain.

The remainder of the paper is organized as follows. Section 2 reviews the related literature. Section 3 describes the research model and gives the baseline model. Section 4 develops a one-manufacturer-one-retailer game model that includes the manufacturer's overconfidence under a wholesale price contract and a cost-sharing contract. Section 5 provides the results of strategies and profit comparisons together with analysis. Section 6 extends the model to the case of a supplier who is unaware of the manufacturer's overconfidence. Conclusions are drawn in Section 7.

2. Literature review

This paper is related to three streams of literature: supply chain innovation; quality improvement and demand-enhancing tools as advertising within a supply chain; and overconfidence, especially in the fields of operations management and empirical research.

In the supply chain innovation literature, Arlbjørn et al. (2011) define supply chain innovation as change directed at enhancing new value creation. Supply chain innovation has a significant impact on improving supply chain performance (Gunday et al., 2011; Hao et al., 2019; Hu et al., 2020). This has led many scholars to study the design of incentive mechanisms that encourage innovation through government subsidy(Chen et al., 2019), internal systems of enterprises(Manso, 2011) as well as the upstream and downstream of the supply chain (Gilbert and Cvsa, 2003; Bhaskaran and Krishnan, 2009; Sanyal and Ghosh, 2013; Eizenberg, 2014; Ghosh and Shah, 2015; Wang and Shin, 2015; Yenipazarli, 2017; Aydin and Parker, 2018; Yang and Chen, 2018; Yu et al., 2021). Among these work, the following studies are particularly relevant for our study because they focus on encouraging partners to invest in innovation. Gilbert and Cvsa (2003) discuss several wholesale pricing mechanisms to stimulate downstream innovation in a supply chain and identify a trade-off between pricing flexibility and strategic commitment to induce downstream innovation. Other studies highlight upstream supplier innovation, which aligns with our research focus. For instance, Yenipazarli (2017) analyzes the upstream eco-efficient innovation and finds that the price sensitivity of customers and unit production cost of the product are important forces driving the supplier to invest more effort in innovation. Bhaskaran and Krishnan (2009) model joint work and decision making for new product development and find that innovation sharing plays an important role for projects experiencing a high level of uncertainty regarding product quality. They also conclude that when firms are similar in their capabilities, the cost of work integration across firms can be controlled. Sanyal and Ghosh (2013) focus on the innovation response of upstream technology suppliers when their downstream buyers shift from regulation to competition and find that the upstream innovation declines after the introduction of downstream competition. Wang and Shin (2015) discuss the impact of supply chain contracts on upstream innovation and confirm that a wholesale price contract will result in underinvestment in innovation. Ghosh and Shah (2015) explore the impact of a cost-sharing contract on upstream innovation in a green supply chain and show that a cost-sharing contract can stimulate the upstream to invest more in innovation. Yang and Chen (2018) investigate the impact of cost-sharing and revenue-sharing contracts on upstream carbon emission abatement efforts and show that a revenue-sharing contract results in greater improvement in efficiency and effort compared to cost-sharing but cannot coordinate the supply chain. Yu et al. (2021) examine the supply chain members' R&D collaboration contract strategies with different payments or sales operation. The essential difference between our work and previous literature is that we not only consider upstream innovation, which enhances market demand but also consider an irrational behavior, overconfidence, of the manufacturer.

In the supply chain literature, quality improvement is also considered as a typical demand-enhancing and coordinating tool in which quality is defined as creative design and conformance of the product (Chakraborty et al., 2019; De Giovanni and Zaccour, 2019). Xie et al. (2011) consider the behavior of the members of a supply chain and find that compared to a risk-neutral supply chain, a risk-averse supply chain has lower, the same and higher quality of products in vertical integration, namely manufacturer's Stackelberg and supplier's Stackelberg. Chakraborty et al. (2019) argue that cost-sharing contract based on quality improvement can result in higher profits in the supply chain. Chen et al. (2017) find that quality improvement can be realized when a new channel is introduced. Zhang et al. (2018) describe an original equipment manufacturer's optimal technology licensing strategy when technology efficiency is uncertain. Zhang et al. (2019) examine the effects of manufacturer encroachment with asymmetric demand information on product quality decisions and the profits of supply chain members. De Giovanni and Zaccour (2019) investigate optimal dynamic or constant pricing and quality improvement strategies with active and passive product return types. Li and Chen (2020) investigate the influence mechanism of the quality efficiency and three kinds of allocation rules on grand coalition stability. In addition to quality improvement, extensive studies on the choice of typical advertising or cooperative advertising in the supply chain demonstrate their impact on consumers' purchasing behaviors. As Aust and Buscher (2014) and Jørgensen and Zaccour (2014) have provided comprehensive reviews of the related research, we focus on some cooperative advertising decisions considering the influence of the decision-makers' behaviors and innovation. Yang et al. (2013) take an initial step to incorporate fairness concerns of channel members into the study of co-op advertising in a distribution channel. They find that co-op advertising allows the manufacturer to improve his own profit as well as the retailer's utility depending on the retailer's fairness concerns. Li et al. (2017) study the dyadic supply chain cooperative advertising problem considering fairness concerns of a manufacturer. Zhou et al. (2018) indicate that cooperative advertising not only encourages a risk-averse retailer to invest much more in local advertising and order more products but also reduces the retailer's risk. Song et al. (2017) describe how both innovation and advertising contribute to product demand. They find that optimal decisions are sensitive to the effects of innovation and advertising, as well as the manufacturer's cost reduction coefficient.

As one of the most persistent, robust, and widespread cognitive biases, overconfidence has been studied in many fields. And we refer the reader to Moore and Healy (2008) and Moore and Schatz (2017) for a comprehensive review of literature, in which they review more than 600 papers and distinguish three types of overconfidence: overestimation (about 49% of the studies and our focus), overplacement, and overprecision. Overestimation means that people believe their abilities or performance are better than they are. The overplacement shows people believe they are better than others. And the third measure of overconfidence is overprecision refers a person's exaggerated certainty on the truth (Moore and Healy, 2008; Ren et al., 2017). In recent operations management research, some scholars capture overprecision as the biased belief that distribution of demand has the same mean but a lower variance than it truly has (Ren and Croson, 2013; Li et al., 2016; Ren et al., 2017; Jain et al., 2018; Kirshner and Shao, 2019; Li, 2019). Ren and Croson (2013) regard overprecision as a negative factor that causes to individuals to make suboptimal decisions in supply chain inventory settings and that is harmful to profits of the supply chain. Jain et al. (2018) consider overprecision bias in the procurement setting where they conclude that overprecision can account for the ordering mistakes of sourcing team members. Li et al. (2016) consider a game between two competing newsvendors with overprecision. They find that overprecision can benefit newsvendors in terms of inventory availability when they compete against each other. Li (2019) extends the role of overprecision in distribution channels and shows that it can reduce the double marginalization effect. In general, the above studies modeling the market demand with overprecision assume that the estimation of the mean is accurate, but the estimation of variance is inaccurate. Different from overprecision, overestimation occurs when the mean is great than its actual value. Some scholars follow this to model the manufacturer's overconfidence in his market efforts as he believes that his performances or abilities are "better-than-fact" (Xiang and Xu, 2020; Xiao et al., 2020). Besides these theoretical analyses, empirical research shows that overconfident executives are inclined to overestimate the expected payoffs from investment and financing (Malmendier and Tate, 2005; Schrand and Zechman, 2012; Pikulina et al., 2017) but few papers have studied the impact of managerial overconfidence on innovations. Galasso and Simcoe (2011) and Tang et al. (2015) confirm that manager attitudes and beliefs are linked to a company's innovation performance, and overconfident CEOs are more likely to take their firms in new technological directions. Hirshleifer et al. (2012) find that companies with overconfident managers invest more in innovation projects because they overestimate the benefits for their companies. Moreover, in the supply chain setting, Phua et al. (2018) and Nelson and Schwartz (2020) demonstrate that manufacturer overconfidence can increase the supplier R&D investment, but does not spillover to the supplier.

As demonstrated, the related theoretical analyses concentrate on the impacts of overconfidence on ordering or pricing decisions in a supply chain, but few scholars study the impact of overconfidence on innovation or quality improvement. Unlike the above empirical research, we employ a game-theoretical analysis to investigate the impact of manufacturer overconfidence and a cooperative contract on the supplier innovation decisions in a supply chain. This unique focus gives rise to some novel results. For example, we find that a manufacturer can motivate the upstream supplier to invest more in innovation by offering different types of contracts. We also investigate the impacts of manufacturer overconfidence on pricing decisions, the supplier investment in innovation, and the choice of the manufacturer's incentive contracts.

3. Basic model without overconfidence

In this section, we consider a rational two-echelon supply chain structure with an upstream supplier (she) and a downstream manufacturer (he) as a benchmark model. In this structure, the supplier invests in innovation to improve a component, which has the potential to increase the added value of the product and market demand. The manufacturer incorporates the component into the product and sells it to consumers. The model timeline of the manufacturer and the supplier is shown in Figure 1. In the initial stage, s=1, the manufacturer and the retailer negotiate a contract. We consider two typical contracts: (i) a wholesale price contract where the supplier sets w, and (ii) a cost-sharing contract in which the manufacturer offers an innovation cost-sharing rate $\varphi(0 < \varphi < 1)$, and then the supplier determines the wholesale price w. In the second stage, s=2, the supplier determines how much to invest in innovation, i. Finally, in the last stage, s=3, the manufacturer decides the selling price and sells the product directly to consumers to make a profit. The manufacturer and the supplier have unit manufacturing costs c_m and c_s, respectively. It should be noted that c_m covers the cost of components purchased by the manufacturer from other suppliers. And it is reasonable to assume that $w > c_s$ and $p > c_m + c_s$. When the supplier decides her level of innovation i, she incurs the innovation cost of $i^2/2$, which indicates that innovation to improve market demand becomes increasingly difficult (D'Aspremont and Jacquemin, 1988; Liu et al., 2012).

