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A game theoretic approach to coordinate price promotion and advertising policies with reference price effects in a two-echelon supply chain

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ABSTRACT

In this paper, the price promotion and manufacturer national advertising are investigated in a manufacturer-retailer supply chain with reference price effects of consumers taken into account. A centralized game is studied followed by the two Stackelberg games of "consumer price promotion" and "retailer-consumer price promotion". In the Stackelberg games, the manufacturer plays the role of the leader and the retailer is the follower. The results obtained indicate that the reference price and the memory factor of the costumer have profound effects on the profits of supply chain members, optimal depth of price promotion and advertising level. If sensitivity of the consumer to the gap between the price and the reference price is large enough, reference price has a considerable effect on the consumer's tendency to buy and the price promotion increases channel profits. Also, it is observed that the memory of the costumer has a positive effect on profits of supply chain members. Moreover, it is also shown that there exists an indifference point for the memory factor at which the reference price impact factor has no effect on the optimal values of the decision variables. Finally, it is observed that channel efficiency is improved by advertising.

1. Introduction

Nowadays, supply chain management is necessary to company success. Supply chain members such as manufacturer and retailer make competitive decisions, e.g. product or service pricing and advertising to increase their profit (Safarzadeh and Rasti-Barzoki, 2019a, 2019b). Price promotion is one of pricing strategies used when firms want to decrease price of the products for a short period in order to increase demand value. Based on the literature, price promotion is defined as reduced price for a given period of time suggested by a higher member in the supply chain (Lin, 2016). The reduced price instigates increased demand and, thereby, enhanced sales revenues. This practice is economically motivated if the extra revenue due to increased demand exceeds the income lost to reduced price. However, price promotion highly affects customer's price expectation. The value of goods in the customer's mind is affected by a mental price, called the 'reference price', which is formed based on previous prices through time. When the price proposed to the customer falls below his reference level, he is additionally motivated to buy more, which instigates increased demand. This is, however, counteracted by the positive gap between the proposed price and the reference one, which leads to a reduction in demand. Another factor affecting demand quantity is price-based promotion policies that play an important role in encouraging costumers to buy more. However, advertising incurs expenses that can be viewed as a kind of investment. A review of the literature on price promotion, reference price, and advertising follows.

Blattberg and Neslin (1990) introduced three of the most famous kinds of sales promotion, namely: 1) trade promotion, from the manufacturer to the retailer; 2) retailer promotion, from the retailer to the consumer; and 3) consumer promotion, from the manufacturer to the consumer (manufacturer promotion). Sigué (2008) studied the effects of price promotion strategies on channel decisions and profits using a two-period model to show that retailers choose retailer promotion while manufacturers might prefer not to concentrate on consumer promotion. Tsao and Sheen (2008) studied a dynamic pricing and promotion model for deteriorating items in need of replenishment. They considered a price- and time-dependent demand function and showed that a proper promotion policy would ensure the retailer's profits. Cai, Zhang, and Zhang (2009) studied the impact of price discount contracts and pricing policies on a dual channel supply chain. They investigated three games including two Stackelberg and one Nash game and show that all scenarios with price discount contracts overcome the

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Table 1
Superscripts.

Centralized game scenario	C
Stackelberg game scenario of consumer price promotion	$S1$
Stackelberg game scenario of retailer-consumer promotion	$S2$
Optimal value	*

Table 2
Subscripts.

w	Manufacturer
r	Retailer

Table 3
Parameters.

A	Market potential
b	Price impact factor
w	Marginal profit
T	Promotion price and advertising duration
T_f	End time of selling season
λ	Impact factor of reference price
β	Memory factor
$\hat{\beta}$	Indifference point
K	Impact factor of national advertising

Table 4
Decision variables.

d	Promotion price depth
A_d	Advertising value

Table 5
Dependent variables.

Π	Profit
$\Delta\Pi^C$	Incremental profit of the centralized channel
$\Delta\Pi_m^{S2}$	Manufacturer's incremental profit in the consumer promotion scenario
$\Delta\Pi_r^{S2}$	Retailer's incremental profit in the consumer promotion scenario
$\Delta\Pi_m^{S3}$	Manufacturer's incremental profit in the retailer-consumer promotion scenario
$\Delta\Pi_r^{S3}$	Retailer's incremental profit in the retailer-consumer promotion scenario
	Channel efficiency in the retailer-consumer promotion scenario (equal to $\frac{\Delta\Pi_m^{S3}+\Delta\Pi_r^{S3}}{\Delta\Pi^C}$)
	Price at time t
	Reference price at time t
$Q(t)$	Demand function

non-contract scenarios. Martín-Herrán et al. (2010) compared business transactions with instant discounts to realize that selection from among the different types of price promotion depends vitally on consumer sensitivity to normal price and promotional depth. Tsao and Sheen (2012) investigated a two-echelon multiple-retailer distribution channel by considering the promotional efforts of retailers and their sales learning curve. They indicated that maintaining the fraction of promotion cost within a proper range increased the profits of all the parties involved in channel coordination. Su and Geunes (2013) studied a multi-period price promotion in a single-supplier but multi-retailer supply chain under asymmetric demand information. Considering a Stackelbeg game, they proposed a stochastic bi-level optimization model and used the linearization technique for its exact solution. Considering three discount- and effort-induced contracts, Saha (2013) studied supply chain coordination when these kinds of coordination mechanisms are applied. The results obtained revealed that proper coordination contracts would guarantee more profits for both the manufacturer and the retailer but only if the conditions were predetermined. Modak, Panda, Sana, and Basu (2014) proposed a two-echelon dual-channel supply chain and studied the effect of the degree of concern of the manufacturer regarding corporate social responsibility on product compatibility. They proposed two decentralized and centralized model and showed that all unit discount with franchise fee resolves the conflict of the channel and provides win-win profits for members of the chain. Modak, Panda, and Sana (2016b) studied pricing policy in a corporate social responsibility two layer supply chain including a manufacturer and two competitive retailers. They found that two-part traffic discount cut out the conflict of the channel and provides win-win profits for a specific range of the franchise fee. Modak, Panda, and Sana (2016a) proposed a multi-channel multi-echelon supply chain and investigated optimal pricing policies under two-part traffic discount and bargaining in centralized and decentralized scenarios of the chain. Modak, Panda, and Sana (2016c) studied a three echelon supply chain with two retailers in the downstream of the chain. The manufacturer supplies the product with a random proportion of imperfect quality items and the retailers may play Stackelberg, Cournot or Collusion game. Their results showed that all unit quality discount with franchise fee resolves channel conflict though unable to provide win-win profits for all members of the chain. Modak, Modak et al. (2018) investigated a two echelon closed loop supply in three different structure and studied the effect of recycling and product quality level on pricing policy. They showed that alternative offer bargaining settles the conflict of the channel and shares the surplus profits between the members in definite proportion.

Some scholars studied the effects of short-term price reductions on firm profitability arising from increased demand as a result of defla-

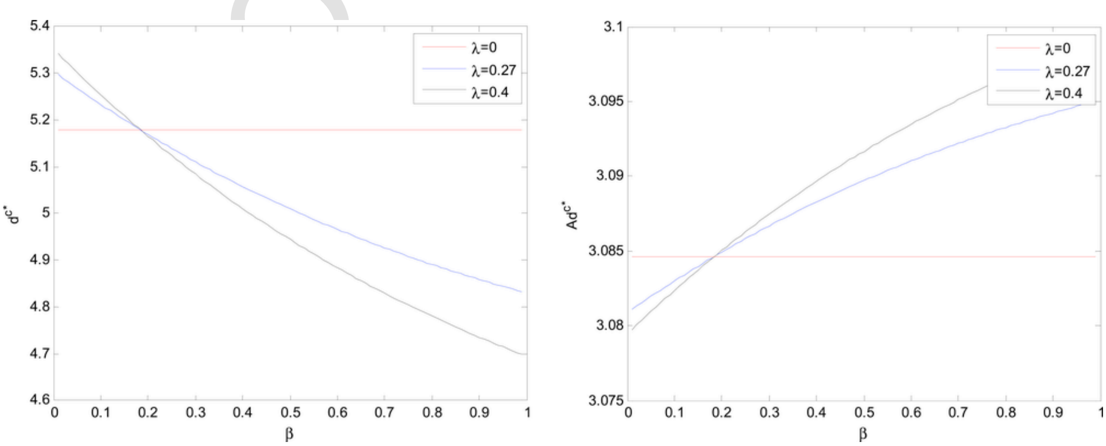

Fig. 1. Effect of memory factor on optimal depths of price promotion and advertising value in the centralized scenario based on values selected for reference price factor.

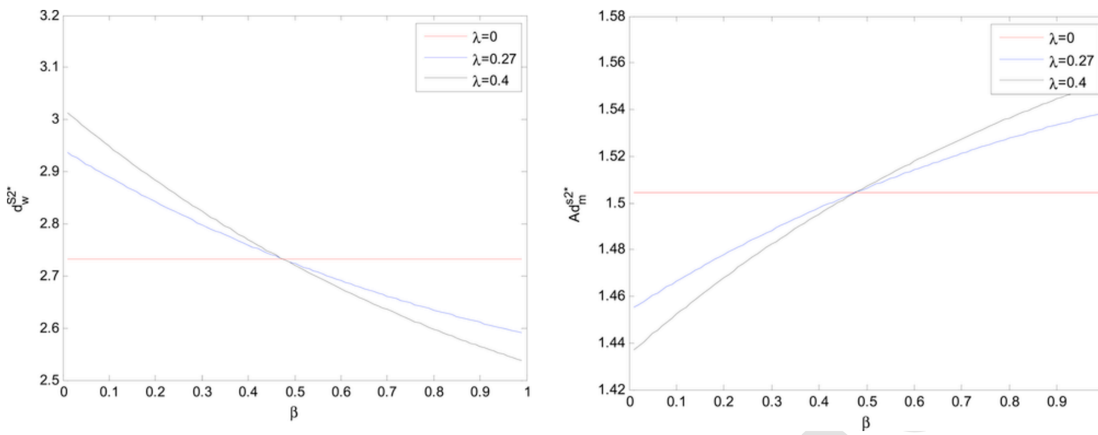

Fig. 2. Effect of memory factor on optimal depths of price promotion and advertising value under the second scenario based on values selected for reference price factor.

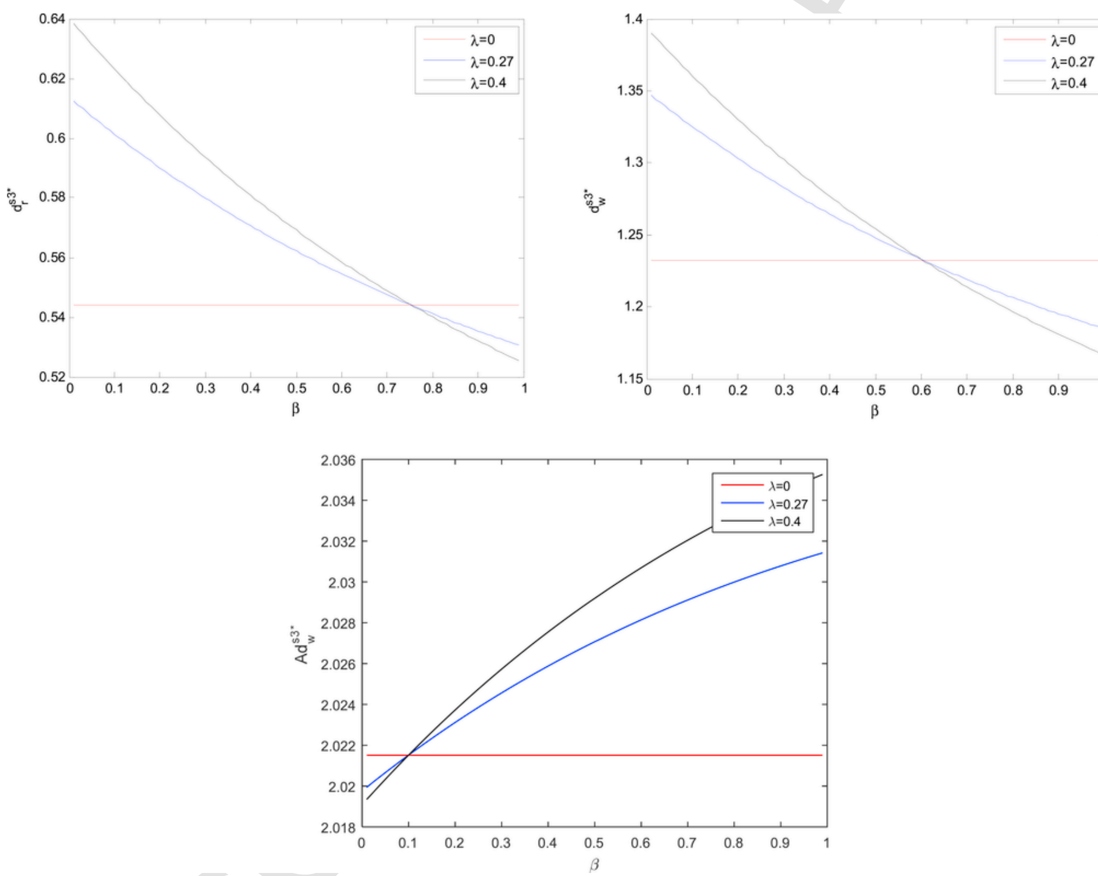

Fig. 3. Effect of memory factor on optimal depths of price promotion and advertising value under the third scenario based on values selected for reference price factor.

Table 6
Data for the sample instances.

w_m	w_r	b	T	T_f	A	K
8	4	1.5	0.2	1	20	0.3

tion. These studies, however, often overlooked the great effects of long-term deflation on the consumer's demand and behavior (Lin, 2016). Greenleaf (1995) observed that, due to the effects of reference price, the optimal policy of pricing for a monopolist could be periodic. Kopalle, Rao, and Assunção (1996) extended Greenleaf's research to a duopoly. They claimed that in case a price rise had a smaller effect on demand than a price decrease of equal-size, then the so-called high-low pricing policy would be the optimal one; otherwise, a constant price would be optimal. Kalyanaram and Winer (1995) examined the effects of reference prices on consumer's decision making to find that it had a consistent and remarkable impact. Fibich, Gavious, and Lowengart (2003) proposed a method for calculating the optimal price when the reference price was an exponentially weighted average of past prices. Fibich, Gavious, and Lowengart (2007) extended a previous study (Fibich et al., 2003) to consider the effect of price promotion. They found that reference price affected price rigidity and flexibility. Popescu and Wu (2007) investigated the dynamic pricing problem in a discrete time model focusing on the reference price. Nasiry and Popescu (2011) continued the work of (Popescu and Wu, 2007) by adding to the problem a different combination of reference prices

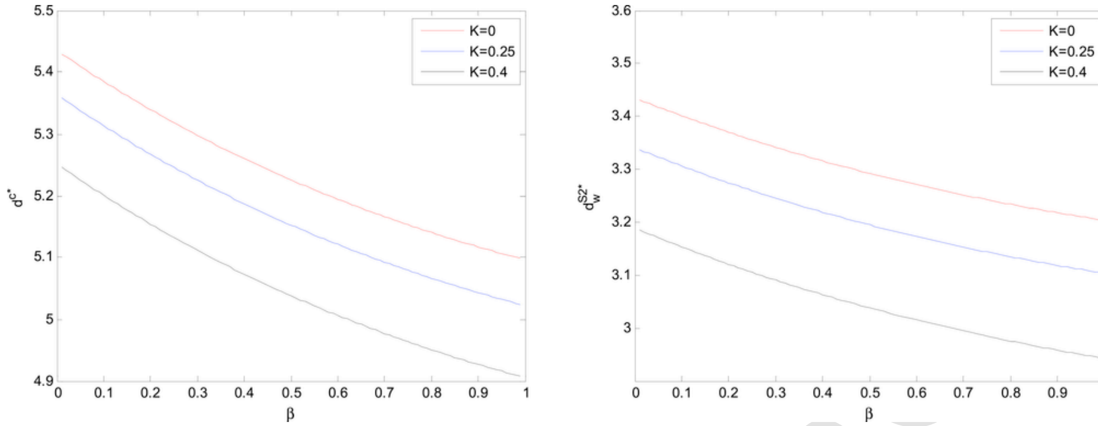

Fig. 4. Effect of memory factor on optimal depths of price promotion and advertising value under the centralized and second scenarios based on the values selected for advertising factor.

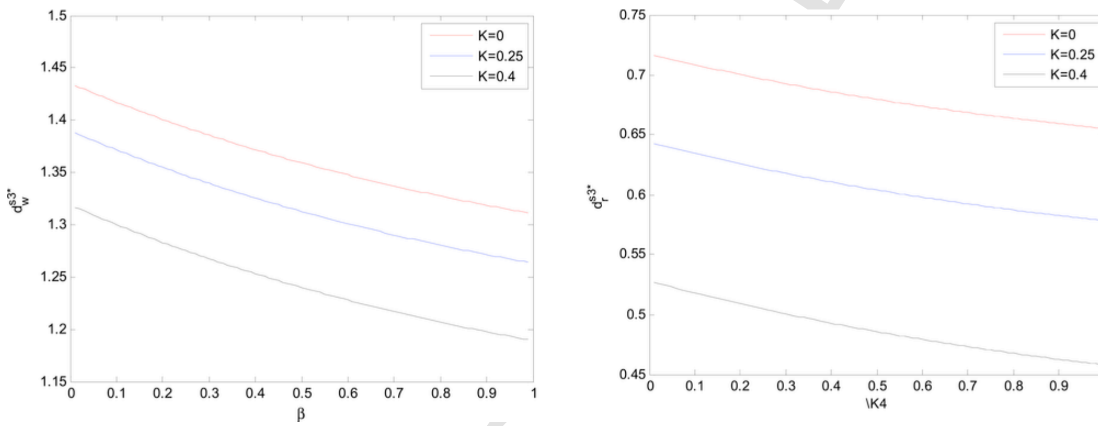

Fig. 5. Effect of memory factor on optimal depths of price promotion under the third scenario based on the values selected for advertising factor.

called 'peak-end anchoring'. They found that optimal prices converged monotonically for loss-averse customers. Geng, Wu, and Li (2010) investigated pricing strategy by considering the effects of reference price under both certain and uncertain demands in a single-retailer single-manufacturer supply chain. They observed that, with asymmetrical effects of the reference price, the retailer sought a periodic promotion strategy rather than a constant price one. Halme and Somervuori (2013) studied the impacts of price changes on demand for compensatory services in the presence of reference prices. They observed stronger reactions by customers to price increases than to price reductions in the case of traditional services. Taudes and Rudloff (2012) studied an integrated pricing/inventory model by concentrating on reference price effects. They developed a closed-form solution that described the relevance between optimal pricing/inventory policy and reference price. X. Chen, Hu, Shum, and Zhang (2016) proposed a joint inventory-pricing model taking into account reference price effects in a stochastic multi-period setting with loss-averse customers. They also incorporated an additive and a multiplicative random variable into the demand based on both finite and infinite horizons. Güler (2013) and Güler et al. (2014) explored a periodic review inventory system. In their system, the random demand depended on both the current and the reference price. M. Güray Güler et al. (2014) used the results reported in (X. Chen et al., 2016) for the model with a non-linear demand. M Güray Güler et al. (2015) extended the model developed in (M Güray Güler, 2013) by considering an infinite bound and qualified the steady-state solution. Zhang et al. (2014) studied the effects of reference price in a pricing model with two periods based on an infinite selling horizon; they also developed a number of contracts in order to coordinate the supply chain. Martín-Herrán and Taboubi (2015) introduced a differential game, as might be encountered with in a bilateral monopoly, which took into account the effects of the reference price. They observed that, for some values of the initial reference price, there is a time interval in which channel decentralization acts more efficiently than coordination. Lin (2016) studied a manufacturer-retailer supply chain accounting for reference price effects and price promotion. Dye and Yang (2016) studied a joint optimal dynamic pricing model with reference price effects considering technology investments for deteriorating products. A. Huang, Dawes, Lockshin, and Greenacre (2017) Studied price elasticity and consumer behavior when price of a higher-price brand changes. Kim (2017) studied the effects of different price promotions on customer retention in service companies. His result shows that customer retention's intention is higher when the customer start using service with free monthly fee rather than free joining fee promotion. More special studies in the field may be found in a review paper by Mazumdar et al. (2005).

