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EFFECT OF FAIRNESS AND OVERCONFIDENCE ON PRICING STRATEGY OF SUBSTITUTE BUNDLES IN A TWO-ECHELON SUPPLY CHAIN

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Abstract. Cognitive biases – fairness and overconfidence, affect the decision-making process. The manufacturer/retailer prefers to sell the products as bundles in a duopoly market because it fetches more benefits to supply chain (SC) partners. Till now, none considered the pricing of substitute bundles, produced and sold at the manufacturer's level. Considering these, the effects of the above cognitive behaviours on the bundling pricing strategy are investigated. We develop several SC models, depending on the partner's cognitive biases, with two manufacturers, producing substitute bundles of two uncorrelated items and selling through a retailer. Using the Stackelberg game, prices and profits are evaluated. It is observed that overconfidence does not increase retailer's and overconfident – manufacturer's profits but is beneficial for another rational manufacturer. Against the retailer's fairness concern, her profit is augmented, but both manufacturers' profits are adversely affected. The combined effect of both cognitive biases is adjuvant for the retailer but maleficent for manufacturers. Managerial insights are presented.

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1. Introduction and motivation

Pricing strategy in supply chain (SC) is very important for the channel members. In this area, studies are available depending upon several factors such as the arrangements of SC (number of partners, connection between partners, etc), nature of the partners (cognitive biases etc), type of the items (single or bundle), etc. There are some investigations on the competition of two manufacturers, each producing a single item through a common retailer [40]. Bundling is a convenient commercial mechanism to boost sales and profit, and nowadays, a number of items are available in bundles in the market [37]. Usually, bundles are sold at a discount relative to the sum of the prices of individual items (McDonald's Happy Meal bundles are an example of product bundling). Hence, consumers have the option to buy these items as a bundle at a lesser price. In this context, what will be the nature of competition if the products at the manufacturers' level are bundled? Cao *et al.* [4] presented

Keywords. Game theory, fairness concern, overconfidence, bundling, supply chain.

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the competition in making the bundles at the manufacturer and retailer's levels. Till now, none has developed game-theoretic competitive models for bundled products at two manufacturers' levels with a common retailer.

A substitute product refers to a product that a consumer perceives as similar or comparable. There are some game theoretical models for two manufacturers producing substitute products, one each and selling through a common retailer [27]. In this case, what will happen if the said substitute products are bundled one? In reality, different manufacturers do bundle of products and sell those, which may be substitutable to consumers through retailers or online channels. For instance, during the lockdown in 2020, Adani Walmart tied up with swiggy for home delivery of edible oil and grain (wheat flour, packaged rice). Similarly, the Fortune brand created bran oil and basmati rice combo and sold it through swiggy as a pure bundle (In the pure bundle, items are not sold individually). Separately, Haldiram and Bikaner offer sweet and namkeen combos, and different beauty brands, such as mcaffeine, Lotus, Sugar, etc., provide bundles consisting of face scrub and body scrub, cream and face wash, lipstick and kajal, etc. Some of the above bundling strategies may not be entirely pure. However, for simplicity, we only consider the pure bundling case. Though in practice, the sale of substitute bundles is in vogue, but in the literature, none has developed game-theoretic SC models for substitute bundles consisting of different items at the manufacturers' level. Therefore, we try to fill up this vacuum, and the present investigation introduces SC models for substitute bundles, each consisting of two uncorrelated items at the manufacturer's level. "Substitute bundles" implies that the components of a bundle are substitutable to the corresponding elements of the other bundle.

All the above studies are carried out for rational channel members. In reality, all SC members are not always rational. Then, what happens if the members are irrational? Different aspects of bounded rationality, such as overconfidence and fairness concern, are often shown by the SC's players. Social responsibility manifests fairness concern among the SC partners. Normally in an SC, each individual tries to maximize her profit. In the face of unfair dealing of partners in profit allocation, fairness concern plays a significant role in decision-making. Individuals compare profits with their partners and feel treated unfairly if they receive less or more than expected shares. In reality, it is observed that retailer is more likely to be fairness concerned [18]. For instance, Guangzhou Friendship Group (GFG) terminated its partnership with Tingyi Holding Corporation (THC), the largest instant noodle manufacturer in China, in 2011. Because of the unilateral increase in the wholesale price of "master kong noodle" by THC, GFG felt unfairly treated in the contract [43].

Apart from the fairness concern, overconfidence is another frequently appearing cognitive bias. Behavioural economists recognize the effect of overconfidence on the strategic decisions of SC members and economic performance. Overconfident individuals believe that their information/measures are more precise or have superior skill and capability than average [3]. It is found that usually, an upstream manufacturer dominates the downstream retailers in an SC. Hence, the manufacturer sometimes exhibits overconfidence behaviour, *i.e.*, the manufacturer anticipates more market demand than actual. For instance, the world's largest manufacturer of polysilicon wafers, Jiang Xi Saiwei LDK Solar Energy High Tech Co LTD., producing photovoltaic products, was bankrupted with loans of 20 billion RMB from 14 banks due to excessive stocking (over-estimation of demand) [26]. Zhou *et al.* [51] defined manufacturers' overconfidence as a belief bias that they overestimate the impact of product greenness on demand and the accuracy of demand uncertainty.

Sometimes, the above-mentioned cognitive biases, *i.e.*, overconfidence and fairness concern, are present simultaneously and influence the SC's decision-making process. For example, a retailer in China at a shopping festival ("Double 11") ordered more products from a large manufacturer, *e.g.*, Procter & Gamble (P&G), with the belief that she had better marketing capabilities than others (overconfidence). However, his profit was lower than expected due to overstock and expenditures. As an outcome, the retailer reduced his order quantity and increased retail price because of the belief that P&G is unfair in sharing the profit [28]. In the literature, though the effects of fairness concern [36], and overconfidence behaviour [24] on SCs have been studied separately, there are scanty investigations [43, 49] with the combined effect of the above two characteristics of SC members. In the context of the above available literature, the following research questions arise:

(a) What will be the pricing strategy in an SC when substitute bundles are sold at the manufacturers' level?

(b) How do the pricing decisions of the decentralized SC with substitute bundle products get affected by the retailer's fairness concern and manufacturer's overconfidence ?
(c) What are the influences of fairness concern intensity, overconfidence, and bundle discount factor on the SC members' decisions?

In this study, we try to generalize the impact of cognitive biases, *i.e.*, fairness and overconfidence, on the strategic decisions of supply chain players for substitute bundles of uncorrelated items. This paper aims to examine the bundling pricing strategies in the presence of channel members' cognitive biases through the game theoretic approach. Here, we consider a decentralized SC system consisting of a fairness-minded retailer, and two competitive manufacturers - one overconfident and the other rational, in a non-cooperative duopoly market where two manufacturers produce substitutable bundles, each one consisting of two distinct products and sell through a common retailer using pure bundling strategy.

The contribution of our study to the literature is in the two areas and their integration. One is in the area of behavioral economics, and the other is in the retailing area. Till now, in the SC area, either the cognitive biases of channel members or bundle pricing strategies are available in the existing literature. The impact of single or combined cognitive biases on strategic decisions for simple two-echelon SC (one manufacturer-one retailer) studies has been investigated [24, 36, 43]. The bundle pricing strategies with bundling at the manufacturer and retailer's level are available [4]. These bundles are not substitutable. However, studies which integrate the bundle pricing strategy of substitute bundles with retailer's fairness and/or manufacturer's overconfidence have not been discussed so far. Thus, pricing strategies in the presence of channel members' cognitive biases in a two-manufacturer-one retailer SC is a new addition to the literature. All possible combinations of retailer's fairness wrt rational and irrational (overconfident) manufacturers are considered. Under some marketing conditions, individuals' profits are determined and compared. We demonstrate that fairness is beneficial to the retailer but detrimental to manufacturers. Also, SC members are benefitted from an overconfident manufacturer.

The novelties of our investigations are:

- For the first time, the pricing problem of two substitutable bundles at the manufacturer's level, consisting of two independent items in a supply chain, is considered.
- Joint effect of fairness concern and overconfidence under bundle pricing strategies in a two-echelon SC is presented.
- Some useful insights for SC partners are presented. Two cognitive biases individually have different effects, sometimes in the opposite way, on the SC members. For example, the retailer's fairness behaviour helps improve her profit, but the manufacturer's overconfidence does not help her.
- Overconfidence in a manufacturer and retailer's fairness concern have a detrimental effect on the overconfident manufacturer separately and jointly. On the contrary, the rational manufacturer is benefited from the overconfident behaviour of the other.
- Besides these, it is observed that the bundling boosts the channel members' profits even in the presence of cognitive biases. This investigation is new to the game-theoretic SC literature.

The paper is arranged as follows: Sections 1–3 give an introduction and motivation, a literature review, and models' set-up, respectively. Section 4 presents three game-theoretic models with different combinations of cognitive biases in SC partners. Sections 5 and 6 furnish the models' comparative and channel members' profit analyses. Some conclusions and managerial insights are presented in Section 7. The analytical solutions of the models, along with their comparisons, are presented in Appendix A–C.

2. Literature survey

Our research relates to the literature survey of five streams: game-theoretic approach, bundling strategies in product pricing, fairness concern, and overconfidence behaviour in the supply chain separately and jointly.

2.1. Game theoretic approach

Game theory embodies an essential way for inter-related decision making, pay-offs, and possible outcomes under some playing rules. Leng and Parlar [23] summarised the basic solution concepts in cooperative and non-cooperative games such as Stackelberg and Nash equilibria. Esmaeili *et al.* [14] solved several seller-buyer SC models by cooperative and non-cooperative game approaches, considering the seller and buyer as leader separately. Taleizadeh *et al.* [38] addressed different games (centralized, vertical Nash, manufacturer, retailer, and third-party Stackelberg) to investigate a closed-loop supply chain. Parsaeifar *et al.* [32] examined a multi-product competitive three-echelon SC through a non-cooperative game-theoretic approach. The suppliers and retailers compete in Nash equilibrium horizontally, and one manufacturer, suppliers, and retailers maintain Stackelberg equilibrium. Sharma [36] investigated channel member's fairness in a two-echelon SC with a supplier and a retailer, where the retailer buys products from the supplier *via* an option contract. Ranjbar *et al.* [34] considered a three-level SC to evaluate optimal pricing and decisions based on different game-theoretic approaches. When there are spillovers from online to offline sales, Chen *et al.* [8] look into the impact of a manufacturer's choice between wholesale and agency selling when choosing an online selling strategy.

2.2. Bundling strategies in product pricing

Product bundling is a socially desirable marketing practice as customers are benefited from this. As a beneficial marketing tool, bundling is categorized as mixed and pure. A bundle is normally formed consisting of a group of complementary items (*e.g.*, Tennis ball and racket), independently related items (*e.g.*, bread and coffee), and same items (*e.g.*, pack of particular soaps). In practice, bundling is of two strategic forms: pure and mixed. In pure bundling, customers do not have the choice to purchase items separately. Mixed bundling allows customers to buy products individually and in a combined way. Most of the studies focus on making a bundle with complementary components [1]. Considering a multi-product manufacturer and a retailer in a two-level supply chain, Pan and Zhou [31] explored the equilibrium outcomes under four different decentralized game models. They identified that selling the complementary product separately always favours the manufacturer's profit. Shao and Li [35] examined the impact of the bundling strategy on the behaviour of SC members in two scenarios of external or internal SC channel rivalry with two types of selling strategies (bundling or unbundling) and two types of product strategies (low or high quality). Giri *et al.* [16] studied the competition between two manufacturers and one retailer in a two-echelon supply chain system in a non-cooperative market where the manufacturer separately produces two complementary products and sells them to a retailer. They established that the revenue using the pure bundling sale is better than individual selling. Jena and Ghadge [21] developed a mathematical model comprising two manufacturers and one retailer to study the advertising strategy and bundling policy under different gaming scenarios and observed that manufacturer bundling is affected more than retailer bundling. For manufacturer bundling, the manufacturer bundles the components, and the retailer sells them as components by unbundling them.

Despite the pervasive literature on bundling, none considered the substitute bundles (of two independent items) at the manufacturer level. The present investigation introduces the pricing and bundling strategies for two substitute bundles (each containing two different items) produced by manufacturers and sold by a common retailer as bundles.

2.3. Fairness concern in supply chain

Due to uneven market power, unequal distribution of total profit among members often results in fairness concerns. Cui *et al.* [18] incorporated fairness in SC members in a dyadic channel and studied the effect of fairness on channel coordination by taking a linear demand function and professed that to attain maximum channel utility; a manufacturer can set the wholesale price higher than his marginal cost for coordinating the channel. Caliskan-Demirag *et al.* [2] extended the result of Cui *et al.* [18] by assuming a non-linear (exponential) demand function. Wei *et al.* [42] investigated the ordering policy of two competing retailers in a two-echelon supply chain by assuming a stochastic demand function and SC members' fairness concern. They obtained optimal decisions for both centralized and decentralized structures using Nash bargaining. Sharma [36] investigated the pricing decisions of one fair-minded manufacturer and retailer in a dyadic supply chain under two different non-cooperative game-theoretic frameworks (manufacturer-led Stackelberg game and Vertical Nash game) and noticed that the manufacturer's (retailer's) profit in the Stackelberg game is decreasing (increasing) in its fairness and is uncertain in the Vertical Nash game. Guan *et al.* [17] investigated different channels with the accumulated goodwill influenced by the levels of quality improvement and advertising effort with both fair-minded channel members. Du and Zhao [11] investigated the combined impacts of fairness and channel preference on the enterprises' operational strategies in a dual channel where manufacturers sell products through an online retailer. Huang *et al.* [19] studied the effect of consumer fairness concern on the optimal decisions of the channel members under different modes of retail channel. Chen *et al.* [9] investigated an e-commerce platform's selling scheme considering consumers' fairness concern. In the present investigation, we consider retailer to be fairness concerned against overconfident/rational manufacturers. The retailer can be fair-minded with respect to either manufacturer or both. Based on the above assumptions, the effect of fairness concern on the profit distribution among SC partners is presented.

2.4. Overconfidence behaviour in supply chain

Overconfidence is a tendency when a decision-maker assesses his/her knowledge in a biased way, and this egotistical belief is prolific in behavioural operations management [3]. Chen *et al.* [6] established an incentive contract design model with a rational risk-neutral manufacturer and an overconfident risk-averse retailer in a two-echelon SC. The result indicates that under two information states, the retailer with overconfidence behaviour has a higher effort extent and lower wholesale price than the rational retailer. Wang *et al.* [41] investigated the impact of the overconfidence behaviour of retailer on the SC and noticed that unless the level of overconfidence exceeds a threshold, the SC is not much affected compared to the basic model. Considering uncertain demand, Zhang *et al.* [46] examined the influence of retailer's overconfidence preference on an SC consisting of a rational manufacturer, one rational retailer, and one overconfident retailer. Li *et al.* [24] studied the effect of overconfidence in a competitive newsvendor setting. Liu *et al.* [25] examined the impacts of the overconfidence behaviour of logistics service integrator in a two-echelon SC. When demand is uncertain, buyer and supplier often become overconfident and discern lower demand variability than reality [20]. Zhou [50] analyzed manufacturer's overconfidence in product greenness through cost-sharing contracts for coordinating an SC. Cheng *et al.* [10] studied the effect of overconfidence of competitive retailers in a green fashion supply chain.

2.5. Fairness and overconfidence behaviour simultaneously

There are few studies with fairness concern and overconfidence among the SC partners. Xiao *et al.* [43] designed different types of optimal contracts to study the interactive impact of fairness and overconfidence in a two-echelon SC. Zhijian *et al.* [49] also analyzed the combined effect of overconfidence and fairness on wholesale price, sales price, sales effort, and expected profits under demand uncertainty.

In the present investigation, we investigate the combined effects of overconfidence bias of a manufacturer and retailer's fairness concern on the performance of the SC. We tabulate our research in connection with the above literature review in Table 1.

After reviewing the existing literature, we find the following research gaps:

(i) None presented the pricing strategy for substitute bundles consisting of independent products at the manufacturer's level and selling through a common retailer in a dyadic supply chain.
(ii) Very few have analyzed interactive impacts of cognitive biases – fairness concern and overconfidence of SC members on optimal outcomes.

We have tried to fill up this vacuum through the present investigation.

TABLE 1. Literature survey.

Authors	Nature of items	Nature of bundle	Pure bundling	Overconfidence	Fairness concern	Channel members
Yan and Bandyopadhyay [44]	Complementary	Independent	✓	×	×	1M and C
Bhargava [1]	Independent	Independent	✓	×	×	2M and 1R
Pu and Zhuge [33]	–	–	–	✓	✓	1M and 1S
Zhang *et al.* [46]	–	–	–	✓	×	1M and 2R
Chen and Wang [5]	–	Independent	×	×	×	1–M and 1–SO
Pan and Zhou [31]	Complementary	Independent	✓	×	×	1M and 1R
Wei *et al.* [42]	Same type	–	–	×	✓	1M and 2R
Sharma [36]	Independent	–	–	×	✓	1M and 1R
Chen *et al.* [7]	Substitute and/ or complementary	Independent	×	×	×	1M and 1R
Xiao *et al.* [43]	–	–	–	✓	✓	1M and 1R
Zhijian *et al.* [49]	Independent	–	–	✓	✓	1M and 1R
Yoshihara and Matsubayashi [45]	Substitute	–	–	×	✓	1M and 2R
Jian *et al.* [22]	–	–	–	×	✓	1M and 1R
Du *et al.* [13]	–	–	–	✓	×	1S and 1M
Our problem	Uncorrelated	Substitute	✓	✓	✓	2M and 1R

Notes. M, R, C, S, SO denotes manufacturer, retailer, customers, supplier, service operator respectively.

3. Model framework

The proposed models are formulated with the following notations and assumptions.

Notations

i	Manufacturer/bundle index, $i = 1, 2$
j	Item index, $j = 1, 2$
Mi	i-th manufacturer
ib	i-th bundle
c_{ij}	Unit production cost of item j produced by i-th manufacturer
$W_{ib}/W_{ib}^{f}/W_{ib}^{fo}$	Wholesale price (decision variable) of bundle-i without fairness and overconfidence/with fairness/with both fairness and overconfidence
$P_{ib}/P_{ib}^{f}/P_{ib}^{fo}$	Selling price (decision variable) of bundle-i without fairness and overconfidence/with fairness/with both fairness and overconfidence
D_{ib}	Customer's demand of bundle-i
$\pi_R/\pi_R^{f}/\pi_R^{fo}$	Profit function of retailer without fairness and overconfidence/with fairness/with both fairness and overconfidence
$\Pi_{Mi}/\Pi_{Mi}^{f}/\Pi_{Mi}^{fo}$	Profit function of i-th manufacturer without fairness and overconfidence/with fairness/with both fairness and overconfidence

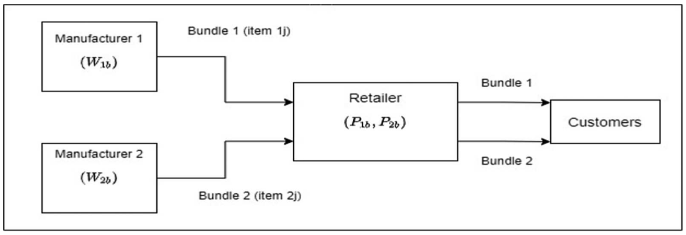

FIGURE 1. Structure of the model.

(Superscripts – "f", "fo" stands for fairness, and (fairness and overconfidence) respectively. "wrt" means with respect to.)

3.1. Assumptions

- A two-echelon SC system of two manufacturers and a common retailer in a non-cooperative market is considered. Each manufacturer produces two uncorrelated items and sells those as a bundle through a common retailer (*cf.* Fig. 1). The bundles are substitutable to each other.
- The model is of a leader-follower structure (Stackelberg game) with two fairness-neutral manufacturers and a fairness-sensitive retailer in which the manufacturers serve as leaders and the retailer act as a follower. Moreover, manufacturer-1 is here overconfident.
- The bundles' demand functions depend linearly on their retail prices [39]. The i-th bundle is sold at a single price (P_{ib}), which is less than the sum of items' prices if they are sold separately. It is assumed that the demand for bundle products increases due to the bundling [16]. Since the bundles are substitutable, the bundle's demand decreases and increases with respect to its own and cross-price. Considering the above facts, the bundles' demands are:

$$D_{1b} = a_1 - \alpha P_{1b} + \beta P_{2b} + \gamma(p_{11} + p_{12} - P_{1b}),\ \ D_{2b} = a_2 - \alpha P_{2b} + \beta P_{1b} + \gamma(p_{21} + p_{22} - P_{2b})$$

where $a_i's$ $(i = 1, 2)$ are the potential market demands for the i-th bundle, α and β are the self-price and cross-price elasticity of bundles ($\alpha > \beta$). γ ($\gamma \geq 0$) is bundle discount factor. Assuming $a_{1b} = a_1+\gamma(p_{11}+p_{12})$, $a_{2b} = a_2 + \gamma(p_{21} + p_{22})$ and $\alpha_1 = \alpha + \gamma$, the demand functions are of the form:

$$D_{1b} = a_{1b} - \alpha_1 P_{1b} + \beta P_{2b},\ \ D_{2b} = a_{2b} - \alpha_1 P_{2b} + \beta P_{1b}.$$

Demands of two substitutable bundles are always non-negative, *i.e.*, $a_{1b},\ a_{2b}$ are sufficiently large.

4. FORMULATION OF MODELS WITH BUNDLES

For the considered two-echelon SC (*cf.* Fig. 1), four main models and several sub-models are formulated and analyzed. The division of the models is presented in the following Figure 2.

4.1. Model 1: Retailer is fair-minded, and $M1$ is overconfident

In this model, we incorporate two cognitive biases into the SC, *i.e.*, the retailer's fairness concern and manufacturer-1's overconfidence. As the manufacturer-retailer is of a leader-follower relationship, the retailer is justifiably the only fairness concerned. When one of the channel members is fair-minded, her objective is to maximize her utility function (given below) rather than maximize her monetary profit [15]. Inequity arises when a fair-minded retailer perceives her outcome as inferior or superior to the manufacturer. A dis-utility occurs if her profit differs from her belief of impartial treatment [18]. When her profit is less than her equality belief, disadvantageous inequality occurs; otherwise, it is advantageous inequality. However, when the manufacturer

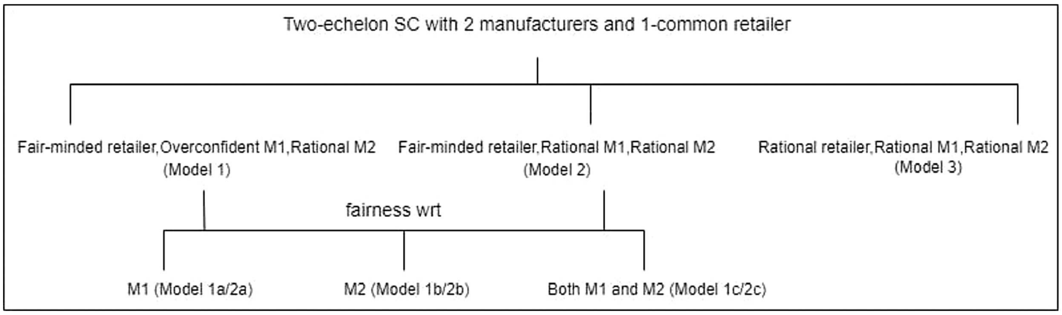

FIGURE 2. Cognitive bias based model structure.

is the Stackelberg leader, disadvantageous inequality is more significant than advantageous inequality for the retailer [12]. Therefore, we consider only the disadvantageous inequality in the retailer's utility function in our set-up.

Thus, the utility function of the fairness-sensitive retailer is given by

$$\pi_R^{fo} = \pi_R - \lambda_1[\Pi_{M1} - \pi_{R1}]^+ - \lambda_2[\Pi_{M2} - \pi_{R2}]^+$$

where $[\Pi_{Mi} - \pi_{Ri}]^+ = \max(\Pi_{Mi} - \pi_{Ri}, 0)$, $\lambda_i(\lambda_i > 0)$ is the retailer's fairness intensity. The higher value of λ_i indicates that channel members care more about fairness in the distribution of profits. Π_{Mi} and $\pi_R(= \pi_{R1}+\pi_{R2})$ are the manufacturers' and retailer's monetary profits, respectively, π_{R1} and π_{R2} are the profits coming from the bundle-1 and bundle-2 respectively.

