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RFID Adoption Strategy and Coordination in a Dual-channel Supply Chain

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Abstract

This paper considers the radio-frequency identification (RFID) adoption decisions in a Dual-channel supply chain where both the manufacturer and the retailer have inventory misplacement problems. Under three RFID adoption strategies, i.e., non-RFID adoption, only the retailer adopts RFID, and the manufacturer adopts RFID for the supply chain, the two channels determine their retail prices or order quantities to engage in a Bertrand or Cournot competition, respectively. We coordinate the Dual-channel supply chain with Revenue-sharing contract and analyze the optimal RFID adoption strategy, and further compare the optimal RFID adoption strategies and coordination parameters under the two competition options. We find that the optimal RFID adoption strategy depends on the channel competition intensity, misplacement rates, and RFID tag cost. An intense channel competition or a high tag cost may be harmful for RFID adoption in the Dual-channel supply chain under both competition options. The retailer is more willing to adopt RFID than the manufacturer although both firms have misplacements. The Revenue-sharing contract can coordinate the Dual-channel supply chain under both competition options regardless of whether the firms adopt RFID. Furthermore, compared with Cournot competition, Bertrand competition is beneficial to promoting RFID adoption and the partners can achieve Pareto improvement easier in the Dual-channel supply chain.

Keywords

Dual-channel Supply Chain; RFID; Inventory Misplacement Problem; Bertrand Competition; Cournot Competition; Revenue-sharing Contract.

1. Introduction

Inventory misplacement, which causes considerable economic losses for the retailing industry, is known as a critical problem for retailers in decentralized supply chains (Rekik, 2011). According to an empirical research, Hardgrave, Aloysius and Goyal (2013) provided a sample of thirteen branch stores from one super retail company, whose counts were 337 stock-keeping units (SKUs) in a single category (hair-care products) per day, they found in the first 10 days, the misplaced items were more than 8 units per day without employing RFID technology, and they expected that the misplacements would continue to increase. Cannella et al. (2015) demonstrated that in supply chains, even though a sufficiently small misplacement rate would result in significant unnecessary orderings according to a simulation experiment. Raman, DeHoratius and Ton (2001) found that the inventory misplacement problem caused a leading retailer to lose about 25% of the revenues. In addition, Heese (2007) revealed that 10% of retail stores' profits were lost due to inventory misplacement problems. Furthermore, an empirical evidence showed that inventory misplacement problems would cause retailers to lose 3%~10% of the revenues (Cannella, Dominguez and Framinan, 2017).

Apparently, manufacturers could stay out of the direct impact of inventory misplacement problems since they don't participate in retailing activities. However, more and more

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manufacturers have established an additional direct sales channel to reach consumers in response to the growth in the Internet and e-commerce in the last 20 years (Xiao and Shi, 2016). For instance, many electronics manufacturers including Apple, Sony, Canon, and Microsoft (Chen, Fang and Wen, 2013), and clothing fashion accessories manufacturers including Coach, Nike, and Adidas (Li, Gilbert and Lai, 2015) have established the direct sales channel to addict customers who prefer to shop online in order to save time and transportation costs. However, when a manufacturer operates an own direct sales channel, it should handle a good deal of product deliveries and returns, which is easy to generate inventory misplacements during warehousing and distribution in the direct channel (Tao et al. 2017). Furthermore, Rekik, Syntetos and Glock (2019) stated that the pernicious effect of misplacements in direct sales (electronic/internet) channels might become even more dramatic compared with that in retail (traditional/in-store) channels, since not only ordering but also sales decisions were made solely based on the inventory level from the information system. Therefore, how to cope with the inventory misplacement problem naturally becomes a challenge for the manufacturer in a Dual-channel supply chain.

Radio-frequency identification (RFID) technology helps firms identify, track and transmit inventory information (Ben-Daya, Hassini and Bahroun, 2019) and has been proved as the most effective technology to eliminate the inventory misplacement problem (Camdereli and Swaminathan, 2010; Fan et al. 2014; Hardgrave, Aloysius and Goyal 2013; Heese, 2007; Zhang, Li and Fan, 2018a), which has been widely used in retailing and manufacturing industries (Hardgrave, Aloysius and Goyal, 2013). In a traditional retail supply chain, a retailer is more motivated to set up an RFID system since only the retailer faces a misplacement error (Donaldson, 2015). For instance, some large-scale retailers (e.g., Wal-Mart and Tesco) require their manufacturers to pastes an RFID tag on each product (Karaer and Lee, 2007); some international brands (e.g., Gap, Prada, Zara and Levi's) also employ RFID technology to solve inventory misplacement problems. However, in a Dual-channel supply chain, not only a retailer but also a manufacturer suffers from misplacement problems, thus the manufacturer may also be active in adopting RFID. For example, Anjos Baby, a children's clothing manufacturer in Brazil, employs an RFID system to optimize inventory management and the misplacement rate is decreased close to zero. (https://www.rfidjournal.com/articles/view?17881.)

Once an upstream enterprise (manufacturer) attaches an RFID tag on each item, then a downstream enterprise (retailer) can reuse the same tags to eliminate its own misplacement problem at zero tag cost, leading to an interesting, one-sided "free-rider" problem, where the retailer would wait to free-ride on the manufacturer's first move, but not vice versa. Therefore, there are three kinds of scenarios in a Dual-channel supply chain regarding whether the manufacturer or the retailer adopts RFID technology. The first scenario is that neither the manufacturer nor the retailer adopts RFID (Scenario N). As such, both players have inventory misplacement problems. The second scenario is that only the retailer adopts RFID technology (Scenario R). Thus, the retailer can avoid the misplacement problem while the manufacturer still suffers from inventory misplacements. The third scenario is that the manufacturer attaches an RFID tag on each product during the production process (Scenario M). As a result, neither the manufacturer nor the retailer experiences misplacement due to the retailer being a free-rider to enjoy the RFID technology. Under such a circumstance, we assume that the retailer will share a proportion of RFID tag cost in its retail channel to enable the manufacturer to adopt RFID technology. It is interesting to discuss that how the Dual-channel supply chain players choose RFID adoption strategies in response to the competition between the direct channel and the retail channel.

Generally speaking, in a Dual-channel supply chain, it is fairly common for channels to choose price competition or quantity competition as their strategic instruments in practice (Reisinger and Ressner, 2009; Tremblay et al., 2013a, 2013b). For example, in the wine industry, the distilled spirits industry and the apparel industry, channels engage in a Bertrand (price) competition. Interestingly, most companies in these industries, such as KWV wines, Wuliangye, GU, H&M and GAP et al., have adopted RFID technology to prevent misplacement problems. However, in the blended liquor industry, channels engage in a Cournot (quantity) competition while they forgo RFID adoption. The sharp contrast in RFID-adoption and non-RFID-adoption practices among the competing channels highlights the competition mode being a possible factor in channels' RFID adoption decisions. Therefore, we compare channels' RFID adoption decisions between Bertrand competition and Cournot competition to explore which competition mode is beneficial to promoting RFID application in a Dual-channel supply chain.

To the best of our knowledge, neither the role of the direct channel's misplacement rate in RFID adoption nor the issue of RFID application under the differentiated competition modes in a Dual-channel setting has been explored in the literature. We hope to fill these gaps by addressing the following research questions:

How would the manufacturer's misplacement rate affect channels' profits and RFID adoption decisions?

What are the equilibrium prices or order quantities and how to coordinate the Dual-channel supply chain considering different RFID adoption scenarios under two competition modes (i.e., Bertrand competition and Cournot competition), respectively?

What is the optimal RFID adoption strategy for the players in the Dual-channel supply chain under two competition modes? Which competition mode is beneficial to promoting RFID adoption?

We consider a supply chain where a manufacturer (she), the Stackelberg leader, distributes her products through an independent retailer (he) and her direct channel. Both firms suffer from inventory misplacement errors and are thus in need of adopting RFID technology. The manufacturer and the retailer sequentially decide whether to adopt RFID. We coordinate the Dual-channel supply chain with different RFID adoption scenarios considering two competition modes (i.e., Bertrand competition and Cournot competition). Our results show that the optimal RFID adoption strategies are determined by the unit RFID tag cost, channels' misplacement rates, and competition intensity. It is unfavorable for the Dual-channel supply chain players to adopt the RFID technology as the tag cost increases and the channel competition is more intense.