Advertising is an important factor affecting consumer demand and a critical lever to enhance firm profitability in the market. Major corporations spend vast sums of money on advertising each year (Pergelova et al., 2010). The literature is imbued with works investigating the effects of advertising on the profitability of supply chain members. For example, Roslow et al. (1993) studied advertising in the supply chain to show that collaboration in advertising investiture could improve the total profit of the supply chain. In the context of supply chains, many researchers have focused on two fields: (i) cooperative (co-op) advertising that involves national advertising by the manufacturer and local advertising by the retailer (Chaab and Rasti-Barzoki, 2016; T.-H. Chen, 2015; Pei and Yan, 2013; Wang et al., 2011; Xie and Neyret, 2009), and (ii) the non-co-op advertising that assumes the re-

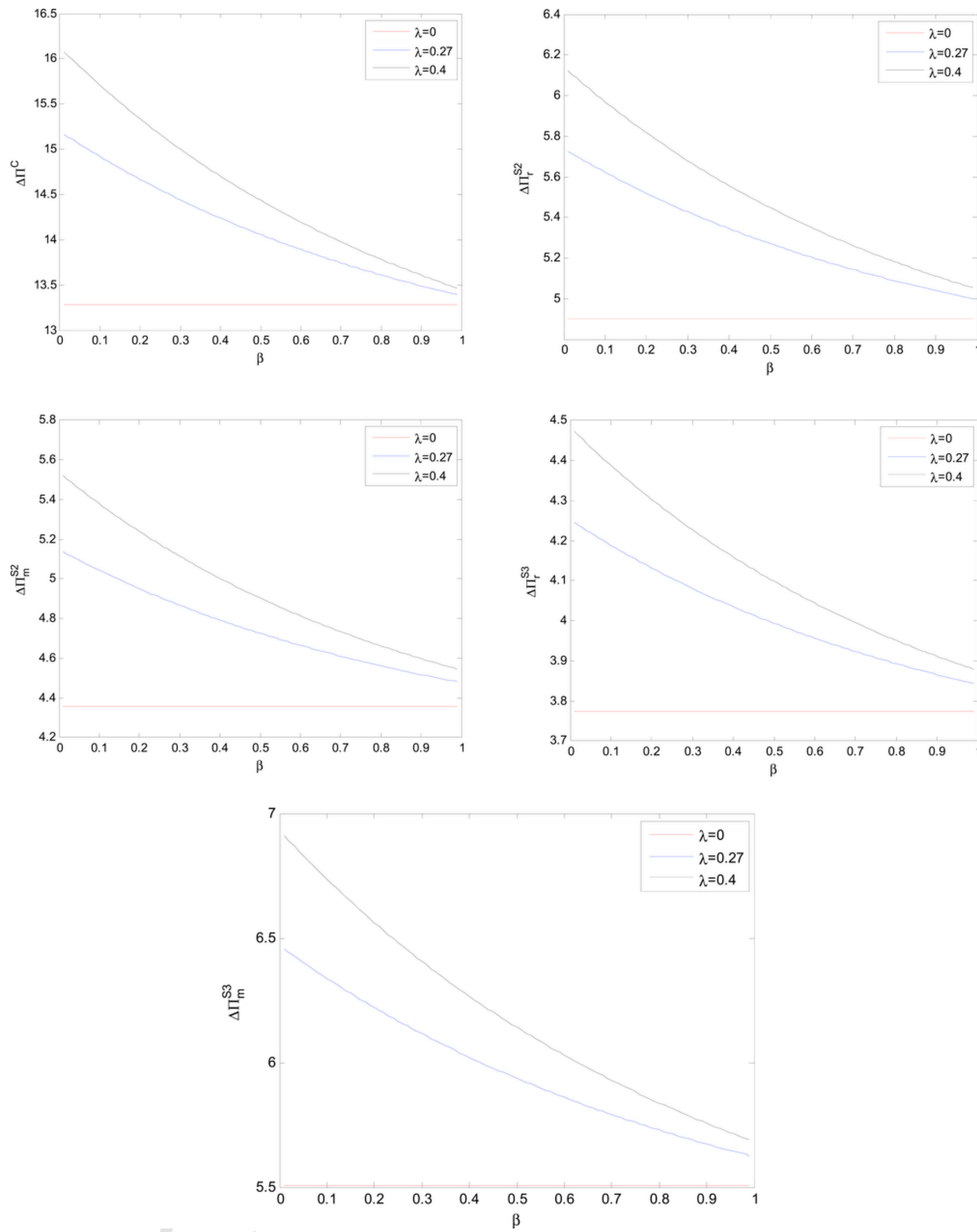

Fig. 6. Effect of memory factor on incremental profits based on values selected for reference price factor.

tailer retains equal or more power than the manufacturer (Achenbaum and Mitchel, 1987; Buzzell et al., 1990; Z. Huang and Li, 2001).

In this paper, as in (Lin, 2016), the concept of reference price is used to consider the long-term impact of deflation on customer behavior. Actually, reference price represents the consumer's mental price. According to this concept, the consumer compares the price suggested by the vendor with the mental price to decide whether or not to purchase a product. The lower the vendor's offer than the reference price, the more eager the customer will be to purchase and the more satisfied they will be; obviously, the reverse is also true. The consumer's mental or reference price is influenced by earlier commodity prices. Thus, deflation can produce changes in the reference price to affect customer behavior and the long-term demand quantity. As already mentioned, no study has yet been conducted on price promotion that simultaneously takes into account the effects of reference price and advertising. The purpose of the paper is to answer the question "Under the effect of price stream during the time, on the memory of the consumer that affects consumer's tendency to buy, the members of the chain how much do discount and how much do advertise?". In this paper, advertising is assumed to be performed at the national level only such that all the advertising costs are borne by the manufacturer.

The structure of the paper is as follows: In Section 2, the problem and its associated assumptions are described. Sections 3, 4, and 5 investigate the three centralized channel, the price promotion of the con-

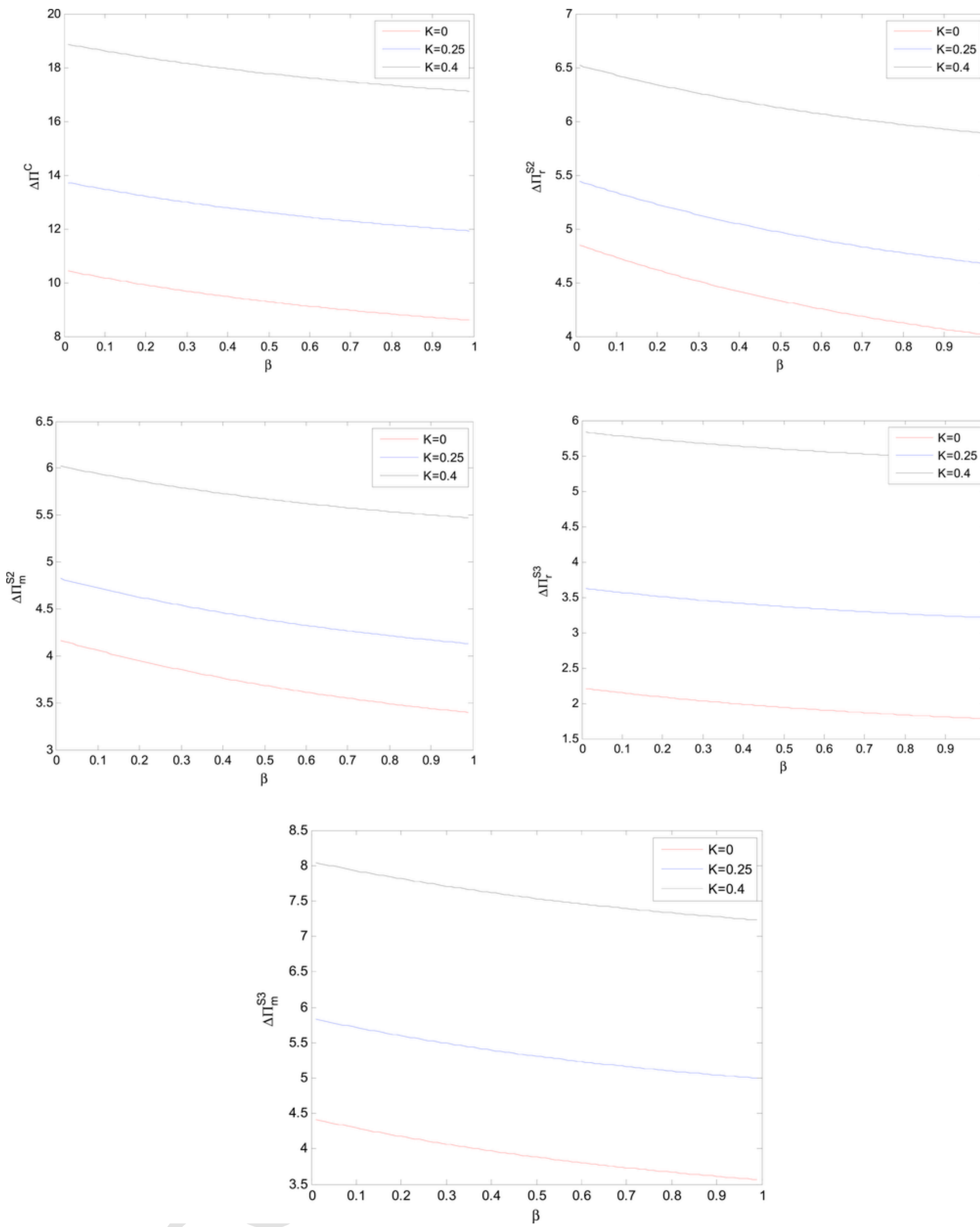

Fig. 7. Effect of memory factor on incremental profits based on values selected for advertising factor.

sumer, and the price promotion of the retailer-consumer scenarios, respectively. Numerical results are reported in summary in Section 6 and conclusions are finally presented in Section 7.

2. Problem definition

2.1. Notations

The notations used in this research are summarized in Tables 1–5.

2.2. Assumptions

We consider a two-echelon supply chain comprising a manufacturer and a retailer. The manufacturer produces one type of product and sends it to the retailer in an exclusive market. The manufacturer acts as the Stackelberg leader, determining his price promotion depth and advertisement level. Also, the retailer, as a follower, specifies his price promotion depth. Selling and advertisement occur in a fixed selling interval $[0,T_f]$.

The effect of price promotion depth on demand is considered to be symmetrical. In other words, positive and negative differences between reference price and product price have identical (numerical) impacts

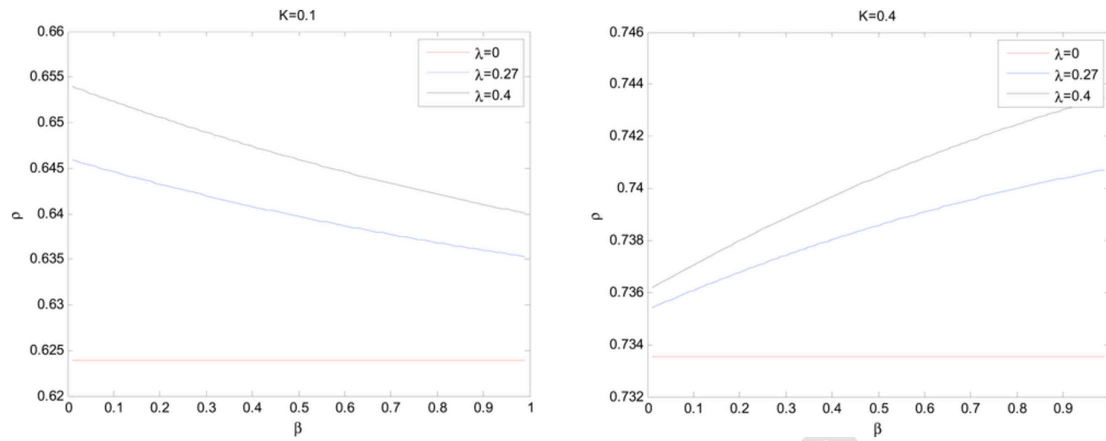

Fig. 8. Effects of memory factor on channel efficiency based on values selected for reference price factor and advertising factor.

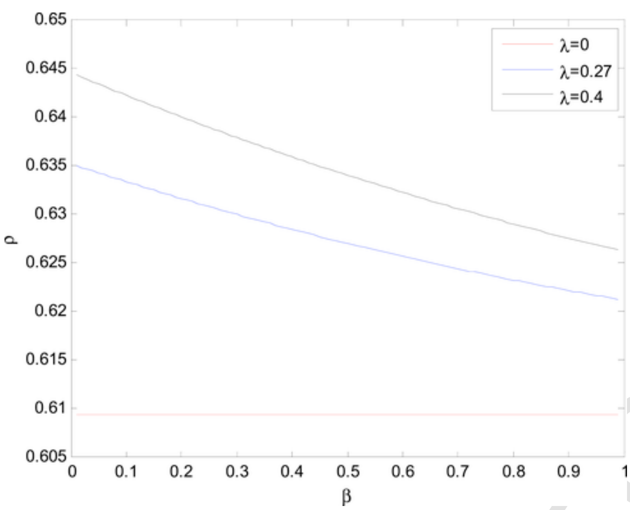

Fig. 9. Effects of memory factor on channel efficiency based on values selected for reference price factor in the absence of advertising (Lin, 2016).

on demand but in opposite directions. If the reference price is less than that of the product, demand rises; otherwise, it reduces customer's willingness to buy, in which case, the demand declines.

The marginal profits of the manufacturer and the retailer with no price promotion are designated by $\acute{w}_m$ and $\acute{w}_r$ respectively. Also, in the case of price promotion, the manufacturer's and the retailer's marginal profits are denoted by w_m and w_r respectively. Moreover, d_m and d_r represent the manufacturer's and retailer's price promotion depths, respectively. Price promotion begins at time zero and continues until $T < T_f$, this time interval is predetermined. Advertisement occurs continually and constantly within this same interval. Based on these assumptions, the marginal profit for each of the supply chain parties may be determined using Eqs. (1) and (2):

$$w_m = \begin{cases} \acute{w}_m - d_m \; 0 \le t \le T \\ \acute{w}_m \; T < t \le T_f \end{cases} \tag{1}$$

$$w_r = \begin{cases} \acute{w}_r - d_r \; 0 \le t \le T \\ \acute{w}_r \; T < t \le T_f \end{cases} \tag{2}$$

2.3. Demand function

Following Greenleaf (1995) and Kopalle et al. (1996), the demand function is assumed to be linear and reference price effects are taken into account as captured by Eq. (3):

$$Q(t) = \begin{cases} A - b.p(t) - \lambda(p(t) - r(t)) + KA_d\frac{t}{T} \; 0 \le t \le T \\ A - b.p(t) - \lambda(p(t) - r(t)) + KA_d \; T < t \le T_f \end{cases} \tag{3}$$

where, $A > b\left(w_m + w_r\right)$ represents market potential, $b > 0$ is the price impact factor, and $\lambda > 0$ is the reference price impact factor showing the consumer's reference price effects. Also, $r(t)$ and $p(t)$ are the reference and product prices at time t, respectively. Higher reference price im-

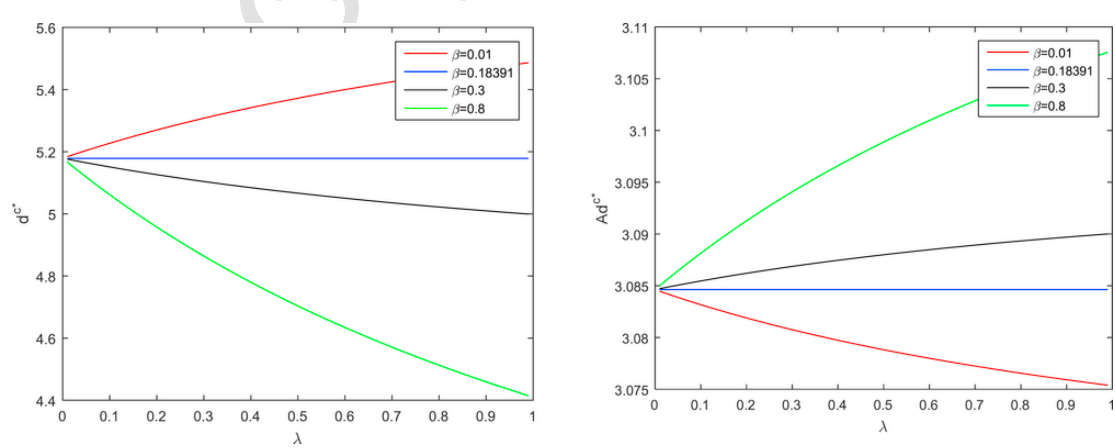

Fig. 10. Effect of reference price factor on optimal depths of price promotion and advertising value in the centralized scenario based on values selected for memory factor.

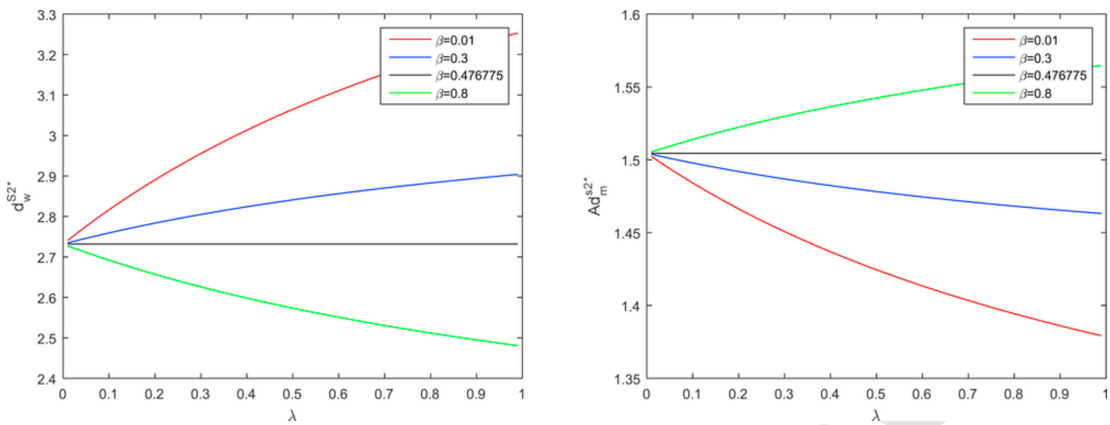

Fig. 11. Effect of reference price factor on optimal depths of price promotion and advertising value under the second scenario based on values selected for memory factor.

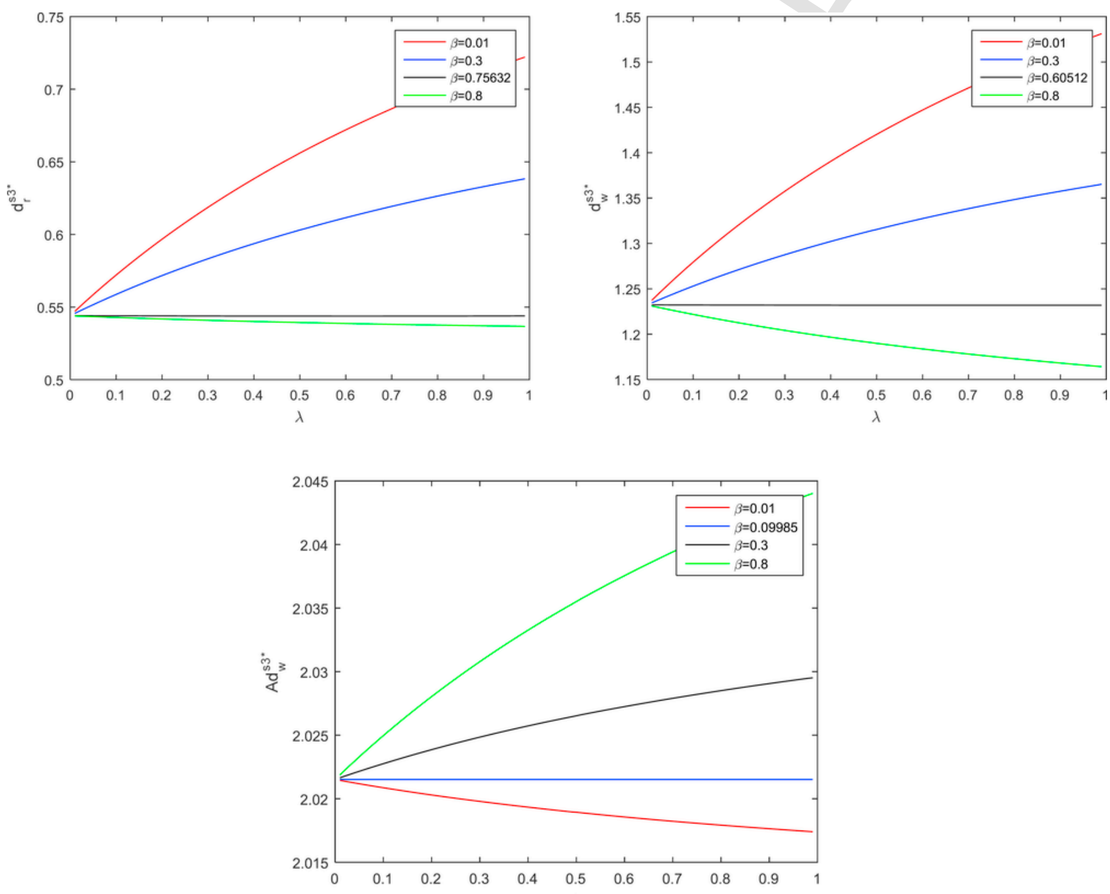

Fig. 12. Effect of reference price factor on optimal depths of price promotion and advertising value under the third scenario based on values selected for memory factor.

pact factors indicate consumers' greater sensitivity to the difference between reference and observed prices. Finally, K and A_d are advertising impact factor and manufacturer's total advertisement in the price promotion interval, respectively, so that advertisement occurs at a rate of $\frac{A_d}{t}$ in that interval. The impact of advertising on demand persists even after T, that is, the endpoint of the promotion price and advertising.

2.4. Price promotion function

Following (Lin, 2016), an exponential weighted function is adopted as the reference price function:

$$r(t) = e^{-\beta t}\left(r(0) + \beta \int_0^t e^{-bx} p(x)\,\mathrm{d}x\right) \tag{4}$$

where, $\beta \in [0, 1]$ is the memory factor. A larger value of β represents a weaker consumer memory such that the reference price relies more on the current retail price. In contrast, smaller values of β indicate the stronger memory of the consumers and their higher likelihood to remain loyal to the product. According to (Fibich et al., 2007), $r(0) = w_m + w_r$. Thus, based on Eqs (1)–(4), the price promotion func-

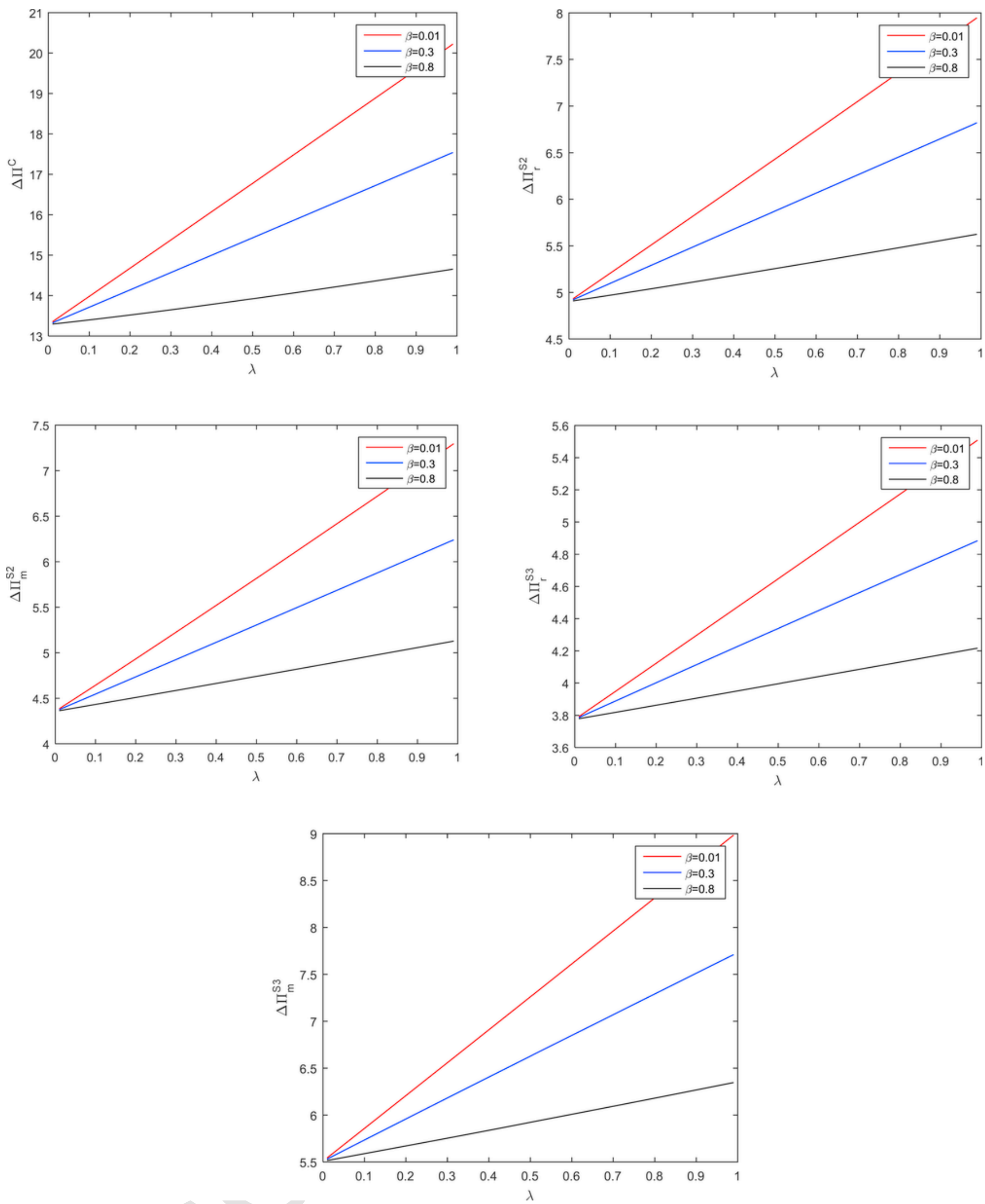

Fig. 13. Effect of reference price factor on incremental profits based on values selected for memory factor.

tion will be as follows:

$$r(t) = \begin{cases} w_m + w_r - (d_m + d_r)\left(1 - e^{-\beta t}\right) & 0 \le t \le T \\ w_m + w_r - (d_m + d_r)\left(e^{-\beta(t-T)} - e^{-\beta t}\right) & T < t \le T_f \end{cases} \quad (5)$$

3. Centralized channel

This Section investigates the centralized manufacturer-retailer channel. If d^C and A_d^C denote the price promotion depth of the company in the specified interval and advertising, the channel profit may then be calculated using Eq. (6) below:

$$\pi = \int_0^{T_f} p(t)\, Q(t)\, \mathrm{d}t - \frac{1}{2} A_d^2 \tag{6}$$

where, the first term denotes the profit gained from sales and the second term represents the advertising cost. Thus:

$$\begin{aligned} \pi^C \left(d^C, A_d^C\right) = T\left(w_m + w_r - d^C\right)\left(A - b\left(w_m + w_r - d^C\right) + \tfrac{1}{2} K A_d^C\right) \\ -T\left(w_m + w_r\right)\left(A - b\left(w_m + w_r\right) + K A_d^C\right) \\ + \left(w_m + w_r - d^C\right) \tfrac{\lambda}{\beta} d^C \left(1 - e^{-\beta T}\right)\left(w_m + w_r\right) \tfrac{\lambda}{\beta} d^C \left(e^{-\beta T} - e^{-\beta T_f} - 1 + e^{-\beta\left(T_f\right.} \right. \\ + T_f\left(w_m + w_r\right)\left(A - b\left(w_m + w_r\right) + K A_d^C\right) - \tfrac{1}{2} A_d^{C^2} \end{aligned}$$

In Equation (7), the impact of advertising on cost is represented by a quadratic term, indicating that it will be more difficult to find more advertisers of the required quality and productivity when advertising impact factor increases. The quadratic effect of advertising on cost has been reported in the literature (Yang et al., 2013).