Now, in this model, the upstream manufacturer-1 experiences another cognitive bias (overconfidence), *i.e.*, she (manufacturer $M1$) overestimates the demand for bundle-1. The overconfident $M1$ overestimates k times the previous demand (D_{1b}). So, the market demand of bundle-1 for $M1$ is given by $D_{1b}^o = kD_{1b} = k\ (a_{1b} - \alpha_1 P_{1b} + \beta P_{2b})$, $k(k > 1)$; being the overconfidence factor and the greater the value of k, the manufacturer is more overconfident. When $k = 1$, the $M1$ becomes rational, and the model reduces to one with the retailer's fairness concern only. Here, the profit function of $M1$ becomes [48]:

$$\Pi_{M1}^{fo} = W_{1b}D_{1b} - (c_{11} + c_{12})D_{1b}^o = (W_{1b} - k(c_{11} + c_{12}))D_{1b}.$$

Formulating as a Stackelberg game model, we optimize,

$$\max_{(W_{1b})} \Pi_{M1}^{fo} = (W_{1b} - k(c_{11} + c_{12}))D_{1b} \text{ and } \max_{(W_{2b})} \Pi_{M2}^{fo} = (W_{2b} - c_{21} - c_{22})D_{2b} \tag{1}$$

and the optimal prices are obtained by solving the retailer's utility function:

$$\begin{aligned}\max_{(P_{1b},P_{2b})} \pi_R^{fo} = &\left[P_{1b} - W_{1b} - \lambda_1(2W_{1b} - P_{1b} - k(c_{11} + c_{12}))^+\right]D_{1b}\\ &+ \left[P_{2b} - W_{2b} - \lambda_2(2W_{2b} - P_{2b} - c_{21} - c_{22})^+\right]D_{2b}.\end{aligned} \tag{2}$$

Based on the positive and negative sign of the term $(2W_{1b} - P_{1b} - k(c_{11} + c_{12}))$ and $(2W_{2b} - P_{2b} - (c_{21} + c_{22}))$, the four scenarios (with $M1$'s overconfidence) arise:

(i) Scenario 1 (Model 1a): $2W_{1b} - P_{1b} - k(c_{11} + c_{12}) > 0$ and $2W_{2b} - P_{2b} - (c_{21} + c_{22}) < 0$, *i.e.*, retailer is fair-minded wrt $M1$ and $M2$ is rational.
(ii) Scenario 2 (Model 1b): $2W_{1b} - P_{1b} - k(c_{11} + c_{12}) < 0$ and $2W_{2b} - P_{2b} - (c_{21} + c_{22}) > 0$, *i.e.*, retailer is fair-minded wrt $M2$.

(iii) Scenario 3 (Model 1c): $2W_{1b} - P_{1b} - k(c_{11} + c_{12}) > 0$ and $2W_{2b} - P_{2b} - (c_{21} + c_{22}) > 0$, *i.e.*, retailer is fair-minded wrt both $M1$ and $M2$.

(iv) Scenario 4: $2W_{1b} - P_{1b} - k(c_{11} + c_{12}) < 0$ and $2W_{2b} - P_{2b} - (c_{21} + c_{22}) < 0$, *i.e.*, retailer and $M2$ are rational.

Now, we solve these problems using the backward induction method, *i.e.*, first, the retailer determines the optimal retail prices of both bundles.

Then manufacturers find the optimal wholesale prices of their corresponding bundles based on the optimal retail prices.

Model 1a: Retailer is fairness concerned wrt overconfident $M1$

Here, the retailer's utility becomes

$$\pi_R^{fo} = [P_{1b} - W_{1b} - \lambda_1(2W_{1b} - P_{1b} - k(c_{11} + c_{12}))]D_{1b} + [P_{2b} - W_{2b}]D_{2b}. \tag{3}$$

Theorem 1. *The optimal values of wholesale prices* $\left(\left(W_{1b}^{fo}\right)_{1a}, \left(W_{2b}^{fo}\right)_{1a}\right)$, *retail prices* $\left(\left(P_{1b}^{fo}\right)_{1a}, \left(P_{2b}^{fo}\right)_{1a}\right)$ *of bundles-1 and 2 and the profits of the manufacturers and retailer under the feasible region* $\Delta_1 \geq 0$ *for this model are given as (* cf. *Appendix A):*

$$\begin{aligned}
\left(W_{1b}^{fo}\right)_{1a} &= k(c_{11} + c_{12}) + \left[(1 + \lambda_1)\left(\alpha_1^2 - \beta^2\right)/\Delta_2\right][\alpha_1 G_3 A_{1b}^o + \beta G_2 A_{2b}^o],\\
\left(W_{2b}^{fo}\right)_{1a} &= (c_{21} + c_{22}) + \left[(1 + 2\lambda_1)\left(\alpha_1^2 - \beta^2\right)/\Delta_2\right][\beta G_4 A_{1b}^o + \alpha_1 G_1 A_{2b}^o],\\
\left(P_{1b}^{fo}\right)_{1a} &= k(c_{11} + c_{12}) + \left[(1 + 2\lambda_1)\left(\alpha_1^2 - \beta^2\right)/\Delta_1\Delta_2\right][\alpha_1 B_6 A_{1b}^o + \beta B_7 A_{2b}^o],\\
\left(P_{2b}^{fo}\right)_{1a} &= (c_{21} + c_{22}) + \left[(1 + 2\lambda_1)\left(\alpha_1^2 - \beta^2\right)/\Delta_1\Delta_2\right][\alpha_1 B_9 A_{2b}^o + \beta B_8 A_{1b}^o],\\
\left(\Pi_{M1}^{fo}\right)_{1a} &= \frac{(1 + \lambda_1)B_5}{\Delta_1\Delta_2 G}[\alpha_1 G_3 A_{1b}^o + \beta G_2 A_{2b}^o]^2,\ \left(\Pi_{M2}^{fo}\right)_{1a} = \frac{(1 + \lambda_1)B_2}{\Delta_1\Delta_2 G}[\beta G_4 A_{1b}^o + \alpha_1 G_1 A_{2b}^o]^2,\\
\left(\pi_R^{fo}\right)_{1a} &= \left(2\alpha_1(1 + \lambda_1)/\left(\alpha_1^2 - \beta^2\right)(\Delta_1 G)^2\right)\Big[\left(\alpha_1^2 Q_1 G_3 + \beta^2 Q_3 G_4\right)\left(A_{1b}^o\right)^2\\
&\quad + \left(\alpha_1^2 G_1 Q_4 + \beta^2 Q_2 G_2\right)\left(A_{2b}^o\right)^2 + \alpha_1\beta(Q_3 G_1 + Q_4 G_4 + Q_2 G_3 + Q_1 G_2)A_{1b}^o A_{2b}^o\Big]
\end{aligned}$$

where $A_{1b}^o = a_{1b} - k\alpha_1(c_{11} + c_{12}) + \beta(c_{21} + c_{22}), A_{2b}^o = a_{2b} - \alpha_1(c_{21} + c_{22}) + k\beta(c_{11} + c_{12})$

The optimal wholesale price for bundle-1 decreases when retailer's fairness increases wrt $M1$, if $1 < \frac{\alpha_1^2}{\beta^2} < \frac{3\lambda_1^2 + 14\lambda_1 + 14}{16(1+\lambda_1)}$ and λ_1 is in the range $\left(\frac{1}{3}\left(1 + \sqrt{7}\right), 2\right)$. Similarly, the optimal wholesale-price for bundle-2 decreases with the increase of retailer's fairness if $\frac{\alpha_1^2}{\beta^2} > \frac{(2+\lambda_1)^2}{2(1+\lambda_1)(2-\lambda_1)}$ and $\frac{1}{6}\left(1 + \sqrt{31}\right) < \lambda_1 < 2$. If the overconfidence of $M1$ becomes higher, the optimal wholesale prices for bundles 1 and 2 increase if $\frac{\alpha_1^2}{\beta^2}$ is higher than a threshold value, $(1 + 2\lambda_1)$. The optimal retail prices of bundle-1 increases with overconfidence factor k, if $\frac{\alpha_1^2}{\beta^2}$ is greater than the threshold value $\left(\frac{(2+\lambda_1)^2}{2(1+\lambda_1)(2-\lambda_1)}\right)$ and λ_1 is within the range $\left(\frac{1}{5}\left(\sqrt{41} - 1\right), 2\right)$. The behaviour of the retail price for bundle-2 with the increment of k is the same as above when $\frac{\alpha_1^2}{\beta^2}$ is greater than the same threshold value as for bundle-1, and the fairness intensity coefficient lies in $\left[\frac{1}{9}\left(\sqrt{97} - 5\right), 2\right)$. Therefore, we conclude that the increase of the overconfidence factor and fairness concern intensity will respectively increase and decrease the wholesale prices of the bundles (*i.e.*, $\partial\left(W_{ib}^{fo}\right)_{1a}/\partial k > 0$ and $\partial\left(W_{ib}^{fo}\right)_{1a}/\partial\lambda_1 < 0$). So, the retailer will set higher selling prices if k increases $\left(\partial\left(P_{ib}^{fo}\right)_{1a}/\partial k > 0\right)$. It is also evident from Figure 3. It can be shown from Figure 4 that when the retailer is fair-minded wrt $M1$, the interactive impacts of fairness concern and overconfidence induce the demand-decreasing effect. Then the profit of $M1$ goes down gradually. From Figure 4, the profit of

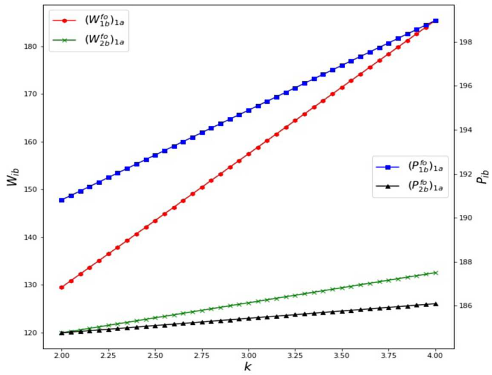

FIGURE 3. Wholesale prices and selling prices of Model 1a *vs.* Overconfidence factor.

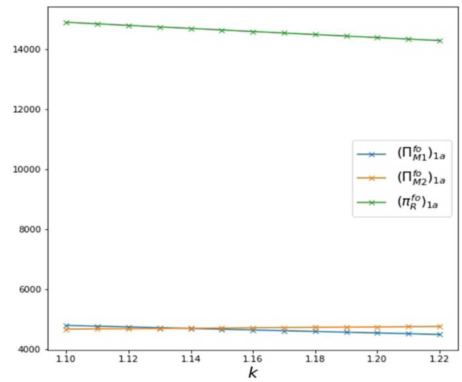

FIGURE 4. Profits of the channel members of Model 1a *vs.* Overconfidence factor.

the rational manufacturer, $M2$, increases with the overconfidence factor k. When $M1$ is overconfident, retail prices P_{ib} $(i = 1, 2)$ increase with k but the retail margin decreases. As the retailer is rational, she does not order the extra amount produced by manufacturer-1 due to her overestimated demand. So, to mitigate the loss, $M1$ increases her wholesale price, and the higher retail prices will decrease the demand. Hence, the retailer achieves lower profit when k increases.

To illustrate Model 1a, the following numerical values for the model parameters are considered: $c_{11} = 25$; $c_{12} = 20$; $c_{21} = 18$; $c_{22} = 22$ (in \$); $a_1 = 110$; $a_2 = 100$; $\alpha = 1$; $\beta = 0.5$; $\gamma = 0.85$; $\lambda_1 = 1.3$. The value of the overconfidence factor k varies from 2 to 4. With the above parametric values except $c_{11} = 18$; $c_{12} = 22$; $c_{21} = 25$; $c_{22} = 20$, we evaluate channel members' profit and present in Figure 4 against overconfidence factor. We also evaluate and present the bundles' wholesale and selling prices against the overconfidence factor in Figure 3. In this case, k varies from 1.11 to 1.22.