Our paper makes several contributions. First, while previous research typically focuses on RFID adoption decision in only retail channel structure, we enrich the previous literature in inventory management filed by considering RFID adoption decision in a Dual-channel structure where both manufacturer and retailer have inventory misplacement problems. Second, most of the prior RFID adoption decision literature is limited to a one-to-one supply chain structure consisting of a manufacturer and a retailer, except Zhang, Li and Fan (2018a), which consider a supply chain consisting of one manufacturer and two competitive retailers, both of whom engage in a Bertrand (price) competition. We investigate two channels engaging in a Bertrand (price) competition and Cournot (quantity) competition, and compare two competition options in terms of the optimal RFID adoption strategy and supply chain coordination. Furthermore, we discuss that which competition option is more conducive to the RFID adoption and supply chain coordination.

The rest of this paper is organized as follows. The related literature is reviewed in Section 2. Section 3 presents the model. Section 4 explores the pricing and quantity strategies with different RFID strategies. Section 5 discusses the optimal RFID adoption strategies under Bertrand and Cournot competitions. Section 6 investigates the comparison of two competition options. Section 7 presents conclusions and future research directions.

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2. Literature Review

Our work is related to three streams of literature: Dual-channel supply chain, RFID adoption strategy in a supply chain, and Revenue-sharing contract. To our knowledge, this paper is the first to study the comparative analysis between Bertrand (price) competition and Cournot (quantity) competition in terms of the optimal RFID adoption strategy and coordination in a Dual-channel supply chain, in which both the manufacturer and the retailer suffer from inventory misplacement problems. We connect the insights from these domains of knowledge to gain deeper understandings of the RFID adoption decision and inventory misplacement problems issues.

The first stream of literature that related to our research is the Dual-channel supply chain. Academic research on the Dual-channel supply chain has significantly proliferated over the recent years, which mainly focused on pricing or quantity decisions, channel selection, and the coordination of the Dual-channel supply chain. We review this stream of literature from three perspectives: (i) how should the players make decisions in the presence of Dual-channel supply chain is an important issue for the supply chain players. Matsui (2017) studied how a manufacturer should set the wholesale price and the direct channel price to maximize its profit in a Dual-channel supply chain. Chen et al. (2017) examined the price and quality decisions in different channel structures. Li et al. (2017) investigated the pricing strategy and the return policy in a Dual-channel supply chain. Zhou et al. (2020) studied the behavior-based price discrimination strategies of the manufacturer in a Dual-channel supply chain with the retailer's information disclosure. (ii) The question of channel selection is arising as the introduction of the direct channel by the manufacturer. Some studies discuss the retailer's channel selection decisions, for example, Wang, Li and Cheng (2016) studied the channel selection of retailer in a multi-channel supply chain and found that operating costs were the critical factor affecting the retailer's channel selection; Zhang, He, and Shi (2017) found that the retailer's channel structure choices depend primarily on consumer preferences. There are also some studies discussing the manufacturer's channel selection decisions, for instance, He, He, and Xu (2019) dealt with the pricing decisions and manufacturer's channel selection in a Dual-channel closed-loop supply chain with government-subsidized; Yang, Shi, and Jackson (2015) studied the channel selection issues of two competing manufacturers selling different products by three types of competitions. (iii) How to coordinate the Dual-channel supply chain is also an interesting topic as the presence of the direct channel changes the channel relationship between the upstream and downstream players. Zheng et al. (2017) examined the impact of the power structure and channel competition on the Dual-channel closed-loop supply chain and coordinated the supply chain with the improved two-part tariff contracts. Chen et al. (2017) found that the two-part tariff contract and the negotiated Revenue-sharing contract could coordinate the Dual-channel supply chain within a particular scope, leading to a win-win situation for the manufacturer and the retailer. Our work differs from the above studies in three dimensions. First, we consider both channels engage in a price competition and in a quantity competition, and tend to explore a comparative analysis between two competition modes, rather than the above research considers only a price competition or a quantity competition and focuses on the pricing or ordering quantity decisions. Second, inventory misplacement is a norm and tough problem in channels whereas these papers disregard such an important factor. By contrary, this work considers both the manufacturer and the retailer suffer from inventory misplacement problems in a Dual-channel supply chain. Third, because these studies ignore the firms' misplacement problems, thus there is no analysis on whether RFID technology should be employed in a Dual-channel supply chain. The current work differs from the above studies in considering the RFID adoption in three scenarios, i.e., neither player adopts RFID technology (Scenario N), only the retailer adopts RFID technology (Scenario R), the manufacturer adopts

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RFID technology while the retailer becomes a free-rider to enjoy the RFID technology (Scenario M), to eliminate one or both firms' inventory misplacement problems.

The second stream of literature that related to our research is the RFID adoption strategy in a supply chain. Many studies indicate that RFID technology is an effective solution to resolve the inventory misplacement problem (Hardgrave, Aloysius and Goyal 2013; Fan et al. 2014). However, since the cost of adopting RFID is relatively high (Chang, Klabjan and Vossen 2010), the scholars are focusing on what kind of strategy should be employed for a better implementing RFID in supply chains (Fan et al. 2015; Wang et al. 2018; Zhang, Li, and Fan 2018), such as only the retailer adopts RFID, or the supply chain players cooperate to adopt RFID, etc. In addition, academic research on RFID deployment also focused on: employing RFID technology may lead to one-sided "free-rider" problem in a supply chain (Whang, 2010); employing RFID technology could promote the information visibility among the firms (Gaukler, Seifert and Hausman, 2007; Heese, 2007; Rekik, Syntetos and Jemai, 2015); and the firms' decision-making on whether or not to employ RFID technology (Chen et al, 2014; Zhang and Yang, 2019). Notably, the above literature discussed RFID deployment in a one-to-one supply chain structure, which only consists of a manufacturer and a retailer. In addition, few papers have started to incorporate retail competition into models. Zhang, Li and Fan (2018a) considered a supply chain consisting of one manufacturer and two competitive retailers. They assumed both retailers engage in a Bertrand (price) competition and showed that one retailer would employ RFID technology while his rival retailer refused to employ RFID technology when the tag price was intermediate. Our work differs from above researches in three aspects. First, the studies discussed above only consider the retailer's inventory misplacement problem and disregard how the manufacturer's misplacement problem affects RFID deployment decisions in a supply chain. By contrary, our work enquires into such effect. Second, the above papers mainly deal with RFID deployment decisions in a traditional supply chain setting, which only consists of retail channel(s). Since lots of manufacturers have launched the Dual-channel distribution strategy in the Internet era (Xiao and Shi, 2016), it is also a critical problem of what the optimal RFID deployment strategy is in a Dual-channel supply chain. Third, previous literature incorporates retail competition into models on RFID deployment considering only a price competition. In contrast, the current work investigates two channels engaging in a Bertrand (price) competition and Cournot (quantity) competition, and compares two competition options in terms of the optimal RFID adoption strategy and supply chain coordination. Furthermore, this wok also discusses that which competition option is more conducive to the RFID adoption and supply chain coordination.

The final stream of literature related to our research is the Revenue-sharing contract, which has been extensively studied in the field of supply chain coordination, such as Cachon and Lariviere (2005), Wang, Jiang and Shen (2004), Arani, Rabbani and Rafiei (2016), etc. We refer to Cachon (2003) and Guo et al. (2017) for comprehensive literature reviews regarding the research on supply chain coordination. Cachon and Lariviere (2005) conducted a comprehensive study that summarized the pros and cons of a Revenue-sharing contract. Yao, Leung and Lai (2008) utilized a Revenue-sharing contract to coordinate the supply chain consisting of one manufacturer and two competing retailers. They showed that the Revenue-sharing contract could lead to a better supply chain performance than a wholesale price contract. Cao, Zhou and Lϋ (2015) proposed an improved Revenue-sharing contract to coordinate the decentralized supply chain in the event of an outage. Zhang et al. (2015) designed a Revenue-sharing contract and a cooperative investment contract, which integrated Revenue-sharing and cost-sharing mechanisms, to coordinate the supply chain consisting of a manufacturer and a retailer. Han et al. (2017) found that the Revenue-sharing contracts could effectively coordinate the closed-loop supply chain and improve the benefits for the supply chain players.

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Table 1. Summary of the related literature and new contributions

Reference	RFID adoption in a supply chain with		Inventory misplacement problems in		Competition options		Coordination
	only retail channel (s)	both direct and retail channels	only downstream enterprise(s)	both upstream and downstream enterprises	Bertrand competition	Cournot competition	
Wang et al. (2018)	✔		✔				
Chen et al. (2014)	✔		✔				✔
Whang (2010)	✔		✔				
Gaukler et al. (2007)	✔		✔				
Rekik (2011)	✔		✔				
Zhang et al. (2018a)	✔		✔		✔		
Wang et al. (2016)	✔		✔				
Xu et al. (2012)	✔		✔				
Zhang & Yang (2019)	✔		✔				
Zhang et al. (2018b)	✔		✔				✔
Fan et al. (2015)	✔		✔				
Xu et al. (2014)							✔
Cachon & Lariviere (2005)						✔	✔
Zhang et al. (2015)							✔
Yao et al. (2008)							✔
Hsieh & Lai (2019)						✔	
Niederhoff & Kouvelis (2019)							✔
Matsui (2017)					✔		
He et al. (2019)						✔	
Liu et al. (2016)					✔		
This paper		✔		✔	✔	✔	✔

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Niederhoff and Kouvelis (2019) explored under what conditions the Revenue-sharing contracts were more effective in improving the system efficiency than the wholesale contract. Noticely, the above papers mainly analyze the Revenue-sharing contract in a traditional supply chain setting, which only consists of retail channel(s). Moreover, a few papers have studied the coordination in the Dual-channel supply chain with Revenue-sharing contract. Xu et al. (2014) proposed a two-way Revenue-sharing contract to coordinate a risk-averse Dual-channel supply chain, and they examined that how the firms' risk attitude affected the Revenue-sharing coefficient. They found that the manufacturer could provide such a contract to encourage the retailer to cooperate and achieve a win-win situation for both players. Our work differs from above researches in three dimensions. First, the studies discussed above focus on how to coordinate a traditional single-channel or Dual-channel supply chain with the Revenue-sharing contract. However, few papers have considered the coordination problem when there is an inventory misplacement problem in a supply chain, especially in a Dual-channel supply chain where both firms face inventory misplacement problems. Second, because these studies ignored the misplacement problems, thus there was no analysis on how to share the firms' profits by adopting Revenue-sharing contract in three RFID employment scenarios under the differentiated competition options. Finally, we compare the Revenue-sharing coefficient that makes both firms be better off under different combinations of RFID adoption scenarios and competition options; whereas no discussions were provided in the above studies.

Furthermore, we provide a comparison table, as shown in Table 1, with the most relevant papers discussed in the literature review, to highlight the research gaps and contributions that this paper will focus on.

3. The Model

In this paper, we consider a two-echelon Dual-channel supply chain that involves a manufacturer (she) distributes products through an independent retailer (he) and her own direct sales channel. For convenience, we index the manufacturer, the retailer, and the supply chain by superscripts m , r , and C , respectively. We consider two competition options of Bertrand and Cournot competition. Following demand functions used by Bolandifar, Kouvelis and Zhang (2016), Savaskan, Bhattacharya and Wassenhove (2004), and Liu et al. (2016), demands in the direct channel (d_m) and the retail channel (d_r) under Bertrand competition are $d_m = a - p_m + \beta p_r$ and $d_r = a - p_r + \beta p_m$, respectively. The linear inverse demand functions are wildly used in related literature (e.g., He, He and Xu 2019; Hsieh and Lai, 2019). The inverse demands in the direct channel and the retail channel under Cournot competition are respectively $p_m = a - d_m - \beta d_r$ and $p_r = a - d_r - \beta d_m$, where a ($a > 0$) is the market potential and β ($\beta \in (0,1)$) is a measure of the substitutability of the two channels. The parameter β is usually interpreted as the competition intensity between the two channels where a larger β indicates a higher degree of competition. p_m and p_r represent the prices sold by the direct channel and the retail channel, respectively.

In the Dual-channel supply chain, both the manufacturer and the retailer have inventory misplacement problems, and their inventory misplacement rates are α_m and α_r , respectively. If the manufacturer produces Q products, $\alpha_m Q$ products cannot be sold due to her misplacement problem, and only $(1-\alpha_m)Q$ products can be used to satisfy the order quantity of the direct channel and the retail channel. Similarly, if the retailer orders q_r products, $\alpha_r q_r$ products cannot be sold due to his misplacement problem, hence, only $(1-\alpha_r)q_r$ products can be used to satisfy the market demand of the retail channel.

The case study finding of Ellis et al. (2018) identifies that more than 99% of the RFID tags have a 99% or higher read-rate. Therefore, we assume that a channel's misplacements can be completely recovered if that channel sells a product with an RIFD tag. This assumption is used in many papers (see Heese, 2007; Camdereli and Swaminathan, 2010; Chen et al., 2014; Zhang, Li and Fan, 2018a). In addition, the fixed cost of RFID is ignored, and only the unit RFID tag cost c_t is considered, which is similar to Wang et al. (2016) and Fan et al. (2015). The reason is that the RFID fixed cost may be a small proportion of the total costs of employing RFID technology, since the channels regularly order huge units of product and leads to large variable RFID tag costs (Zhang et al, 2018b).

When the manufacturer adopts RFID technology (Scenario *M*), the retailer can free-ride on the manufacturer's RFID adoption and then there is no inventory misplacement problem for both channels (i.e., $\alpha_r = \alpha_m = 0$). The retailer shares θc_t per RFID tag cost of the retail channel to enable the manufacturer to adopt RFID technology. When only the retailer adopts RFID technology (Scenario *R*), his inventory misplacement problem is completely eliminated (i.e., $\alpha_r = 0$) while the manufacturer still has a misplacement problem. When neither the manufacturer nor the retailer adopts RFID technology (Scenario *N*), both firms have inventory misplacement problems.

In this paper, we assume that the manufacturer is a Stackelberg leader and the retailer is a follower. We consider two games, an RFID adoption game and an operations game. The sequence of events is as follows.

First, both firms decide RFID adoption decisions. Specifically, the manufacturer first decides whether or not to adopt RFID technology, after which the retailer decides whether to adopt RFID based on the manufacturer's RFID adoption strategy.

Second, both firms decide operations decisions. Specifically, when the two channels engage in a Bertrand competition (pricing game), a finding of Matsui (2017) identifies that the manufacturer should post her direct selling price earlier than the retailer's retail price under a Dual-channel structure; therefore, we assume that the manufacturer sets the wholesale price and the direct selling price simultaneously, and then the retailer decides his retail price. When the two channels engage in a Cournot competition (quantity game), a finding of Ha, Long and Nasiry (2015) indicates that the manufacturer should always post the direct channel's order quantity after observing the retail channel's order quantity under aDual-channel structure; thus, we assume that the manufacturer first announces the wholesale price, after which the retailer decides his order quantity, and then the manufacturer sets her direct selling quantity.

In order to avoid trivial cases, we make a few additional mild assumptions. The assumptions $\alpha_m < 1 - c_m / a = \bar{\alpha}_m$ and $c_t < (1-\beta)[a(1-\alpha_m) - c_m]/(1-\alpha_m) = \bar{c}_t$ state that the sales are non-negative and the partners should be profitable in the potential market, which is a rather weak requirement. We also assume the manufacturer and the retailer are both risk-neutral and information is completely symmetrical.

4. Firms' Pricing and Quantity Strategies

According to the firms' RFID adoption decisions, we establish the firms' profit models with three different scenarios under Bertrand competition and Cournot competition in the Dual-channel supply chain: Non-RFID adoption (Scenario *N*), only the retailer adopts RFID (Scenario *R*) and the manufacturer adopts RFID (Scenario *M*). In each scenario, we also analyze three settings (i.e., decentralized setting, centralized setting and coordination setting), and obtain the optimal prices / order quantities and contract parameters. For convenience, we index the cases under Bertrand competition and Cournot competition by subscripts $i = b$ and $i = g$, respectively.

4.1. Scenario N: Non-RFID Adoption

In Scenario *N*, neither the manufacturer nor the retailer adopts RFID technology. Thus, both two firms have inventory misplacement problems. For the manufacturer, only $(1-\alpha_m)Q_i^N$ products are available to satisfy the demand of the two channels. In addition, for the retailer, only $(1-\alpha_r)q_{r,i}^N$ products can be sold to customers. The profits of the manufacturer, the retailer and the Dual-channel supply chain are formulated as $\pi_{m,i}^N$, $\pi_{r,i}^N$ and $\pi_{C,i}^N$, respectively, leading to

$$\begin{cases} \pi_{m,i}^N = p_{m,i}^N q_{m,i}^N + w_i^N q_{r,i}^N - c_m Q_i^N \\ \pi_{r,i}^N = p_{r,i}^N (1-\alpha_r) q_{r,i}^N - w_i^N q_{r,i}^N \\ \pi_{C,i}^N = p_{m,i}^N q_{m,i}^N + p_{r,i}^N (1-\alpha_r) q_{r,i}^N - c_m Q_i^N \end{cases}$$

We solve the problem by backward induction with $q_{m,b}^N = a - p_{m,b} + \beta p_{r,b}$ and $q_{r,b}^N = (a - p_{r,b} + \beta p_{m,b})/(1-\alpha_r)$ if the two channels engage in a Bertrand competition, while $p_{m,g}^N = a - q_{m,g} - \beta(1-\alpha_r) q_{r,g}$ and $p_{r,g}^N = a - (1-\alpha_r) q_{r,g} - \beta q_{m,g}$ if the two channels engage in a Cournot competition. In addition, $Q_i^N = (q_{r,i}^N + q_{m,i}^N)/(1-\alpha_m)$. We obtain the two firms' optimal profits in the decentralized supply chain and the optimal profit of the centralized supply chain as shown in Proposition 1.

Proposition 1. *In* Scenario *N:*

(i) Under Bertrand *competition, the optimal profits of the retailer and the manufacturer with decentralized setting are* respectively $\pi_{r,b}^{N*} = \left(\frac{a}{4} - \frac{[1-(1-\alpha_r)\beta] c_m}{4(1-\alpha_m)(1-\alpha_r)} \right)^2$ *and* $\pi_{m,b}^{N*} = \frac{(3+\beta)a^2}{8(1-\beta)} - \frac{[1+(1-\alpha_r)(2+\beta)] a c_m}{4(1-\alpha_m)(1-\alpha_r)} - \frac{[2(1-\alpha_r)\beta - (1-\alpha_r)^2 (2-\beta^2) - 1] c_m^2}{8(1-\alpha_m)^2 (1-\alpha_r)^2}$ *; the optimal profit with centralized setting is* $\pi_{C,b}^{N*} = \frac{1}{2(1-\beta)} a^2 - \frac{(2-\alpha_r) a c_m}{2(1-\alpha_r)(1-\alpha_m)} + \frac{[(1-\alpha_r)^2 - 2\beta(1-\alpha_r) + 1] {c_m}^2}{4(1-\alpha_r)^2 (1-\alpha_m)^2}$.

(ii) Under Cournot competition, *the optimal profits of the retailer and the manufacturer with decentralized setting are* $\pi_{r,g}^{N*} = 2(2-\beta^2)[\frac{a(1-\beta)}{(8-5\beta^2)} - \frac{1-\beta(1-\alpha_r)}{(8-5\beta^2)(1-\alpha_m)(1-\alpha_r)} c_m]^2$ *and* $\pi_{m,g}^{N*} = \frac{{c_m}^2 [4(3-4\alpha_r + 2{\alpha_r}^2) - 8\beta(1-\alpha_r) - \beta^2 (1-\alpha_r)^2]}{4(8-5\beta^2)(1-\alpha_m)^2 (1-\alpha_r)^2} + \frac{a c_m [-12 + \beta(8+\beta) + 8\alpha_r - (4+\beta)\beta\alpha_r]}{2(8-5\beta^2)(1-\alpha_m)^2 (1-\alpha_r)^2} + \frac{a^2 [12 - \beta(8+\beta)]}{4(8-5\beta^2)}$, *respectively; the optimal profit with* centralized *setting is* $\pi_{C,g}^{N*} = \frac{1}{2(1+\beta)} [a^2 - \frac{(2-\alpha_r) a c_m}{(1-\alpha_r)(1-\alpha_m)} - \frac{\left[2\beta(1-\alpha_r) - (1-\alpha_r)^2 - 1\right] {c_m}^2}{2(1-\beta)(1-\alpha_r)^2 (1-\alpha_m)^2}]$.

On the basis of Proposition 1, with $\partial \pi_{C,i}^{N*} / \partial \alpha_m < 0$, we show that $\pi_{C,i}^{N*}$ decreases in the manufacturer's misplacement rate α_m when neither firm adopts RFID technology. Therefore, the manufacturer's misplacement rate is an important factor which cannot be ignored in a Dual-channel supply chain. In addition, it is easy to prove $\pi_{C,i}^{N*} > \pi_{m,i}^{N*} + \pi_{r,i}^{N*}$, which indicates that the total profit under the centralized supply chain is larger than that under the decentralized supply chain. We consider a Revenue-sharing contract and investigate coordination issues under this contract in Scenario N. To coordinate the Dual-channel system, the order quantities must be equal for the centralized and decentralized systems. Then we obtain the following proposition.

Proposition 2. *In Scenario N: under Bertrand / Cournot competition, the profits of the decentralized setting under a Revenue-sharing contract are the same as that of the centralized setting if and only if* $\hat{w}_b^{N*} = 2(1-\hat{\varphi}_b^{N*})(1-\alpha_r)\{\frac{a\beta}{4(1-\beta)} + \frac{c_m [2-\beta(1-\alpha_r)]}{4(1-\alpha_m)(1-\alpha_r)}\}$ /

$\hat{w}_g^{N*}=(1-\hat{\varphi}_g^N)[\frac{a\beta(1-\alpha_r)}{2(1+\beta)}-\frac{(\beta^2-\beta\alpha_r+\beta-2)c_m}{2(1-\beta^2)(1-\alpha_m)}]$. *In addition, if the Revenue-sharing coefficient satisfies* $\hat{\varphi}_b^N\in[1/2,3/4]$ / $\hat{\varphi}_g^N\in[\frac{4-\beta^4}{8-5\beta^2},1-\frac{8(2-\beta^2)(1-\beta^2)^2}{(8-5\beta^2)^2}]$, *the Revenue-sharing contract makes both firms be better off compared with the decentralized setting.*

Proposition 2 states that the Revenue-sharing contract can coordinate the Dual-channel supply chain when neither firm adopts RFID, regardless of whether the two channels engage in a Bertrand competition or Cournot competition. Further, with $\partial\hat{w}_i^{N*}/\partial\beta>0$, we know that $\hat{w}_i^{N*}$ increases in β. This finding implies that if the channel competition is more intense, the manufacturer will increase the wholesale price to reduce the retailer's order quantity, which makes her direct channel obtain more profits. In addition, through $\partial\hat{w}_i^{N*}/\partial\alpha_m>0$, we can see that $\hat{w}_i^{N*}$ increases in α_m. The finding suggests that the more serious the manufacturer's misplacement problem is, the higher wholesale prices she can set. This is because the manufacturer raises her wholesale price to cover her loss from the misplaced items.

Moreover, with $\partial\hat{w}_b^{N*}/\partial\alpha_r<0$, we know that when the retailer's misplacement problem becomes more serious, the manufacturer will set a lower wholesale price under *Bertrand competition*. An intuitive explanation is that an increase in α_r will force the retailer to *raise his retail price* to cover his loss from the misplacement. Thus, the retail channel's demand decreases and the manufacturer will lower the wholesale price to attract more orders from the retailer. Interestingly, this finding is not true when two channels engage in *Cournot competition*. We have $\partial\hat{w}_g^{N*}/\partial\alpha_r<0$ if $\alpha_m\in(0,1-c_m/a(1-\beta)]$, while $\partial\hat{w}_g^{N*}/\partial\alpha_r>0$ if $\alpha_m\in(1-c_m/a(1-\beta),\bar{\alpha}_m)$. This finding implies that when the manufacturer's misplacement rate is small (i.e., $\alpha_m\in(0,1-c_m/a(1-\beta)]$) / large (i.e., $\alpha_m\in(1-c_m/a(1-\beta),\bar{\alpha}_m)$), the manufacturer may decrease/increase her wholesale price if the retailers' misplacement problem is more serious. The reason is that an increase in α_r will force the retailer to *increase his order quantity* to satisfy the demand. When the manufacturer's misplacement rate is small (i.e., $\alpha_m\in(0,1-c_m/a(1-\beta)]$), she may have sufficient products to satisfy the demand of the two channels, thus the manufacturer will lower the wholesale price. However, when the manufacturer's misplacement rate is large (i.e., $\alpha_m\in(1-c_m/a(1-\beta),\bar{\alpha}_m)$), she may have insufficient products to satisfy the retailer's order quantity, then the product is scarce and the manufacturer will increase the wholesale price.

4.2. Scenario R: Only the Retailer Adopts RFID

Since the retailer has inventory misplacement problem, he is well motivated to adopt RFID technology to avoid unnecessary ordering. If the manufacturer forgoes RFID adoption, some retailers paste RFID tags to the products one by one before the products are put into storage, perhaps some retailers entrust the manufacturers to paste an RFID tag on each product during the production process and bear the whole RFID tag costs. In Scenario R, the retailer's misplacement problem was completely eliminated because of adopting RFID technology. Thus, the retailer's order quantity can be all for satisfying the market demand. However, the manufacturer still has misplacement error and the total number of products that can be used to satisfy both channels are $(1-\alpha_m)Q_i^R$. The profits of the manufacturer, the retailer and the supply chain are formulated as $\pi_{m,i}^R$, $\pi_{r,i}^R$ and $\pi_{C,i}^R$, respectively, leading to

$$\begin{cases}\pi_{m,i}^R=w_i^Rq_{r,i}^R+p_{m,i}^Rq_{m,i}^R-c_mQ_i^R\\ \pi_{r,i}^R=(p_{r,i}^R-w_i^R-c_t)q_{r,i}^R\\ \pi_{C,i}^R=(p_{r,i}^R-c_t)q_{r,i}^R+p_{m,i}^Rq_{m,i}^R-c_mQ_i^R\end{cases}$$

We solve the problem by backward induction with $q_{m,b}^R = a - p_{m,b} + \beta p_{r,b}$ and $q_{r,b}^R = a - p_{r,b} + \beta p_{m,b}$ if the two channels engage in a Bertrand competition, while $p_{m,g}^R = a - q_{m,g} - \beta q_{r,g}$ and $p_{r,g}^R = a - q_{r,g} - \beta q_{m,g}$ if the two channels engage in a Cournot competition. In addition, $Q_i^R = (q_{r,i}^R + q_{m,i}^R)/(1-\alpha_m)$. We obtain the two firms' optimal profits in the decentralized supply chain and the optimal profit in the centralized supply chain as shown in Proposition 3.

Proposition 3. *In Scenario R:*

(i) Under Bertrand *competition, the optimal profits of the retailer and the manufacturer with decentralized setting are respectively* $\pi_{r,b}^{R*} = \frac{1}{16}[a - \frac{(1-\beta)c_m}{1-\alpha_m} - c_t]^2$ *and* $\pi_{m,b}^{R*} = \frac{1}{8}[{c_t}^2 - 2(1-\beta)(\frac{a}{1-\beta} - \frac{c_m}{1-\alpha_m})c_t + (3+\beta)(1-\beta)(\frac{a}{1-\beta} - \frac{c_m}{1-\alpha_m})^2]$*; the optimal profit with centralized setting is* $\pi_{C,b}^{R*} = \frac{1}{4}\{{c_t}^2 - 2[a - \frac{(1-\beta)c_m}{1-\alpha_m}]c_t + \frac{2}{1-\beta}[a - \frac{(1-\beta)c_m}{1-\alpha_m}]^2\}$.

(ii) Under Cournot competition*, the optimal profits of the retailer and the manufacturer with decentralized setting are respectively* $\pi_{r,g}^{R*} = \frac{2(2-\beta^2)}{(8-5\beta^2)^2}[a(1-\beta) - \frac{(1-\beta)c_m}{1-\alpha_m} - c_t]^2$ *and* $\pi_{m,g}^{R*} = \frac{1}{(8-5\beta^2)}\{\frac{[12-\beta(8+\beta)][{c_m}^2 + a^2(1-\alpha_m)^2]}{4(1-\alpha_m)^2} + \frac{2(1-\beta)c_m c_t}{(1-\alpha_m)} + {c_t}^2 - 2a(1-\beta)c_t - \frac{a[12-\beta(8+\beta)]c_m}{2(1-\alpha_m)}\}$ *; the optimal profit with centralized setting is* $\pi_{C,g}^{R*} = \frac{1}{4(1+\beta)}[\frac{1}{1-\beta}{c_t}^2 - 2(a - \frac{c_m}{1-\alpha_m})c_t + 2(a - \frac{c_m}{1-\alpha_m})^2]$.

From Proposition 3, with $\partial\pi_{C,i}^{R*}/\partial\alpha_m < 0$, we show that $\pi_{C,i}^{R*}$ also decreases in the manufacturer's misplacement rate α_m when only the retailer adopts RFID technology. Moreover, we also have $\pi_{C,i}^{R*} > \pi_{m,i}^{R*} + \pi_{r,i}^{R*}$. We consider a Revenue-sharing contract and investigate coordination issues under this contract in Scenario R. To coordinate the Dual-channel system, the order quantities must be equal for the centralized and decentralized systems. Then we obtain the following proposition.

Proposition 4. *In* Scenario R *: under Bertrand / Cournot competition, the profits of the decentralized setting under a Revenue-sharing contract are the same as that of the centralized setting if and only if*

$$\hat{w}_b^{R*} = (1-\hat{\varphi}_b^R)[\frac{a\beta}{2(1-\beta)} + \frac{(2-\beta)c_m}{2(1-\alpha_m)} - \frac{\hat{\varphi}_b^R c_t}{1-\hat{\varphi}_b^R}] \;/\; \hat{w}_g^{R*} = \frac{(1-\hat{\varphi}_g^R)}{2(1+\beta)}[a\beta + \frac{(2+\beta)c_m}{1-\alpha_m} + \frac{(2-\beta^2)c_t}{1-\beta}] - c_t.$$

In addition, if the Revenue-sharing coefficient satisfies $\hat{\varphi}_b^R \in [1/2, 3/4]$ */* $\hat{\varphi}_g^R \in [\frac{4-\beta^4}{8-5\beta^2}, 1 - \frac{8(2-\beta^2)(1-\beta^2)^2}{(8-5\beta^2)^2}]$*, the Revenue-sharing contract makes both firms be better off compared to the decentralized setting.*

Proposition 4 indicates that the Revenue-sharing contract can coordinate the Dual-channel supply chain when only the retailer adopts RFID, regardless of whether the two channels engage in Bertrand competition or Cournot competition. Further, with $\partial\hat{w}_i^{R*}/\partial\beta > 0$, we know that $\hat{w}_i^{R*}$ increases in β. This finding implies that if the channel competition is more intense, the manufacturer will increase the wholesale price to reduce the retailer's order quantity, which makes her direct channel obtain more profits. In addition, through $\partial\hat{w}_i^{R*}/\partial\alpha_m > 0$, we can see that $\hat{w}_i^{R*}$ increases in α_m. The finding suggests that the more serious the manufacturer's misplacement problem is, the higher wholesale prices she can set. This is because the manufacturer raises her wholesale price to cover her loss from the misplaced items. Moreover, with $\partial\hat{w}_i^{R*}/\partial c_t<0$, we know that $\hat{w}_i^{R*}$ decreases in c_t. The reason is that the retailer bears the whole RFID tag costs in this scenario, thus the manufacturer will lower the wholesale price accordingly in order to attract more orders from the retailer.

4.3. Scenario M: The Manufacturer Adopts RFID

In order to eliminate the misplacement, the manufacturer may paste an RFID tag on each product during the production process. Thus, the manufacturer's direct channel does not have misplacement problem. In addition, the manufacturer delivers the retailer products with RIFD tags that can help him avoid manual errors in placing inventory whereby the retailer's misplacement problem can be effectively eliminated. We assume that the retailer shares $\theta_i c_t$ ($\theta_i\in[0,1]$) per RFID tag cost of the retail channel's product to motivate the manufacturer to adopt RFID technology, while the manufacturer bears the whole RFID tag costs of the direct channel. The profits of the manufacturer, the retailer and the supply chain are formulated as $\pi_{m,i}^M$, $\pi_{r,i}^M$ and $\pi_{C,i}^M$, respectively, leading to

$$\begin{cases}\pi_{m,i}^M=w_i^M q_{r,i}^M+p_{m,i}^M q_{m,i}^M-c_m Q_i^M-c_t q_{m,i}^M-(1-\theta_i)c_t q_{r,i}^M\\ \pi_{r,i}^M=(p_{r,i}^M-w_i^M)q_{r,i}^M-\theta_i c_t q_{r,i}^M\\ \pi_{C,i}^M=p_{r,i}^M q_{r,i}^M+p_{m,i}^M q_{m,i}^M-(c_m+c_t)Q_i^M\end{cases}$$

We solve the problem by backward induction with $q_{m,b}^M=a-p_{m,b}+\beta p_{r,b}$ and $q_{r,b}^M=a-p_{r,b}+\beta p_{m,b}$ if the two channels engage in a Bertrand competition, while $p_{m,g}^M=a-q_{m,g}-\beta q_{r,g}$ and $p_{r,g}^M=a-q_{r,g}-\beta q_{m,g}$ if the two channels engage in a Cournot competition. In addition, $Q_i^M=q_{r,i}^M+q_{m,i}^M$. We obtain the two firms' optimal profits in the decentralized supply chain and the optimal profit in the centralized supply chain as shown in Proposition 5.

Proposition 5. *In Scenario M:*

(i) Under Bertrand competition, the optimal profits of the retailer and the manufacturer with decentralized setting are respectively $\pi_{r,b}^{M*}=[a-(1-\beta)(c_m+c_t)]^2/16$ *and* $\pi_{m,b}^{M*}=(3+\beta)[a-(1-\beta)(c_m+c_t)]^2/8(1-\beta)$ *; the optimal profit with centralized setting is* $\pi_{C,b}^{M*}=[a-(1-\beta)(c_m+c_t)]^2/2(1-\beta)$.

(ii) Under Cournot competition, the optimal profits of the retailer and the manufacturer with decentralized setting are $\pi_{r,g}^{M*}=2(2-\beta^2)(1-\beta)^2(a-c_m-c_t)^2/(8-5\beta^2)^2$ *and* $\pi_{m,g}^{M*}=(12-\beta^2-8\beta)(a-c_m-c_t)^2/4(8-5\beta^2)$ *respectively; the optimal profit with centralized setting is* $\pi_{C,g}^{M*}=(a-c_m-c_t)^2/2(1+\beta)$.

From Proposition 5, it is easy to prove $\pi_{C,i}^{M*}>\pi_{m,i}^{M*}+\pi_{r,i}^{M*}$. We consider a Revenue-sharing contract and investigate coordination issues under this contract in Scenario M. To coordinate the Dual-channel system, the order quantities must be equal for the centralized and decentralized systems. Then we obtain the following proposition.

Proposition 6. *In Scenario M: under Bertrand / Cournot competition, the profits of the decentralized setting under a Revenue-sharing contract are the same as that of the centralized setting if and only if*

$$\hat{w}_b^{M*}=(1-\hat{\varphi}_b^M)\left[\frac{a\beta}{2(1-\beta)}+\frac{(2-\beta)(c_m+c_t)}{2}\right]-\theta_b c_t\ /\ \hat{w}_g^{M*}=(1-\hat{\varphi}_g^M)\left[\frac{a\beta}{2(1+\beta)}+\frac{(2+\beta)(c_m+c_t)}{2(1+\beta)}\right]-\theta_g c_t.$$

In addition, if the Revenue-sharing coefficient satisfies

$$\hat{\varphi}_b^M\in[1/2,3/4]\ /\ \hat{\varphi}_g^M\in[\frac{4-\beta^4}{8-5\beta^2},1-\frac{8(2-\beta^2)(1-\beta^2)^2}{(8-5\beta^2)^2}],$$

the Revenue-sharing contract makes both firms be better off compared to the decentralized setting.

Proposition 6 indicates that the Revenue-sharing contract can coordinate the Dual-channel supply chain when the manufacturer adopts RFID, regardless of whether the two channels engage in a Bertrand competition or a Cournot competition. Further, Proposition 6 states that the retailer pays the manufacturer $\hat{w}_i^{M*}$ per unit product, and he also pays an additional price $\theta_i c_t$ as the shared cost for each RFID tag attached on each product of the retail channel. In scenario *M*, the manufacturer in essence charges $\hat{w}_b^{M*}+\theta_b c_t=(1-\hat{\varphi}_b^M)\left[\frac{a\beta}{2(1-\beta)}+\frac{(2-\beta)(c_m+c_t)}{2}\right]$ / $\hat{w}_g^{M*}+\theta_g c_t=(1-\hat{\varphi}_g^M)\left[\frac{a\beta}{2(1+\beta)}+\frac{(2+\beta)(c_m+c_t)}{2(1+\beta)}\right]$ per unit product of the retail channel when the two channels engage in a Bertrand/Cournot competition. It is possible to understand $(1-\hat{\varphi}_b^M)\left[\frac{a\beta}{2(1-\beta)}+\frac{(2-\beta)(c_m+c_t)}{2}\right]$ / $(1-\hat{\varphi}_g^M)\left[\frac{a\beta}{2(1+\beta)}+\frac{(2+\beta)(c_m+c_t)}{2(1+\beta)}\right]$ as equal to a new optimal wholesale price if the retailer refuses to share RFID tag costs of the retail channel's products.

5. RFID Adoption Strategies

From proposition 1, proposition 3 and proposition 5, we find that the total profits under the centralized supply chain are higher than that under the decentralized Dual-channel supply chain. Therefore, we discuss the RFID adoption strategy from the perspective of maximizing the centralized system's profit. As long as $\pi_{C,i}^{M*}\ge\pi_{C,i}^{N*}$ and $\pi_{C,i}^{M*}\ge\pi_{C,i}^{R*}$, then Scenario M will be the optimal RFID adoption strategy; as long as $\pi_{C,i}^{R*}\ge\pi_{C,i}^{M*}$ and $\pi_{C,i}^{R*}\ge\pi_{C,i}^{N*}$, then Scenario R will be the optimal RFID adoption strategy; as long as $\pi_{C,i}^{N*}\ge\pi_{C,i}^{M*}$ and $\pi_{C,i}^{N*}\ge\pi_{C,i}^{R*}$, then no firm would like to adopt RFID. Consequently, the RFID adoption strategies in the Dual-channel supply chain can be obtained as the following proposition.

Proposition 7. *i) When the manufacturer's misplacement rate* $\alpha_m\in(0,\bar{\alpha}_{m,i}]$*: the manufacturer adopting RFID (i.e., Scenario M) is the optimal strategy if and only if* $c_t\in(0,\bar{c}_{t1,i}]$*; the retailer adopting RFID (i.e., Scenario R) is the optimal strategy if and only if* $c_t\in(\bar{c}_{t1,i},\bar{c}_{t3,i}]$*; no firm adopting RFID (i.e., Scenario N) is the optimal strategy if and only if* $c_t\in(\bar{c}_{t3,i},\bar{c}_t)$.

ii) When the manufacturer's misplacement rate $\alpha_m\in(\bar{\alpha}_{m,i},\bar{\alpha}_m)$*: the manufacturer adopting RFID (i.e., Scenario M) is the optimal strategy if and only if* $c_t\in(0,\bar{c}_{t2,i}]$*; no firm adopting RFID (i.e., Scenario N) is the optimal strategy if and only if* $c_t\in(\bar{c}_{t2,i},\bar{c}_t)$.

Where $\bar{\alpha}_{m,b}=\frac{a(2-\alpha_r)-2(1-\beta)c_m-\chi_1}{2[2a-(1-\beta)c_m](1-\alpha_r)}$, $\bar{\alpha}_{m,g}=\frac{a(2-\alpha_r)-2c_m-\chi_2}{2(2a-c_m)(1-\alpha_r)}$,

$$\bar{c}_{t1,b}\ \frac{a(1-\alpha_m)-(1-2\alpha_m)(1-\beta)c_m-\chi_3}{(1-2\beta)(1-\alpha_m)},$$

$$\bar{c}_{t1,g}=\frac{(1-\beta)\left[(1-\alpha_m)a-(1-2\alpha_m)c_m-\sqrt{(1-\alpha_m)^2a^2-\left[(1-\beta-2\beta\alpha_m)(2a-c_m-2\alpha_m a)+2\alpha_m(\beta-\alpha_m)c_m\right]c_m/(1-\beta)}\right]}{(1-2\beta)(1-\alpha_m)}$$

$$,\ \bar{c}_{t2,b}=\left\{a-\sqrt{a^2-\frac{(1-\beta)c_m}{(1-\alpha_r)(1-\alpha_m)}\left[(2-\alpha_r)a-\frac{((1-\alpha_r)-2\beta+1/(1-\alpha_r))c_m}{2(1-\alpha_m)}\right]}\right\}/(1-\beta)-c_m,$$

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$$\bar{c}_{t2,g} = a - c_m - \sqrt{a^2 - \frac{(2-\alpha_r)ac_m}{(1-\alpha_r)(1-\alpha_m)} - \frac{\left[2(1-\alpha_r)\beta - (1-\alpha_r)^2 - 1\right]c_m{}^2}{2(1-\beta)(1-\alpha_r)^2(1-\alpha_m)^2}},\ \bar{c}_{t3,i}\ \frac{\alpha_r c_m}{(1-\alpha_r)(1-\alpha_m)},$$

$$\chi_1 = \sqrt{a^2(2-3\alpha_r)^2 + 2(1-\beta)c_m{}^2[2-2\beta(1-\alpha_r)-(2-\alpha_r)\alpha_r] - 4\{2(1-\alpha_r)^2 - \beta[2-(4-\alpha_r)\alpha_r]\}ac_m},$$

$$\chi_2 = \sqrt{a^2(2-3\alpha_r)^2 + 2\left(2+\alpha_r^2/(1-\beta)-2\alpha_r\right)c_m{}^2 - 4\left[2-\left(4-(2-\beta)\alpha_r/(1-\beta)\right)\alpha_r\right]ac_m},$$

$$\chi_3 = \sqrt{a^2(1-\alpha_m)^2 - 2(1-\alpha_m)(1-\beta-2\beta\alpha_m)ac_m + (1-\beta)(1-\beta-4\beta\alpha_m+2\alpha_m^2)c_m^2}.$$

A striking result described in proposition 7 declares that the manufacturer's misplacement rate and the unit RFID tag cost will affect the optimal RFID adoption strategy in the Dual-channel supply chain, regardless of whether the two channels engage in a Bertrand competition or Cournot competition. This highlights a *new* finding that the manufacturer's misplacement rate is another important factor which impacts the adoption of RFID technology in the Dual-channel supply chain.

When the *unit* RFID tag cost is low, adopting RFID technology is the optimal RFID strategy for the Dual-channel supply chain. This is because the firms are more willingly to adopt RFID to avoid unnecessary ordering. When the unit RFID tag cost is high, the revenue increment from adopting RFID cannot offset the high RFID cost. Therefore, no firm adopting RFID is the optimal strategy for the Dual-channel supply chain. It can be seen that a low unit RFID tag cost is benefit for companies to adopt RFID.

Yet the manufacturer's misplacement rate is the key driving force for the retailer to adopt RFID alone. When the manufacturer's misplacement rate is low (i.e., $c_t \in (0, \bar{c}_{t1,i}]$), the manufacturer is willing to adopt RFID if the unit RFID tag cost is low while forgoes RFID adoption if the unit RFID tag cost is moderate (i.e., $c_t \in (\bar{c}_{t1,i}, \bar{c}_{t3,i}]$). Surprisingly, the retailer will adopt RFID technology alone in the Dual-channel supply chain to eliminate his retail channel's misplacements. This is mainly because when the manufacturer adopts RFID technology, she not only bears the whole RFID tag costs from the direct channel, but also bears a proportion of RFID tag costs from the retail channel. On the contrary, the retailer only needs to bear the whole RFID tag costs from the *retail* channel when he adopts RFID alone. In other words, when the manufacturer has a small misplacement rate, the retailer's free-riding behavior weakens the manufacturer's willingness to adopt RFID technology although the retailer shares a proportion of RFID tag costs from the retail channel. However, as the manufacturer's misplacement rate increases, the manufacturer's willingness to adopt RFID technology also increases. Then the retailer can eliminate his retail channel's misplacements by simply sharing a portion of the RFID tag costs when the manufacturer's misplacement rate is high (i.e., $\alpha_m \in (\bar{\alpha}_{m,i}, \bar{\alpha}_m)$) and the unit RFID tag cost is low (i.e., $c_t \in (0, \bar{c}_{t2,i}]$).

We further examine the impacts of the channel *competition* intensity and the misplacement rates on the RFID cost thresholds, and present the result in the following lemma.

Corollary 1. *i) Both $\bar{c}_{t1,i}$ and $\bar{c}_{t2,i}$ decrease in β, there is no correlation between $\bar{c}_{t3,i}$ and β;*

ii) $\bar{c}_{t1,i}$, $\bar{c}_{t2,i}$ and $\bar{c}_{t3,i}$ all increase in α_m; both $\bar{c}_{t2,i}$ and $\bar{c}_{t3,i}$ increase in α_r, there is no correlation between $\bar{c}_{t1,i}$ and α_r.

Corollary 1 (i) indicates that when the channel competition is more intense, the manufacturer is less likely to adopt RFID while the retailer's RFID cost threshold (i.e., $\bar{c}_{t3,i}$) is irrelevant to the competition intensity, regardless of whether the two channels engage in Bertrand competition or Cournot competition. This finding implies that when the channel competition is fierce, the manufacturer is not under pressure to avoid unnecessary producing but would rather avoid the retailer's one-sided "free-rider" problem. Accordingly, a more intense channel competition is harmful to the application and promotion of RFID technology in a Dual-channel supply chain. Corollary 1 (ii) shows that under Bertrand competition or Cournot competition, the more serious the channels' misplacement problems are, the higher tag costs the firms can bear in the Dual-channel supply chain.

6. Comparison of Equilibrium Outcomes under Two Competition Modes

This section will compare Bertrand competition and Cournot competition in a Dual-channel supply chain from three aspects: sensitivity, RFID adoption strategy and supply chain coordination.

6.1. Comparative Analysis of Sensitivity

We discuss the impact of inventory misplacement rates, unit RFID tag cost, and channel competition intensity on the optimal profit of the Dual-channel supply chain under two competition modes, as shown in the following proposition.

Proposition 8.

(i) $\partial\pi_{C,i}^{N*}/\partial\alpha_m<0$, $\partial\pi_{C,i}^{N*}/\partial\alpha_r<0$, $\partial\pi_{C,i}^{R*}/\partial\alpha_m<0$, $\partial\pi_{C,i}^{R*}/\partial c_t<0$, $\partial\pi_{C,i}^{M*}/\partial c_t<0$.

(ii) $\partial\pi_{C,b}^{N*}/\partial\beta>0$, $\partial\pi_{C,b}^{R*}/\partial\beta>0$, $\partial\pi_{C,b}^{M*}/\partial\beta>0$; $\partial\pi_{C,g}^{N*}/\partial\beta<0$, $\partial\pi_{C,g}^{R*}/\partial\beta<0$, $\partial\pi_{C,g}^{M*}/\partial\beta<0$.

Proposition 8 indicates that under two competitive modes, with the increase of inventory misplacement rates or of unit tag cost, *the* total profit of the Dual-channel supply chain will always decrease regardless of whether the firms adopt RFID or not. However, the channel competition intensity has an opposite effect on the Dual-channel supply chain's total profits under two competition modes. Specifically, a higher intensity of channel competition is beneficial for the supply chain members under Bertrand competition, while it is disadvantageous for the members under Cournot competition. The reason is that the increase of competition intensity will bring higher equilibrium prices, which indicates the double marginalization effect is weakened under the Bertrand competition. Therefore, an intense channel competition promotes the supply chain to obtain more profits under Bertrand competition.

6.2. Comparative Analysis of Optimal RFID Adoption Strategy

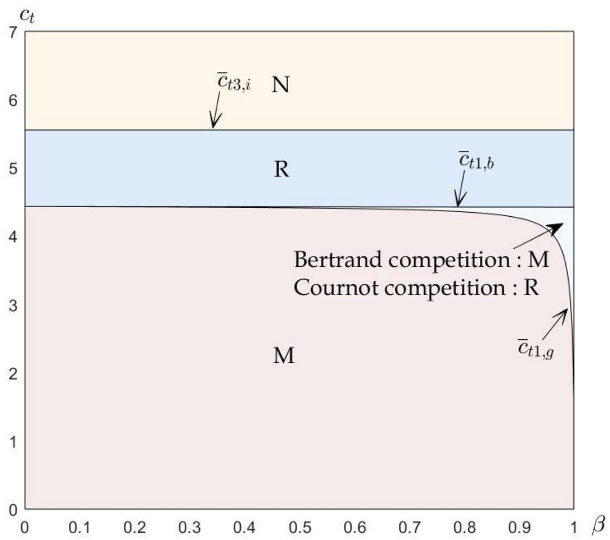

Figure 1. Equilibrium graph based on β under two competition modes
$(a=500, c_m=20, \alpha_r=0.2, \alpha_m=0.1)$

We compare the optimal RFID adoption strategy under Bertrand competition and Cournot competition in this subsection. Proposition 7 indicates the unit tag cost thresholds that the Dual-channel supply chain can bear are different under two competitive modes. Figure 1 shows that an intense channel competition may be harmful to promoting RFID adoption in the Dual-channel supply chain under both competitive modes. We observe that as the channel competition intensity changes, the tag cost thresholds $\overline{c}_{t1,i}$ that ensure both firms to adopt RFID under two competition modes gradually become different. In general, the unit tag cost thresholds $\overline{c}_{t1,i}$ that the Dual-channel supply chain can bear under Bertrand competition is higher than that under Cournot competition. As the channel competition intensity increases, the difference of the unit tag cost thresholds $\overline{c}_{t1,i}$ between the two competitive modes increase. When the channel competition is fierce, the tag cost threshold $\overline{c}_{t1,g}$ decreases obviously under Cournot competition and thus the Bertrand competition mode is beneficial to promoting RFID adoption in the Dual-channel supply chain.

6.3. Comparative Analysis of Supply Chain Coordination

With the above analysis, we find that the revenue sharing contract can coordinate the Dual-channel supply chain regardless of whether the firms adopt RFID or not under both competition modes. Thus, the total profits of the decentralized Dual-channel supply chain are equal to that under the centralized Dual-channel supply chain. The revenue sharing contract redistributes the total profits to achieve Pareto improvement of the supply chain members. However, the coordination revenue sharing coefficients are different under two competitive modes. Therefore, this subsection compares the coordination parameters of the three scenarios under two competition modes and discusses the impact of competition modes on the coordination of the Dual-channel supply chain, as shown in the following proposition.

Proposition 9.

(i) Under Bertrand competition, the interval of Revenue-sharing coefficient that can make both firms be better off is the same in N, R and M scenarios, i.e., $\hat{\varphi}_b \in (1/2, 3/4)$.

(ii) Under Cournot competition, the interval of Revenue-sharing coefficient that can make both firms be better off is the same in N, R, and M scenarios, i.e., $\hat{\varphi}_g \in (\underline{\varphi}, \overline{\varphi})$. *Further,* $\partial\underline{\varphi}/\partial\beta > 0$, $\partial\overline{\varphi}/\partial\beta > 0$ *and* $\partial\Delta\varphi/\partial\beta < 0$.

Where $\underline{\varphi} = (4-\beta^4)/(8-5\beta^2)$, $\overline{\varphi} = 1-8(2-\beta^2)(1-\beta^2)^2/(8-5\beta^2)^2$ *and* $\Delta\varphi = \overline{\varphi} - \underline{\varphi}$.

Proposition 9 shows that under both competition modes, whether the Dual-channel supply chain adopts RFID will not affect the revenue sharing coefficients that make both firms better off. However, the revenue sharing coefficients under Cournot competition are affected by channel competition intensity. Specifically, as the channel competition intensity increases, the upper and lower bounds of the revenue sharing coefficient also increase. Only the retailer shares a larger percentage of profits to the manufacturer can the firms achieve Pareto improvement. Moreover, the range of coordinated revenue sharing coefficients decreases when channel competition intensity increases, which means the more intense the channel competition is, the more difficult the Dual-channel supply chain can be coordinated under Cournot competition.

We plot the outcomes in the space of φ and β in order to understand changes in the Revenue-sharing coefficients with competition intensity, as showed in Figure 2. From Figure 2, we find that as long as the Revenue-sharing coefficient and the competition intensity pair (φ, β) is in the yellow area, the Dual-channel supply chain partners can achieve Pareto improvement under both competition modes. When the pair (φ, β) is in the pink area, only under Cournot competition can the Dual-channel supply chain partners achieve Pareto improvement. Further, when the pair (φ, β) is the blue area, the Pareto improvement can be achieved under only Bertrand competition.

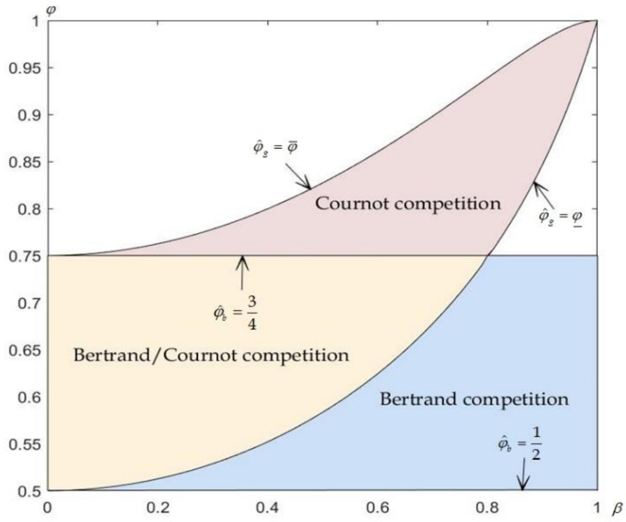

Figure 2. The change of the Revenue-sharing coefficients under two competition options ($a=500, c_m=20, \alpha_r=0.2, \alpha_m=0.2$)

Both the upper and lower bounds of the Revenue-sharing coefficient interval under Bertrand competition are smaller than that under Cournot competition, respectively. Under Bertrand competition, the channel competition intensity does not affect the upper and lower bounds of the revenue sharing coefficient interval. However, under Cournot competition, both the upper and lower boundaries are positively related to competition intensity; furthermore, we find that the feasible zone of Revenue-sharing coefficient, which makes both firms be better off, decreases in competition intensity. The finding shows that the Dual-channel supply chain partners can achieve Pareto improvement easier under Bertrand competition compared with under Cournot competition. Moreover, this advantage increases as channel competition intensity increases.

7. Conclusion

Generally speaking, retailers in supply chains are more concerned about the inventory misplacement problems and manufacturers might tend to ignore this problem since they don't participate in retailing activities which would bring inventory misplacement problems. However, if a manufacturer operates a direct sales channel in a Dual-channel supply chain can no longer stay out of the severe effect of an inventory misplacement problem. We investigate the optimal RFID adoption strategy and coordination contracts for the Dual-channel supply chain, where both a manufacturer and a retailer have inventory misplacement problems. In addition, the manufacturer distributes her products through the independent retailer as well as her direct sales channel. In terms of whether the RFID is adopted by the manufacturer or the retailer, we consider three RFID adoption strategies, i.e., neither partners adopts RFID, only the retailer adopts RFID, and the manufacturer attaches an RFID tag on each product during the production process. We discuss both Bertrand competition and Cournot competition for the Dual-channel supply chain to explore how the competition options would affect the optimal RFID adoption strategies.

Firstly, we examine the optimal prices and order quantities under the three RFID adoption strategies, and coordinate the decentralized supply chain according to the centralized system decisions by the Revenue-sharing contract for each RFID adoption strategy. We find that the

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Revenue-sharing contract can effectively coordinate the Dual-channel supply chain where both players suffer from misplacement problems, leading to Pareto improvements can be achieved for firms in each RFID adoption strategy.

Secondly, we explore the optimal RFID adoption strategy for the supply chain players. We find that the optimal choice of RFID adoption strategy mainly depends on the RFID tag cost, inventory misplacement rates, and channel competition intensity. Specifically, when the tag cost is low, the Dual-channel supply chain is powered by RFID technology under two competitive modes; when the unit RFID tag cost is high, neither manufacturer nor retailer will adopt RFID technology. High tagging costs constrain the supply chain to adopt RFID technology. In addition, both firms' inventory misplacement rates are related to the RFID strategy of the Dual-channel supply chain. When the manufacturer's inventory misplacement rate is low and the unit RFID tag cost is moderate, the retailer is more willing to adopt RFID technology than the manufacturer. When bot firms' inventory misplacement rates are high, adopting RFID technology to completely eliminate the inventory misplacement problems can maximize the total profits of the Dual-channel supply chain. Furthermore, the channel competition is not conducive to the adoption of RFID technology in the Dual-channel supply chain.

Thirdly, we investigate how the competition options would affect the choice of RFID technology for the Dual-channel supply chain. Our results show that it is more conducive to promoting firms to adopt RFID technology in the Dual-channel supply chain if the supply chain is in an industry conducting with a Bertrand competition. Specifically, the difference of optimal RFID choice for the Bertrand and Cournot competition modes is mainly reflected by the tag cost thresholds. The main performance is that the tag cost threshold under Bertrand competition is larger than that under Cournot competition. This result shows that under the Bertrand competition, the Dual-channel supply chain is more inclined to adopt RFID technology.

Lastly, the relevant parameters for achieving coordination of the Dual-channel supply chain under two competitive modes are different. Specifically, the wholesale price in a coordination supply chain under Bertrand competition is higher than that under Cournot competition; the revenue sharing coefficient of the supply chain under Cournot competition is higher than that under Bertrand competition. Moreover, the impact of channel competition intensity on supply chain coordination under Cournot competition is more prominent. When the channel competition is mild, the supply chain players can be coordinated under two competition modes; when the channel competition is fierce, the Bertrand competition is more conducive to the Pareto improvement for the Dual-channel supply chain players.

Our papers have some limitations and can be extended from several extensions. Firstly, this paper considers the manufacturer as a Stackelberg leader, and it might get more interesting insights when a retailer serves as a leader in a Dual-channel supply chain. Secondly, we only consider the symmetry of information among supply chain members. It will be interesting to incorporate demand information asymmetry into supply chain members in future research. Lastly, this is challenging to consider the effect of retailer competing in a Dual-channel supply chain, including a manufacturer and two competing retailers. In addition, we can also consider two competitive supply chains in the future research.

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Appendix

<u>Proof of Proposition 1:</u>

Bertrand competition: (i) