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Coordinated Coordination of a supply chain with loss-averse consumers in service quality

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We develop a two-period game model to study the coordination mechanism for a supply chain with loss-averse consumers who are assumed to have dwindling sensitivity to service quality gain relative to loss. We find that all-unit quantity discount coupling with service subsidy rate can coordinate the retailer’s price and service quality decisions together in each period. When consumers become more loss-averse in service quality, the coordinated wholesale price in the first period might increase; whereas that in the second period decreases. With Pareto coordination mechanism, larger loss-aversion might weaken the supplier’s bargaining power. We provide managerial insights on how to adjust the coordinated contract when the consumers’ loss-aversion and reference value of service quality level change.

Keywords: supply chain management; reference effect; loss-aversion; coordination mechanism; game theory

1. Introduction

When making purchasing decisions for valuable products, consumers are often sensitive to the related services offered with the products. For example, in the auto industry, service such as auto loans, insurance and maintenance package, is very important for consumers to select a brand or a dealer. To cut cost, Home Depot decided to lower its consumer service quality level at the end of 2000. Though they understood that they would lose some consumers by doing this, the market response was much more than they had anticipated; consumer satisfaction plunged, and store sales growth dropped and even went negative in the later several years (Ton 2012). Learning from the above unsurprising example, one may suggest that we should always try to improve service quality whenever it is possible. However, the reality is not as simple as thought, and the decision of improving the service quality level may not be easy. Firms such as Wallace Company and Florida Power & Light have suffered serious financial difficulties after having made a big investment to improve service quality, without the expected demand boost (Rust, Zahorik, and Keiningham 1995).

The above practice implies that the consumers’ expectation to service quality is not only affected by the absolute service quality level, but also a certain reference point, known as the reference dependence, which has been widely recognised in areas such as decision sciences, experimental economics, behaviour finance and marketing (Baucells, Weber, and Welfens 2011). The study of loss-aversion explains that consumers’ riskless choices depend on a reference point and have asymmetric response effect of behavioural intention on product attributes such as price and service quality. Evidence from the home delivery service industry indicates that consumers are loss-averse in service quality, where a consumer’s utility depends on a service quality reference point in the sense that the negative effect of service quality loss on consumers’ loyalty is higher than the positive effect of service quality gain (Hsu et al. 2010). In some industries such as auto, realty, personal computer and furniture, when the service quality level of one retailer is below the reference level, e.g. an expectation or the previous level, which is perceived as a service quality loss, consumers are very sensitive to the service quality loss caused by the change because of feeling disutility (implicit cost). For example, when furnished a disappointing service quality level, complaints are incurred and unsatisfied consumers might transfer to the rival. However, when the service quality level is higher than the reference point, which is perceived as a service quality gain, consumers tend to become less sensitive to the service quality, although it indeed brings satisfaction as well as demand increase. To study such a phenomenon, we introduce a two-period model that defines the reference point for the service quality level in period 2 by the service quality level in period 1, and explicitly incorporates the asymmetric

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service sensitivity to demand in period 2. *One of our main objectives is to explore the implications of service quality loss-aversion on equilibrium decisions and coordination mechanism in a supply chain.*

The way of reducing loss from a low service quality level is to improve the service quality, which incurs an extra cost. Hence a retailer has to make a trade-off between the benefit and the cost of investing on service quality improvement. Such a decision should be associated with the pricing policy. For example, traditional dealers of GM (General Motors Company) make a higher service investment and also price higher than deep discounting dealers. From the viewpoint of supply chain management, the decision has an impact on all members of the supply chain. In a distribution channel, an independent downstream retailer might set a retail price and service investment that are not desirable for the upstream manufacturer, e.g. extremely low price and service quality level. Even if the order quantity is aligned, the retailer might still mismatch the retail price and service quality level (e.g. a lower service quality level and higher retail price than the optimal decisions of the centralised system), which hurts channel performance. Such a conflict requires coordinating the retail price and service quality level decisions together. *The second objective is to address the coordination mechanism in the presence of loss-aversion and reference dependence on service quality and explore the implication of the endogenous reference value of service quality level (RV) on the coordination mechanism.*

To the best of our knowledge, few publications on supply chain management have considered the reference effect on service factor and the asymmetric response to the service quality deviation. We explicitly model this in a two-period supply chain consisting of one supplier and one retailer who jointly determines service quality level and retail price in each period by assuming that the service sensitivity has a dwindling fraction if the service quality level exceeds RV. We find that offering a combined scheme coupling all-unit quantity discount contract with service subsidy contract can coordinate the retailer’s decisions under endogenous RV. With a sufficiently small dwindling fraction, the supplier increases the coordinated wholesale price in period 1, whereas decreases that for period 2, when consumers become more loss-averse in service quality.

### 2. Literature review

This paper is closely related to three different fields in the literature, reference-dependent effect, price–service management and supply chain coordination.

Reference-dependent preference (e.g. loss-aversion) is originally developed to describe choice behaviour among risky prospects (Kahneman and Tversky 1979), which is followed by loss-averse newsvendor models (Wang and Webster 2009; Ho, Lim, and Cui 2010). The concept has also been extended to analyse riskless choice (Tversky and Kahneman 1991). For example, reference price has a large impact on the retailer’s pricing policy (Greenleaf 1995; Kopalle et al. 2012). Nasiry and Popescu (2011) find that the dynamic pricing either evolves to constant or steady-state price because of the reference price effect. Besides pricing, the reference-dependent evaluation also applies to other attributes such as product quality (Hardie, Johnson, and Fader 1993) and product fitness dimension (Zhou 2011), where consumers are actually more loss-averse in other attributes than price (Tversky and Kahneman 1991; Hardie, Johnson, and Fader 1993). Different from the above, we will use the theory of riskless choice to explore the case that consumers are loss-averse in service quality, which has not been studied in the literature.

The formation of reference point is crucial to the impact of reference dependence. Reference point could either depend on expectations (Heidhues and Köszegi 2008), status quo or past level. In repeat purchase markets, memory-based reference price with a weighted average of the past observed price is often adopted (Greenleaf 1995; Kopalle, Rao, and Assuncão 1996; Nasiry and Popescu 2011; Kopalle et al. 2012). In competitive markets, ex ante contracts (Hart and Moore 2008; Fehr, Hart, and Zehnder 2009) provide a reference for ex post trade and products of the retailer visited first by consumers become the reference one (Zhou 2011). In some supply chains, an upstream member could control a downstream member’s decision by suggesting a reference point for its consumers (Yang, Munson, and Chen 2010). To focus on the implication of reference dependence, we define the reference point for service quality level operationally as the service quality level of the previous period.

Service is regarded as an important instrument to affect demand besides the retail price. Consumers are sensitive to services measured by the factors such as the delivery time, processing rate and fill rate (Ray and Jewkes 2004; Maglaras and Zeevi 2005; Allon and Federgruen 2007; Bernstein and Federgruen 2007), as well as post-sale service, delivery security, product quality and effort (Iyer 1998; Tsay and Agrawal 2000). Consumers do feel additional cost (besides explicit fee) incurred by low service levels (Lederer and Li 1997; Cachon and Harker 2002) and consumers’ perception of the product value is intertwined with quality of service (measured by waiting time) (Afèche and Mendelson 2004). As a result, firms often manipulate both price and service-related measures for competition and channel profit extraction, e.g. Ha, Long, and Nasiry (2015) show that when the manufacturer can distort quality, encroachment will hurt the downstream retailer in a variety of cases. All the above works imply that a higher service level enhances the demand;
however, little has been done to address the implication of consumers’ reference-dependent preference for service quality. Motivated by the industry evidence of loss-aversion in service quality (Hsu et al. 2010), we fill this gap by modelling consumers’ asymmetric response to service quality deviation with a general service-sensitive kindled demand function.

Supply chain coordination aims to raise system efficiency. Various contracts such as buyback, sales rebate, revenue-sharing, price discount and quantity discount, have been proposed to coordinate supply chains (Cachon 2003; Cachon and Lariviére 2005; Moon, Feng, and Ryu 2015). Researchers try to design contracts to coordinate the service decision of the downstream member in a supply chain. Ernst and Powell (1998) show how a manufacturer could induce the retailer to provide a desired retail service level by a side payment. Xiao et al. (2005) focus on the effect of demand disruptions on the price-subsidy rate contract coordinating the sales promotion investments of the competing retailers. Some papers extend to focus on coordinating both the price (or quantity) and service-related decisions of decentralised supply chains. For example, mixed mechanisms such as rebate–returns (Taylor 2002), quantity discount based on revenue-sharing (Cachon and Lariviére 2005), buyback coupling with cost-sharing or markdown allowance (Krishnan, Kapuscinski, and Butz 2004) are proposed to coordinate the retail effort decision in addition to the order quantity. Channel competition raises the complications for coordination, e.g. Tsay and Agrawal (2000) and Iyer (1998) show that quantity discount or two-part tariff are not sufficient to coordinate a channel with two symmetric retailers under the price and service competition, whereas Raju and Zhang (2005) draw contrast conclusion in the channel with a dominant retailer. Almost all the above works about price and service coordination are based on the one-period setting, avoiding the complication that arises under multiple-period or infinite-horizon setting. There are attempts to address the coordination issue for multiple, especially two, periods (Donohue 2000; Barnes-Schuster, Bassok, and Anupindi 2002; Yang et al. 2011), but most of them do not involve the service decision. One exception is Bernstein and Federgruen (2007) that investigate the coordination problem in a periodic review infinite-horizon setting with a network of retailers competing on both price and service level. We try to coordinate the joint decisions of price and service quality level in a two-period supply chain with one supplier and one retailer. However, we differentiate our model from Bernstein and Federgruen (2007) in the following aspects: (i) They assume that retailers replenish inventory with base-stock policy under random demands, while we assume that the retailer operates in a JIT (Just-in-time) mode in which the retailer does not carry inventories across periods; (ii) They define a steady-state service level in terms of long run in their model. Under static pricing, their model reduces to a single stage game, and even if they allow price variation across time stationary price remains to be the equilibrium strategy. In contrast, we allow variations in both price and service level across the two periods. Further, they assume risk-neutral of supply chain members and instead we incorporate consumers’ service quality reference-dependent preference and loss-aversion, which complicates the price-service trade-off in each period as well as the coordination mechanism; (iii) We couple quantity discount and service subsidy to coordinate the two-period supply chain with loss-averse consumers in service quality, whereas their coordination mechanism charges a constant wholesale price and backlogging penalty.