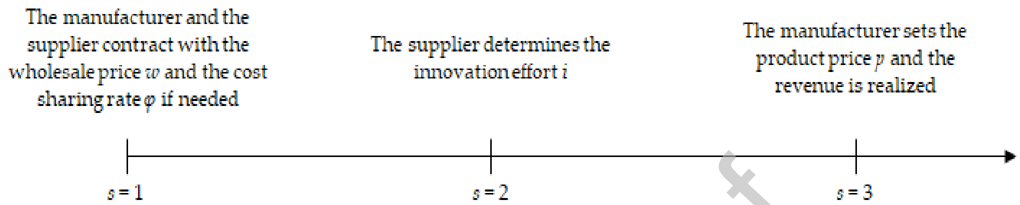

Figure 1: The Model Timeline

Referring to the theoretical models in supply chain innovation and quality improvement (Chen et al., 2019; De Giovanni and Zaccour, 2019; Liu et al., 2012; Zhang et al., 2018), we have a two-part consumer demand function, $q_1 = a - p + \Theta i$ that depends on the selling price and innovation effort, where a, p and Θ are positive. The first part captures the impact of price on sales with a linear, downward-sloping function $a - p$, where the parameter a denotes the basic market potential, p is the selling price, and $a > p$. The second part Θi represents the effect of innovation on demand, which is derived from the innovation of the supplier. And the Θ indicates the demand-enhancing effectiveness of innovation (per unit of effort). Moreover, as the effect of innovation is usually uncertain with regard to technology performance and market acceptance(Zhang et al., 2018; Zhou et al., 2020), we define Θ as a continuous random variable to characterize the uncertainty on the range of $(0, \hat{\Theta})$ with mean μ and variance σ^2 and has a cumulative distribution function $F(\Theta)$ and probability density function $f(\Theta)$.

In the supply chain, members are completely rational and only care about their own monetary payoffs. Based on the research of Ghosh and Shah (2015), Zhang et al. (2018) and the above model hypothesis, we have these profit functions in the case of a wholesale price contract.

$$\max_{p} E\left[\pi_m^{wn}\left(p,w,i\right)\right] = \int_0^{\hat{\Theta}} \left(p - c_m - w\right)\left(a - p + \mu\, i\right) f\left(\Theta\right)\, \mathrm{d}\Theta \tag{1}$$

$$\max_{i,w} E\left[\pi_s^{wn}\left(p,w,i\right)\right] = \int_0^{\hat{\Theta}} \left(w - c_s\right)\left(a - p + \mu\, i\right) f\left(\Theta\right)\, \mathrm{d}\Theta - i^2/2 \tag{2}$$

The superscript wn indicates that the manufacturer and that the retailer adopt the wholesale price contract while being fully rational. In order to deal with this problem in a similar but more convenient manner, we apply an appropriate deformation for the related variables as follows: $p' = p - c_m - c_s$, $w' = w - c_s$, $a' = a - c_m - c_s$. It is easy to see that p',w' and a' are all positive. With these redefinitions of the variables, the profit functions in (1) and (2) can be rewritten as:

$$\max_{p'} E\left[\pi_m^{wn}\left(p',w',i\right)\right] = \int_0^{\hat{\Theta}} \left(p' - w'\right)\left(a' - p' + \mu\, i\right) f\left(\Theta\right)\, \mathrm{d}\Theta \tag{3}$$

$$\max_{i,w'} E\left[\pi_s^{wn}\left(p',w',i\right)\right] = \int_0^{\hat{\Theta}} w'\left(a' - p' + \mu\, i\right) f\left(\Theta\right)\, \mathrm{d}\Theta - i^2/2 \tag{4}$$

For simplicity, we assume c_m, $c_s = 0$ and remove the superscript ($'$) from the above expression after this section.

3.1. Centralized case

To set up a benchmark for our later analyses, we first consider the centralized decision-making structure in which decisions are optimized from the standpoint of the whole supply chain. The centralized decision problem is to determine the level of innovation i and selling price p to maximize the total supply chain's profit π_{sc}:

$$\max_{p} E\left[\pi_{sc}\left(p,i\right)\right] = \int_0^{\hat{\Theta}} p\left(a - p + \mu\, i\right) f\left(\Theta\right)\, \mathrm{d}\Theta - i^2/2 \tag{5}$$

It can be easily verified that Problem (5) has a unique solution

$$\left(i_{sc}^{*}, p_{sc}^{*}\right) = \left(\frac{a\mu}{-\mu^2+2}, \frac{a}{-\mu^2+2}\right) \tag{6}$$

and the optimal profit for the whole supply chain is

$$\pi_{sc}^{*} = \frac{a^2}{-2\,\mu^2 + 4} \tag{7}$$

where the subscript sc stands for the total supply chain and the superscript $*$ denotes optimal solution for centralized decision-making. Because $i_{sc}^{*},\ p_{sc}^{*},\ \pi_{sc}^{*} > 0$, we have $\mu \in \big(0, \sqrt{2}\big)$.

3.2. Decentralized case

In the decentralized case, each member of the supply chain attempts to optimize their own profit, and they follow the model timeline. We consider two scenarios: a wholesale price contract and a cost-sharing contract. Under a wholesale price contract, the supply chain members' profit functions are represented by Equation (3) and (4). Under a cost-sharing contract, we have

$$\max_{p,\varphi} E\big[\pi_m^{cn}\,(p, w, i, \varphi)\big] = \int_0^{\hat{\Theta}} (p - w)\,(a - p + \mu\, i)\, f\,(\Theta)\ \mathrm{d}\Theta - \varphi\, i^2/2 \tag{8}$$

$$\max_{i,w} E\big[\pi_s^{cn}\,(p, w, i, \varphi)\big] = \int_0^{\hat{\Theta}} w\,(a - p + \mu\, i)\, f\,(\Theta)\ \mathrm{d}\Theta - (1 - \varphi)\, i^2/2 \tag{9}$$

The superscript cn indicates that a cost-sharing contract is adopted and the supply chain members are fully rational. We employ the standard backward induction to solve this problem. In Table 1, we list the equilibrium results, including the selling price, the wholesale price, the level of innovation, the cost-sharing rate, the equilibrium profits of the manufacturer and the supplier, and the supply chain's profit.

Proposition 1. *The equilibrium values in Table 1 are in the following order when the manufacturer is completely rational:* $i_{sc}^{*} > i^{cn} > i^{wn}$; $\pi_m^{cn} > \pi_m^{wn}$; $\pi_s^{cn} > \pi_s^{wn}$; $\pi_{sc}^{*} > \pi_{sc}^{cn} > \pi_{sc}^{wn}$.

The proof of this proposition is provided in Appendix A.

The results in Proposition 1 are similar to and consistent with those of existing studies (Ghosh and Shah, 2015; Yenipazarli, 2017). From Proposition 1, we make the

Table 1: Equilibrium results when channel members do not have overconfidence.

Case	Centralized case	Wholesale price contract	Cost-sharing Contract
Cost sharing rate	-	-	$\varphi^{cn} = \frac{\mu^2}{8}$
The level of innovation	$i^*_{sc} = \frac{a\mu}{-\mu^2+2}$	$i^{wn} = \frac{a\mu}{-\mu^2+4}$	$i^{cn} = \frac{2a\mu}{-3\mu^2+8}$
Selling price	$p^*_{sc} = \frac{a}{-\mu^2+2}$	$p^{wn} = \frac{3a}{-\mu^2+4}$	$p^{cn} = \frac{3a(-\mu^2+8)}{4(-3\mu^2+8)}$
Wholesale price	-	$w^{wn} = \frac{2a}{-\mu^2+4}$	$w^{cn} = \frac{a(-\mu^2+8)}{2(-3\mu^2+8)}$
Manufacturer's profit	-	$\pi^{wn}_m = \frac{a^2}{(-\mu^2+4)^2}$	$\pi^{cn}_m = \frac{a^2(\mu^2+8)}{16(-3\mu^2+8)}$
Supplier's profit	-	$\pi^{wn}_s = \frac{a^2}{2(-\mu^2+4)}$	$\pi^{cn}_s = \frac{a^2(-\mu^2+8)}{8(-3\mu^2+8)}$
Supply chain's profit	$\pi^*_{sc} = \frac{a^2}{-2\mu^2+4}$	$\pi^{wn}_{sc} = \frac{a^2(-\mu^2+6)}{2(-\mu^2+4)^2}$	$\pi^{cn}_{sc} = \frac{a^2(-\mu^2+24)}{16(-3\mu^2+8)}$

following two observations. First, compared with the wholesale price contract, the cost-sharing contract encourages the supplier to invest more in innovation and increases each member's profit. Second, if the supply chain members are completely rational, neither a wholesale price contract nor a cost-sharing contract can lead to channel coordination.

4. Overconfident Manufacturer

As previously discussed, studies have divided overconfidence into three categories: overestimation, overplacement and overprecision(Moore and Healy, 2008). While overprecision reflects the decision maker's overconfident bias with regard to market demand(Ren and Croson, 2013; Li et al., 2016; Li, 2019), a few research describes overconfidence as an overly optimistic expectation about its ability or outcome is more than it likely is(Malmendier and Tate, 2005; Schrand and Zechman, 2012; Pikulina et al., 2017). For the impact on firm innovation, there are also some empirical and theoretical researches measuring overconfidence as the inclination to overestimate the performance(Galasso and Simcoe, 2011; Hirshleifer et al., 2012; Phua et al., 2018; Tang et al., 2015; Xu et al., 2019). Following Nelson and Schwartz (2020), we consider an overconfident manufacturer whose overconfidence does not spillover to the supplier. In conclusion, this section investigates the case where the manufacturer is overconfident as overestimating the impact of the supplier's innovation on market demand (De la Rosa, 2011; Galasso and Simcoe, 2011; Phua et al., 2018; Tang et al., 2015). The supplier is aware of his overconfidence, but ignores his bias as she holds heterogeneous belief about the impact of innovation (Nelson and Schwartz, 2020). The market demand function resulting from the overconfident manufacturer is $q_2 = a - p + \Theta_o i$, where Θ_o is a continuous random variable on the range of $(\varepsilon, \hat{\Theta} + \varepsilon)$ with mean $(\mu + \varepsilon)$ and variance σ^2. In other words, $\varepsilon(\varepsilon \geq 0)$ represents the manufacturer's overconfidence coefficient, and εi indicates the amount of market demand that the manufacturer overestimates. The greater ε is, the greater the overconfidence of the manufacturer.

In order to study more deeply the impact of the manufacturer's overconfidence on the supply chain decision-making, this section also considers two possible contracts: a wholesale price contract and a cost-sharing contract.

4.1. The wholesale price contract

Under a wholesale price contract, where the manufacturer purchases components from the supplier at a fixed price, the supplier's decision function is consistent with the rational case that maximizes her profit. The manufacturer maximizes his utility because he is overconfident. The decision-makers then solve:

$$\max_{p} E\big[u_m^{wo}(p, w, i)\big] = \int_{\varepsilon}^{\hat{\Theta}+\varepsilon} (p - w)\left(a - p + (\mu + \varepsilon)\, i\right) f(\Theta)\, \mathrm{d}\Theta \tag{10}$$

$$\max_{i,w} E\big[\pi_s^{wo}(p, w, i)\big] = \int_{\varepsilon}^{\hat{\Theta}+\varepsilon} w\left(a - p + \mu\, i\right) f(\Theta)\, \mathrm{d}\Theta - i^2/2 \tag{11}$$

The superscript wo indicates that the manufacturer is overconfident under a wholesale price contract. According to the decision order, we employ the standard backward induction to solve this game.

Lemma 1. *If an overconfident manufacturer negotiates a wholesale price contract with a supplier, the level of innovation and the wholesale price charged by the supplier in equilibrium are*

$$\left(i^{wo}, w^{wo}\right) = \left(\frac{a(\mu - \varepsilon)}{(2 + \mu - \varepsilon)(2 - \mu + \varepsilon)}, \frac{2a}{(2 + \mu - \varepsilon)(2 - \mu + \varepsilon)}\right) \tag{12}$$

and the equilibrium selling price and the firm-level profits are

$$p^{wo} = \frac{a(\mu\varepsilon - \varepsilon^2 + 3)}{(2 + \mu - \varepsilon)(2 - \mu + \varepsilon)} \tag{13}$$

$$\left(\pi_s^{wo},\pi_m^{wo}\right)=\left(\frac{a^2}{2\left(2+\mu-\varepsilon\right)\left(2-\mu+\varepsilon\right)},\frac{a^2\left(\mu\,\varepsilon-\varepsilon^2+1\right)}{\left(2+\mu-\varepsilon\right)^2\left(2-\mu+\varepsilon\right)^2}\right) \tag{14}$$

The proof is provided in Appendix B.

We have $i^{wo}\geq 0$ and $p^{wo}>w^{wo}>0$, so $\varepsilon\in(0,\mu)$.

Corollary 1. *When a manufacturer engages in overconfident behavior under a wholesale price contract, there are:*

(a) $\frac{\partial i^{wo}}{\partial\varepsilon}<0$*;* $\frac{\partial w^{wo}}{\partial\varepsilon}<0$*;* $\frac{\partial p^{wo}}{\partial\varepsilon}<0$*.*

(b) $\frac{\partial\pi_s^{wo}}{\partial\varepsilon}<0$*;* $\frac{\partial\pi_m^{wo}}{\partial\varepsilon}<0$*.*

The proof is provided in Appendix C.

Corollary 1 indicates that under a wholesale price contract overconfidence has a negative impact on both innovation and prices. Although the manufacturer overestimates market demand, the actual sales fail to meet expectations. The higher the market demand estimated by the manufacturer, the lower the selling price will be in order to achieve the expected sales. From the perspective of an overconfident manufacturer, he wants his supplier to invest more in innovation. However, under a wholesale price contract he has no incentive to contribute to innovation, and the supplier takes on all innovation costs herself. The belief that the manufacturer can gain more from innovation without sharing the cost leads the supplier to invest less in innovation. This lower level of supplier investment likely reduces the supplier's innovation cost and may also result in new components that fail to meet manufacturer's expectations. This in turn leads to a reduction in the supplier's wholesale price. Furthermore, because both innovation and prices are lower, the supplier and the manufacturer profit functions decrease due to overconfidence.

4.2. The cost-sharing contract

When the manufacturer and supplier enter into a cost-sharing contract, the supplier invests in innovation and the manufacturer shares a fraction of the supplier's upfront cost of investment. In this case, for any given participation rate $\varphi\,(\varphi\in(0,1))$ dictated by the manufacturer, the decision functions of the supplier and the manufacture are:

$$\max_{p,\varphi} E\left[u_m^{co}\left(p,w,i,\varphi\right)\right]=\int_{\varepsilon}^{\hat{\Theta}+\varepsilon}\left(p-w\right)\left(a-p+\left(\mu+\varepsilon\right)i\right)f\left(\Theta\right)\,\mathrm{d}\Theta-\varphi\,i^2/2 \tag{15}$$

$$\max_{i,w} E\left[\pi_s^{co}(p,w,i,\varphi)\right] = \int_{\varepsilon}^{\hat{\Theta}+\varepsilon} w\,(a-p+\mu\,i)\,f(\Theta)\;\mathrm{d}\Theta - (1-\varphi)\,i^2/2 \tag{16}$$

The superscript *co* indicates that the manufacturer is overconfident under a cost-sharing contract. We solve this problem by backward induction.

Lemma 2. *If an overconfident manufacturer chooses a cost-sharing contract, the supplier's equilibrium innovation level and wholesale price are*

$$\left(i^{co}, w^{co}\right) = \left(\frac{2a\,(\mu+\varepsilon)}{-3\,\mu^2-2\,\mu\,\varepsilon-11\,\varepsilon^2+8}, \frac{a\,(-\mu^2-2\,\mu\,\varepsilon-13\,\varepsilon^2+8)}{2\,(-3\,\mu^2-2\,\mu\,\varepsilon-11\,\varepsilon^2+8)}\right) \tag{17}$$

and the equilibrium selling price, cost-sharing rate and firm-level profits are

$$\left(p^{co}, \varphi^{co}\right) = \left(\frac{a\,(-3\,\mu^2+2\,\mu\,\varepsilon-31\,\varepsilon^2+24)}{4\,(-3\,\mu^2-2\,\mu\,\varepsilon-11\,\varepsilon^2+8)}, \frac{\mu^3+\mu^2\varepsilon+11\,\mu\,\varepsilon^2-13\,\varepsilon^3+16\,\varepsilon}{8\,(\mu+\varepsilon)}\right) \tag{18}$$

$$\left(\pi_s^{co}, \pi_m^{co}\right) = \left(\frac{a^2\,(-\mu^2-2\,\mu\,\varepsilon-13\,\varepsilon^2+8)}{8\,(-3\,\mu^2-2\,\mu\,\varepsilon-11\,\varepsilon^2+8)}, \frac{a^2\,(117\,\varepsilon^4-60\,\mu\,\varepsilon^3-2\,\varepsilon^2\,(21\,\mu^2+104)-4\,\mu\,\varepsilon\,(3\,\mu^2+8)-3\,\mu^4-16\,\mu^2+64)}{16\,(-3\,\mu^2-2\,\mu\,\varepsilon-11\,\varepsilon^2+8)^2}\right) \tag{19}$$

The proof is provided in Appendix D.

Because $i^{co} \geq 0$, $p^{co} > w^{co} > 0$, and $0 < \varphi^{co} < 1$, we obtain $\varepsilon \in \left(0, \frac{-\mu+2\sqrt{-8\,\mu^2+22}}{11}\right)$. Moreover, $\frac{-\mu+2\sqrt{-8\,\mu^2+22}}{11} > 0$ has to be true, so $\mu \in \left(0, \frac{2\sqrt{6}}{3}\right)$.