It is assumed that:

$$b_1 = A - b\left(w_m + w_r\right) \tag{8}$$

$$b_2 = \frac{\lambda e^{-\beta\left(T_f - T\right)}\left(1 - e^{-\beta T}\right) + \beta b T}{\beta} \tag{9}$$

$$b_3 = \frac{\lambda\left(1 - e^{-\beta T}\right) + \beta b T}{\beta} \tag{10}$$

Using the exposition in Equations (8)–(10) will yield.

$$\begin{aligned} \pi^C \left(d^C, A_d^C\right) = T\left(w_m + w_r - d^C\right)\left(b_1 + \tfrac{1}{2} K.A_d^C\right) \\ -T\left(w_m + w_r\right)\left(b_1 + K A_d^C\right) + \left(w_m + w_r - d^C\right) d^C b_3 \\ + \left(w_m + w_r\right) d^C \left(b_2 - b_3\right) + T_f\left(w_m + w_r\right)\left(b_1 + K A_d^C\right) - \tfrac{1}{2} A_d^{C^2} \end{aligned} \tag{11}$$

To investigate the concavity condition for Relation (11), we may obtain the Hessian matrix for Eq. (7) as follows:

$$H = \begin{bmatrix} -2b_3 & -\frac{1}{2}KT \\ -\frac{1}{2}KT & -1 \end{bmatrix} \tag{12}$$

According to (12), $H_{1,1}$ is negative and the concavity condition for (11) is, therefore, obtained as in (13) below.

$$|H| > 0 \Rightarrow 8b_3 > K^2 T^2 \tag{13}$$

Assuming that Inequality (13) holds, the optimal values for price promotion depth and advertising value are determined using a first order condition.

$$d^{C*} = \frac{\left(w_m + w_r\right)\left(4b_2 + K^2 T^2 - 2K^2 T T_f\right) - 4Tb_1}{8b_3 - K^2 T^2} \tag{14}$$

$$A_d^{C\,*} = \frac{2K\left(\left(w_m + w_r\right)\left(T\left(b_3 - b_2\right) + 2b_3\left(2T_f - T\right)\right) + T^2 b_1\right)}{8b_3 - K^2 T^2} \tag{15}$$

Therefore, the optimum profit will be as follow.

$$\begin{aligned} \Pi^{C*} = \Pi_m + \Pi_r \\ + \left(w_m + w_r\right)\left(\tfrac{1}{2} K.A_d^{C*}\left(2T_f - T\right) + b_2 d^{C*}\right) \\ -T d^{C*}\left(\tfrac{1}{2} K.A_d^{C*} + b_1\right) - \tfrac{1}{2} A_d^{C*2} - b_3 d^{C*^2} \end{aligned} \tag{16}$$

where, $\Pi_r = w_r T_f b_1$ and $\Pi_m = w_m T_f b_1$, respectively, represent each of the retailer's and manufacturer's profits with no promotion and no advertising. According to (13), the denominators of Eqs. (14) and (15) are positive, while all the terms in the numerator are also positive. This means that the advertising value is always positive at its optimal point. This is while, given the numerator in Eq. (10), the optimal price promotion depth may be negative.

For a negative optimal price promotion depth, $\lambda < \frac{4A - (w_m + w_r)\left(8b + K^2 T - 2K^2 T_f\right)}{4(w_m + w_r) e^{-\beta T_f}\left(e^{\beta T} - 1\right)}$ and the reference price fails to provide enough incentives for the consumer to buy. In this situation, the effect of price promotion on marginal profit dominates its effect on demand. Thus, channel profit increases with increasing price in the promotion interval despite the resulting reduced demand. Although a negative price promotion might increase the short-term profits of the chain, it raises the long-term risk of changing the brand opted for by the consumer. As a result, market potential is reduced in the long-term, which does not favor the manufacturer's profit.

When $\lambda > \frac{4A - (w_m + w_r)\left(8b + K^2 T - 2K^2 T_f\right)}{4(w_m + w_r) e^{-\beta T_f}\left(e^{\beta T} - 1\right)}$, reference price has a great effect on the consumer's tendency to buy and the price promotion effect on demand outweighs that on marginal profits. In this condition, price promotion is positive and price reduction during the price promotion interval increases channel profits.

With some mathematical operations, it may be shown that there is an indifference point for the memory factor at which the reference price factor has no effect on either the optimal depth of price promotion or the optimal value of advertising. We first explore the depth of price promotion. Substituting $\lambda = 0$ in Eq. (14) (b_2,b_3 are related to λ) yields Eq. (17) below:

$$d^{C*}\Big|_{\lambda=0} = \frac{\left(4bT + K1^2 T\left(T - 2T_f\right)\right)\left(w_m + w_r\right) - 4T\left(A - b\left(w_m + w_r\right)\right)}{8bT - K^2 T^2} \tag{17}$$

Solving $d^{C*}\big|_{\lambda=0} = d^{C*}$ to obtain β and with some mathematical operations, the indifference point for the price promotion is obtained as follows:

$$\widehat{\beta}_d = \frac{\mathrm{Log}\left(\frac{\left(8b - K^2 T\right)(w_m + w_r)}{2\left(K^2\left(2T_f - T\right) - 8b\right)(w_m + w_r) + 8A}\right)}{T_f - T} \tag{18}$$

It is clear from Eq. (18) that $\widehat{\beta}_d$ does not depend on λ. Consequently, this point may be adopted as the indifference point for the optimal depth of price promotion. In other words, for $\beta = \widehat{\beta}_d$, the value of λ has no effect on the optimal depth of price promotion.

Similar to what was observed in the case of depth of price promotion, substituting $\lambda = 0$ in Eq. (15) yields Eq. (19) below:

$$A_d^{C*}\Big|_{\lambda=0} = \frac{2K\left(T^2\left(A - b\left(w_m + w_r\right)\right) - \left(bT^2 - 2bT\left(2T_f - T\right)\right)\left(w_m + w_r\right)\right)}{8bT - K^2T^2} \quad (19)$$

Solving $A_d^{C*}\Big|_{\lambda=0} = A_d^{C*}$ to obtain β, the indifference point of the optimal value for advertising is derived as follows:

$$\widehat{\beta}_A = \frac{\text{Log}\left(\frac{\left(8b - K^2T\right)\left(w_m + w_r\right)}{2\left(K^2\left(2T_f - T\right) - 8b\right)\left(w_m + w_r\right) + 8A}\right)}{T_f - T} \quad (20)$$

It is interesting to note that the indifference points for both price promotion and advertising are equal. In the Section on numerical results, this equality is shown in Fig. 1 for an instance of the problem.

4. Price promotion of the consumer

In this scenario, the manufacturer presents a price promotion directly to the consumer without the interference of the retailer. Hence, the retailer's marginal profit remains the same before and after the price promotion. Using Relations (1) to (6), the retailer's and manufacturer's profits are determined as follows:

$$\pi_r^{S2} = w_r\left(T_f\left(A - b\left(w_m + w_r\right)\right) + bTd_m^{S2} + d_m^{S2}\frac{\lambda}{\beta}e^{-\beta\left(T_f - T\right)}\left(1 - e^{-\beta T}\right) + \frac{1}{2}KTA_d^{S2} + KA_d^{S2}\left(T_f - T\right)\right) \quad (21)$$

$$\begin{aligned}\pi_m^{S2}\left(d_m^{S2}, A_d^{S2}\right) = &\left(A - b\left(w_m + w_r\right)\right)\left(w_mT_f - d_m^{S2}T\right) \\ &+ bTd_m^{S1}\left(w_m - d_m^{S2}\right) + w_md_m^{S2}\frac{\lambda}{\beta}e^{-\beta\left(T_f - T\right)}\left(1 - e^{-\beta T}\right) \\ &- d_m^{S22}\frac{\lambda}{\beta}\left(1 - e^{-\beta T}\right) + \tfrac{1}{2}K.T.w_mA_d^{S2} \\ &+ KA_d^{S2}\left(w_m - d_m^{S2}\right)\left(T_f - T\right) - \tfrac{1}{2}A_d^{S2^2}\end{aligned} \quad (22)$$

By substituting Relations (8) to (10) in Eqs. (21) and (22), we have.

$$\pi_r^{S2}\left(d_m^{S2}, A_d^{S2}\right) = w_r\left(T_fb_1 + d_m^{S2}b_2 + \frac{1}{2}KTA_d^{S2} + KA_d^{S2}\left(T_f - T\right)\right) \quad (23)$$

$$\begin{aligned}\pi_m^{S2}\left(d_m^{S2}, A_d^{S2}\right) = &\, b_1\left(w_mT_f - d_m^{S2}T\right) + d_m^{S2}\left(w_mb_2 - d_m^{S2}b_3\right) \\ &+ \tfrac{1}{2}KTw_mA_d^{S2} + KA_d^{S2}\left(w_m - d_m^{S2}\right)\left(T_f - T\right) - \tfrac{1}{2}A_d^{S2^2}\end{aligned} \quad (24)$$

Now, the concavity condition may be investigated for Relation (24). The Hessian matrix of this equation is the one in (21).

$$H = \begin{bmatrix} -2b_3 & -K\left(T_f - T\right) \\ -K\left(T_f - T\right) & -1 \end{bmatrix} \quad (25)$$

where, $H_{1,1}$ is negative and the concavity condition for Relation (24) may, therefore, be obtained as follows:

$$2b_3 > K^2\left(T_f - T\right)^2 \quad (26)$$

If Inequality (26) holds, the optimal values for both price promotion depth and advertising under S1 scenario will be as follows:

$$d_m^{S2\,*} = \frac{w_mK^2T\left(3T_f - T\right) - 2w_mK^2T_f^2 + 2b_2w_m - 2b_1T}{2b_3 - K^2\left(T_f - T\right)^2} \quad (27)$$

$$A_d^{S2*} = \frac{\left(T_f - T\right)\left(Tb_1 + w_m\left(b_3 - b_2\right)\right) + T_fw_mb_3}{2b_3 - K^2\left(T_f - T\right)^2} \quad (28)$$

The retailer's and manufacturer's optimum profits may, therefore, be obtained as in the following:

$$\Pi_r^{S2*} = \Pi_r + \frac{w_r}{2}\left(d_m^{S2*}b_2 + KA_d^{S2*}\left(2T_f - T\right)\right) \quad (29)$$

$$\begin{aligned}\Pi_m^{S2*} = &\, \Pi_m - b_1d_m^{S2*}T + d_m^{S2*}\left(w_mb_2 - d_m^{S2*}b_3\right) \\ &+ \frac{1}{2}KTw_mA_d^{S2\,*} + KA_d^{S2\,*}\left(w_m - d_m^{S2*}\right)\left(T_f - T\right) - \frac{1}{2}A_d^{S2\,*2}\end{aligned} \quad (30)$$

If Inequality (26) holds, the denominator of Eqs. (27) and (28) will be positive. According to $b_3 > b_2$, all the terms in the numerator of Eq. (28) will also be positive. So, the optimal advertising value is always positive under both S2 and centralized scenarios. On the other hand, the optimal price promotion depth can be negative based on the numerator of Eq. (28). Under this scenario, if the impact factor of the reference price is large enough $\left(\lambda > \frac{K^2\beta w_m\left(T_f - T\right)\left(2T_f - T\right) - 2b\beta T\left(2w_m + w_r\right)}{2w_me^{-\beta\left(T_f - T\right)}\left(1 - e^{-\beta T}\right)}\right)$, the effect of price promotion on demand then dominates its marginal profit. Thus, the manufacturer's profit increases with decreasing price. In this situation, the retailer's profit increases due both to the increase in demand and the retailer's constant marginal profit.

When $\lambda < \frac{K^2\beta w_m\left(T_f - T\right)\left(2T_f - T\right) - 2b\beta T\left(2w_m + w_r\right)}{2w_me^{-\beta\left(T_f - T\right)}\left(1 - e^{-\beta T}\right)}$, the effect of price promotion on marginal profit dominates that on demand, whereby price promotion becomes negative. In this situation, the manufacturer's profit increases with increasing price over the given interval despite the decreasing demand. It is worth noting that the retailer's profit decreases due to the reducing demand and the constant marginal profit of the retailer.

Similar to what was observed in the case of centralized channel, the indifference points for the optimal depth of price promotion and the optimal value of advertising are obtained using Eqs. (27) and (28). Solving $d_m^{S2*}\Big|_{\lambda=0} = d_m^{S2*}$ and $A_d^{S2*}\Big|_{\lambda=0} = A_d^{S2*}$ to obtain β yields the indifference points as follows:

$$\hat{\beta}_d = \hat{\beta}_A = \frac{\mathrm{Log}\left(\frac{\left(2bT+K^2\left(T_f-T\right)^2\right)w_m}{2bT(2w_m+w_r)-2A_0T-K^2\left(2T_f-T\right)(Tf-T)w_m}\right)}{T_f-T} \tag{31}$$

Under the consumer price promotion scenario, just as in the centralized channel, the two indifference points are seen to be equal. This is shown in Figure (2) for an instance of the problem in the Section on numerical results.

5. Price promotion of retailer-consumer

In this Section, a Stackelberg game between the manufacturer, as the leader, and the retailer, as the follower, is investigated. Both the manufacturer and the retailer determine their price promotion depths and the manufacturer specifies the advertising value. According to Eqs. (1)–(6), the retailer's profit is calculated as follows:

$$\pi_r^{S3}\left(d_r^{S3}\right) = w_r\left(T_f\left(A-b\left(w_m+w_r\right)\right)+bT\left(d_m^{S3}+d_r^{S3}\right) + \left(d_m^{S3}+d_r^{S3}\right)\frac{\lambda}{\beta}e^{-\beta\left(T_f-T\right)}\left(1-e^{-\beta T}\right)\right)$$

$$-d_r^{S3}\left(\left(d_m^{S3}+d_r^{S3}\right)\frac{\lambda}{\beta}\left(1-e^{-\beta T}\right) + T\left(A-b\left(w_m+w_r-\left(d_m^{S3}+d_r^{S3}\right)\right)\right)\right)$$

$$+\frac{1}{2}KTA_d^{S3}\left(w_r-d_r^{S3}\right)+w_rKA_d^{S3}\left(T_f-T\right) \tag{32}$$

By substituting Relations (8) to (10) in (32), we get.

$$\pi_r^{S3}\left(d_r^{S3}\right) = w_r\left(T_fb_1+\left(d_m^{S3}+d_r^{S3}\right)b_2\right)$$

$$-d_r^{S3}\left(Tb_1+\left(d_m^{S3}+d_r^{S3}\right)b_3\right) + \frac{1}{2}KTA_d^{S3}\left(w_r-d_r^{S3}\right)+w_rKA_d^{S3}\left(T_f-T\right) \tag{33}$$

The concavity condition of Equation (33) may now be investigated. The second derivative for Eq. (33) is obtained as follows.

$$\frac{\mathrm{d}\pi_r^{S3}\left(d_r^{S3}\right)}{\mathrm{d}d_r^{S3}} = -2b_3<0 \tag{34}$$

Therefore, Eq. (32) is concave and the retailer's optimal depth of price promotion is determined using (30) below.

$$d_r^{S3*} = \frac{2\left(w_rb_2-d_m^{S3}b_3-Tb_1\right)-KTA_d^{S3}}{4b_3} \tag{35}$$

It is clear from Eq. (35) that the retailer's price promotion depth may be negative under certain conditions. In addition, it is observed that the retailer's price promotion depth decreases with increasing advertising value. By increasing the manufacturer's price promotion depth, however, the retailer's also increases at the same rate.

Based on Eqs. (1) to (6) and (8) to (10), the manufacturer's profit may be obtained as follows.

$$\pi_m^{S3}\left(d_r^{S3}\right) = w_m\left(T_fb_1+\left(d_m^{S3}+d_r^{S3}\right)b_2\right)$$

$$-d_m^{S3}\left(Tb_1+\left(d_m^{S3}+d_r^{S3}\right)b_3\right)+\frac{1}{2}KTA_d^{S3}\left(w_m-d_m^{S3}\right)$$

$$+w_mK.A_d^{S3}\left(T_f-T\right)-\frac{1}{2}A_d^{S3\,2} \tag{36}$$

By substituting (35) in (36), we get.

$$\pi_m^{S3}\left(d_m^{S3},A_d^{S3}\right) =$$

$$w_m\left(T_fb_1 + b_2\left(d_m^{S3}-\frac{2\left(Tb_1+d_mb_3-w_rb_2\right)+KTA_d^{S3}}{4b_3}\right)\right)$$

$$-d_m^{S3}\left(Tb_1 + b_3\left(d_m^{S3}-\frac{2\left(Tb_1+d_mb_3-w_rb_2\right)+KTA_d^{S3}}{4b_3}\right)\right)$$

$$+\frac{1}{2}KTA_d^{S3}\left(w_m-d_m^{S3}\right)+w_mKA_d^{S3}\left(T_f-T\right)-\frac{1}{2}A_d^{S3\,2} \tag{37}$$

The Hessian matrix for Eq. (37) is now derived to investigate its concavity condition:

$$H = \begin{bmatrix} -b_3 & -\frac{1}{4}KT \\ -\frac{1}{4}KT & -1 \end{bmatrix} \tag{38}$$

Based on the negativity of $H_{1,1}$ in the Hessian matrix, its concavity will be.

$$16b_3>K^2T^2 \tag{39}$$

If Inequality (39) holds, a first order condition may be employed to determine both the optimal value of price promotion depth and advertising value under the S3 scenario. Thus:

$$A_d^{S3\,*} = \frac{2K\left(T^2b_1+Tb_2\left(w_r-3w_m\right)+4w_mb_3\left(2T_f-T\right)\right)}{16b_3-K^2T^2} \tag{40}$$

$$d_m^{S3\,*} = \frac{K^2Tw_m\left(T\left(b_2+2b_3\right)-4T_fb_3\right)+8b_3\left(b_2\left(w_m-w_r\right)-Tb_1\right)}{b_3\left(16b_3-K^2T^2\right)} \tag{41}$$

Substitution of Eqs. (40) and (41) in (36) yields (37).