Model 1b: Retailer is fairness concerned wrt $M2$ (rational)

Thus, the retailer's utility is:

$$\pi_R^{fo} = [P_{1b} - W_{1b}]D_{1b} + [P_{2b} - W_{2b} - \lambda_1(2W_{2b} - P_{2b} - c_{21} - c_{22})]D_{2b}. \tag{4}$$

Theorem 2. *For Model 1b, the optimal values of wholesale prices* $\left(\left(W_{1b}^{fo}\right)_{1b}, \left(W_{2b}^{fo}\right)_{1b}\right)$, *retail prices* $\left(\left(P_{1b}^{fo}\right)_{1b}, \left(P_{2b}^{fo}\right)_{1b}\right)$ *of bundles-1 and -2 and the profits of the manufacturers and retailer under the feasible* *region* $\Delta_1 \geq 0$ *are as follows (*cf. *Appendix A):*

$$\left(W_{1b}^{fo}\right)_{1b} = k(c_{11}+c_{12}) + \left[(1+2\lambda_1)\left(\alpha_1^2-\beta^2\right)/\Delta_2\right][\alpha_1 G_1 A_{1b}^o + \beta G_4 A_{2b}^o],$$
$$\left(W_{2b}^{fo}\right)_{1b} = (c_{21}+c_{22}) + \left[(1+\lambda_1)\left(\alpha_1^2-\beta^2\right)/\Delta_2\right][\beta G_2 A_{1b}^o + \alpha_1 G_3 A_{2b}^o],$$
$$\left(P_{1b}^{fo}\right)_{1b} = k(c_{11}+c_{12}) + \left[(1+2\lambda_1)\left(\alpha_1^2-\beta^2\right)/\Delta_1\Delta_2\right][\alpha_1 B_9 A_{1b}^o + \beta B_8 A_{2b}^o],$$
$$\left(P_{2b}^{fo}\right)_{1b} = (c_{21}+c_{22}) + \left[(1+2\lambda_1)\left(\alpha_1^2-\beta^2\right)/\Delta_1\Delta_2\right][\alpha_1 B_6 A_{2b}^o + \beta B_7 A_{1b}^o],$$
$$\left(\Pi_{M1}^{fo}\right)_{1b} = \frac{(1+\lambda_1)B_2}{\Delta_1\Delta_2 G}[\alpha_1 G_1 A_{1b}^o + \beta G_4 A_{2b}^o]^2,\ \left(\Pi_{M2}^{fo}\right)_{2b} = \frac{(1+\lambda_1)B_5}{\Delta_1\Delta_2 G}[\beta G_2 A_{1b}^o + \alpha_1 G_3 A_{2b}^o]^2,$$
$$\left(\pi_R^{fo}\right)_{1b} = \left(2\alpha_1(1+\lambda_1)/\left(\alpha_1^2-\beta^2\right)(\Delta_1 G)^2\right)\Big[\left(\alpha_1^2 Q_1 G_3 + \beta^2 Q_3 G_4\right)(A_{2b}^o)^2 + \left(\alpha_1^2 G_1 Q_4 + \beta^2 Q_2 G_2\right)(A_{1b}^o)^2 + \alpha_1\beta(Q_3 G_1 + Q_4 G_4 + Q_2 G_3 + Q_1 G_2)A_{1b}^o A_{2b}^o\Big].$$

In this scenario, where the retailer is fair-minded wrt $M2$, and $M1$ is overconfident, the behaviour of wholesale prices for bundles-1 and 2 are the same as those of bundles 2 and 1 as in Model 1a. Explicitly, wholesale price for bundle-2 decreases with the fairness of the retailer under the same condition for the behaviour of bundle-1 of Model 1a, *i.e.*, $1 < \frac{\alpha_1^2}{\beta^2} < \frac{3\lambda_1^2+14\lambda_1+14}{16(1+\lambda_1)}$ and $\frac{1}{3}(1+\sqrt{7}) < \lambda_1 < 2$. Similarly, the optimal wholesale price for bundle-1 decreases with λ_1 under the same condition for the behaviour of bundle-2 in Model 1a *i.e.*, $\frac{\alpha_1^2}{\beta^2} > \frac{(2+\lambda_1)^2}{2(1+\lambda_1)(2-\lambda_1)}$ and $\frac{1}{6}\left(1+\sqrt{31}\right) < \lambda_1 < 2$. But the manufacturers' wholesale prices increase due to overconfidence, as in Model 1a. The optimal retail price for bundle-1 increases when $M1$ is more and more overconfident, if $\frac{\alpha_1^2}{\beta^2}$ is greater than $\frac{(2+\lambda_1)(4\lambda_1+7)}{(1+\lambda_1)(\lambda_1+10)}$ and $\lambda_1 \in (0,2)$. Also, it is observed analytically that the optimal retail price for bundle-2 behaves in the same way as bundle-1 if $\frac{\alpha_1^2}{\beta^2}$ is greater than the threshold value $\left(\frac{(2+\lambda_1)^2}{2(1+\lambda_1)(2-\lambda_1)}\right)$ and λ_1 in the range $\left(\frac{1}{5}\left(\sqrt{41}-1\right),2\right)$. Similarly, it can be inferred that the profits of the channel members in this scenario behave the same as in Model 1a.

Here, the optimal values of the decision variables for Models 1a and 1b are derived for the feasible region $\Delta_1 \geq 0$. The bound $\Delta_1 \geq 0$ implies $\frac{\alpha_1^2}{\beta^2} \geq 1 + \frac{\lambda_1^2}{4(1+\lambda_1)}$ which is the joint concavity condition of the profit function.

With the input parameters as in Model 1a, wholesale prices, retail prices, and profits are evaluated, and behaviours of these decision variables against overconfidence are the same as Figures 3 and 4 in Model 1a.

Model 1c: Retailer is fairness concerned wrt both $M1$ and $M2$

When the retailer is fair-minded wrt both manufacturers, the disadvantageous inequalities of the retailer with two manufacturers occur with the respective amount of fairness exhibited by the retailer. To avoid the analytical complexity, we here consider that retailer expresses fairness with the same intensity wrt both manufacturers. Then, the retailer's utility becomes:

$$\pi_R^{fo} = [P_{1b} - W_{1b} - \lambda_1(2W_{1b} - P_{1b} - k(c_{11}+c_{12}))]D_{1b} + [P_{2b} - W_{2b} - \lambda_1(2W_{2b} - P_{2b} - c_{21} - c_{22})]D_{2b}.$$

Theorem 3. *In Model 1c, the optimal values of wholesale prices* $\left(\left(W_{1b}^{fo}\right)_{1c}, \left(W_{2b}^{fo}\right)_{1c}\right)$, *retail prices* $\left(\left(P_{1b}^{fo}\right)_{1c}, \left(P_{2b}^{fo}\right)_{1c}\right)$ *of bundles-1 and -2 and the profits of manufacturers and retailer are given as:*

$$\left(W_{1b}^{fo}\right)_{1c} = k(c_{11}+c_{12}) + \frac{(1+\lambda_1)[\beta A_{2b}^o + 2\alpha_1 A_{1b}^o]}{(1+2\lambda_1)(4\alpha_1^2-\beta^2)},\ \left(W_{2b}^{fo}\right)_{1c} = (c_{21}+c_{22}) + \frac{(1+\lambda_1)[2\alpha_1 A_{2b}^o + \beta A_{1b}^o]}{(1+2\lambda_1)(4\alpha_1^2-\beta^2)},$$
$$\left(P_{1b}^{fo}\right)_{1c} = k(c_{11}+c_{12}) + \left[3\alpha_1\left(2\alpha_1^2-\beta^2\right)A_{1b}^o + \beta\left(5\alpha_1^2-2\beta^2\right)A_{2b}^o\right]/\left[2\left(\alpha_1^2-\beta^2\right)\left(4\alpha_1^2-\beta^2\right)\right],$$

$$\left(P_{2b}^{fo}\right)_{1c} = (c_{21}+c_{22}) + \left[3\alpha_1\left(2\alpha_1^2-\beta^2\right)A_{2b}^o + \beta\left(5\alpha_1^2-2\beta^2\right)A_{1b}^o\right]/\left[2\left(\alpha_1^2-\beta^2\right)\left(4\alpha_1^2-\beta^2\right)\right],$$

$$\left(\Pi_{M1}^{fo}\right)_{1c} = \frac{\alpha_1(1+\lambda_1)}{2(1+2\lambda_1)(4\alpha_1^2-\beta^2)^2}[\beta A_{2b}^o + 2\alpha_1 A_{1b}^o]^2,\ \left(\Pi_{M2}^{fo}\right)_{1c} = \frac{\alpha_1(1+\lambda_1)}{2(1+2\lambda_1)(4\alpha_1^2-\beta^2)^2}[\beta A_{1b}^o + 2\alpha_1 A_{1b}^o]^2,$$

$$\left(\pi_R^{fo}\right)_{1c} = \frac{\alpha_1^2(1+\lambda_1)}{4(\alpha_1^2-\beta^2)(4\alpha_1^2-\beta^2)^2}\left[\alpha_1(4\alpha_1^2+5\beta^2)((A_{1b}^o)^2+(A_{2b}^o)^2) + 2\beta(8\alpha_1^2+\beta^2)A_{1b}^o A_{2b}^o\right].$$

In this case, when the base market demand for bundle-1 is greater than that of bundle-2, *i.e.*, $a_{1b} > a_{2b}$ and the overconfidence factor is greater than the ratio of the production costs of bundles-2 and 1, *i.e.*, $k > \frac{c_{21}+c_{22}}{c_{11}+c_{12}}$, the wholesale price of bundle-1 is higher than that of bundle-2 ($W_{1b} > W_{2b}$). The optimal retail prices for the bundles maintain the same conditions as that of the wholesale prices of bundles (*i.e.*, $P_{1b} > P_{2b}$). Furthermore, wholesale prices for the bundles increase with the overconfidence factor, k, and decrease if the retailer's fairness concern increases (*i.e.*, $\partial W_{ib}^{fo}/\partial k > 0$ and $\partial W_{ib}^{fo}/\partial\lambda_1 < 0$). These results are justified similarly as in Model 1a. Therefore, overconfidence positively impacts manufacturers' selling prices, whereas fairness concern wrt both manufacturers have a negative effect on it. The optimal retail prices are not affected by the retailer's fairness and increase with the overconfidence factor k ($\partial P_{ib}^{fo}/\partial k > 0$ and $\partial P_{ib}^{fo}/\partial\lambda_1 = 0$). The profit of $M1$ decreases with the increase in the overconfidence factor, k, but $M2$ gets an advantage from the overconfidence behaviour of $M1$, and her profit shrinks due to the retailer's fairness. It is noticed that the retailer's profit behaves the same as in Models 1a and 1b wrt the increase of the overconfidence factor, k.

The proof of the above three Theorems 1–3 are given in Appendix A. In this case, the pictorial representation of decision variables against the overconfidence factor is the same as Figures 3 and 4 in Model 1a.

4.2. Model 2: Retailer is fairness concerned and manufacturers are rational

In this model, we remove the $M1$'s overconfidence from Model 1. Here, only the retailer exerts cognitive bias, *i.e.*, fairness concern. If we put $k = 0$ in Model 1, we get the utilities of the rational manufacturers and the fair-minded retailer. We have considered similar scenarios as to Model 1 based on the retailer's fairness.

Models 2a and 2b: Retailer is fairness concerned wrt i-th manufacturer

As there is no difference between $M1$ and $M2$, so we study the fairness concern of the retailer wrt either of the manufacturer, which will cover both manufacturers' cases. Thus, we study the fairness concern of the retailer wrt i-th manufacturer, $i = 1, 2$. In this scenario, the retailer's utility becomes:

$$\pi_R^f = [P_{ib} - W_{ib} - \lambda_1(2W_{ib} - P_{ib} - c_{i1} - c_{i2})]D_{ib} + \left[P_{(3-i)b} - W_{(3-i)b}\right]D_{(3-i)b}, \quad i = 1, 2. \tag{5}$$

By replacing 1 as i and 2 as $(3-i)$ and putting $k = 0$ in Model 1a, we get the optimal prices and corresponding profits of this scenario for the feasible region $\Delta_1 \geq 0$.

When the retailer is fair-minded wrt i-th manufacturer, it is observed that the wholesale prices of both the manufacturers decrease with the fairness concern intensity parameter (λ_1) (*cf.* Fig. 5). Further, it is analytically proved that $\left(\partial\left(W_{ib}^f\right)_{2a}/\partial\lambda_1\right) < 0$, if $1 < \frac{\alpha_1^2}{\beta^2} < \frac{3\lambda_1^2+14\lambda_1+14}{16(1+\lambda_1)}$, $\frac{1}{3}\left(1+\sqrt{7}\right) < \lambda_1 < 2$ and $\left(\partial\left(W_{(3-i)b}^f\right)_{2a}/\partial\lambda_1\right) < 0$, if $\frac{\alpha_1^2}{\beta^2} > \frac{(2+\lambda_1)^2}{2(1+\lambda_1)(2-\lambda_1)}$, $\frac{1}{6}\left(1+\sqrt{31}\right) < \lambda_1 < 2$.