Combined with the above conclusions that $\mu \in (0, \sqrt{2})$ and $\varepsilon \in (0, \mu)$, we can finally obtain $\varepsilon \in (0, \varepsilon^*)$ where $\varepsilon^* = \min\left\{\mu, \frac{-\mu+2\sqrt{-8\,\mu^2+22}}{11}\right\}$ finally.

Corollary 2. *Based on the above equilibrium values within the cost-sharing contract, we have:*

(a) $\frac{\partial \varphi^{co}}{\partial \varepsilon} > 0$; $\frac{\partial i^{co}}{\partial \varepsilon} > 0$.

(b) $\frac{\partial p^{co}}{\partial \varepsilon} > 0$; *if* $0 < \varepsilon < \varepsilon_1$, $\frac{\partial w^{co}}{\partial \varepsilon} > 0$ *and if* $\varepsilon_1 < \varepsilon < \varepsilon^*$, $\frac{\partial w^{co}}{\partial \varepsilon} < 0$.

(c) $\frac{\partial \pi_m^{co}}{\partial \varepsilon} < 0$; *if* $0 < \varepsilon < \varepsilon_1$, $\frac{\partial \pi_s^{co}}{\partial \varepsilon} > 0$ *and if* $\varepsilon_1 < \varepsilon < \varepsilon^*$, $\frac{\partial \pi_s^{co}}{\partial \varepsilon} < 0$.

where $\varepsilon_1 = \frac{-7\,\mu^2+2\sqrt{12\,\mu^4-14\,\mu^2+4}+4}{\mu}$

See Appendix D for a formal proof.

From Corollary 2, we learn that the cost-sharing rate incurred by the manufacturer is increasing with his overconfidence. This means that when he has a high level of overconfidence, the manufacturer bears a higher proportion of innovation cost because he believes that innovation will benefit him. Because innovation costs are shared, the supplier is willing to invest more in innovation. Furthermore, the greater the share borne by the manufacturer, the more the supplier invests. We also note that the wholesale price is convex with regard to overconfidence, which first increases with overconfidence and then decreases. This occurs because innovation increases the component production cost, and the wholesale price rises to ensure the supplier's profit. Nevertheless, when $\varepsilon \in \left(\varepsilon_1, \varepsilon^*\right)$, the innovation cost is almost shared by the manufacturer, which causes component production costs to fall, leading to a subsequent drop in the wholesale price. In terms of the manufacturer's pricing decision, the selling price rises with increasing overconfidence. This may possibly be due to the manufacturer's satisfaction with the investment and results of innovation. With his increasing overconfidence the manufacturer invests more in innovation, and in order to profit from this investment, he raises his selling price.

An analysis of the firm-level profits reveals that the profit of an overconfident manufacturer decreases with increasing overconfidence. Because his share of the innovation cost is higher, the return is not directly proportional to the investment, and the actual sales are not as high as he thought. The supplier's profit is a concave function of overconfidence level. This means that slight overconfidence can increase the supplier's profit, indicating that overconfidence does not necessarily damage the supply chain performance.

5. Managerial Analysis

In this section, we perform two analyses. The first examines the effect of overconfidence. We compare the equilibrium variables and profits when the manufacturer is overconfident with those when he is rational. The second investigates operational strategies of the supply chain members. We compare the profits of each member under the two different contracts.

Proposition 2. *The equilibrium innovation efforts with an overconfident manufacturer occur in the following order compared to the centralized supply chain values:*

(a) if $0 < \varepsilon < \varepsilon_2$, $i_{sc}^{*} > i^{co} > i^{wo}$*;*

(b)if $\varepsilon_2 \leq \varepsilon < \varepsilon^{*}$,$i^{co} \geq i_{sc}^{*} > i^{wo}$*;*

where $\varepsilon_2 = \frac{\sqrt{-11\,\mu^4+44\,\mu^2+4}-2}{11\,\mu}$*;*

See Appendix E for a formal proof.

To demonstrate the impact of manufacturer overconfidence on innovation more clearly, we numerically analyze the results where the parameters are $a = 100, \mu = 0.7$. The results of the numerical analysis are shown in Figure 2. From Proposition 2 and Figure 2, we reach two conclusions. First, whether or not the manufacturer is overconfident, innovation level under a cost-sharing contract remains higher than under a wholesale price contract. This is because in a cost-sharing contract the manufacturer shares the cost of innovation, which encourages the supplier to invest more in innovation. Second, we reach the important conclusion that the level of innovation under a cost-sharing contract can be higher than under a centralized case when $\varepsilon \in (\varepsilon_2, \varepsilon^{*})$. Previous studies have pointed out that although a cost-sharing contract encourages the supplier to invest more in innovation, the innovation level will not be higher than it is under the centralized case (Bernstein and Kök, 2009; Ghosh and Shah, 2015). We come to a different conclusion because the manufacturer's overconfidence increases the cost-sharing rate under a cost-sharing contract. Moreover, the higher the level of overconfidence, the greater the cost-sharing rate (see Corollary 2). Given this relationship, when the level of overconfidence reaches a certain threshold, the cost-sharing rate can be very high. That is, the manufacturer shares a high proportion of the supplier's innovation cost. In doing so, the supplier's innovation cost and risk of loss are less than they would be in the centralized case and given the possibility to gain more profit. This increases the supplier's willingness to invest more in innovation. To sum up, under a wholesale price contract, overconfidence is inversely proportional to innovation; under a cost-sharing contract, overconfidence is conducive to supplier innovation.

Proposition 3. *Compared to the case of a rational manufacturer, when a manufacturer is overconfident, the equilibrium values and profits under a wholesale price contract are in the following order:*

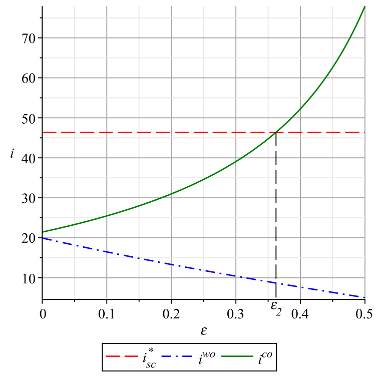

Figure 2: The influence of ε on i

(a) $i^{wo} < i^{wn}$; $w^{wo} < w^{wn}$; $p^{wo} < p^{wn}$;

(b) $\pi_s^{wo} < \pi_s^{wn}$; $\pi_m^{wo} < \pi_m^{wn}$;

(c) $\pi_{sc}^{wo} < \pi_{sc}^{wn}$.

See Appendix F for a formal proof.

From Proposition 3(a), we conclude that under a wholesale price contract manufacturer overconfidence negatively affects all the decision variables. According to the heterogeneous belief, the market demand expectations of manufacturer are higher than those of the supplier. Meanwhile, the manufacturer does not offer any incentives to the supplier to innovate under a wholesale price contract, which means the supplier has to bear all of innovation cost and investment risks. This burden may explain why supplier innovation is lower than it is when the manufacturer is rational. When the level of innovation is lower, the quality of the new supplier component does not meet the manufacturer's expectations, leading to a reduction in the wholesale price so that the supplier can still sell her product. Intuitively, this is consistent with a general belief. When faced with overconfident manufacturers who are unwilling to invest resources, suppliers do not respond in kind and instead become relatively cautious in innovation investment.

When there is a mismatch in the level of confidence, the selling price of the overconfident manufacturer is lower than it is when he is rational. When estimated demand is higher than actual sales, the manufacturer decides to lower the selling price in order to achieve the expected product sales. Another possible reason for the lower sales price in the case of overconfidence is the lower level of supplier innovation which does not meet the manufacturer's requirements.

Proposition 3(b) and 3(c) indicate that under a wholesale price contract manufacturer overconfidence hurts the profits of each member in the supply chain. For the supplier, although lower innovation reduces the production cost of her components, market demand also decreases. This lower demand with the reduction in the wholesale price, causes the supplier's profit to also decline. For the manufacturer, overconfidence does not increase his actual sales but does reduce his selling price. Coupled with lower innovation, the manufacturer's profit is lower than it would be in the rational case. Therefore, the total profit is smaller than it would be for the rational case. All in all, overconfidence negatively affects in a wholesale price contract. In view of this, the manufacturer is better not to reveal his overconfidence to his suppliers if he is willing to employ only a wholesale price contract.

Proposition 4. *Compare the case of an overconfident manufacturer with that of a rational one under a cost-sharing contract, the equilibrium values and profits are as follows:*

(a) $\varphi^{co} > \varphi^{cn}$; $i^{co} > i^{cn}$;

(b) $p^{co} > p^{cn}$; *if* $0 < \varepsilon < \varepsilon_3$, $w^{co} > w^{cn}$ *and if* $\varepsilon_3 \leq \varepsilon < \varepsilon^*$, $w^{co} \leq w^{cn}$;

(c) $\pi_m^{co} < \pi_m^{cn}$; *if* $0 < \varepsilon < \varepsilon_3$, $\pi_s^{co} > \pi_s^{cn}$ *and if* $\varepsilon_3 \leq \varepsilon < \varepsilon^*$, $\pi_s^{co} \leq \pi_s^{cn}$;

(d) $\pi_{sc}^{co} < \pi_{sc}^{cn}$;

where $\varepsilon_3 = \frac{\mu^3}{-7\mu^2+4}$.