Compared with the existing works, our model is new in the following aspects: First, we explicitly model the consumers’ loss-averse preference for the service quality by a kindled demand function with a dwindling sensitivity to service quality gain, which complicates the decisions of the players and coordination mechanism. Second, we combine the quantity discount with service subsidy to coordinate the retail price and service quality level, with a focus on the impact of reference dependence on the coordinated contract. Third, we endogenise the RV and design a coordination mechanism under the two-period model.

3. The basic model

Consider a two-period game model of a supply chain consisting of one supplier (manufacturer) and one retailer. Both players independently maximise their individual profits. In each period, the supplier produces and sells the product to the retailer at a unit wholesale price, and the retailer further sells the product to end consumers. The retailer also provides certain service for the product, aiming to boost the demand. Evidence from industries indicates that consumers are loss-averse in service quality (Hsu et al. 2010). The retailer decides both the retail price and service quality level at the beginning of each period, given the wholesale-price contract from the supplier. The event sequence of the game is as follows:

(i) At the beginning of period 1,
   (a) the supplier offers a wholesale-price contract \( (w_1) \) to the retailer;
   (b) then the retailer reacts by setting the retail price and service quality level \( (p_1, s_1) \) and orders a quantity of \( q_1 \) from the supplier.
At the beginning of period 2, with known \((p_1, s_1)\) and \(q_1\),

(a) the supplier offers another wholesale-price contract \(w_2\) to the retailer;
(b) then the retailer reacts by setting the retail price and service quality level \((p_2, s_2)\) and orders a quantity of \(q_2\) from the supplier.

We will use the following notation to define our problem.

\[ a_i \] the market base for the retailer in period \(i\), \(a_i > 0\)
\[ c \] the unit production cost of the supplier in each period
\[ w_t \] the unit wholesale price announced by the supplier for period \(t\), \(w_t \geq c\), \(t = 1, 2\)
\[ p_t \] the retail price announced by the retailer for period \(t\)
\[ s_t \] the service quality level provided by the retailer for period \(t\), \(s_t > 0\)
\[ \eta_t \] service cost factor of the retailer during period \(t\), \(1/\eta_t\) represents the service investment efficiency
\[ d_t \] the demand for the retailer during period \(t\)
\[ q_t \] the order quantity for the retailer during period \(t\)
\[ \beta \] the sensitivity of consumer to the retail price of the previous period, \(0 \leq \beta < 1\)
\[ \theta \] the sensitivity of consumer to service quality level below RV (perceived as service quality loss), \(\theta > 0\)
\[ \alpha \] the dwindling fraction of the sensitivity to service quality gain, referring to as dwindling fraction, \(0 \leq \alpha < 1\)
\[ \pi_t^R / \pi_t^S / \pi_t^{SC} \] the profit of the retailer/supplier/supply chain during period \(t\)
\[ \hat{\pi}_{tc}^R / \hat{\pi}_{tc}^S / \hat{\pi}_{tc}^{SC} \] the total profit of the retailer/supplier/supply chain during the two periods
\[ \hat{\lambda}_2 \] the fraction of the retailer’s profit in the coordinated supply chain during period 2
\[ \hat{\lambda} \] the fraction of the retailer’s profit in the coordinated two-period supply chain

Reference dependence on service quality implies that RV exists, and consumers’ overall evaluation of service quality depends on RV. As reference price is commonly defined based on memory in previous research (Greenleaf 1995; Kopalle, Rao, and Assuncão 1996; Nasiry and Popescu 2011), we assume that, for the two-period supply chain, the service quality level in period 1 \(s_1\) is presented as RV of the second period. Hence, consumers would use \(s_1\) to evaluate the utility gain or loss from the service quality offered in the second period. Owing to that consumers exhibit loss-aversion in service quality (Hsu et al. 2010), two cases have to be distinguished for the demand faced by the retailer in period 2 (see Figure 1).

In period 2 with a given \(s_1\), if the actual service quality level falls below RV \((s_2 < s_1)\), service loss is incurred and the demand is represented by the standard linear price–service demand function:

\[ d_2(p_2, s_2 | s_1) = a_2 - p_2 + \theta s_2 + \beta p_1, \]

where \(\theta\) is the sensitivity of consumer to service quality level below RV; and \(\beta\) is the sensitivity of consumer to the retail price of the previous period, which captures the impact of the period 1’s price on the demand function of period 2. The assumption here is that larger period 1’s retail price increases the market potential of period 2 because some consumers transfer from period 1 to period 2. Inter-temporal consumer rationality (Besanko and Winston 1990; Jerath, Netessine, and Veeraraghavan 2010) can be used to explain this increase. In other words, consumers might strategically postpone their purchase when facing multi-period pricing. Moreover, the larger the period 1’s retail price, the larger the probability that consumers wait to buy in period 2 rather than in period 1 will be. In contrast, if the actual service quality level is higher than RV \((s_2 > s_1)\), service gain is achieved and the demand function of period 2 is modified as follows:

![Figure 1. Demand versus service quality level for the retailer in period 2 with a given \(s_1\).](image)
\[ d_2(p_2, s_2|s_1) = a_2 - p_2 + \theta s_1 + \theta(1 - \alpha)(s_2 - s_1) + \beta p_1, \]

where \( 0 \leq \alpha < 1 \) is the dwindling fraction of the sensitivity to service quality gain, implying the loss-aversion in service quality. Two demands are identical at \( \alpha = 0 \). Combining the above two cases, we have the following demand function for period 2:

\[ d_2(p_2, s_2|s_1) = a_2 - p_2 + \theta \min\{s_2, s_1\} + \theta(1 - \alpha)\max\{s_2 - s_1, 0\} + \beta p_1 = a_2 - p_2 + \theta s_2 - \theta(1 - \alpha)(s_2 - s_1) + \beta p_1. \]  \hspace{1cm} (1)

Equation (1) reflects a reference-dependent effect and loss-aversion in the service quality. That is, for the case of the service quality level in period 2 (\( s_2 \)) below RV, the service sensitivity is \( \theta \); however, for the case above RV, it dwindles to \( (1 - \alpha)\theta \). Larger dwindling fraction (\( \alpha \)) implies that consumers are more loss-averse in service quality level. This is consistent with the spirit of the previous research on reference dependence and loss-aversion in price and product quality (Greenleaf 1995; Kopalle, Rao, and Assunção 1996; Nasiry and Popescu 2011) and in travel time and cost (Hess, Rose, and Hensher 2008). Unlike the previous work, we model the effects of loss-aversion in service quality level, which takes the retailer an explicit monetary investment. As a result, the retailer has to make a trade-off between the benefit and cost of service quality investment. Another difference is that we explicitly describe the asymmetric characteristics of service sensitivity for consumers by incorporating the dwindling fraction \( \alpha \), which makes the analysis more traceable.

To provide a benchmark, we assume that the demand of the retailer in period 1 also follows standard linear price–service function:

\[ d_1(p_1, s_1) = a_1 - p_1 + \theta s_1, \]  \hspace{1cm} (2)

Similar to Tsay and Agrawal (2000) and Gilbert and Cvsa (2003), we assume that the service cost of the retailer for providing the service quality level \( s_1 \) in period \( t \) is \( \eta_1 s_1 \), i.e. improving service quality has a diminishing return on service expenditure. It is easy to add a constant marginal cost into the service cost structure, which does not affect the main results of this paper because we only need to make a variable substitution. The larger the service cost factor \( \eta_1 \), the lower the service investment efficiency \((1/\eta_2)\) of the retailer will be.

The retailer decides the retail price and service quality level to maximise his profit during the two periods:

\[ \tilde{\pi}^R(p_1, s_1, p_2, s_2) = \tilde{\pi}^R(p_1, s_1) + \delta \tilde{\pi}^R(p_2, s_2), \]  \hspace{1cm} (3)

where \( \tilde{\pi}^R(p_1, s_1) = (p_1 - w_1)d_1(p_1, s_1) - \frac{1}{2} \eta_1 s_1^2 \), \( \tilde{\pi}^R(p_2, s_2) = (p_2 - w_2)d_2(p_2, s_2|s_1) - \frac{1}{2} \eta_2 s_2^2 \), and \( 0 < \delta < 1 \) is the discount factor.

Considering the retailer’s optimal response in retail price and service quality level, the supplier decides the wholesale price to maximise her profit during the two periods:

\[ \tilde{\pi}^S(w_1, w_2) = \tilde{\pi}^S_1(w_1) + \delta \tilde{\pi}^S_2(w_2), \]  \hspace{1cm} (4)

where \( \tilde{\pi}^S_1(w_1) = (w_1 - c)d_1(p_1(w_1), s_1(w_1)) \), \( \tilde{\pi}^S_2(w_2) = (w_2 - c)d_2(p_2(w_2), s_2(w_2)|s_1) \).

We solve this game by employing the backward induction technique in the next sections.

4. Equilibrium outcome of the decentralised supply chain

In this section, we consider the equilibrium decisions of the decentralised supply chain without coordination.\(^3\) From (3) and (4), we derive the following proposition.

**Proposition 1.** Assume \( \eta_1 > \tilde{\eta}_1 = \max\left\{ \frac{[\beta_1(\alpha + \beta_2)]^2}{2\beta_1(\alpha + \beta_2) - 4\beta_1^2}, \frac{2\beta_1^2}{4 - 4\beta_1^2}, \frac{\beta_1(\alpha + \beta_2)^2}{\beta_1(\alpha + \beta_2)} \right\} \) and \( \eta_2 > \tilde{\eta}_2 = \max\left\{ \frac{[\beta_2(\alpha + \beta_1)]^2}{2\beta_2(\alpha + \beta_1) - 4\beta_2^2}, \frac{2\beta_2^2}{4 - 4\beta_2^2}, \frac{\beta_2(\alpha + \beta_1)^2}{\beta_2(\alpha + \beta_1)} \right\} \).

In the decentralised supply chain with two periods, we have

(1) in period 2, with a known retail price \( p_1 \) and service quality level \( s_1 \) in period 1, and a given wholesale price \( w_2 \), the retailer will set the optimal retail price and service quality level as follows:

\[ p_2^{d_1}(w_2) = \begin{cases} p_1^1(w_2), & \text{if } s_1 < s_1^1(w_2) \\ p_1^R(w_2), & \text{if } s_1 > s_1^R(w_2) \\ p_2^{R_2}(w_2), & \text{otherwise} \end{cases}, \]  \hspace{1cm} (5)

\[ s_2^{d_1}(w_2) = \begin{cases} s_1^1(w_2), & \text{if } s_1 < s_1^1(w_2) \\ s_2^R(w_2), & \text{if } s_1 > s_1^R(w_2) \\ s_1, & \text{otherwise} \end{cases}. \]  \hspace{1cm} (6)
where \( M(\alpha, \omega_2) = (a_2 - \omega_2 + \alpha \theta_1 + \beta p_1)B_2(\alpha) \). \( B_2(\alpha) = 2 - (1 - \alpha)^2 \theta^2 / \eta_2 \). \( p^R_1(\omega) = \omega_2 + M(\theta, \omega_2) \), \( p^R_2(\omega) = \omega_2 + M(0, \omega_2) \), \( p^{II}_1(\omega) = \omega_2 + M(1, \omega_2) \), \( \bar{s}^I_1(\omega) = 1 - \omega_2 \theta_2 / \eta_2 \), \( s^I_1(\omega) = \bar{s}_1(\omega) = 0M(0, \omega_2) / \eta_2 \), \( \bar{s}_1(\omega) = (1 - \alpha)\theta(a_2 + \beta p_1 - \omega_2) / (2\eta_2 - (1 - \alpha) \beta^2) \).

(2) In period I, with a given wholesale price \( \omega_1 \) and considering the supplier's response in wholesale price in period 2, the retailer will set the optimal retail price and service quality level as follows:

\[
p^{I}I_1(\omega) = \begin{cases} 
\omega_1 + \alpha(\omega_1 - \omega_2) + \beta \eta_1 s^{II}(\omega) / \theta(\beta + 2\alpha), & \text{if } s^{II}(\omega) \leq \omega_1 \\
\omega_1 + \alpha(\omega_1 - \omega_2) + (\beta \eta_1 + \beta \theta)(\theta(2 + \beta), & \text{otherwise}
\end{cases}
\]

\[
s^{II}(\omega) = \begin{cases} 
s^{II}_1(\omega), & \text{if } s^{II}(\omega) \leq \omega_1 \\
s^{II}_1(\omega), & \text{otherwise}
\end{cases}
\]

where \( B(\omega) = 2 - (4B_2(\omega) + 2\alpha(\omega + \beta)\theta^2 + \beta^2 \eta_1) / 4\eta_1 B_2(\omega) \). \( s^{II}_1(\omega) = \theta(a_2 - \omega_2 + \beta \theta_1 \omega_1 + (\beta \eta_1 + \beta \theta_1)(2 + \beta)) / 2(\beta \eta_1 + \beta \theta_1) \). \( s_1^1(\omega) = (1 - \alpha) \theta(a_2 - \omega_2 + \beta \theta_1 \omega_1 + (\beta \eta_1 + \beta \theta_1)(2 + \beta)) / (2\alpha(\omega + \beta)\theta^2 + \beta^2 \eta_1) \).

Proofs of all propositions and corollaries are given in Appendix 1.

Note that Case (II) is equivalent to Case (I) with \( \alpha = 0 \). Thus, for simplicity, we use \( \alpha = 0 \) to refer to Case (II) throughout this paper without any specification. The conditions \( \eta_1 > \eta_2 > \eta_2 > \eta_2 \) mean that the service investments should not be too inexpensive, which is consistent with those assumptions made in Tsay and Agrawal (2000) and Xiao and Yang (2009). We assume that these conditions hold throughout this paper. When \( R_2 \) is sufficiently small, \( M(\alpha, \omega_2) \) is the price mark-up of the retailer in period 2. Thus, the retailer will withdraw from the market in period 2 if \( M(\alpha, \omega_2) \leq 0 \). Equations (5) and (6) imply that the higher the price mark-up, the higher both the optimal retail price and service quality level will be in period 2.

It is shown from Proposition 1 that the optimal decentralised decisions of the retailer in period 2 depend on \( R_2 \). In general, the higher the \( R_2 \), the higher the actual service quality level and retail price will be. If \( R_2 \) is sufficiently small, then the retailer offers a service quality level (\( s_1^2(\omega_2) \)) higher than \( R_2 \), because the demand-enhancing effect of service quality (positive) exceeds the negative effect from increasing service cost; whereas offers a service quality level (\( s_1^2(\omega_2) \)) lower than \( R_2 \) to avoid a high service cost, if it is sufficiently large. Otherwise, the retailer offers service quality level equal to \( R_2 \). A high service quality level is always accompanied by a high retail price.

5. Coordination via a quantity discount–service subsidy contract
5.1 The optimal decisions of the centralised two-period supply chain

To provide a benchmark, we first consider the optimal decisions of the centralised two-period supply chain where a central planner jointly decides the retail price and the service quality level for both periods to maximise the channel profit of the supply chain. Thus, in the centralised supply chain, the central planner will maximise the channel profit during the two periods:

\[
\pi^{SC}(p_1, s_1, p_2, s_2) = \pi^{SC}_1(p_1, s_1) + \delta \pi^{SC}_2(p_2, s_2),
\]

where \( \pi^{SC}_1(p_1, s_1) = (p_1 - c) d_1(p_1, s_1) - \frac{1}{2} \eta_1 s_1^2 \), and \( \pi^{SC}_2(p_2, s_2) = (p_2 - c) d_2(p_2, s_2) s_1^1 - \frac{1}{2} \eta_2 s_2^2 \).

From (7), we derive Proposition 2.

**Proposition 2.** In the centralised supply chain with two periods, we have

(1) In period 2, with a known retail price \( p_1 \) and service quality level \( s_1 \) in period 1, the optimal retail price and service quality level are given by

\[
p^{cII}_2 = \begin{cases} 
p^{cII}_2(\omega), & \text{if } s_1 < s_1(\omega) \\
p^{cII}_2(\omega), & \text{if } s_1 > \bar{s}_1(\omega) \\
\bar{s}_1(\omega), & \text{otherwise}
\end{cases}
\]

and

\[
\bar{s}^c_2 = \begin{cases} 
\bar{s}^c_2(\omega), & \text{if } s_1 < \bar{s}_1(\omega) \\
\bar{s}^c_2(\omega), & \text{if } s_1 > \bar{s}_1(\omega) \\
\bar{s}_1(\omega), & \text{otherwise}
\end{cases}
\]
\( p_{2}^{(II, s)} = p_{2}^{(I, c)}, p_{2}^{(III, s)} = p_{2}^{(II, c)}, s_{2}^{I, s} = s_{2}^{I, c}, s_{2}^{II, s} = s_{2}^{II, c}. \)

(2) In period 1, the optimal retail price and service quality level are given by

\[
p_{1}^{(s)} = \begin{cases} p_{1}^{(I, s)}, & \text{if } s_{1}^{I} < s_{1}^{(s)} \cr p_{1}^{(II, s)}, & \text{if } s_{1}^{I} > s_{1}^{(s)} \end{cases},
\]

where

\[
s_{1}^{I} = \frac{(a_{1} - \epsilon_{1} + (2 + \epsilon_{1})(s_{1} - 0) + \beta(0 + s_{1})/B_1(s_{1}))}{\eta_{1}B_1(s_{1})},
\]

\[
B_1(x) = 2 - \frac{(B_2(x) + 2\beta\eta_{1}(1 + \beta))\delta^2 + \delta\epsilon_{1}\eta_{1}}{\eta_{1}B_1(x)},
\]

\[
p_{1}^{(II, s)} = c + \frac{\delta\eta_{1}(1 + \beta)}{\eta_{1}B_1(s_{1})},
\]

\[
s_{1}^{(s)} = \frac{(a_{1} - \epsilon_{1} + (2 + \epsilon_{1})(s_{1} - 0) + \beta(0 + s_{1})/B_2(s_{1}))}{\eta_{2}B_2(s_{1})},
\]

\[
B_2(x) = 2 - \frac{(B_2(x) + 2\beta\eta_{1}(1 + \beta))\delta^2 + \delta\epsilon_{1}\eta_{1}}{\eta_{1}B_2(x)}.
\]

From Proposition 2, it follows that for the second-period centralised supply chain, the optimal decisions and profits also depend on two thresholds for RV, which are larger than that of the decentralised setting. Thus, for any RV, the retailer in the decentralised supply chain always sets a lower service quality level and a higher retail price than that in the centralised supply chain, which hurts both members. Thus, the supplier has an incentive to coordinate the retailer’s price–service decisions in each period via quantity discount–service subsidy (QDS) contracts.