$$d_r^{S3\,*} = \frac{K^2T^2\left(w_m\left(b_2+b_3\right)-w_rb_2\right)+4b_3\left(b_2\left(3w_r-w_m\right)-Tb_1\right)+2K^2TT_fb_3}{b_3\left(16b_3-K^2T^2\right)}$$

To determine the optimal depth of the retailer's price promotion, we assume.

$$Q = \frac{\left(2Tb_1-2w_rb_2+KTA_m^{S3*}\right)}{4b_3} - \frac{d_r^{S3*}}{2}$$

The retailer's and manufacturer's optimum profits may then be derived as in (38) and (39), respectively:

$$\Pi_r^{S2*} = \Pi_r + w_rb_2\left(d_r^{S3*} - \frac{A_d^{S3*}}{2b_3}\right)$$

$$+d_r^{S3*}\left(\frac{A_d^{S3*}}{2} - Tb_1 - A_d^{S3*}b_3\right) + Kw_rA_d^{S3*}\left(T_f - T\right)$$

$$+\frac{K}{2}A_d^{S3*}T\left(w_r - d_r^{S3*}\right) \tag{43}$$

$$\Pi_m^{S2*} = \Pi_m + Kw_mA_d^{S3*}\left(T_f - T\right)$$

$$+\frac{K}{2}A_d^{S3}T\left(w_m - d_m^{S3*}\right) - \frac{1}{2}A_d^{S3*2}$$

$$+d_m^{S3*}\left(Qb_3 - Tb_1\right) - Qw_mb_2 \tag{44}$$

Based on Inequality (39), the denominator in Eq. (40) is positive and its numerator can be rewritten as $2K\left(T^2b_1+Tw_rb_2+w_mb_3\left(8T_f-7T\right)+3Tw_m\left(b_3-b_2\right)\right)$. Given $b_3>b_2$, the numerator will also be positive and the manufacturer's advertising optimal value will, therefore, be always positive.

The indifference points for the optimal depth of the retailer's price promotion and the manufacturer's price promotion could not be parametrically determined, but Figure (3) in the Section on numerical results shows that such points exist in the retailer-consumer's price promotion scenario. The indifference point for the optimal value of advertising may be obtained from Eq. (40) and solving $A_d^{S3*}\big|_{\lambda=0} = A_d^{S3*}$ obtain β as follows:

$$\widehat{\beta}_A = \frac{\mathrm{Log}\left(\frac{\left(K^2T-16b\right)\left(3w_m-w_r\right)}{16A_0+4\left(K^2\left(2T_f-T\right)-16b\right)w_m}\right)}{T_f-T} \tag{45}$$

Unlike in the two prior scenarios, in the retailer-consumer price promotion scenario, the indifference points for both the optimal depth of price promotion and the optimal value of advertising are not equal in this scenario as also shown in Figure (3) for an instance of the problem.

6. Numerical results

In this Section, numerical analysis is used to demonstrate the effects of memory factor and reference price factor on price promotion depth and advertising level under different scenarios for different values of reference price and advertising factor. The effects of memory factor and reference price factor are also investigated on optimal promotion depth, optimal advertising level, incremental profits of the supply chain members, and channel efficiency. The values for the problem parameters, except for advertising factor, are taken from Lin [6] as reported in Table 6. Figs. 1–3 illustrate the effects of memory factor on price promotion depth and advertising value under the three centralized, consumer price promotion, and retailer-consumer price promotion scenarios, respectively. Also, the effects of advertising factor on price promotion depth are shown in Figs. 4–6. Three levels of 0, 0.27, and 0.4 are considered for the reference price factor and the three levels of 0, 0.25, and 0.4 for the advertising factor. A value of 0.27 is considered for reference price factor for all the cases shown in Figures (4), (5) and (7).

Figures (6) and (7) show the effects of memory factor on incremental profits of the supply chain members for different levels of reference price factor and advertising factor, respectively. Figure (8) shows the effects of memory factor on channel efficiency for different levels of reference price factor and advertising factor. Figure (9) is taken from (Lin, 2016) that indicates the effects of memory factor on channel efficiency for different levels of reference price factor in the absence of advertising.

Figs. 10–12 illustrate the effects of reference price factor on price promotion depth and advertising value under the three centralized, consumer price promotion, and retailer-consumer price promotion scenarios, respectively. The values 0.01, 0.3, 0.8 and the indifference point are considered for memory factor in Figs. 10–12. We note again, we could not find explicit equations for indifference point of price promotion of manufacturer and retailer in the 3rd scenario. Thus, the values for indifference point in Sub Figs. 1 and 2 of Figure (3) are obtained by trial and error. Figure (13) shows the effects of reference price factor on incremental profits of the supply chain members for different levels of memory factor.

It is evident from Figs. 1–3 that optimal price promotion depth decreases under all the three scenarios with increasing values of memory factor. Lower values of memory factor indicate that the customer's stronger memory, which leads to the customer's better reaction to decreases in price and increases in market demand. Consequently, the decision-maker is able to absorb more of the market demand by reducing the price. A point of intersection is also detected in all the price promotion depth charts shown in Figs. 1–3. For values of memory factor below this point, the price promotion depth increases with increasing impact factor of the reference price; otherwise, it decreases. Figs. 10–12 illustrate better these situations. At this intersection, however, the value of memory factor has no effect on the optimal depth of price promotion.

Regarding advertising, the optimal value of advertising increases under all the scenarios investigated with increasing values of memory factor. In this case, the customer is persuaded into buying more at less advertising efforts if he has a stronger memory (i.e., a lower value of memory factor). There also exists a point of indifference in the charts corresponding to the effect of memory factor on advertising value such that, for values of memory factor below this point, the optimal advertising value decreases with increasing impact factor of reference price; otherwise, it increases (see Figs. 10–12). According to Figs. 4–6, the optimal depth of price promotion decreases under all the scenarios with increasing values of advertising factor. In other words, a greater amount of demand is absorbed by advertising and fewer price reductions will be required with higher values of advertising impact factor.

Two points may be detected in Figures (6), (7) and (13). Firstly, the incremental profits decrease with increasing memory impact factor while curve becomes steeper for higher values of reference price factor. Secondly, for a given memory factor, the incremental profit increases with increasing reference price factor. In other words, the consumer loses his trust and both the manufacturer and the retailer suggest slighter promotion depths to keep their marginal profits as the memory factor increases. As a result, there is a lower consumer surplus, which prevents market demand growth. This leads to lower promotion depths proposed by the manufacturer and the retailer to the less loyal consumers who buy less, thereby reducing the incremental profits and consumer surplus. Figures (6) and (7) also indicate larger incremental profits for higher advertising impact factors.

According to Figure (8), lower values of memory factor improve channel efficiency for low values of advertising impact factor. In this situation, small values of memory factor force the manufacturer and the retailer to suggest higher values of promotion depth, which, in turn, results in increasing market demand. This equalizes the interests of both the manufacturer and the retailer and improves channel yield. For higher values of advertising impact factor, when the consumers are less loyal, the effect of advertising level dominates that of decreasing promotion depth, whereby channel efficiency is improved. Moreover, according to this Figure, channel efficiency is improved as a result of higher values of both the reference price factor and the advertising factor. Finally, it is observed in Figures (8) and (9) that advertising has a direct bearing on improving channel efficiency for both high and low values of advertising impact factor.

7. Concluding remarks and future research directions

This article used the game-theoretic approach to explore the determination of advertising and price promotion values under the centralized and two Stackelberg scenarios while long-term cost reduction was also considered. The novelty of this study is to consider price promotion, the effect of reference price and advertising simultaneously in a manufacturer-retailer supply chain. The concept of reference price was used to consider the long-term effects of changes in price. The results obtained revealed that both the consumer's memory and the price impact factors have profound effects on the optimal price promotion depth and optimal advertising value. We summarize results and managerial insights observed from this research as follows: First, in the case of negative depth for price promotion, although a negative price promotion increases the short-term profits, it raises the long-term risk of brand switching. As a result, market potential is reduced in the long-term, which does not favor the manufacturer's profit. Second, if sensitivity of consumer to the gap between the price and the reference price is large enough, the depth of price promotion is positive. In this case, reference price has a considerable effect on the consumer's tendency to buy and the price promotion effect on demand dominates that on marginal profits and price reduction increases channel profits. Third, for a certain value of memory factor, in all scenarios, value of the reference price factor does not affect optimal value of price promotion and advertising level. In scenarios 1 and 2, these indifference points are the same for price promotion depth and advertising level. Fourth, increasing value of the memory factor decreases optimal depth of price promotion. Lower values of memory factor indicate that the customer's stronger memory, which leads to the customer's better reaction to reduction in price and increases in demand. Therefore, the decision-maker is able to absorb more of the market demand by reducing the price. Fifth, increasing value of the memory factor increases the optimal level of advertising. In this case, the customer is persuaded into buying more at less advertising efforts if he or she has a stronger memory. Sixth, the incremental profits decrease with increasing memory impact factor. In this case, the consumer loses his trust and both the manufacturer and the retailer suggest slighter promotion depths to keep their marginal profits as the memory factor increases. Seventh, advertising had an explicit effect on improving channel efficiency and incremental profits of supply chain members.

As already mentioned, the memory factor of the consumer profoundly affects optimal value of decision variables and channel efficiency. In this research, we investigated effects of memory factor and advertising on demand, independently. In future work, we may take into account the effect of advertising on the memory of the costumer and his loyalty in the presence of effect of reference price. Another research direction is to take the interval length of promotion as a decision variable. Increasing the interval of promotion may increase profit in short-term. However, it may decrease mental price of the customer that lead to decreasing customer's sensitivity to price reduction which implies decreasing profit in long-term.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jretconser.2019.05.028.

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