See Appendix G for a formal proof.

First, we conclude from Proposition 4 that an overconfident manufacturer is willing to contribute more to innovation costs than a rational one because he believes that innovation can bring him more sales and benefits. Different from the rational case, sharing the cost of innovation allows the supplier to devote more funds to innovation. A further benefit is that, the supplier also anticipates profiting from increased market demand. Unlike the wholesale price contract shown in Proposition 3, the manufacturer overconfidence under a cost-sharing contract can induce the supplier to invest more in innovation. This indicates that through cost-sharing behaviors an overconfident manufacturer can stimulate the supplier to carry out component innovation.

Our numerical analysis shown in Figure 3, where $a = 100, \mu = 0.7$, reveals that the wholesale price in the overconfident case is not always greater than that in the rational case. This is because innovation can increase market demand while consuming certain funds. Initially, the supplier invests in innovation, which increases the production cost of components. In response, she raises the wholesale price to maintain her profit. At the same time, as the level of overconfidence increases, the manufacturer is motivated to bear most of the innovation cost. This results in greater profits with less investment for the supplier than would result in the rational case. To cooperate with the manufacturer, the supplier reduces her wholesale price. A similar process of change occurs for the supplier's profit, as shown in Figure 4. As can be seen, slight overconfidence has a positive impact on the supplier's profit because of the increased wholesale price. But when the wholesale price in the overconfident case is lower than in the rational case, the supplier's profit will also fall below that in the rational case.

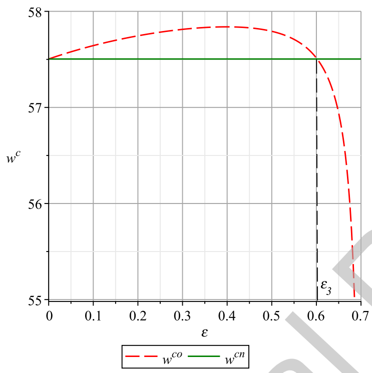

Figure 3: The influence of ε on w^c

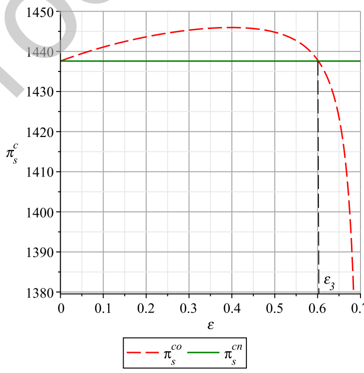

Figure 4: The influence of ε on π_s^c

For the manufacturer, higher investment in innovation and anticipated improvement in product quality lead an overconfident manufacturer to increase his selling price to ensure a profit. Though innovation increases market sales, the higher retail price has a negative impact. According to Proposition 4(c) in addition to contributing more to the cost of innovation, the manufacturer fails to realize his expected profit, and thus earns less that if he were fully rational. Because the decline in the manufacturer's profit is greater than the increase in the supplier's profit, the total profit of the supply chain is also reduced compared to the rational situation as shown in Proposition 4(d). In summary, under a cost-sharing contract, although the manufacturer's overconfidence does not improve his profit, it does introduce a new level of innovation to the product. At the same time, a lower degree of overconfidence can provide more benefits from innovation to the supplier.

Proposition 5. *The equilibrium values of profits under the two types of contracts are in the following order when the manufacturer is overconfident:*

(a) if $0 < \varepsilon < \varepsilon_4$, $\pi_m^{co} > \pi_m^{wo}$*; and if* $\varepsilon_4 \leq \varepsilon < \varepsilon^*$, $\pi_m^{co} \leq \pi_m^{wo}$*;*

(b) $\pi_s^{co} > \pi_s^{wo}$*;*

where ε_4 *is the unique positive solution of* $(H.2) = 0$.

The proof process and information on (H.2) is provided in Appendix H.

From Proposition 5, we can draw the following conclusions. Although a cost-sharing contract can motivate the supplier to invest more in innovation, this is not always the choice of the manufacturer. As Proposition 1 indicates, a rational manufacturer will definitely choose a cost-sharing contract from the perspective of profit maximization (Ghosh and Shah, 2015). However, we come to a different conclusion that when overconfidence reaches a certain threshold ε_4, the manufacturer's profit under a wholesale price contract is higher than it would be under a cost-sharing contract. This is because, under a cost-sharing contract, an overconfident manufacturer has such a great share of the innovation cost, which causes him to lose profit as the innovation investment and the cost-sharing rate increase (see Proposition 4). To analyze this relationship more intuitively, we carry out a numerical study where the parameters are $a = 100, \mu = 0.7$, and the result is shown in Figure 5.

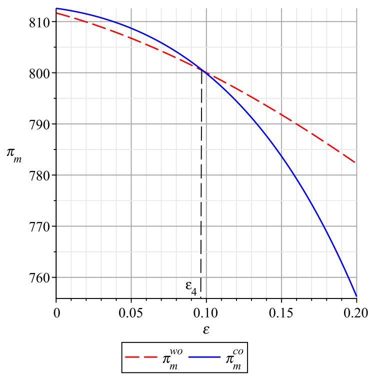

Figure 5: The impact of overconfidence ε on π_m

For the supplier, a cost-sharing contract can help her with the cost of innovation. And in the case of overconfidence, the cost-sharing rate is higher. She can make more profit by bearing less investment. Thus, she always wants the manufacturer to provide a cost-sharing contract.

6. Extension: Overconfident Manufacturer and Unaware Supplier

In this section, we extend our scope to the case where the supplier is biased and is totally unaware of the manufacturer's overconfidence. As to utility functions of the supply chain members, we refer to the analysis process in Du et al. (2019) and Li (2019). We still consider the two types of contracts, a wholesale price contract and a cost-sharing contract. The superscript wu and cu reflect the fact that the supplier is unaware of the manufacturer's overconfidence under each of the two contracts.

Under a wholesale price contract, when a supplier is unaware of manufacturer overconfidence, she behaves as though it solves Equation (4) by anticipating the manufacturer's problem of Equation (3). Thus, the equilibrium wholesale price w^{wu} and innovation level i^{wu} are described in Table 1. For the manufacturer with an overconfidence parameter ε, his pricing decisions accordingly follows Lemma 1 and the equilibrium retail price p^{wu} is from Equation (13). The ensuing supplier's equilibrium profit is then

$$\pi_s^{wu} = -\frac{\left(\mu^4 + 2\mu^3\varepsilon + 16 + \left(-3\varepsilon^2 - 8\right)\mu^2 + 16\mu\varepsilon\right)a^2}{2\left(\mu^2 - 4\right)^2\left(2 + \mu - \varepsilon\right)\left(-2 + \mu - \varepsilon\right)} \tag{20}$$

while the manufacturer's equilibrium profit is

$$\pi_m^{wu} = -\frac{a^2\left(\varepsilon^2\mu^2 - \varepsilon\,\mu^3 - 2\,\varepsilon^2 - \mu^2 + 4\right)\left(\varepsilon^2\mu^2 - \varepsilon\,\mu^3 - 4\,\mu\,\varepsilon + \mu^2 - 4\right)}{\left(-2 - \mu + \varepsilon\right)^2\left(2 - \mu + \varepsilon\right)^2\left(\mu^2 - 4\right)^2} \tag{21}$$

We now describe the equilibrium solutions with a cost-sharing contract when the manufacturer is overconfident and the supplier lacks an awareness of this bias. The supplier's behaviors and decisions are described in Section 3.2. The manufacturer's equilibrium retail price and cost-sharing rate are from Equation (18). The supplier's and the manufacturer's equilibrium profit are then

$$\pi_s^{cu} = \frac{a^2\left(\mu^2 - 8\right)}{2\left(3\,\mu^2 - 8\right)}\left(\frac{\mu^2 - 8}{3\,\mu^2 - 8} - \frac{1}{4}T_1\right) - \frac{2\left(1 - \varphi\right)a^2\mu^2}{\left(3\,\mu^2 - 8\right)^2} \tag{22}$$

and

$$\pi_m^{cu} = a^2 \left(\frac{1}{4} T_1 - \frac{\mu^2 - 8}{2\,(3\,\mu^2 - 8)} \right) \left(\frac{\mu^2 - 8}{3\,\mu^2 - 8} - \frac{1}{4} T_1 \right) - \frac{2\,\varphi\, a^2 \mu^2}{(3\,\mu^2 - 8)^2} \tag{23}$$

where $T_1 = \frac{31\,\varepsilon^2 - 2\,\varepsilon\,\mu + 3\,\mu^2 - 24}{11\,\varepsilon^2 + 2\,\varepsilon\,\mu + 3\,\mu^2 - 8}$ and φ is given in Equation (18).

Because it is difficult to determine the relationships between the decision-makers' profits and relevant parameters, we employ a numerical analysis to study the effect of unawareness. We still use the parameters, $a = 100, \mu = 0.7$. From the numerical analysis, we obtain the following results.

Remark 1. *Under a wholesale price contract, a supplier's unawareness can benefit both biased supply chain members; that is,* $(\pi_m^{wu}, \pi_s^{wu}) > (\pi_m^{wo}, \pi_s^{wo})$*. However, only the supplier earns more than in the rational case; that is* $\pi_s^{wu} > \pi_s^{wn}$ *and* $\pi_m^{wu} < \pi_m^{wn}$*.*

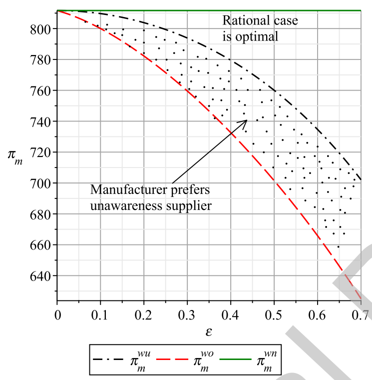

Figure 6: The influence of unawareness on π_m

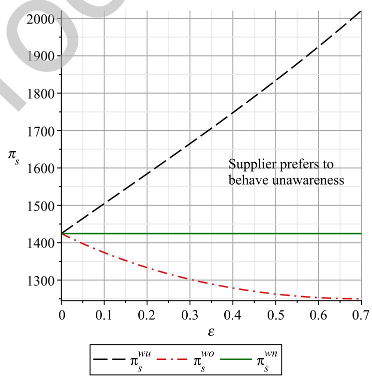

Figure 7: The influence of unawareness on π_s

As shown in Figure 6 and Figure 7, we know that under a wholesale price contract, the manufacturer and the supplier can achieve a higher profit when the latter is unaware of the manufacturer's overconfidence, compared to the situation where she is aware. That is, although the manufacturer's overconfidence hurts the supply chain members, as shown in Proposition 3, each member firm in the supply chain can benefit from their simultaneous (but not singular) biases. Because the supplier lacks awareness, she maintains her innovation investment in the component and increases her wholesale price more than if she were aware of the manufacturer's overconfidence. Simultaneously, when an overconfident manufacturer fails to reach the expected sales volume, he will reduce his retail price in order to increase sales. The supplier's profit yields double benefits, that are not only higher than when the manufacturer is overconfident, but also higher than when both are rational. For an overconfident manufacturer, his profit increases because the sales volume increases in response to both the component innovation and the decline in the retail price. This increase makes up for any loss that could result from the reduction in the retail price, leading to a higher profit when the supplier is aware of the manufacturer's overconfidence. However, the profit of an overconfident manufacturer can not reach the same level as when both are rational. Extending Proposition 3, Remark 1 indicates that under a wholesale price contract, the supplier is better off when she is not influenced by the manufacturer's overconfidence and continuously invests in the innovation. Moreover, a manufacturer should be rational under a wholesale price contract. His suboptimal strategy would be to not reveal his overconfident status to suppliers.

Remark 2. *Under a cost-sharing contract, the supplier's lack of awareness leads to lower profits for biased supply chain members, that is* $(\pi_m^{cu}, \pi_s^{cu}) < (\pi_m^{co}, \pi_s^{co})$.

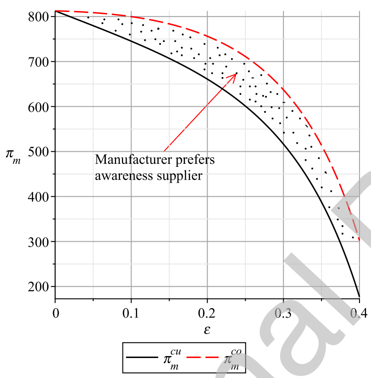

Figure 8: The influence of unawareness on π_m

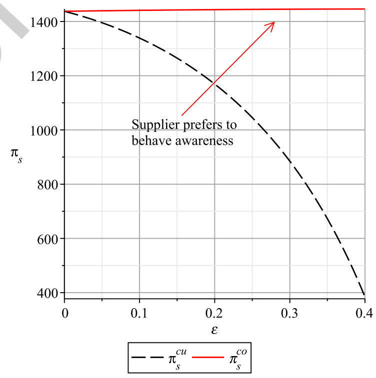

Figure 9: The influence of unawareness on π_s

Different from Remark 1, under a cost-sharing contract, the supplier's unawareness is harmful to the supply chain members' profits, as shown in Figure 8 and Figure 9. When the supplier is unaware that the manufacturer is overconfident, her investment in innovation is lower than when she is aware, even though the manufacturer bears more of the innovation costs. An increased retail price and low level of innovation cause sales to fall, which in turn reduces the profit of each firm. Therefore, under a cost-sharing contract, the manufacturer guides innovation investment by increasing the proportion he contributes to the innovation costs. Under a cost-sharing contract, it is better for the manufacturer to inform the supplier of his overconfidence in innovation so that he can increase his innovation investment; otherwise the profits of each enterprise will be negatively affected.

Remark 3. *The comparisons of supply chain profits under the different scenarios are as follows.*

(a) under a wholesale price contract: $\pi_{sc}^{wu} > \pi_{sc}^{wn} > \pi_{sc}^{wo}$*, but in a cost-sharing contract:* $\pi_{sc}^{cn} > \pi_{sc}^{co} > \pi_{sc}^{cu}$*;*

(b) when overconfidence exceeds a certain threshold whether a supplier is aware or unaware of a manufacturer's overconfidence, the total profit under a wholesale price contract can be higher than it is in a cost-sharing contract.

Given Remark 1 and 2, it is easy to obtain Remark 3(a) which shows that a supplier's lack of awareness has different effects. Under a wholesale price contract, the supply chain is better off when each member is biased, namely an overconfident manufacturer and an unaware supplier. Under a cost-sharing contract, the same insight as from Proposition 3 continues to hold in the supply chain setting.

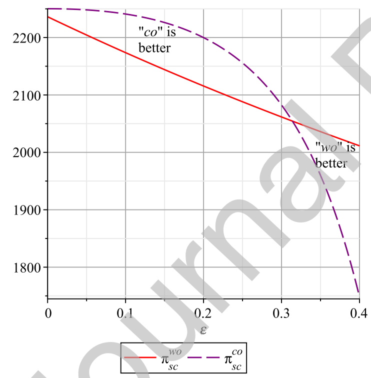

Figure 10: The comparisons of π_{sc}^{wo} and π_{sc}^{co}

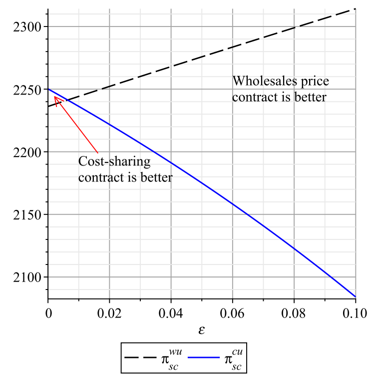

Figure 11: The comparisons of π_{sc}^{wu} and π_{sc}^{cu}

As shown in Figure 10 and Figure 11, we know that when the overconfidence level is 0, the total profit of a supply chain under a cost-sharing contract is higher than that under a wholesale price contract. Therefore, when overconfidence is low, the supply chain profit under a cost-sharing contract is higher. However, when overconfidence exceeds the threshold value, the supplier invests more in innovation. With a decrease in the ROI in innovation, the profit of the entire supply chain begins to decline, and is lower than that under a wholesale price contract. Moreover, according to Remark 1 and 2, we also know that when a supplier is unaware of manufacturer overconfidence, the profit of the supplier under a wholesale price contract increases dramatically with an increase in the level of overconfidence level, but decreases under a cost-sharing contract. This leads to the conclusion that when a supplier is unaware wholesale price contract can, in some cases, be more favorable for the supply chain.

7. Conclusion

Both in practice and in scholarly work, overconfidence has been widely recognized as a critical behavioral bias. Considering the scarce research attention to the effects of overconfidence on supply chain innovation, we develop a model to address this issue. Specifically, we focus on the influence of a manufacturer's overconfidence on a supplier's innovation investment. We also compare two incentive modes (i.e., a wholesale price contract and a cost-sharing contract) via a game-theoretical approach. We conclude that overconfidence is not necessarily a negative factor. On the contrary, this bias can have a positive effect as revealed by the new insights into the decision-making process for both the manufacturer and the supplier that we provide here.

First, the impact of the manufacturer's overconfidence on the level of supplier's equilibrium innovation depends on the type of incentive contract. Under a wholesale price contract, the manufacturer's overconfidence has detrimental effects on the innovation effort level. Under a cost-sharing contract, however, the level of innovation increases with the increase in the manufacturer's overconfidence, and is even higher than in a centralized one.

Second, under a wholesale price contract, the manufacturer's overconfidence harms both a rational supplier and himself because the profit decreases. This is because, without an overconfident manufacturer's resource commitment, the supplier may act with caution and reduce the investment in innovation. And the decreasing innovation effort leads to the decline of wholesale and retail prices, which negatively impacts on the profits of the supply chain members finally.

Third, for an upstream supplier cooperative with an overconfident manufacturer, the cost-sharing contract is always more profitable than a wholesale price contract. However, when overconfidence reaches a certain threshold, the manufacturer's profit under a wholesale price contract is higher than it would be under a cost-sharing contract where he bears too much innovation investment.

Fourth, when we extend our scope to the case when the supplier is unaware of manufacturer overconfidence, we find that under a wholesale price contract unawareness is beneficial to both biased parties. However, for a cost-sharing contract, the manufacturer should actively avoid the supplier's unaware state, which can reduce profits.