### 5.2 Coordination mechanism for the second-period supply chain

The coordination of the whole supply chain during the two periods requires that the retailer is coordinated in period 2. From the previous sections, we know that in period 2, the retailer decides the service quality level and order quantity lower than the optimal level of the system, which incurs inefficiency of the second-period supply chain. Thus, considering that the retailer has set the retail price \( p_1 \) and the service quality level \( s_1 \) in period 1, we first investigate how the supplier can coordinate the retailer’s retail price and service quality level in period 2. To achieve the optimal efficiency, we assume that, the supplier offers a QDS in period 2 (QDS2) to the retailer, including a quantity discount scheme (Cachon 2003; Cachon and Lariviere 2005)

\[
w_2(q_2) = \begin{cases} w_2, & \text{if } q_2 \geq d_2(p_2^{s}, s_2^{s}) \text{ and a service subsidy rate scheme} \cr w_2, & \text{if } q_2 < d_2(p_2^{s}, s_2^{s}) \end{cases}
\]

(Ernst and Powell 1998; Xiao et al. 2005)

\[
\gamma_2(s_2) = \begin{cases} \gamma_2, & \text{if } s_2 \geq s_2^{s} \text{ with } w_2 < \hat{w}_2 \text{ and } 0 < \gamma_2 \leq 1, \text{ the breakpoints of} \cr 0, & \text{if } s_2 < s_2^{s} \end{cases}
\]

where \( \gamma_2 \) is the global optimal quantity and service quality level in period 2. Under the QDS2 contract, the retailer obtains subsidy \( \gamma_2 \) for each unit of service investment, if and only if he invests in the service quality not lower than the optimal level of the system in period 2. Also the supplier charges the retailer a lower unit wholesale price \( w_2 \), if he orders the products with quantity no lower than the optimal quantity of the system in period 2.

Under the QDS2 scheme, we know that the retailer solves the following problem at the beginning of period 2:

\[
\max_{p_2, s_2} \pi_2^{s}(p_2, s_2) = (p_2 - w_2(q_2)) [a_2 - p_2 + \theta s_2 - \alpha(0 - s_2)^{+} + \beta p_1] - \frac{1}{2}(1 - \gamma_2(s_2))\eta_2s_2^2.
\]

To coordinate the second-period supply chain, the supplier should set the QDS2 contract to induce the retailer to set retail price and service quality level equal to that of the second-period centralised supply chain. Based on Propositions 1 and 2 and Equation (8), we derive the following proposition.

### Proposition 3

With a known retail price \( p_1 \) and service quality level \( s_1 \) in period 1, the second-period supply chain is coordinated, if the supplier offers a QDS2 contract with \( w_2 = \tilde{w}_2 \), \( \tilde{w}_2 > \hat{w}_2 = \max\{\tilde{w}_2, \tilde{w}_2\} \), \( 0 < \lambda_2 < 1 \), \( i = I, II, III \), where

\[
(1) \quad \tilde{w}_2^I = (1 - \frac{\alpha(0 - s_2) + \beta p_1}{2\eta_2})M(\tilde{s}_2, c) + c,
\]

\[
\hat{w}_2^I = (1 - \frac{\alpha(0 - s_2) + \beta p_1}{2\eta_2})M(\tilde{s}_2, c) + c,
\]

\[
(2) \quad \tilde{w}_2^{II} = (1 - \frac{\alpha(0 - s_2) + \beta p_1}{2\eta_2})M(0, c) + c,
\]

\[
\hat{w}_2^{II} = (1 - \frac{\alpha(0 - s_2) + \beta p_1}{2\eta_2})M(0, c) + c,
\]

\[
(3) \quad \tilde{w}_2^{III} = (1 - \frac{-1}{2\eta_2}(a_2 - c + \beta p_1))M(\tilde{s}_2, c) + c,
\]

\[
\hat{w}_2^{III} = (1 - \frac{-1}{2\eta_2}(a_2 - c + \beta p_1))M(\tilde{s}_2, c) + c.
\]
It is shown from Proposition 3 that QDS$_2$ can coordinate the retailer’s joint decisions of retail price and service quality level in period 2. Proposition 3 complements the literature by explicitly modelling the impact of service quality loss-averse behaviour of consumers on coordination mechanism, and concluding that the supplier benefits from utilising such an irrational behaviour. It is intuitive that a larger subsidy rate of service investment is accompanied by a larger unit wholesale price in the all-unit quantity discount contract, because the supplier needs to raise the wholesale price to compensate the increased service investment subsidy. And the coordinated unit wholesale price is decreasing in the retailer’s profit share ($\lambda_2$). Larger consumer sensitivity to previous period’s retail price ($\beta$ or retail price of period 1 $p_1$) results in a higher coordinated wholesale price of period 2, due to consumers are more likely to transfer from period 1 to period 2.

Note that a single all-unit quantity discount contract does not guarantee coordination of the supply chain, i.e. the retailer chooses a combination of retail price and service quality level different from that of the centralised supply chain, because the investment cost of service quality falls entirely on the retailer. Thus, we add a service subsidy contract to induce the retailer to set the optimal service quality level as well as the optimal retail price for the system. In addition, $\lambda_2$ is the retailer’s profit share when the second-period supply chain is coordinated by QDS$_2$, where $0 < \lambda_2 < 1$ indicates that QDS$_2$ achieves arbitrary profit distribution between the two supply chain members.

From Propositions 1–3, we derive the following corollary, which gives the Pareto condition of the coordination mechanism proposed in Proposition 3.

**Corollary 1.** The QDS$_2$ coordination mechanism Pareto dominates the decentralised setting without the QDS$_2$ coordination mechanism, if and only if either (i) $\frac{1}{2} < \lambda_2 < \frac{3}{4}$ for $s_1 < s_1(c)$ or $s_1 > s_1(c)$; or (ii) $1 - \frac{3(a_2 - c + \theta s_1 + \beta p_1)^2}{4(a_2 - c + \theta s_1 + \beta p_1)^2 - 8\eta_1 \gamma_2} < \lambda_2 < 1 - \frac{(a_2 - c + \theta s_1 + \beta p_1)^2}{2(a_2 - c + \theta s_1 + \beta p_1)^2 - 4\eta_1 \gamma_2}$ for $s_1(c) \leq s_1 \leq s_1(c)$.

Corollary 1 implies that both the supplier and the retailer are better off under the QDS$_2$ coordination mechanism only when the supplier sets appropriate unit wholesale prices. The supplier cannot be better off using the QDS$_2$ coordination mechanism if the wholesale prices are too low; and the retailer becomes worse off if the wholesale prices are too high. Moreover, by comparing Parts (i) and (ii), we find that the lower and upper bounds of the Pareto coordination mechanism are decreased, whereas its Pareto range is enlarged in the case where the retailer sets the service quality level equal to RV. Thus, we conclude that, if the retailer adopts a constant service quality level policy in period 2, e.g. every day high service quality level, it will make coordination easier in period 2.

To better understand the coordination mechanism design for the supplier in period 2, we study the effects of some parameters on the coordinated QDS$_2$ by a numerical example, where the default values of all parameters are used as: $a_2 = 10, c = 1.0, \theta = 0.5, \eta_2 = 1.0, \gamma_2 = 0.5, \lambda_2 = 0.3, \alpha = 0.5, \beta = 0.1, p_1 = 9.5$ and $s_1 = 2.0$. Figures 2 and 3 describe how the coordinated QDS$_2$ depends on RV and dwindling fraction, respectively, and Figure 4 describes the effect of service investment efficiency and RV on the coordinated QDS$_2$.

From Figures 2–4, we derive the following observations:
From Figure 2, we know that, in general, the larger the RV($s_1$), the larger the coordinated unit wholesale price in period 2 will be. For the low branch of the coordinated unit wholesale price $w_2$, it is a piece-wise increasing function of RV. At the two breakpoints, it is continuous, because the supplier needs to induce the same service quality level and retail price. That is, the supplier should adjust the coordination mechanism gradually according to the change of RV.

- It is shown from Figure 3 that if RV is sufficiently small (not greater than its smaller threshold $s_1(c)$), the dwindling fraction has a negative impact on the coordinated unit wholesale price, because increasing dwindling fraction weakens the retailer’s motivation of extra service investment relative to RV. Figure 4 indicates that the lower the service cost factor ($\eta_2$), the larger the coordinated unit wholesale price in period 2, because the high efficiency encourages service investment for the retailer and the supplier shares the benefit. Similarly, the service sensitivity below RV ($\theta$) has a positive impact on the coordinated unit wholesale price (see Figures 2 (a) and (b)).