Consequently, it is realized that increase of fairness intensity wrt i-th manufacturer has an adverse impact on retail prices of the i-th bundle whereas positive effect on the other bundle (*cf.* Fig. 5). From the above results, it is clear that the fairness concern of the retailer brings down the revenue of both manufacturers. Hence, the retailer's profit increases with the fairness concern intensity parameter, whereas the manufacturers' profits decrease with that. Therefore, the retailer gets an advantage because of her fairness behaviour, but the manufacturers sacrifice their profits (*cf.* Fig. 6).

To illustrate Models 2a and 2b, the same numerical values of the model parameters of Model 1a are considered. We evaluate and present bundles' wholesale and retail prices in Figure 5 and the corresponding profits of members in Figure 6 against fairness concern intensity λ_1. When $i = 1, l = 2a$ and when $i = 2, l = 2b$. In this case, λ_1 varies from 1.3 to 1.8.

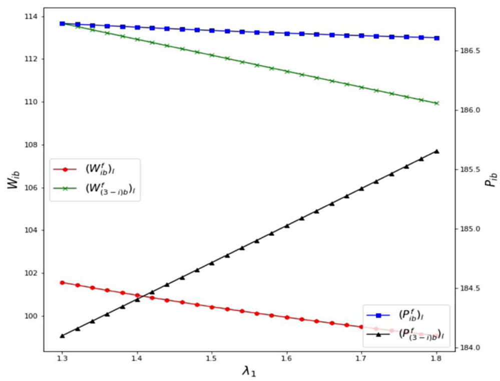

FIGURE 5. Wholesale prices and selling prices of Model 2a *vs.* Fairness concern coefficient (when $l = 1$).

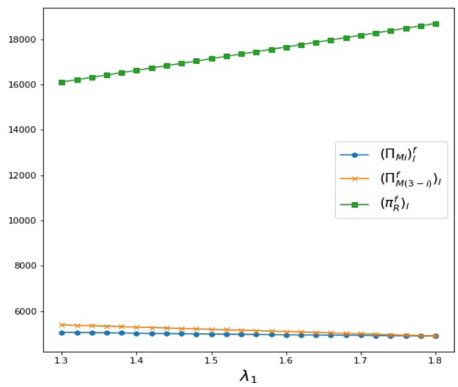

FIGURE 6. Profits of channel members of Model 2a *vs.* Fairness concern coefficient (when $l = 1$).

Model 2c: Retailer is fairness concerned wrt both manufacturers

Considering $k = 0$ in Model 1c, the retailer's utility becomes:

$$\pi_R^f = \sum_{i=1,2} [P_{ib} - W_{ib} - \lambda_1(2W_{ib} - P_{ib} - c_{i1} - c_{i2})]D_{ib}. \tag{6}$$

The optimal decisions and the corresponding profits are derived similarly by considering $k = 0$ in Model 1c. In this case, the wholesale price for bundle-1 surpasses that of bundle-2 when the production cost and base market demand of bundle-1 are higher than those of bundle-2 (*i.e.*, $(c_{11} + c_{22} > c_{21} + c_{22})$ and $(a_{1b} > a_{2b})$). It is ascertained that the profit of $M2$ is less than that of $M1$ when the market base demand relation between the bundles are same as above, but the production cost of bundle-2 is higher than that of bundle-1 $(c_{11} + c_{22} < c_{21} + c_{22})$. It is perceived that the optimal selling prices of retailer for both bundles are the same as for the base model (Model 3). So, it can be concluded that fairness concern intensity λ_1 has no impact on retail prices, and hence retail prices remain unchanged. When retailer exhibits more fairness, the manufacturers decrease their wholesale prices to care for the fairness concern of the retailer (*i.e.*, $\partial\left(W_{ib}^f\right)_{2c}/\partial\lambda_1 < 0$). As a result, manufacturers' profit decreases with the increment of retailer's fairness concern $(\partial(\Pi_{Mi}^f)_{2c}/\partial\lambda_1 < 0)$. But interestingly, fairness concern wrt both the manufacturers increases the profit of the retailer if she gradually exhibits more and more fairness $\left(\partial(\pi_R^f)_{2c}/\partial\lambda_1 > 0\right)$. These results are verified, and a similar type of behaviour of the profit functions of the chain members as in Model 2a is observed. In this case, also, the pictorial representation of decision variables against λ_1 are same as Figures 5 and 6 as in Model 2a.

4.3. Model 3: Retailer and manufacturers are rational (without any cognitive bias)

In this case, we eliminate the manufacturer's overconfidence and retailer's fairness from Model 1. Here all the channel members are rational. If we put $k = 0$ and $\lambda_1 = 0$ in Model 1c, we get the optimal decisions and corresponding profits for this scenario.

5. Dissection of results

In this section, we compare the optimal values of the decision variables, namely, wholesale and retail prices of supply chain members for different models. These comparisons furnish a clear vision of the impact of overconfidence and/or fairness concern on the optimal solutions of the above SCs. The following propositions are proposed to compare the results of the above models.

5.1. Comparison of prices

5.1.1. Comparison of bundles' wholesale prices for different models

Proposition 4. *The optimal wholesale prices of the bundles of Models 1a, 2a, and 3 satisfy the following comparative relations:*

(i) $\left(W_{1b}^f\right)_{2a} < W_{1b}$ *and* $\left(W_{1b}^f\right)_{2a} \leq \left(W_{1b}^{fo}\right)_{1a}$ *holds if* $\frac{\alpha_1^2}{\beta^2} \geq \frac{24+23\lambda_1}{16(1+\lambda_1)}$ *and* $\frac{1}{2} \leq \lambda_1 < 2$.

(ii) $\left(W_{2b}^f\right)_{2a} < W_{2b}$ *and* $\left(W_{2b}^f\right)_{2a} \leq \left(W_{2b}^{fo}\right)_{1a}$ *holds if* $\frac{\alpha_1^2}{\beta^2} > \frac{(2+\lambda_1)^2}{2(1+\lambda_1)(2-\lambda_1)}$.

An algebraic comparison of the wholesale prices of different models gives the above result. It is observed that the wholesale prices of bundles in the case without any cognitive biases (Model 3) and the case considering fairness concern and overconfidence behaviour simultaneously (Model 1a) are higher than the case considering only fairness concern of the retailer where he exerts fairness with $M1$ (Model 2a).

The first part of the proposition implies that $\left(W_{1b}^f\right)_{2a} \leq W_{1b}$ when $\frac{\alpha_1^2}{\beta^2} \geq \frac{24+23\lambda_1}{16(1+\lambda_1)}$ and $\frac{1}{2} \leq \lambda_1 < 2$. Here, the first constraint physically implies that the square of the ratio of self-price elasticity to the cross-price elasticity is sufficiently large to be greater than a threshold value($\frac{24+23\lambda_1}{16(1+\lambda_1)}$) depending on λ_1.

The second part of the proposition demands that, $\left(W_{2b}^f\right)_{2a} < W_{2b}$ holds when $\frac{\alpha_1^2}{\beta^2} > \frac{(2+\lambda_1)^2}{2(1+\lambda_1)(2-\lambda_1)}$. This justifies the first part of Proposition 4 ((i) and (ii)).

From the proposition for the wholesale prices of both the bundles, we note that the higher overconfidence level resulted in, the higher wholesale price, *i.e.*, $\left(W_{ib}^f\right)_{2a} \leq \left(W_{ib}^{fo}\right)_{1a}$ for $i = 1, 2$. When $M1$ is overconfident about the market demand, she raises the wholesale prices even when the retailer is focused on the fairness of the allocation of profits. Hence fairness behaviour with $M1$ has an adverse effect on the manufacturer's wholesale price. The power of bargaining between retailer and manufacturer is enhanced with the escalation of fairness concern of the retailer. In this situation, the retailer will force the manufacturers to reduce the wholesale price to a certain amount so that their individual profit is not compromised and fairness is guaranteed.

Proposition 5. *The optimal wholesale prices of the bundles for the Models 1b, 2b, and 3 follow the comparative relations below:*

(i) $\left(W_{1b}^f\right)_{2b} < W_{1b}$ *and* $\left(W_{1b}^f\right)_{2b} \leq \left(W_{1b}^{fo}\right)_{1b}$ *holds if* $\frac{\alpha_1^2}{\beta^2} > \frac{(2+\lambda_1)^2}{2(1+\lambda_1)(2-\lambda_1)}$.

(ii) $\left(W_{2b}^f\right)_{2b} < W_{2b}$ *and* $\left(W_{2b}^f\right)_{2b} \leq \left(W_{2b}^{fo}\right)_{1b}$ *holds if* $\frac{\alpha_1^2}{\beta^2} \geq \frac{24+23\lambda_1}{16(1+\lambda_1)}$ *and* $\frac{1}{2} \leq \lambda_1 < 2$.

Algebraic comparison of the wholesale prices of different models when the retailer is fair-minded wrt $M2$ follows the same kind of relations as in Proposition 4. The explanation of the above proposition can be derived following that of Proposition 4. The remarks about bundles 1 and 2 of Proposition 4 are respectively applied to bundles 2 and 1 of Proposition 5.

Proposition 6. *The relations of the wholesale prices of bundles for Models 1c, 2c and 3 are the following:* (i) $\left(W_{ib}^{f}\right)_{2c} < W_{ib}$, (ii) $\left(W_{ib}^{f}\right)_{2c} \leq \left(W_{ib}^{fo}\right)_{1c}$, $i = 1, 2$.

This proposition furnishes that the optimal wholesale prices of both bundles, when the retailer is fair-minded with both manufacturers, follow similar relations as Proposition 4. Therefore, combining the above propositions, it is concluded that cognitive biases such as overconfidence make wholesale prices higher, and the fairness behaviour of the retailer lowers the wholesale price of the manufacturers.

Proofs of Propositions 4–6 are presented in Appendix B.

5.1.2. Comparison of bundles' retail prices of different models

Proposition 7. *When the retailer is fair-minded wrt M1, the retail prices satisfy the following relations:*

(i) $\left(P_{1b}^{f}\right)_{2a} \leq \left(P_{1b}^{fo}\right)_{1a}$ *if* $\frac{\alpha_1^2}{\beta^2} > \frac{(2+\lambda_1)^2}{2(1+\lambda_1)(2-\lambda_1)}$ *and* $\frac{1}{5}\left(\sqrt{41}-1\right) < \lambda_1 < 2$,

(ii) $\left(P_{2b}^{f}\right)_{2a} \leq \left(P_{2b}^{fo}\right)_{1a}$ *if* $\frac{\alpha_1^2}{\beta^2} > \frac{(2+\lambda_1)^2}{2(1+\lambda_1)(2-\lambda_1)}$ *and* $\frac{1}{9}\left(\sqrt{97}-5\right) < \lambda_1 < 2$.

The above relations are obtained analytically from Models 1a and 2a. It is observed that if the retailer is fair-minded wrt $M1$, then retail prices (P_{ib}, $i = 1, 2$) of the bundles of Model 1a (with fairness concern and overconfidence behaviour simultaneously) are higher than those of Model 2a (with retailer's fairness concern only).

The first part of the Proposition 7 ((i)) implies that when retailer is fair-minded wrt rational $M1$ (Model 2a), the optimal retail price for bundle-1 is lower than the case where $M1$ is overconfident (Model 1a), if $\frac{\alpha_1^2}{\beta^2}$ is greater than some threshold value $\left(\frac{(2+\lambda_1)^2}{2(1+\lambda_1)(2-\lambda_1)}\right)$ and the fairness concern co-efficient lies in $\left(\frac{1}{5}\left(\sqrt{41}-1\right), 2\right)$. Again, the optimal retail price for bundle-2 follows the same relations as those of bundle-1 with the restrictions- $\frac{\alpha_1^2}{\beta^2}$ is higher than $\frac{(2+\lambda_1)^2}{2(1+\lambda_1)(2-\lambda_1)}$ and $\frac{1}{9}\left(\sqrt{97}-5\right) < \lambda_1 < 2$.

Proposition 8. *When the retailer is fair-minded wrt M2, the retail prices satisfy the relations:*

(i) $\left(P_{1b}^{f}\right)_{2b} \leq \left(P_{1b}^{fo}\right)_{1b}$ *if* $\frac{\alpha_1^2}{\beta^2} > \frac{(2+\lambda_1)(4\lambda_1+7)}{(1+\lambda_1)(\lambda_1+10)}$,

(ii) $\left(P_{2b}^{f}\right)_{2b} \leq \left(P_{2b}^{fo}\right)_{1b}$ *if* $\frac{\alpha_1^2}{\beta^2} > \frac{(2+\lambda_1)^2}{2(1+\lambda_1)(2-\lambda_1)}$ *and* $\frac{1}{5}\left(\sqrt{41}-1\right) < \lambda_1 < 2$.

Analytical comparisons of retail prices of different models when the retailer is fair-minded with $M2$ follow the same kind of relations as in Proposition 7 under different constraints. In this case, the optimal retail prices for bundle-1 with overconfident $M1$ are greater than those for bundle-1 with rational $M1$ if the square of the ratio of self-price to the cross price is higher than the threshold value $\frac{(2+\lambda_1)(4\lambda_1+7)}{(1+\lambda_1)(\lambda_1+10)}$. Similarly, the optimal retail price for bundle-2 follows the same inequality as for bundle-1 if $\frac{\alpha_1^2}{\beta^2} > \frac{(2+\lambda_1)^2}{2(1+\lambda_1)(2-\lambda_1)}$ and $\frac{1}{5}\left(\sqrt{41}-1\right) < \lambda_1 < 2$. Therefore, we conclude that the manufacturer's overconfidence forces the retailer to decide with a higher price.

Proposition 9. *When retailer is fair-minded wrt both manufacturers,* $P_{ib} = \left(P_{ib}^{f}\right)_{2c} \leq \left(P_{ib}^{fo}\right)_{1c}$, $i = 1, 2$.

The proposition implies that $\left(P_{ib}^{f}\right)_{2c} \leq \left(P_{ib}^{fo}\right)_{1c}$. These are of the same type as in earlier propositions. Now, if the retailer is fair-minded wrt both manufacturers, it follows from the proposition that $P_{ib} = \left(P_{ib}^{f}\right)_{2c}$. This implies that the retail prices of the bundles are not affected by the retailer's fairness concern. It further suggests that decision of a partner with higher bargaining power dominates over a lesser bargaining power partner. Proofs of Propositions 7–9 are presented in Appendix C.

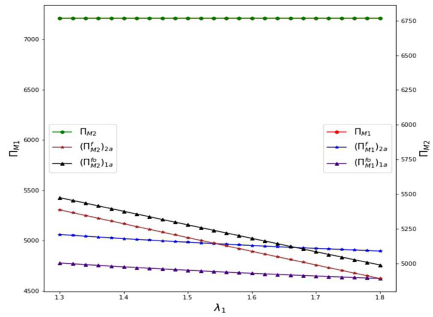

FIGURE 7. Profits of Mi $(i = 1, 2)$ *vs.* Fairness concern coefficient.

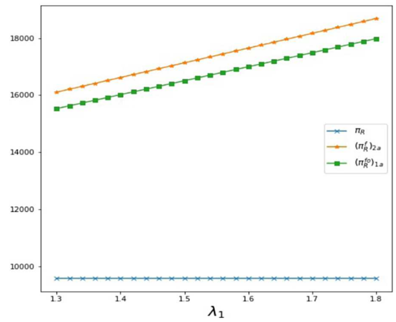

FIGURE 8. Retailer's profit *vs.* Fairness concern coefficient.

6. Profit analysis of the channel members for different models

In this section, optimal profits of channel members wrt fairness concern coefficient λ_1 and overconfidence factor k are compared numerically to establish the relations between the models.

6.1. Retailer is fair-minded wrt $M1$

Here, we consider Models 1 and 2, in which retailer is fairness concerned wrt $M1$.

6.1.1. *Profit analysis wrt* λ_1

To study this, we assume the parametric values as $c_{11} = 18$; $c_{12} = 22$; $c_{21} = 25$; $c_{22} = 20$; $a_1 = 110$; $a_2 = 100$; $\alpha = 1$; $\beta = 0.5$; $k = 1.11$; $\gamma = 0.85$. Following the feasibility conditions, the value of the fairness concern intensity λ_1 is varied from 1.3 to 1.8. With this input data, we evaluate $M1$, $M2$, and retailer profits of all Models 1a, 2a, and 3 for different values of λ_1, which are depicted in Figures 7 and 8.

From Figure 7, it is noticed that the profit of $M1$ is highest when all the channel members are rational (Model 3), followed by the case where manufacturers are rational, and the retailer is fair-minded with $M1$ (Model 2a) and the case where retailer and manufacturers are cognitive biased (Model 1a). From this illustration of profits of $M1$, we find that $\left(\Pi^{fo}_{M1}\right)_{1a} \leq \left(\Pi^{f}_{M1}\right)_{2a} < \Pi_{M1}$. It is also observed that the profit of $M1$ follows a declining trend with the improvement of the retailer's fairness concern, *i.e.*, $M1$ sacrifices some of her profit due to the retailer's fairness. This signifies that the manufacturer cannot be too invasive in choosing her pricing strategy when the retailer is fairness concerned. Besides this, the overconfidence in $M1$ reduces her profit. Thus, the interactive impacts of fairness and overconfidence generate lower profit for $M1$.

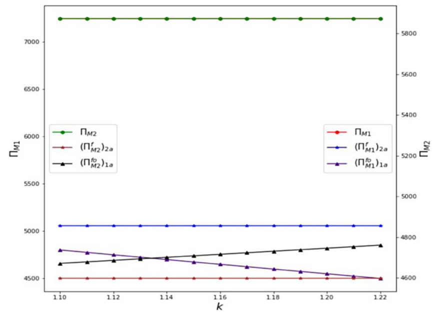

FIGURE 9. Profit of Mi ($i = 1, 2$) *vs.* Overconfidence factor.

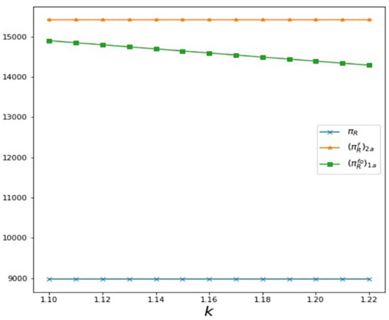

FIGURE 10. Retailer's profit *vs.* Overconfidence factor.

Now, also from Figure 7, it is realised that profits of $M2$ for the considered models follow the relation: $(\Pi^{f}_{M2})_{2a} \leq (\Pi^{fo}_{M2})_{1a} < \Pi_{M2}$. Here, as the retailer's fairness intensity (λ_1) wrt $M1$ increases, the profit of $M2$ decreases. This is because the retailer wants the profits of manufacturers to be equitable. Besides this, the overconfidence behaviour of $M1$ becomes an advantage to $M2$ as she is rational, and hence her profit is enhanced.

From Figure 8, we observe that profit of the retailer is highest when she is fair-minded wrt rational manufacturer $M1$ (Model 2a), followed by the cases where she is fair-minded with overconfident $M1$ (Model 1a) and all channel members are rational (Model 3) sequentially. Thus the retailer's profit follows the relation: $\pi_R < \left(\pi^{fo}_{R}\right)_{1a} < (\pi^{f}_{R})_{2a}$. Now when the fairness coefficient λ_1 increases, the retailer gets the advantage of her fairness. The joint effect of fairness and overconfidence lifts the retailer's profit because of her fairness though overconfidence has a detrimental effect on her profit.

6.1.2. Profit analysis wrt k

To study this, we assume the same previous numerical values. Following the earlier constraints, k varies from 1.11 to 1.22. With this input data, we evaluate $M1$, $M2$, and retailer's profits for all Models 1a, 2a, and 3 with different values of k, which are depicted in Figures 9 and 10.

Figure 9 describes the hierarchical relations of $M1$–$M2$ for different models, and the relations are the same derived in the previous comparisons wrt λ_1 (*cf.* Sect. 6.1.1). The other conclusions, wrt λ_1 derived earlier, are also true wrt k. From Figure 10, it is perceived that the relations between retailer's profits for different models are the same as in the previous case wrt λ_1 (*cf.* Sect. 6.1.1).

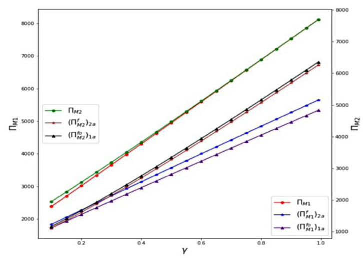

FIGURE 11. Profit of Mi $(i = 1, 2)$ *vs.* Bundle discount factor.

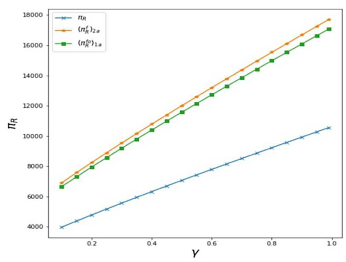

FIGURE 12. Retailer's profit *vs.* Bundle discount factor.

6.1.3. Profit analysis wrt γ

To study this, we assume the same previous numerical values and γ varies from 0.1 to 0.99. From the numerical illustration, it may be suggested that the demand for the bundles increases with the bundle discount factor. It is due to the lower price of the bundle than the sum of individual product's price. Hence, the profits of both the manufacturers and retailer increase with the higher value of the bundling discount factor (Figs. 11 and 12). Therefore, we can recommend that the bundling of items will improve the performance of the supply chain members.

Similarly, we have considered Models 1 and 2, with the scenario retailer, is fair-minded (i) with $M2$ and (ii) with $M1$ and $M2$. Here also, we analyze the profits of different models wrt λ_1, k and γ. It is observed that the same type of behaviour of profits for SC partners is found as in Section 6.1.

7. CONCLUSIONS

7.1. General conclusions

The present investigation adds theoretically some ideas in the retailing of bundled products in the presence of SC members' cognitive biases, *i.e.*, fairness and overconfidence. In detail, this study considers a two-level supply chain consisting of two competing manufacturers and one retailer. Manufacturers produce substitute bundles and sell through one retailer in a supply chain, in which market demand is influenced by the bundles' prices and two cognitive biases – fairness and overconfidence. Three optimization models, namely, integrating both cognitive biases, i.e., retailer's fairness and overconfident manufacturer simultaneously (Model 1), considering only the retailer's fairness (Model 2) and the rational channel members (Model 3), have been discussed. We analyzed the effects of these two cognitive biases on optimal solutions, comprehending the wholesale and retail prices and profits of the channel members for each model. Further, this study analyzes pure bundling in a decentralized channel. The consideration of substitutable bundles in this study is newly introduced in the supply chain literature. This present investigation theoretically contributes to the existing literature by establishing a bridge between behavioral economics and supply chain retail management. The impact analysis of cognitive biases on the bundling pricing strategy and channel members' profit contributes to the behavioral aspect of the supply chain management research domain.

Analyzing our theoretical and numerical results, we have the following conclusions:

(i) It is interesting to note that the manufacturer's overconfidence and the retailer's fairness concern affect the retailer's profit differently. The retailer is benefited if she is fair-minded only; however, the overconfident nature of the manufacturer will have a reverse effect on the retailer's profit. Conversely, the joint consideration of both cognitive biases benefits the retailer. In this case, the fairness behaviour of the retailer overpowers the manufacturer's overconfidence. So we conclude that fairness concern is always helpful for the retailer.
(ii) With fair-minded retailer, if $M1$ and $M2$ are respectively overconfidence and rational, overconfidence has a detrimental effect on $M1$. Contrary to this, the profit of $M2$ has a benign effect due to the overconfidence of $M1$. However, the retailer's fairness concern has a negative effect on both manufacturers.
(iii) The analytical study suggests that the retailer's fairness concern has a negative impact on optimal bundles' wholesale prices.
(iv) If the retailer is fair-minded wrt both of the rational manufacturers, then the retail prices are unaffected by her fairness concern.
(v) It is observed that the bundle discount factor intensifies the profits for all channel members in each model, even with two cognitive biases. Therefore, a substitute bundling strategy could be a favourable strategy to inflate channel members' profit.

7.2. Managerial insights

From the practical perspective, our research provides some effective managerial implications. This study indicates how the overconfidence and fairness of channel members impact their pricing strategy as well as profit. Further, different possible combinations of cognitive biases have been discussed by representing the various models. Finally, numerical comparison of profits is done to find out the best model. The findings are listed below:

– For the considered supply chain structure, both manufacturers should lower their wholesale prices for the bundles if the retailer is fairness concerned.
– SC management should be more vigilant about the manufacturer's overconfidence as it declines the profits of its own as well as the retailer except for the other manufacturer.
– Fairness concern of the retailer is harmful to both the manufacturers, whereas it is always advantageous for the retailer. This signifies that the manufacturer can not be too invasive in choosing her pricing strategy when the retailer is fairness concerned.
– Both simultaneous choices of cognitive behaviours are suitable for the utilities of the retailer but not for the manufacturer to make more profit.
– It also may be suggested that the demands of the bundles increase with the bundle discount factor; therefore, we recommend that the bundling of items will improve the performance of the supply chain members.

7.3. Limitations and future research

The limitations of the present investigation are as follows: We have considered a two-echelon SC with three members – two manufacturers and one retailer only. However, this can be extended to larger SC. Fairness and overconfidence are cognitive behaviours that have been represented by crisp values in this study, though these can not be strictly represented deterministically. There are several directions for future research. The limitations mentioned above can be removed in future studies. Other cognitive biases, such as "dominant", "altruistic", etc., can be imposed on the supply chain members. These cognitive biased models can be formulated and analyzed in different types of markets such as the "hungry market", etc. The models can also be formulated in fuzzy or rough environments where the model parameters, such as wholesale prices, retail prices, price elasticities, bundling discount factor, cognitive biases, etc., are imprecise and/or vague.

Appendix A.

Proof of Theorem 1. We first solve the retailer's problem expressed by equation (3). Then, the first and second-order conditions are given by

$$\frac{\partial\left(\pi_R^{fo}\right)_{1a}}{\partial P_{1b}} = -2\alpha_1(1+\lambda_1)P_{1b} + \beta(2+\lambda_1)P_{2b} + \alpha_1(1+2\lambda_1)W_{1b} - \beta W_{2b} + (1+\lambda_1)a_{1b} - k\lambda_1\alpha_1(c_{11}+c_{12}) = 0$$

$$\frac{\partial\left(\pi_R^{fo}\right)_{1a}}{\partial P_{2b}} = -2\alpha_1 P_{2b} + \beta(2+\lambda_1)P_{1b} + \alpha_1 W_{2b} - \beta(1+2\lambda_1)W_{1b} + a_{2b} + k\beta\lambda_1(c_{11}+c_{12}) = 0$$

$$\frac{\partial^2\left(\pi_R^{fo}\right)_{1a}}{\partial P_{1b}^2} = -2\alpha_1(1+\lambda_1) < 0,\quad \frac{\partial^2\left(\pi_R^{fo}\right)_{1a}}{\partial P_{2b}^2} = -2\alpha_1 < 0 \text{ and } \frac{\partial^2\left(\pi_R^{fo}\right)_{1a}}{\partial P_{1b}\partial P_{2b}} = \frac{\partial^2\left(\pi_R^{fo}\right)_{1a}}{\partial P_{2b}\partial P_{1b}} = \beta(2+\lambda_1).$$

Now we check for the concavity of the retailer's profit function.

$$H = \begin{vmatrix} -2\alpha_1(1+\lambda_1) & \beta(2+\lambda_1) \\ \beta(2+\lambda_1) & -2\alpha_1 \end{vmatrix} = \left[4\alpha_1^2(1+\lambda_1) - \beta^2(2+\lambda_1)^2\right] = \Delta_1.$$

Thus, we can say that the Hessian matrix is negative definite when $\Delta_1 \geq 0$ and hence the retailer's profit function is jointly concave in P_{1b} and P_{2b}.

Solving the first order conditions of the retailer for P_{1b} and P_{2b}, we get,

$$P_{1b} = [(1+2\lambda_1)B_4W_{1b} - \lambda_1 B_4 k(c_{11}+c_{12}) + \alpha_1\beta\lambda_1 W_{2b} + 2\alpha_1(1+\lambda_1)a_{1b} + \beta(2+\lambda_1)a_{2b}]/\Delta_1 \tag{A.1}$$

$$P_{2b} = \left[B_1W_{2b} + \alpha_1\beta\lambda_1^2 k(c_{11}+c_{12}) - \alpha_1\beta\lambda_1(1+2\lambda_1)W_{1b} + (1+\lambda_1)\{2\alpha_1 a_{2b} + \beta(2+\lambda_1)a_{1b}\}\right]/\Delta_1. \tag{A.2}$$

Then, we solve manufacturer-1's problem. The first and second-order conditions are given by $\frac{\partial(\Pi_{M1}^{fo})_{1a}}{\partial W_{1b}} = \frac{1}{\Delta_1}[-2B_2(W_{1b} - k(c_{11}+c_{12})) + B_3(W_{2b} - c_{21} - c_{24}) + B_1A_{1b}^o + \alpha_1\beta\lambda_1 A_{2b}^o] = 0$ and $\frac{\partial^2(\Pi_{M1}^{fo})_{1a}}{\partial W_{1b}^2} = -\frac{-2B_2}{\Delta_1} < 0$. Thus, the manufacturer-1 ($M1$)'s profit is concave in W_{1b}.

And for manufacturer-2, the first and second-order conditions are given by

$$\frac{\partial\left(\Pi_{M2}^{fo}\right)_{1a}}{\partial W_{2b}} = \frac{1}{\Delta_1}[-2B_5(W_{2b} - c_{21} - c_{22}) + (1+2\lambda_1)B_3(W_{1b} - k(c_{11}+c_{12})) - \alpha_1\beta\lambda_1(1+\lambda_1)A_{1b}^o + (1+\lambda_1)B_4A_{2b}^o] = 0$$

and $\frac{\partial^2(\Pi_{M2}^{fo})_{1a}}{\partial W_{2b}^2} = -\frac{-2B_5}{\Delta_1} < 0$. Hence the manufacturer-2 ($M2$)'s profit is concave in W_{2b}. After solving the first-order conditions, the optimal values of the manufacturers' decisions are as

$$\left(W_{1b}^{fo}\right)_{1a} = k(c_{11}+c_{12}) + \left[(1+\lambda_1)\left(\alpha_1^2-\beta^2\right)/\Delta_2\right][\alpha_1G_3A_{1b}^o + \beta G_2A_{2b}^o] \tag{A.3}$$

$$\text{and } \left(W_{2b}^{fo}\right)_{1a} = c_{21} + c_{22} + \left[(1+2\lambda_1)\left(\alpha_1^2-\beta^2\right)/\Delta_2\right][\beta G_4A_{1b}^o + \alpha_1G_1A_{2b}^o]. \tag{A.4}$$

Now, using (A.3) and (A.4), from (A.1) and (A.2), we obtain-

$$\left(P_{1b}^{fo}\right)_{1a} = k(c_{11}+c_{12}) + \left[(1+2\lambda_1)(\alpha_1^2-\beta^2)/\Delta_1\Delta_2\right][\alpha_1B_6A_{1b}^o + \beta B_7A_{2b}^o] \tag{A.5}$$

$$\left(P_{2b}^{fo}\right)_{1a} = c_{21} + c_{22} + \left[(1+2\lambda_1)(\alpha_1^2-\beta^2)/\Delta_1\Delta_2\right][\alpha_1 B_9 A_{2b}^o + \beta B_8 A_{1b}^o]. \tag{A.6}$$

Hence, manufacturer-1 ($M1$)'s and manufacturer-2 ($M2$)'s profits in this model is given by

$$\left(\Pi_{M1}^{fo}\right)_{1a} = \frac{(1+\lambda_1)B_5}{\Delta_1\Delta_2 G}[\alpha_1 G_3 A_{1b}^o + \beta G_2 A_{2b}^o]^2 \text{ and } \left(\Pi_{M2}^{fo}\right)_{1a} = \frac{(1+\lambda_1)B_2}{\Delta_1\Delta_2 G}[\beta G_4 A_{1b}^o + \alpha_1 G_1 A_{2b}^o]^2.$$

The profit of the retailer in this model become-

$$\left(\Pi_R^{fo}\right)_{1a} = \frac{2\alpha_1(1+\lambda_1)}{(\Delta_1 G)^2(\alpha_1^2-\beta^2)}\Big[\big(\alpha_1^2 Q_1 G_3 + \beta^2 Q_3 G_4\big)(A_{1b}^o)^2 + \big(\alpha_1^2 G_1 Q_4 + \beta^2 Q_2 G_2\big)(A_{2b}^o)^2 + \alpha_1\beta(Q_3 G_1 + Q_4 G_4 + Q_2 G_3 + Q_1 G_2)A_{1b}^o A_{2b}^o\Big].$$

Model 1a: Effect of fairness concern intensity λ_1 on the wholesale prices

Differentiating (A.3) wrt λ_1, we get

$$\frac{\partial\left(W_{1b}^{fo}\right)1a}{\partial\lambda_1} = \frac{(\alpha_1^2-\beta^2)}{\Delta_2}\Big[\alpha_1\big\{16\alpha_1^2(1+\lambda_1) - \beta^2\big(3\lambda_1^2+14\lambda_1+14\big)\big\}A_{1b}^o + \beta\big\{2\alpha_1^2(6\lambda_1+5) - \beta^2(2+\lambda_1)(3\lambda_1+4)\big\} + (1+\lambda_1)\big(\alpha_1^2-\beta^2\big) \times (\alpha_1 G_3 A_{1b}^o + \beta G_2 A_{2b}^o)\Big\{2\big(\alpha_1^2-\beta^2\big)^2\big[3\beta^2(1+\lambda_1)(2+\lambda_1) - 8\alpha_1^2(3+4\lambda_1)\big]\Big\}\Big].$$

Now, Let $\phi_1(\lambda_1) = 8(3+4\lambda_1) - 3(1+\lambda_1)(2+\lambda_1) = 18 + 23\lambda_1 - 3\lambda_1^2$, $\phi_1'(\lambda_1) = 23 - 6\lambda_1$.

$$\phi_1(\lambda_1)_{(\lambda_1=0)} = 18 > 0 \text{ and } \phi_1(\lambda_1)_{(\lambda_1=2)} = 52 > 0 \phi_1'(\lambda_1) > 0 \text{ when } \lambda_1 < \frac{23}{6} \simeq 3.$$

Therefore, $\phi_1'(\lambda_1) > 0$ for $0 < \lambda_1 < 2$. [As, $\left(W_{1b}^{fo}\right)_{1a} > 0$ if G_2 and G_3 are greater than 0 which implies that $(0 < \lambda_1 \leq 2]$.

$$\phi_1(\lambda_1) > \phi_1(\lambda_1)_{(\lambda_1=0)} \Longrightarrow 18 + 23\lambda_1 - 3\lambda_1^2 > 18 > 0.$$

Therefore, $\phi_1(\lambda_1) > 0$. Hence, $\frac{\partial}{\partial\lambda_1}[\frac{1}{\Delta_2}] < 0$.

Now, $\frac{\partial}{\partial\lambda_1}\{(1+\lambda_1)G_3\} < 0$ if $\frac{\alpha_1^2}{\beta^2} < \frac{3\lambda_1^2+14\lambda_1+14}{16(1+\lambda_1)}$.

Let $\phi_2(\lambda_1) = 3\lambda_1^2 + 14\lambda_1 + 14 - 16(1+\lambda_1) = 3\lambda_1^2 - 2\lambda_1 - 2$. $\phi_2(\lambda_1)_{(\lambda_1=0)} = -2 < 0$, $\phi_2(\lambda_1)_{(\lambda_1=2)} = 6 > 0$. Therefore, $\phi_2(\lambda_1) = 0$ for some $0 < \lambda_1 < 2$.

$$\phi_2(\lambda_1) = 0 \Longrightarrow 3\lambda_1^2 - 2\lambda_1 - 2 = 0 \Longrightarrow \lambda_1 = \frac{1}{3}\left(1 \pm \sqrt{7}\right).$$

Hence, $\phi_2(\lambda_1) > 0$ when $\frac{1}{3}\left(1 \pm \sqrt{7}\right) < \lambda_1 < 2$.

Again, $\frac{\partial}{\partial\lambda_1}\{(1+\lambda_1)G_2\} < 0$ if $\frac{\alpha_1^2}{\beta^2} < \frac{(2+\lambda_1)(3\lambda_1+4)}{2(5+6\lambda_1)}$.

Let $\phi_3(\lambda_1) = (2+\lambda_1)(3\lambda_1+4) - 2(5+6\lambda_1) = 3\lambda_1^2 - 2\lambda_1 - 2(=\phi_2(\lambda_1))$.

Hence, $\frac{\partial\left(W_{1b}^{fo}\right)_{1a}}{\partial\lambda_1} < 0$ if $1 < \frac{\alpha_1^2}{\beta^2} < \min\left\{\frac{3\lambda_1^2+14\lambda_1+14}{16(1+\lambda_1)}, \frac{(2+\lambda_1)(3\lambda_1+4)}{2(5+6\lambda_1)}\right\} = \frac{3\lambda_1^2+14\lambda_1+14}{16(1+\lambda_1)}$ and $\lambda_1 \in \left[\frac{1}{3}\left(1 \pm \sqrt{7}\right), 2\right]$.

A similar procedure was done for the wholesale price of bundle 2 when the retailer is fair-minded with manufacturer-1.

Model 1a: Effect of overconfidence factor k on wholesale prices

Differentiating ($A.3$) wrt k, we get

$$\frac{\partial}{\partial k}\left[\left(W_{1b}^{fo}\right)_{1a}\right] = \frac{(c_{11}+c_{12})}{\Delta_2}\left[\Delta_2 + (1+\lambda_1)\left(\alpha_1^2-\beta^2\right)\left(\beta^2 G_2 - \alpha_1^2 G_3\right)\right].$$

Now, $\Delta_2 + (1+\lambda_1)\left(\alpha_1^2-\beta^2\right)\left(\beta^2 G_2 - \alpha_1^2 G_3\right) = \left(\alpha_1^2-\beta^2\right)^2\left[8\alpha_1^2(1+\lambda_1)+\lambda_1 G\right] > 0$.
Hence, $\frac{\partial}{\partial k}\left[\left(W_{1b}^{fo}\right)_{1a}\right] > 0$. Similarly, we have proved that $\frac{\partial}{\partial k}\left[\left(W_{2b}^{fo}\right)_{1a}\right] > 0$ if $\frac{\alpha_1^2}{\beta^2} > 1+2\lambda_1$.

Model 1a: Effect of overconfidence factor k on the retail prices

$(P_{1b}^{fo})_{1a} > 0$ if $\frac{\alpha_1^2}{\beta^2} > \max\{\frac{(2+\lambda_1)(4+3\lambda_1)}{8(1+\lambda_1)}, \frac{(2+\lambda_1)^2}{2(1+\lambda_1)(2-\lambda_1)}\} = \frac{(2+\lambda_1)^2}{2(1+\lambda_1)(2-\lambda_1)}$ and $\frac{1}{5}\left(\sqrt{41}-1\right) < \lambda_1 < 2$.

$$\frac{\partial}{\partial k}\left[\left(P_{1b}^{fo}\right)_{1a}\right] = \frac{2\alpha_1^2(1+\lambda_1)(c_{11}+c_{12})}{\Delta_1 G}[4(1+\lambda)B_4 + \beta^2(2+\lambda)] > 0 \text{ if } B_4 > 0.$$

Hence, $\frac{\partial}{\partial k}\left[\left(P_{1b}^{fo}\right)_{1a}\right] > 0$ if $\frac{\alpha_1^2}{\beta^2} > \frac{(2+\lambda_1)^2}{2(1+\lambda_1)(2-\lambda_1)}$ and $\frac{1}{5}\left(\sqrt{41}-1\right) < \lambda_1 < 2$.
Similarly, we have proved that $\frac{\partial}{\partial k}\left[\left(P_{2b}^{fo}\right)_{1a}\right] > 0$ if $\frac{\alpha_1^2}{\beta^2} > \frac{(2+\lambda_1)^2}{2(1+\lambda_1)(2-\lambda_1)}$ and $\frac{1}{9}\left(\sqrt{97}-5\right) < \lambda_1 < 2$. □

Proof of Theorems 2 and 3 can be done similarly like Theorem 1.

Appendix B. Analysis of wholesale prices

Proof of Proposition 4: First Part of (i). The comparison of wholesale prices of bundle-1 of model 2a with model 3 is:

$$W_{1b} - \left(W_{1b}^{f}\right)_{2a} = \frac{1}{\Delta_2(4\alpha_1^2-\beta^2)}\left[\beta\left\{\Delta_2 - (1+\lambda_1)\left(\alpha_1^2-\beta^2\right)\left(4\alpha_1^2-\beta^2\right)G_2\right\}A_{2b} + \alpha_1\left\{2\Delta_2 - (1+\lambda_1)\left(\alpha_1^2-\beta^2\right)\left(4\alpha_1^2-\beta^2\right)G_3\right\}A_{1b}\right].$$

Co-efficient of A_{2b} is $\Delta_2-(1+\lambda_1)(\alpha_1^2-\beta^2)(4\alpha_1^2-\beta^2)G_2 = \lambda_1(\alpha_1^2-\beta^2)[8\alpha_1^4+\beta^4(2+\lambda_1)^2+\alpha_1^2\beta^2(\lambda_1+6)(2\lambda_1-1)]$.
Hence, co-efficient of $A_{2b} > 0$ if $2\lambda_1 - 1 > 0 \Longrightarrow \lambda_1 \geq \frac{1}{2}$.
Again, co-efficient of A_{1b} is $2\Delta_2-(1+\lambda_1)(\alpha_1^2-\beta^2)(4\alpha_1^2-\beta^2)G_3 = (\alpha_1^2-\beta^2)\lambda_1[2\alpha_1^2\{16\alpha_1^2(1+\lambda_1)-\beta^2(23\lambda_1+24)\}+\beta^4(2+\lambda_1)(3\lambda_1+5)]$.
Hence, co-efficient of $A_{1b} > 0$ if $\frac{\alpha_1^2}{\beta^2} \geq \frac{23\lambda_1+24}{16(1+\lambda_1)}$.
Therefore, $W_{1b} > \left(W_{1b}^{f}\right)_{2a}$ if $\frac{1}{2} \leq \lambda_1 < 2$ and $\frac{\alpha_1^2}{\beta^2} \geq \frac{23\lambda_1+24}{16(1+\lambda_1)}$. we get the proof of (1) if retailer is fair-minded with $M1$. Second Part of (1) has been done similarly and we obtain $\left(W_{1b}^{fo}\right)_{1a} > \left(W_{1b}^{f}\right)_{2a}$ and if $\frac{1}{2} \leq \lambda_1 < 2$ and $\frac{\alpha_1^2}{\beta^2} \geq \frac{23\lambda_1+24}{16(1+\lambda_1)}$.
Similarly, the comparison of the wholesale prices of bundle-2 if the retailer is fair-minded with $M1$ was done in the same process, and it follows the same relations when $\frac{\alpha_1^2}{\beta^2} > \frac{(2+\lambda_1)^2}{2(1+\lambda_1)(2-\lambda_1)}$. □

Proof of Propositions 5 and 6 has been done by a similar process as Proposition 4.

Appendix C. Analysis of retail prices

Proof of Proposition 7: First Part of (i). The comparison of selling Prices of bundle-1 for Models 2a and 1a: $\left(P_{1b}^{f}\right)_{2a}$ and $(P_{1b}^{fo})_{1a}$ are greater than 0 if B_6 & $B_7 > 0$.

i.e., if $\frac{\alpha_1^2}{\beta^2} > \max\left\{\frac{(2+\lambda_1)(4+3\lambda_1)}{8(1+\lambda_1)}, \frac{(2+\lambda_1)^2}{2(1+\lambda_1)(2-\lambda_1)}\right\} = \frac{(2+\lambda_1)^2}{2(1+\lambda_1)(2-\lambda_1)}$ and $\frac{1}{5}(\sqrt{41}-1) < \lambda_1 < 2$.

$$\left(P_{1b}^{fo}\right)_{1a} - \left(P_{1b}^{f}\right)_{2a} = \frac{2\alpha_1^2(1+\lambda_1)(k-1)(c_{11}+c_{12})}{\Delta_1 G}[4(1+\lambda)B_4 + \beta^2(2+\lambda)] > 0 \text{ if } B_4 > 0.$$

$$B_4 > 0 \Longrightarrow \frac{\alpha_1^2}{\beta^2} > 1 + \frac{\lambda_1}{2}.$$

Therefore, $\left(P_{1b}^{f}\right)_{2a} \leq \left(P_{1b}^{fo}\right)_{1a}$ if $\frac{\alpha_1^2}{\beta^2} > \frac{(2+\lambda_1)^2}{2(1+\lambda_1)(2-\lambda_1)}$ and $\frac{1}{5}(\sqrt{41}-1) < \lambda_1 < 2$.

Following a similar procedure comparison of bundle-2 for these two cases is done and it follows the same relation if $\frac{\alpha_1^2}{\beta^2}$ is greater than the same threshold value as of the previous, and $\frac{1}{9}\left(\sqrt{97}-5\right) < \lambda_1 < 2$. □

Proof of Propositions 8 and 9 was done in similar way as above.

Nomenclature

We define the following expressions:

$$\begin{aligned}
&\Delta_1 = 4\alpha_1^2(1+\lambda_1) - \beta^2(2+\lambda_1)^2, \qquad \Delta_2 = (1+2\lambda_1)(\alpha_1^2-\beta^2)^2 G, \quad G = 16\alpha_1^2(1+\lambda_1) - \beta^2(2+\lambda_1)^2\\
&G_1 = 8\alpha_1^2(1+\lambda_1) - \beta^2(2+\lambda_1)(3\lambda_1+4), \quad G_2 = 2\alpha_1^2(3\lambda_1+2) - \beta^2(2+\lambda_1)^2\\
&G_3 = 8\alpha_1^2(1+\lambda_1) - \beta^2(2+\lambda_1)(\lambda_1+4), \quad G_4 = 2\alpha_1^2(\lambda_1+1)(2-\lambda_1) - \beta^2(2+\lambda_1)^2\\
&Q_1 = (1+\lambda)(B_6 - \Delta_1 G_3), \quad Q_2 = (1+\lambda_1)(B_7 - \Delta_1 G_2), \quad Q_3 = (B_8 - \Delta_1 G_4), \quad Q_4 = (B_9 - \Delta_1 G_1)\\
&B_1 = 2\alpha_1^2(1+\lambda_1) - \beta^2(2+\lambda_1), \quad B_2 = 2\alpha_1(1+2\lambda_1)(\alpha_1^2-\beta^2), \quad B_3 = \beta(2+\lambda_1)(\alpha_1^2-\beta^2)\\
&B_4 = 2\alpha_1^2 - \beta^2(2+\lambda_1), \quad B_6 = (1+\lambda_1)B_4G_3 + \beta^2\lambda_1 G_4 + 2(1+\lambda_1)(\alpha_1^2-\beta^2)G\\
&B_5 = 2\alpha_1(1+\lambda_1)(\alpha_1^2-\beta^2), \quad B_7 = (1+\lambda_1)B_4G_2 + \alpha_1^2\lambda_1 G_1 + (2+\lambda_1)(\alpha_1^2-\beta^2)G,\\
&B_8 = B_1G_4 - \alpha_1^2\lambda_1(1+\lambda_1)G_3 + (1+\lambda_1)(2+\lambda_1)(\alpha_1^2-\beta^2)G,\\
&B_9 = B_1G_1 - \beta^2\lambda_1(1+\lambda_1)G_2 + 2(1+\lambda_1)(\alpha_1^2-\beta^2)G\\
&B_{10} = 12\alpha_1^2\beta^2(1+\lambda_1)(2+\lambda_1) - \beta^4(2+\lambda_1)^3 - 16\alpha_1^4(1+\lambda_1)^2\\
&B_{11} = 4\alpha_1^2(1+\lambda_1)(2-\lambda_1) - \beta^2(2+\lambda_1)^3, \quad B_{12} = 4\alpha_1^2(1+\lambda_1)(2+3\lambda_1) - \beta^2(2+\lambda_1)^3.
\end{aligned}$$

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