Despite the importance of the managerial insights for upstream innovation with an overconfident manufacturer, this work has a few limitations. First, we refer to De la Rosa (2011), Galasso and Simcoe (2011), Phua et al. (2018) and Tang et al. (2015), measuring overconfidence by overestimating innovation performance. However, it would be of interest to investigate the effect of being overprecise. Second, this study assumes that the supplier is dependent on an overconfident manufacturer for orders. In reality, however, the power structure of the supply chain can sometimes switch so that the upstream supplier becomes the focus while the downstream firm become the follower (Sanyal and Ghosh, 2013; Aydin and Parker, 2018). It would be interesting to determine how the change in power structure impacts the performance of the supply chain. Third, in the setting of this paper, supplier innovation never fails, even though in reality innovation does sometimes fail, a factor that is seldom taken into consideration. Future work might point to innovation uncertainty so that the risk of technology development is included.

Appendix A. The Proof of Proposition 1

Our conclusions can be directly verified according to the results in Table 1.

Appendix B. The Proof of Lemma 1

In this set up, we solve for the manufacturer's utility function first.

$$\max_{p} E\left[u_m^{wo}\left(p, w, i\right)\right] = \int_{\varepsilon}^{\hat{\Theta}+\varepsilon} \left(p - w\right)\left(a - p + \left(\mu + \varepsilon\right) i\right) f\left(\Theta\right) \mathrm{d}\Theta \tag{B.1}$$

The first-order condition

$$\frac{\partial u_m^{wo}\left(p,w,i\right)}{\partial p}=0 \tag{B.2}$$

The second order condition

$$\frac{\partial^2 u_m^{wo}\left(p,w,i\right)}{\partial p^2}=-2<0 \tag{B.3}$$

Thus, the manufacturer's utility function is strictly concave in p. Equating the first-order condition to 0 we obtain

$$p\left(w,i\right)=\frac{a+\left(\mu+\varepsilon\right)i+w}{2} \tag{B.4}$$

Solving for the supplier's profit function

$$\max_{i,w} E\left[\pi_s^{wo}\left(p,w,i\right)\right]=\int_{\varepsilon}^{\hat{\Theta}+\varepsilon} w\left(a-p+\mu\, i\right)f\left(\Theta\right)\,\mathrm{d}\Theta-i^2/2 \tag{B.5}$$

We substitute the value of $p\left(w,i\right)$ into the above equation and write the second order condition of w and i as

$$H\left(w,i\right)=\begin{bmatrix}\frac{\partial^2\pi_s^{wo}(w,i)}{\partial w^2} & \frac{\partial^2\pi_s^{wo}(w,i)}{\partial w\partial i}\\ \frac{\partial^2\pi_s^{wo}(w,i)}{\partial i\partial w} & \frac{\partial^2\pi_s^{wo}(w,i)}{\partial i^2}\end{bmatrix}=\begin{bmatrix}-1 & \frac{\mu-\varepsilon}{2}\\ \frac{\mu-\varepsilon}{2} & -1\end{bmatrix} \tag{B.6}$$

The determinant is $1-\frac{(\mu-\varepsilon)^2}{4}>0$. The Hessian $H\left(w,i\right)$ is negative definite. Thus supplier's profit function is jointly concave in w and i. Equating the first order conditions to 0 we get

$$i^{wo}=\frac{a\left(\mu-\varepsilon\right)}{\left(2+\mu-\varepsilon\right)\left(2-\mu+\varepsilon\right)} \tag{B.7}$$

$$w^{wo}=\frac{2a}{\left(2+\mu-\varepsilon\right)\left(2-\mu+\varepsilon\right)} \tag{B.8}$$

The following optimal retail price is obtained

$$p^{wo}=\frac{a\left(\mu\,\varepsilon-\varepsilon^2+3\right)}{\left(2+\mu-\varepsilon\right)\left(2-\mu+\varepsilon\right)} \tag{B.9}$$

The manufacturer's profit function is $\pi_m^{wo}(p, w, i) = (p - w)(a - p + \mu i)$. Bringing in the equilibrium solution of decision variables, we can obtain

$$\pi_m{}^{wo} = \frac{a^2(\mu\varepsilon - \varepsilon^2 + 1)}{(2 + \mu - \varepsilon)^2(2 - \mu + \varepsilon)^2} \tag{B.10}$$

$$\pi_s{}^{wo} = \frac{a^2}{2(2 + \mu - \varepsilon)(2 - \mu + \varepsilon)} \tag{B.11}$$

Appendix C. The Proof of Corollary 1

The partial derivative of i^{wo} with respect to ε gives

$$\frac{\partial i^{wo}}{\partial \varepsilon} = -\frac{a(\mu^2 - 2\mu\varepsilon + \varepsilon^2 + 4)}{(-2 + \mu - \varepsilon)^2(2 + \mu - \varepsilon)^2} < 0 \tag{C.1}$$

The partial derivative of w^{wo} with respect to ε gives

$$\frac{\partial w^{wo}}{\partial \varepsilon} = -\frac{4a(\mu - \varepsilon)}{(-2 + \mu - \varepsilon)^2(2 + \mu - \varepsilon)^2} < 0 \tag{C.2}$$

The partial derivative of p^{wo} with respect to ε gives

$$\frac{\partial p^{wo}}{\partial \varepsilon} = -\frac{a(\mu^3 - 2\mu^2\varepsilon + (\varepsilon^2 + 2)\mu + 2\varepsilon)}{(-2 + \mu - \varepsilon)^2(2 + \mu - \varepsilon)^2} < 0 \tag{C.3}$$

The partial derivative of π_s^{wo} with respect to ε gives

$$\frac{\partial \pi_s^{wo}}{\partial \varepsilon} = -\frac{a^2(\mu - \varepsilon)}{(-2 + \mu - \varepsilon)^2(2 + \mu - \varepsilon)^2} < 0 \tag{C.4}$$

The partial derivative of π_m^{wo} with respect to ε gives

$$\frac{\partial \pi_m^{wo}}{\partial \varepsilon} = \frac{a^2(\mu^3 - 3\mu\varepsilon^2 + 2\varepsilon^3 + 4\varepsilon)}{(2 + \mu - \varepsilon)^3(-2 + \mu - \varepsilon)^3} < 0 \tag{C.5}$$

Appendix D. The Proof of Lemma 2 and Corollary 2

Because the solving process of the optimal p^{co}, w^{co} and i^{co} is similar to Lemma 1, we do not repeat it here. At this point, we obtain:

$$p^{co}(\varphi) = -\frac{a(\mu\varepsilon - \varepsilon^2 - 3\varphi + 3)}{\mu^2 - 2\mu\varepsilon + \varepsilon^2 + 4\varphi - 4} \tag{D.1}$$

$$w^{co}(\varphi) = \frac{2a(\varphi - 1)}{\mu^2 - 2\mu\varepsilon + \varepsilon^2 + 4\varphi - 4} \tag{D.2}$$

$$i^{co}(\varphi) = -\frac{a(\mu - \varepsilon)}{\mu^2 - 2\mu\varepsilon + \varepsilon^2 + 4\varphi - 4} \tag{D.3}$$

Substituting (D.1), (D.2) and (D.3) into the manufacturer utility function (15). Thus, we can get the manufacturer utility function $u_m^{co}(\varphi)$ containing only the cost sharing rate φ. The first-order condition

$$\frac{\partial u_m^{co}(\varphi)}{\partial p} = \frac{(\mu - \varepsilon)(-13\varepsilon^3 + 11\varepsilon^2\mu + (\mu^2 - 8\varphi + 16)\varepsilon + \mu(\mu^2 - 8\varphi))a^2}{2(\mu^2 - 2\mu\varepsilon + \varepsilon^2 + 4\varphi - 4)^3} = 0 \tag{D.4}$$

The second-order partial derivative of $u_m^{co}(\varphi)$ with respect to φ gives

$$\frac{\partial u_m^{co}(\varphi)}{\partial \varphi} = -\frac{32a^2(\mu + \varepsilon)^4}{(\mu - \varepsilon)^2(8 - 3\mu^2 - 2\mu\varepsilon - 11\varepsilon^2)^3} < 0 \tag{D.5}$$

Thus, the manufacturer's utility function is strictly concave in φ. Equating the first-order condition to 0, we get:

$$\varphi^{co} = \frac{\mu^3 + \mu^2\varepsilon + 11\mu\varepsilon^2 - 13\varepsilon^3 + 16\varepsilon}{8(\mu + \varepsilon)} \tag{D.6}$$

Substituting (D.6) into (D.1), (D.2) and (D.3), we can get:

$$p^{co} = \frac{a(-3\mu^2 + 2\mu\varepsilon - 31\varepsilon^2 + 24)}{4(-3\mu^2 - 2\mu\varepsilon - 11\varepsilon^2 + 8)} \tag{D.7}$$

$$\left(i^{co}, w^{co}\right) = \left(\frac{2a(\mu + \varepsilon)}{-3\mu^2 - 2\mu\varepsilon - 11\varepsilon^2 + 8}, \frac{a(-\mu^2 - 2\mu\varepsilon - 13\varepsilon^2 + 8)}{2(-3\mu^2 - 2\mu\varepsilon - 11\varepsilon^2 + 8)}\right) \tag{D.8}$$

Since we know the optimal cost-sharing rate, retail price, wholesale price, and innovation level, the profits of the supplier and the manufacturer are as follows:

$$\left(\pi_s^{co},\pi_m^{co}\right)=\left(\frac{a^2\left(-\mu^2-2\,\mu\,\varepsilon-13\,\varepsilon^2+8\right)}{8\left(-3\,\mu^2-2\,\mu\,\varepsilon-11\,\varepsilon^2+8\right)},\right.$$
$$\left.\frac{a^2\left(117\,\varepsilon^4-60\,\mu\,\varepsilon^3-2\,\varepsilon^2\left(21\,\mu^2+104\right)-4\,\mu\,\varepsilon\,\left(3\,\mu^2+8\right)-3\,\mu^4-16\,\mu^2+64\right)}{16\,\left(-3\,\mu^2-2\,\mu\,\varepsilon-11\,\varepsilon^2+8\right)^2}\right) \tag{D.9}$$

The Lemma 2 is proved. The Corollary 2 is similar to Corollary 1, and we will not repeat.

Appendix E. The Proof of Proposition 2

Comparing the level of innovation in different cases, we obtain:

$$i^{co}-i^{wo}=\frac{a\left(-13\,\varepsilon^3+11\,\mu\,\varepsilon^2+\left(\mu^2+16\right)\varepsilon+\mu^3\right)}{\left(3\,\mu^2+2\,\mu\,\varepsilon+11\,\varepsilon^2-8\right)\left(2+\mu-\varepsilon\right)\left(-2+\mu-\varepsilon\right)}>0\Leftrightarrow i^{co}>i^{wo} \tag{E.1}$$

$$i^*_{sc}-i^{wo}=\frac{a\left(\mu^2\varepsilon-\mu\,\varepsilon^2+2\,\mu+2\,\varepsilon\right)}{\left(\mu^2-2\right)\left(2+\mu-\varepsilon\right)\left(-2+\mu-\varepsilon\right)}>0\Leftrightarrow i^*_{sc}>i^{wo} \tag{E.2}$$

$$i^*_{sc}-i^{co}=-\frac{a\left(\mu^3+11\,\mu\,\varepsilon^2-4\,\mu+4\,\varepsilon\right)}{\left(\mu^2-2\right)\left(3\,\mu^2+2\,\mu\,\varepsilon+11\,\varepsilon^2-8\right)} \tag{E.3}$$

where $\Delta_1=\mu^3+11\,\mu\,\varepsilon^2-4\,\mu+4\,\varepsilon$, which determines the sign of Equation E.(3). Δ_1 is continuous with ε in $\varepsilon\in(0,\varepsilon^*)$ and $\Delta_1=0$ when $\varepsilon_2=\frac{\sqrt{-11\,\mu^4+44\,\mu^2+4}-2}{11\,\mu}$. Thus, we have:

$$0<\varepsilon<\varepsilon_2\Leftrightarrow\Delta_1<0\Leftrightarrow i^*_{sc}>i^{co} \tag{E.4}$$

$$\varepsilon_2\le\varepsilon<\varepsilon^*\Leftrightarrow\Delta_1\ge 0\Leftrightarrow i^*_{sc}\le i^{co} \tag{E.5}$$

In summary, the Proposition 2 is proved.

Appendix F. The Proof of Proposition 3

Similarly, we use the difference method to prove the conclusion. According to equilibrium values, we obtain:

$$i^{wo}-i^{wn}=-\frac{a\varepsilon\,\left(\mu^2-\mu\,\varepsilon+4\right)}{\left(2+\mu-\varepsilon\right)\left(-2+\mu-\varepsilon\right)\left(\mu^2-4\right)}<0\Leftrightarrow i^{wo}<i^{wn} \tag{F.1}$$

$$w^{wo} - w^{wn} = -\frac{2a\varepsilon\ (2\,\mu - \varepsilon)}{(2 + \mu - \varepsilon)\,(-2 + \mu - \varepsilon)\,(\mu^2 - 4)} < 0 \Leftrightarrow w^{wo} < w^{wn} \tag{F.2}$$

$$p^{wo} - p^{wn} = -\frac{a\varepsilon\ (\mu^3 - \mu^2\varepsilon + 2\,\mu + \varepsilon)}{(2 + \mu - \varepsilon)\,(-2 + \mu - \varepsilon)\,(\mu^2 - 4)} < 0 \Leftrightarrow p^{wo} < p^{wn} \tag{F.3}$$

For the profits of both parties and the supply chain under a wholesale price contract, we have:

$$\pi_s^{wo} - \pi_s^{wn} = -\frac{a^2\varepsilon\ (2\,\mu - \varepsilon)}{2\,(2 + \mu - \varepsilon)\,(-2 + \mu - \varepsilon)\,(\mu^2 - 4)} < 0 \Leftrightarrow \pi_s^{wo} < \pi_s^{wn} \tag{F.4}$$

$$\pi_m^{wo} - \pi_m^{wn} = \frac{a^2\varepsilon\,[(\mu^2 - 2)\,\mu^3 - (\mu^2 - 2)^2\,\varepsilon - 2\,\mu\ (\mu - \varepsilon)\,(\mu + 2\,\varepsilon) - \varepsilon\ (\varepsilon^2 + 4)]}{(2 + \mu - \varepsilon)^2\,(-2 + \mu - \varepsilon)^2\,(\mu^2 - 4)^2} < 0 \Leftrightarrow \pi_m^{wo} < \pi_m^{wn} \tag{F.5}$$

$$\pi_{sc}^{wo} - \pi_{sc}^{wn} = \frac{a^2\varepsilon\ (3\,\mu^4\varepsilon - 4\,\mu^3\varepsilon^2 + \mu^2\varepsilon^3 + 8\,\mu^3 - 20\,\mu^2\varepsilon + 24\,\mu\,\varepsilon^2 - 6\,\varepsilon^3 - 32\,\mu)}{2\,(2 + \mu - \varepsilon)^2\,(-2 + \mu - \varepsilon)^2\,(\mu^2 - 4)^2} < 0 \Leftrightarrow \pi_{sc}^{wo} < \pi_{sc}^{wn} \tag{F.6}$$

Appendix G. The Proof of Proposition 4

Because these proof processes are similar to Proposition 3, so we will not repeat.

Appendix H. The Proof of Proposition 5

We compare the manufacturers' profits under the two different contracts:

$$\pi_m^{co} - \pi_m^{wo} = -\frac{a^2\,(3\,\varepsilon + \mu)\,[-13\,\varepsilon^3 + 11\,\mu\,\varepsilon^2 + (\mu^2 + 16)\,\varepsilon + \mu^3]\Delta_2}{16\,(3\,\mu^2 + 2\,\mu\,\varepsilon + 11\,\varepsilon^2 - 8)^2\,(2 + \mu - \varepsilon)^2\,(-2 + \mu - \varepsilon)^2} \tag{H.1}$$

$$\Delta_2 = 3\,\varepsilon^4 - 12\,\mu\,\varepsilon^3 + 6\,\left(3\,\mu^2 + 4\right)\varepsilon^2 + 12\,\left(-\mu^3 + 4\,\mu\right)\varepsilon + 3\,\mu^4 - 8\,\mu^2 \tag{H.2}$$

(H.2) determines the sign of Equation (H.1). By putting in special values, we obtain $\Delta_2 \mid_{\varepsilon=0} < 0$ and $\Delta_2 \mid_{\varepsilon=\frac{\mu}{2}} > 0$. We also obtain $\frac{\partial \Delta_2}{\partial \varepsilon} \mid_{\varepsilon=0} = -12\mu\,(\mu^2 - 4) > 0$ and $\frac{\partial^2 \Delta_2}{\partial \varepsilon^2} = 36\,(\varepsilon - \mu)^2 + 48 > 0$. According to the zero-point theorem, because Δ_2 is continuous with respect to ε, there is a value $\varepsilon_4 \in \left(0, \frac{\mu}{2}\right)$ such that $\Delta_2 = 3\,\varepsilon_4^4 - 12\,\mu\,\varepsilon_4^3 + 6\,(3\,\mu^2 + 4)\,\varepsilon_4^2 +$

$12\left(-\mu^3+4\,\mu\right)\varepsilon_4+3\,\mu^4-8\,\mu^2=0 \Leftrightarrow \pi_m^{co}=\pi_m^{wo}$. Therefore, we obtain:

$$0<\varepsilon<\varepsilon_4 \Leftrightarrow \Delta_2<0 \Leftrightarrow \pi_m^{co}>\pi_m^{wo} \tag{H.3}$$

$$\varepsilon_4 \leq \varepsilon<\varepsilon^* \Leftrightarrow \Delta_2 \geq 0 \Leftrightarrow \pi_m^{co} \leq \pi_m^{wo} \tag{H.4}$$

To determine supplier profits in the overconfident case, we have:

$$\pi_s^{co}-\pi_s^{wo}=\frac{a^2\left(-13\,\varepsilon^3+11\,\mu\,\varepsilon^2+\left(\mu^2+16\right)\varepsilon+\mu^3\right)\left(\mu-\varepsilon\right)}{8\left(3\,\mu^2+2\,\mu\,\varepsilon+11\,\varepsilon^2-8\right)\left(2+\mu-\varepsilon\right)\left(-2+\mu-\varepsilon\right)}>0 \Leftrightarrow \pi_s^{co}>\pi_s^{wo} \tag{H.5}$$

Therefore, Proposition 5 is proved.

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