5.3 Coordination mechanism of the whole supply chain

To coordinate the supply chain for both periods, the supplier should provide QDS contracts for periods 1 and 2, respectively, so that the retailer sets retail price and service quality level equal to those of the centralised supply chain in two periods, respectively. In the previous section, we know that if the supplier offers the QDS$_2$ scheme given by Proposition 3, then the supply chain is coordinated in period 2, and the retailer obtains a fraction $\lambda_2$ of the optimal channel profit in

![Figure 3. Coordinated QDS$_2$ versus dwindling fraction.](image1)

![Figure 4. Coordinated QDS$_2$ versus service cost factor and RV.](image2)
period 2, i.e. \( \tilde{\pi}^R(z_2, w_1, \hat{w}_2) = \lambda_2 \tilde{\pi}^{SC2} \). Expecting that the supplier will design such a QDS2 scheme to coordinate the retailer’s decision in period 2, the supplier should offer another QDS contract in period 1 (QDS1) with a quantity discount scheme \( w_1(q_1) = \begin{cases} \frac{w_1}{w_1}, & \text{if } q_1 \geq d_1(p^*_1, s^*_1) \\ \frac{w_1}{w_1}, & \text{if } q_1 < d_1(p^*_1, s^*_1) \end{cases} \) and a service subsidy rate scheme \( \gamma(s_1) = \begin{cases} \gamma_1, & \text{if } s_1 \geq s^*_1 \\ 0, & \text{if } s_1 < s^*_1 \end{cases} \) with \( 0 < \gamma_1 \leq 1 \) so that the retailer’s retail price and service quality level in period 1 are the same as those of the centralised supply chain. Thus, in period 1, the retailer solves the following problem:

\[
\max \tilde{\pi}^R(p_1, s_1) = (p_1 - w_1(q_1))(a_1 - p_1 + \theta s_1) - \frac{1}{2}(1 - \gamma_1(s_1))\eta_1 s_1^2 + \delta \tilde{\pi}^{SC2}.
\]  

(9)

From Propositions 2 and 3 and Equation (9), we derive the following proposition.

**Proposition 4.** The two-period supply chain is coordinated, if for period 2, the supplier offers QDS2 given by Proposition 3, and for period 1, the supplier offers QDS1 that satisfies \( \tilde{w}_1 > \hat{w}_1 = \max \{ \hat{w}'_1, \hat{w}''_1 \} \), \( 0 < \lambda < 1, \gamma_1 \geq \gamma'_1 \), where

\[
\gamma_1 = \begin{cases} 
\left[ \frac{B_1(x)(\eta_1^{e_{1s}} - \eta_1^{s_{1s}})}{\eta_1 B_1(x) - \delta \tilde{\pi}^{(z_1)}(x + \beta)(a_1 - c + \theta \delta^2 + \theta \delta^2)} \right]^2, & \text{if } s_1^{e_{1s}} < s_1^e(c) \\
\frac{1}{2}(a_1 - p_1^{e_{1s}} - \theta \delta^2) + \delta \frac{\tilde{\pi}^{(z_1)}}{B_2(x)}(a_1 - p_1^{e_{1s}} + \theta \delta^2), & \text{if } s_1^{e_{1s}} > s_1^e(c),
\end{cases}
\]

\[
w_1 = \begin{cases} 
\left(1 - \lambda\right) p_1^{e_{1s}} + \lambda c - \frac{\delta \tilde{\pi}^{(z_1)}}{B_2(x)}(a_1 - p_1^{e_{1s}} + \theta \delta^2), & \text{if } s_1^{e_{1s}} < s_1^e(c) \\
\left(1 - \lambda\right) p_1^{e_{1s}} + \lambda c - \frac{\delta \tilde{\pi}^{(z_1)}}{B_2(x)}(a_1 - p_1^{e_{1s}} + \theta \delta^2), & \text{if } s_1^{e_{1s}} > s_1^e(c),
\end{cases}
\]

\[
\tilde{w}_1 = \begin{cases} 
a_1 + \lambda \delta \tilde{\pi}^{(z_1)} + \lambda c - \frac{\delta \tilde{\pi}^{(z_1)}}{B_2(x)}(a_1 - p_1^{e_{1s}} + \theta \delta^2), & \text{if } s_1^{e_{1s}} < s_1^e(c) \\
\left(1 - \lambda\right) a_1 + \lambda c - \frac{\delta \tilde{\pi}^{(z_1)}}{B_2(x)}(a_1 - p_1^{e_{1s}} + \theta \delta^2), & \text{if } s_1^{e_{1s}} > s_1^e(c),
\end{cases}
\]

\[
\hat{w}_1 = \begin{cases} 
a_1 + \lambda \delta \tilde{\pi}^{(z_1)} + \lambda c - \frac{\delta \tilde{\pi}^{(z_1)}}{B_2(x)}(a_1 - p_1^{e_{1s}} + \theta \delta^2), & \text{if } s_1^{e_{1s}} < s_1^e(c) \\
\left(1 - \lambda\right) a_1 + \lambda c - \frac{\delta \tilde{\pi}^{(z_1)}}{B_2(x)}(a_1 - p_1^{e_{1s}} + \theta \delta^2), & \text{if } s_1^{e_{1s}} > s_1^e(c),
\end{cases}
\]

\[
\chi^I = 2\lambda(p_1^{e_{1s}} + \theta s_1^{e_{1s}}) - \left(1 - \gamma_1 - \lambda\right) \eta_2 s_1^{e_{1s}} + \frac{\delta \tilde{\pi}^{(z_{1s})}}{B_2(x)}(a_1 - p_1^{e_{1s}} + \theta \delta^2)^2 - \frac{\delta \tilde{\pi}^{(z_1)}}{B_2(x)}(a_1 - p_1^{e_{1s}} + \theta \delta^2)^2,
\]

\[
\chi^H = 2\lambda(p_1^{e_{1s}} + \theta s_1^{e_{1s}}) - \left(1 - \gamma_1 - \lambda\right) \eta_2 s_1^{e_{1s}} + \frac{\delta \tilde{\pi}^{(z_{1s})}}{B_2(x)}(a_1 - p_1^{e_{1s}} + \theta \delta^2)^2 - \frac{\delta \tilde{\pi}^{(z_1)}}{B_2(x)}(a_1 - p_1^{e_{1s}} + \theta \delta^2)^2, \quad \chi^H = 4\lambda(p_1^{e_{1s}} + \theta s_1^{e_{1s}}) - \left(1 - \gamma_1 - \lambda\right) \eta_2 s_1^{e_{1s}} + \frac{\delta \tilde{\pi}^{(z_{1s})}}{B_2(x)}(a_1 - p_1^{e_{1s}} + \theta \delta^2)^2 - \frac{\delta \tilde{\pi}^{(z_1)}}{B_2(x)}(a_1 - p_1^{e_{1s}} + \theta \delta^2)^2,
\]

\[
\Gamma^I = \lambda(2(p_1^{e_{1s}} + \theta s_1^{e_{1s}}) - \eta_1 s_1^{e_{1s}} - \delta \tilde{\pi}^{(z_1)}) - \frac{\delta \tilde{\pi}^{(z_{1s})}}{B_2(x)}(a_1 - p_1^{e_{1s}} + \theta \delta^2)^2,
\]

\[
\Gamma^H = \lambda(2(p_1^{e_{1s}} + \theta s_1^{e_{1s}}) - \eta_1 s_1^{e_{1s}} - \delta \tilde{\pi}^{(z_1)}) - \frac{\delta \tilde{\pi}^{(z_{1s})}}{B_2(x)}(a_1 - p_1^{e_{1s}} + \theta \delta^2)^2.
\]
\[
\Gamma^{III} = \frac{\lambda}{2} \left( p_1^{c,III} - c \right) (a_1 - p_1^{c,III} + \theta s_1^{c,III}) - (\eta_1 + \delta \eta_2) s_1^{c,III} + \frac{(\eta_2 + \delta \eta_2)(a_1 + \epsilon + \eta_1)}{2} \right] - \frac{\lambda (\eta_1 + \delta \eta_2)(a_1 + \epsilon + \eta_1)^2}{2 \eta_1 + \delta \eta_2}.
\]

5.4 Numerical studies

Under the coordination mechanism given by Proposition 4, the two-period supply chain is coordinated and the retailer obtains a fraction \( \lambda \) of the total optimal channel profit. Figures 5–9 describe the effect of parameters such as dwindling fraction, service investment subsidy rate and service investment efficiency on the coordination mechanism, where we assume the same default values for all parameters as Figure 2 except \( a_1 = 13, \alpha = 0.2, \theta = 1.0, \eta_1 = 2.0, \lambda = 0.3, \gamma_1 = 0.5, \beta = 0.1, \) and \( \delta = 0.95. \)

From Figures 5–9, we derive the following observations:

- As is shown in Figure 5, we find that the two-period coordination mechanism depends on the relative magnitude of the service investment efficiencies to a large degree. In general, the higher the service cost factor (\( \eta_2 \) or \( \eta_1 \)) the lower the coordinated unit wholesale prices. In particular, the service cost factor of either period has a larger impact on the coordinated unit wholesale price of that period than that of the other period.

- From Figure 5(a), we know that, as the service cost factor in period 1 increases, the supplier will decrease the coordinated wholesale price in period 2, if it is sufficiently high, because decreasing service investment efficiency in period 1 lowers the retail price of period 1 so that the market potential of period 2 (i.e. inter-temporal pricing effect) and lowers RV for period 2 so that the service quality level in period 2 as well. Otherwise, the supplier decreases that more slightly, because the retailer sets its service quality level lower than that in period 1 (RV), which is independent of RV as a result.

- If the dwindling fraction is sufficiently small, the supplier raises the coordinated unit wholesale price in period 1, while lowers that in period 2 as the dwindling fraction increases (i.e. up–down strategy); otherwise, it keeps a constant wholesale price (see Figure 6). The reason is that, with a sufficiently small dwindling fraction, the supply chain benefits from the low–high service quality level strategy in two periods and the benefit increases in the dwindling fraction. Thus, the supplier expects to induce a higher service quality level in period 2 than period 1 by strategically adjusting the unit wholesale prices. That is, when consumers become more loss-averse in the service quality, the up–down wholesale price strategy in two respect periods enhances channel coordination in the two periods.

- According to Figure 7, we know that, the coordinated unit wholesale price in period 1 is generally increasing in the service investment subsidy rate \( \gamma_1 \). This positive effect is strengthened by a higher service investment efficiency in period 1, if the subsidy rate is sufficiently large. It is shown from Figure 8 that, the retailer’s total

![Figure 5. Two-period coordination mechanism versus service cost factor.](image-url)
Figure 6. Two-period coordination mechanism versus dwindling fraction.

Figure 7. Two-period coordination mechanism versus service subsidy rate in period 1.

Figure 8. Two-period coordination mechanism versus the retailer’s profit share.
coordinated profit share of two periods ($\lambda$) has a negative effect on the unit wholesale price in period 1. As the total coordinated profit share increases, the gap between the low branch and lower bound of the high branch of the unit wholesale price in period 1 dwindles. In general, the larger the consumer sensitivity to previous period’s retail price ($\beta$), the larger the coordinated wholesale price of period 1 will be (see Figure 9). However, when the fraction of the retailer’s profit in the coordinated supply chain during period 2 ($\lambda_2$) is sufficiently small and $\beta$ is sufficiently high, the lower bound of the coordinated wholesale price of period 1 ($w_1$) is slightly decreasing in $\beta$ (see Figure 9(a)).

Figures 10–12 investigate how the dwindling fraction, service sensitivity and service investment efficiency of two periods influence the Pareto range of coordination mechanism for the two periods, where we assume the same default values for all parameters as those in Figure 5, except $\eta_1 = 1.5$.

---

**Figure 9.** Coordinated QDS$_1$ versus consumer sensitivity to previous period’s retail price.

**Figure 10.** Pareto range of coordination mechanism versus dwindling fraction.
From Figures 10–12, we derive the following observations:

- The two players are better off under the QDS coordination mechanism only when the supplier sets an appropriate unit wholesale price in period 1 ($\hat{\lambda} \leq \lambda \leq \bar{\lambda}$). The supplier cannot be better off if the unit wholesale price in period 1 is too low ($\lambda > \bar{\lambda}$); and the retailer becomes worse accepting the QDS coordination mechanism if it is too high ($\lambda < \hat{\lambda}$). It is demonstrated from Figure 10 that, when the dwindling fraction is sufficiently small, the lower (upper) bound of $\lambda$ is decreasing (increasing) in the dwindling fraction, which means that the supplier might obtain a lower or higher fraction of profit, because although increasing the dwindling fraction discourages service investment in period 1, it encourages a higher service investment in period 2 relative to period 1. However, when it is sufficiently large, both bounds of $\lambda$ are increasing in the dwindling fraction, which means that the supplier should obtain a lower fraction of profit, because in this setting, increasing dwindling fraction discourages the retailer’s service investment in both periods and the supplier has to bear a part of loss incurred to the retailer.

- As is shown in Figure 11, we find that, in general, the larger the service sensitivity $\theta$, the smaller the lower bound and the larger the upper bound of $\lambda$ will be, which implies that the supplier might obtain a higher or lower

![Figure 11. Pareto range of coordination mechanism versus $\theta$.](image1)

![Figure 12. Pareto range of coordination mechanism versus service cost factor of two periods.](image2)
fraction of profit. That is because a high service sensitivity strengthens the demand-enhancing effect of service, which increases the demand rate in both periods, and increases cost from a high service investment.

- In general, as the service investment efficiencies decrease, the lower bound of $\lambda$ increases, whereas the upper bound of $\lambda$ decreases, which means that the supplier should obtain either a lower or higher fraction of profit (see Figure 12). On one hand, the supplier has to bear a part of loss from the increasing service investment cost to the retailer. On the other hand, the supplier benefits from the low–high or everyday high service quality level strategy in two periods. Thus, with endogenous RV, decreasing service investment efficiency does not always increase the supplier’s bargaining power.

6. Conclusions and further research

Service is an important competitive edge for firms, in particular, for retailers. A good service can bring satisfaction and attract more consumers, and a bad service may lose consumers. However, providing better service needs a higher service cost. Retailers have to make a trade-off between the benefit and the cost from providing a higher service quality level. What makes the problem more difficult is that consumers evaluate the service quality level relative to a reference value, and that loss-averse consumers are more sensitive to a negative than positive service deviation from the reference value. We explicitly model the reference-dependent evaluation about service quality level for loss-averse consumers by introducing a kindled demand function in which a dwindling fraction is incorporated into service sensitivity for the case when the service quality level is above the reference point.

We explore how to coordinate a supplier-retailer supply chain with reference-dependent and loss-averse consumers via contracts without a fixed payment. We consider a two-period model by regarding the service quality level in period 1 as the reference point in period 2, i.e. endogenising the reference point. We design a mechanism combining all-unit quantity discount and subsidy for service investment to coordinate the supply chain in both periods, and analyse the impacts of reference dependence and loss-aversion of consumers on the coordination mechanism. We also study the equilibrium outcome of the decentralised supply chain and the effects of some factors such as dwindling fraction on coordination mechanism, and give the Pareto condition of coordination mechanism.

The philosophy from the coordination mechanism for a supply chain with two periods in our model can be applied to coordinate a supply chain with multiple-period in which the service quality level for a period is regarded as the reference point of service quality level in the subsequent period. We only consider the reference-dependent effect in service quality level but omit the price dimension. Considering the implication of both price and service quality level reference effects on the coordination mechanism may be interesting. The question of how to form the reference point and what mechanism the supplier designs to induce retailers to reveal their real information is also very interesting but challenging when the retailer has an incentive to conceal private information.

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Notes

1. This assumption isolates the effects of consumers’ reference-dependent and loss-averse preference for service quality on the coordination mechanism, because it avoids retailer stockpiling in the first period, which would affect the decisions made in the second period. Actually, JIT assumption is very common in the literature on marketing and operations, e.g. Martín-Herrán, Sigué, and Zaccour (2010) assume that the retailer orders exactly the quantity he sells in the first period. In practice, to reduce or even
eliminate forward buying, manufacturers use marketing vehicles such as scan-back rebate in which the retailer is rewarded based on the actual sales rather than the purchased quantities (Drèze and Bell 2003; Kurata and Yue 2008).

2. We add the subscripts ‘1’ and ‘2’ to denote the parameters, decisions and profits of the players in periods 1 and 2, respectively.

3. We add the superscripts ‘d’ and ‘c’ to represent the optimal decisions for the decentralised and centralised settings, respectively.

4. For symmetry, we assume the default value for $\eta_1 = 1.0$ in Figure 5.

References


Appendix I.

Proof of Proposition 1(i). For \( s_2 > s_1 \), the Hessian matrix of \( \tilde{\pi}_2^E(p_2, s_2) \) on \( (p_2, s_2) \) is \( H_1 = \begin{bmatrix} -2 & (1 - z) \theta \\ (1 - z) \theta & -\eta_2 \end{bmatrix} \). From \( \eta_2 > \bar{\eta}_2 \), it follows that \( |H_1| > 0 \) such that \( H_1 \) is negatively definite, i.e., \( \tilde{\pi}_2^E(p_2, s_2) \) is jointly concave on \( (p_2, s_2) \). Thus, if \( s_2 > s_1 \), in period 2, the unique optimal retail price and service quality level of the retailer satisfy the first-order conditions:

\[
\frac{\partial \tilde{\pi}_2^E}{\partial p_2} = -2(p_2 - w_2) + \theta(1 - z)s_2 + a_2 + \beta p_1 - w_2 + \theta s_2 = 0, \tag{A.1}
\]

\[
\frac{\partial \tilde{\pi}_2^E}{\partial s_2} = (1 - z)\theta(p_2 - w_2) - \eta_2 s_2 = 0. \tag{A.2}
\]

From (A.2), we have \( s_2 = (1 - \alpha)\theta(p_2 - w_2)/\eta_2 \). If \( s_2 \leq s_1 \), we can similarly prove the uniqueness of the optimal retail price of the retailer which satisfies the first-order condition

\[
\frac{\partial \tilde{\pi}_2^E}{\partial p_2} = -2(p_2 - w_2) + a_2 + \beta p_1 - w_2 + \theta s_2 = 0. \tag{A.1'}
\]

Inserting \( s_2 \) into (A.1)/(A.1'), we obtain the optimal retail price of the retailer

\[
p_2^E(w_2) = w_2 + M(z, w_2). \tag{A.3}
\]

where \( M(\alpha, w_2) = (a_2 - w_2 + \alpha b_1 + \beta p_1)B_3(\alpha) \). Furthermore, the optimal service quality level of the retailer is \( \hat{s}_2^E(w_2) = (1 - z)\theta(p_2^E(w_2) - w_2)/\eta_2 = (1 - z)\theta M(z, w_2)/\eta_2 \).
From (A.3), we know that the retailer’s optimal retail price for $s_2 \leq s_1$ is equivalent to the above case with $\alpha = 0$. That is, the unique optimal retail price and service quality level of the retailer is $p^{\text{opt}}_2(w_2) = w_2 + M(0,w_2)$, and $s^{\text{opt}}_2(w_2) = \delta M(0,w_2)/\eta_2$. Let $s^{\text{opt}}_2(w_2) = \delta^2 s_2^{\text{opt}}(w_2)$, we get a threshold for $s_2$, i.e. $s_2^{\text{opt}}(w_2) = 2\delta s_2 M(0,w_2)/(\eta_1 + \eta_2)$. Let $s^{\text{opt}}_1(w_2) = \delta s_2^{\text{opt}}(w_2)$, we get a threshold for $s_1$, i.e. $s_2^{\text{opt}}(w_2) = \delta M(0,w_2)/\eta_2$. Thus, we divide the discussion into two cases:

(i) for $s_1 \leq s_1^{\text{opt}}(w_2)$ (i.e. $s_2^{\text{opt}}(w_2) \leq s_2^{\text{opt}}(w_2)$), it follows from (A.3) that if $s_1 \leq s_1^{\text{opt}}(w_2)$, where

$$s_1^{\text{opt}}(w_2) = \left(1 - \delta^2 s_1 M(0,w_2)/(\eta_1 + \eta_2)\right)^2/(2\delta s_2 M(0,w_2)/(\eta_1 + \eta_2)),$$

which is an increasing function of $s_1$. Further, we get $s_1^{\text{opt}}(w_2) = \delta M(0,w_2)/\eta_2$. The optimal retail price and service quality level of the retailer is $p_2^{\text{opt}}(w_2) = p_2^{\text{opt}}(w_2)$, and $s_2^{\text{opt}}(w_2) = s_2^{\text{opt}}(w_2)$. If $s_2 > s_2^{\text{opt}}(w_2)$, then $p_2^{\text{opt}}(w_2) = s_2^{\text{opt}}(w_2)$, and $s_2^{\text{opt}}(w_2) = s_2^{\text{opt}}(w_2)$; otherwise $s_2^{\text{opt}}(w_2)$ is optimal service quality level of the retailer is $s_2^{\text{opt}}(w_2)$, and (b) for $s_1 < s_2^{\text{opt}}(w_2)$, $s_2^{\text{opt}}(w_2)$ is optimal service quality level of the retailer is $s_2^{\text{opt}}(w_2)$.

(ii) for $s_1 > s_1^{\text{opt}}(w_2)$ (i.e. $s_2^{\text{opt}}(w_2) < s_2^{\text{opt}}(w_2)$), we have (a) for $s_1 > s_2^{\text{opt}}(w_2)$, the optimal service quality level of the retailer is $s_2^{\text{opt}}(w_2)$, and (b) for $s_1 < s_2^{\text{opt}}(w_2), s_2^{\text{opt}}(w_2)$ are both interior solutions. The best interior solution is the one that leads to higher profits. A comparison of the retailer’s profit shows that

$$\Delta(s_1) = \pi^R(p_2^*(w_2), s_2^*(w_2), s_1) - \pi^R(p_2^*(w_2), s_2^*(w_2), 0) = (B_2(x)M^2(x,w_2) - B_2(0)M^2(0,w_2))/2,$$

which is an increasing function of $s_1$. Further, we have $\Delta(0) = (B_2(0) - B_2(0))\alpha_2 + \beta p_1 - w_2^2/2\delta^2 s_2^2/(2B_2(0)) < 0$, and $\Delta(s_1^{\text{opt}}(w_2)) = \pi^R(p_2^*(w_2), s_1^{\text{opt}}(w_2)) - \pi^R(p_2^*(w_2), s_2^{\text{opt}}(w_2), 0) < 0$. This implies $\Delta(s_1) < 0$ for $s_1 \in [s_2^{\text{opt}}(w_2), s_1^{\text{opt}}(w_2)]$. Hence, the optimal service quality level is $s_2^{\text{opt}}(w_2)$, and $s_2^{\text{opt}}(w_2), s_2^{\text{opt}}(w_2) < s_2^{\text{opt}}(w_2)$. It follows from $s_1 > s_1^{\text{opt}}(w_2) > s_2^{\text{opt}}(w_2)$ that the optimal service quality level reduces to the second branch, i.e. $s_2^{\text{opt}}(w_2)$ for $s_1 > s_1^{\text{opt}}(w_2)$. Similarly, we have $p_2^{\text{opt}}(w_2) = p_2^{\text{opt}}(w_2)$ for $s_1 > s_1^{\text{opt}}(w_2)$.

Combining Cases (i) and (ii), we derive Proposition 1(i).
From $\eta_1 > \hat{\eta}_1$ and $\eta_2 > \hat{\eta}_2$, it follows that the Hessian matrix of (A.7) on $(p_1, s_1)$ is negatively definite, which guarantees that (A.7) is jointly concave on $(p_1, s_1)$. Thus, from the first-order condition, we get the unique optimal retail price and service quality level $p_1^{\text{II}}(w_1) = w_1 + \frac{\theta_{p_1}^2}{2\theta_1^2 + \beta_1^2 s_1^2} \left( \frac{\partial^2}{\partial s_1^2} \right)_{s_1 = s_1^*}$. Thus, Proposition 1(ii) holds.

**Proof of Proposition 2.** Similar to Proposition 1(i), we derive the unique optimal retail price and service quality level for period 2 in the centralised supply chain given by Proposition 2(i). Further, we know that for $s_1 < s_1^*(c)$, the optimal profit for the centralised supply chain in period 2 is $\pi^{\text{SC}}(p_2^{\text{II}}, s_2^{\text{II}}) = (a_2 - c + \theta_2 s_2 + \beta_2 p_2)/2B_2(x)$. Thus, in period 1, the central planner solves the following problem:

$$\max_{p_1, s_1} \pi^{\text{SC}}(p_1, s_1, p_2^{\text{II}}, s_2^{\text{II}}) = (p_1 - c)(a_1 - p_1 + \theta_1 s_1) - \eta_1 s_1^2/2 + \delta(a_2 - c + \theta_2 s_1 + \beta_2 p_1)/2B_2(x).$$  

(A.8)

Hessian matrix of (A.8) on $(p_1, s_1)$ is $H_3 = \left[ -2 + \frac{\theta_{p_1}^2}{\theta_{s_1}^2}, \frac{\theta_{p_1}^2}{\theta_{s_1}^2} \right]$. (A.8) is jointly concave, if $H_3$ is negatively definite. From $\eta_1 > \hat{\eta}_1^*$, it follows that (A.8) is jointly concave on $(p_1, s_1)$ due to $\left| H_3 \right| > 0$. Thus, For $s_1 < s_1^*(c)$, the unique system optimal retail price and service quality level for period 1 satisfy the first-order conditions:

$$\frac{\partial \pi^{\text{SC}}}{\partial p_1} = -2(p_1 - c) + a_1 - c - \theta_1 s_1 + \delta \theta(a_2 - c + \theta_2 s_1 + \beta_2 p_1)/B_2(x) = 0,$$

(A.9)

$$\frac{\partial \pi^{\text{SC}}}{\partial s_1} = \theta_1 p_1 - \eta_1 s_1 = 0.$$  

(A.10)

From (A.9) and (A.10), we have $p_1(s_1) = c + \frac{a_1 - c - \theta_1 s_1 + \delta \theta(a_2 - c + \theta_2 s_1 + \beta_2 p_1)/B_2(x)}{\theta_1}$. For $s_1 > s_1^*(c)$, we can similarly prove the uniqueness of the optimal service quality level of the system for period 1 which satisfies the first-order condition

$$\frac{\partial \pi^{\text{SC}}}{\partial s_1} = \theta_1 p_1 - \eta_1 s_1 = 0.$$  

(A.10')

Inserting $p_1(s_1) = c + \frac{a_1 - c - \theta_1 s_1 + \delta \theta(a_2 - c + \theta_2 s_1 + \beta_2 p_1)/B_2(x)}{\theta_1}$ into (A.10)/(A.10'), we obtain the optimal service quality level

$$s_1^{\text{II}} = \sqrt{\frac{a_1 - c + \delta \theta(a_2 - c + \beta_2 p_1)/B_2(x)}{\eta_1 \theta_1}}.$$  

(A.11)

and the optimal retail price $p_1^{\text{II}} = c + \frac{a_1 - c - \theta_1 s_1 + \delta \theta(a_2 - c + \beta_2 p_1)/B_2(x)}{\theta_1}$, if $s_1^* < s_1^*(c)$.

From (A.11), we know that the optimal service quality level of the system for $s_1 > s_1^*(c)$ is equivalent to the above case with $\alpha = 0$. That is, the optimal retail price and quality level is $s_1^{\text{II}} = s_1^*(1) = \theta_1[a_1 - c + \delta \theta(a_2 - c + \beta_2 p_1)/B_2(x)]/(\eta_1 \theta_1)$ and $p_1^{\text{II}} = c + \eta_1 s_1^{\text{II}}/H_3$, if $s_1^* > s_1^*(c)$.

For $s_1^*(c) \leq s_1 \leq s_1^*(c)$, the optimal profit for the centralised supply chain in period 2 is $\pi^{\text{SC}}(p_2^{\text{II}}, s_2^{\text{II}}) = \frac{1}{2}(a_2 - c + \theta_2 s_2 + \beta_2 p_2)^2 - \frac{1}{2} \theta_2 s_2^2$. Thus, in period 1, the central planner solves the following problem:

$$\max_{p_1, s_1} \pi^{\text{SC}}(p_1, s_1, p_2^{\text{II}}, s_2^{\text{II}}) = (p_1 - c)(a_1 - p_1 + \theta_1 s_1) - \frac{1}{2} \theta_1 s_1^2 + \frac{1}{2} \theta_2 s_2^2.$$  

Similar to the proof of Proposition 1, from $\eta_1 > \hat{\eta}_1^*$ and $\eta_2 > \hat{\eta}_2^*$, it follows that $\pi^{\text{SC}}(p_1, s_1, p_2^{\text{II}}, s_2^{\text{II}})$ is jointly concave on $(p_1, s_1)$. Thus, from the first-order condition, we get the unique optimal service quality level and retail price

$$s_1^{\text{II}} = \frac{a_1 - c - \theta_1 s_1 + \delta \theta(a_2 - c + \beta_2 p_1)/B_2(x)}{\theta_1}.$$  

From (A.11), we know that the optimal service quality level for period 1 is $s_2^{\text{II}} = s_2^*(c) = (a_2 - c + \theta_2 s_2 + \beta_2 p_2)/2B_2(x)$, which is concave for a function of $s_2$. Thus, from the first-order condition it is uniquely maximised by $s_2^{\text{II}} = (a_2 - c + \theta_2 s_2^*/B_2(x)) = (a_2 - c + \theta_2 s_2^*/B_2(x))$, and its maximum profit is $\pi^{\text{SC}}(p_2^*, s_2^*, w_2) = \frac{1}{2} \theta_2 s_2^*/(2B_2(x))$.

(ii) If the retailer would like to take $w_2$, then we have

(a) if the retailer wants to offer the service investment subsidy, then it follows from Proposition 1 that it is optimal to provide a service quality level $s_2 = s_2^{\text{II}}$, and offer retail price $p_2^{\text{II}} = p_2^{\text{II}}(s_2, w_2)$, and so that its optimal profit is $\pi^{\text{SC}}(p_2^{\text{II}}, s_2^{\text{II}}, w_2) = (M(x, c) + c - w_2)\pi^*(x, c)/(2\eta_2), \text{under which the supply chain is coordinated. As the retailer’s fraction of profit share in period 2 is } \lambda_2, \text{we have } w_2 = \frac{1}{\lambda_2} \left( \frac{1}{2} \theta_1 s_1^2 + \frac{1}{2} \theta_2 s_2^2 \right) - \frac{1}{2} \theta_2 s_2^2.$

(b) if the retailer gets no service investment subsidy, then it will set $p_2$ and $s_2$ to maximise $\pi^{\text{SC}}(p_2, s_2, w_2) = (p_2 - w_2)q_2^{\text{II}} - \eta_2 s_2^2/2$, s.t. $d_2 - p_2 + (1 - \gamma_2)\theta_3 s_2 + \beta_3 p_2 = q_2^{\text{II}}$. Using the constraint, we can rewrite the profit as $\pi^{\text{SC}}(s_2, w_2) = (a_2 - c + \theta_2 s_2 + \beta_3 p_2 - \eta_2 s_2^2/2)$, which is a concave function of $s_2$. Thus, from the first-order condition it is uniquely maximised by $s_2^{\text{II}} = (1 - \gamma_2)\theta_3 s_2^*/B_2(x) = (1 - \gamma_2)M(x, 0)/\eta_2$, and its maximum profit is $\pi^{\text{SC}}(s_2^*, w_2) = \lambda_2 \pi^{\text{SC}}(s_2^*, s_2^*) = \lambda_2 \pi^{\text{SC}}(s_2^*, w_2) = \lambda_2 \pi^{\text{SC}}(s_2^*, w_2) = \frac{1}{2} \theta_2 s_2^2.$

(iii) implying that the retailer prefers to share investment cost with the supplier.
\[ \pi_{R_1} = \pi_{R_1}(p_{R_1}, s_{R_1}, \gamma_1, w_1) = \left( a_1 - w_1 \right) \left( 1 - \gamma_1 \right) \eta_1 s_{R_1}^2 + \psi_{R_1} \left( \theta_{R_1} \right), \]

which is a concave function of \( s_{R_1} \). Thus, from the first-order condition it is uniquely maximised by

\[ p_{R_1} = \pi_{R_1}'(s_{R_1}, \gamma_1, w_1) = \left( a_1 - w_1 \right) \left( 1 - \gamma_1 \right) \eta_1 s_{R_1} + \psi_{R_1}' \left( \theta_{R_1} \right) \]

and its maximum profit is \( \pi_{R_1}^{\star} = \pi_{R_1}(p_{R_1}^{\star}, s_{R_1}^{\star}, \gamma_1, w_1) = \left( a_1 - w_1 \right) \left( 1 - \gamma_1 \right) \eta_1 s_{R_1}^{\star} + \psi_{R_1}' \left( \theta_{R_1} \right) \left( 1 - \gamma_1 \right) \eta_1 s_{R_1}^{\star} / 2. \]

(b) If the retailer does not share service investment with the supplier, then it will set the retail price and service quality level to maximise

\[ p_{R_1}^B = \pi_{R_1}^B(p_{R_1}, s_{R_1}, w_1) = \left( a_1 - w_1 \right) \left( 1 - \gamma_1 \right) \eta_1 s_{R_1}^2 + \psi_{R_1} \left( \theta_{R_1} \right), \]

and its maximum profit is \( \pi_{R_1}^B = \pi_{R_1}^B(p_{R_1}^B, s_{R_1}^B, w_1) = \left( a_1 - w_1 \right) \left( 1 - \gamma_1 \right) \eta_1 s_{R_1}^2 / 2. \]

Let \( \pi_{R_1}^B = \pi_{R_1}^{B^*} \), we get the threshold for \( w_1 \), i.e.

\[ \omega_1^B = c + 2M(\gamma, \pi_2(z)) \left( 1 - \frac{\theta_1^2 \theta_3^2 / c^2}{(2M(\gamma, \pi_2(z)))^2} \right). \]

Similarly, we get another threshold \( \omega_3^B = 1 - \sqrt{2} \omega_2^B / c \), where \( \omega_2^B - \omega_3^B = M(\gamma, \pi_2(z)) \left( 1 - \sqrt{2} \right) / \left( 2M(\gamma, \pi_2(z)) \right)^2 \geq 0 \), and \( \omega_3^B - \omega_2^B = \left( 1 - \sqrt{2} \right) M(\gamma, \pi_2(z)) / 4 > 0 \). Thus, we have \( \omega_2^B > \omega_3^B \), i.e. there is a quantity discount. Thus, the supply chain is coordinated.

Similar to Case (I), we can show the coordinated contract for Cases (II) and (III). Thus, Proposition 3 holds. \( \square \)

**Proof of Proposition 4.** From Proposition 3, we know that, in period 2, if the supplier offers QDS, proposed in Proposition 3, we have

\[ q_{D_2}(y_2, w_2, \gamma_2) = q_{D_2}^B(y_2, w_2, \gamma_2) = \frac{y_2}{w_2}, \]

so that \( p_{R_2} = \pi_{R_2}(p_{R_2}, s_{R_2}, w_2) = \pi_{R_2}^{B^*} \). That is, the supply chain is coordinated in period 2.

In the following, we consider three cases (I) \( s_{R_2} < \gamma_2 \); (II) \( s_{R_2} > \gamma_2 \); (III) \( s_{R_2} = \gamma_2 \).

(i) For \( s_{R_2} < \gamma_2 \), then the retailer’s optimal profit in period 2 is \( \pi_{R_2}^B(\omega_2(q_2), \gamma_2(s_2)) = \lambda_2(a_2 - c + \pi_{R_2}^B) / (2B_2(z)) \).

(ii) For \( s_{R_2} > \gamma_2 \), then it is optimal to order a quantity of \( q_2^{c^*} = d_1 \left( p_{c^*}, s_{c^*}, \gamma_2 \right) \) in period 1. Thus, we have

(a) if the retailer wants to obtain service investment subsidy, then it will set retail price and service quality level to maximise

\[ \pi_{R_2} = \pi_{R_2}(p_{R_2}, s_{R_2}, \omega_2) = \left( a_1 - \omega_2 \right) \left( 1 - \gamma_2 \right) \eta_2 s_{R_2} + \psi_{R_2} \left( \theta_{R_2} \right), \]

which is a concave function of \( s_{R_2} \). Thus, from the first-order condition, maximum profit is uniquely achieved by

\[ p_{R_1} = \pi_{R_1}'(s_{R_1}, \gamma_1, w_1) = \left( a_1 - w_1 \right) \left( 1 - \gamma_1 \right) \eta_1 s_{R_1} + \psi_{R_1}' \left( \theta_{R_1} \right) \]

and its maximum profit is \( \pi_{R_1}^{\star} = \pi_{R_1}(p_{R_1}^{\star}, s_{R_1}^{\star}, \gamma_1, w_1) = \left( a_1 - w_1 \right) \left( 1 - \gamma_1 \right) \eta_1 s_{R_1}^{\star} + \psi_{R_1}' \left( \theta_{R_1} \right). \]

Let \( \pi_{R_1}^{\star} = \pi_{R_1}^{B^*} \), we get the threshold for \( w_1 \) (i.e. \( \omega_1^B \)) given by Proposition 4. Similarly, by solving \( \pi_{R_1}^{B^*} = \pi_{R_1}^{B^*} \), we get another threshold \( \omega_3^B \) given by Proposition 4.

Note that \( \pi_{R_1}^{B^*} \) is a convex and decreasing function of \( \omega_1 \). Thus, to induce the retailer to choose the globally optimal retail price and service quality level, the supplier would like to set \( \omega_2 > \max \{ \omega_2^B, \omega_3^B \} \). Thus, the supply chain is coordinated.

Similar to Case (I), we can show coordination mechanism for Cases (II) and (III). Thus, Proposition 4 holds. \( \square \)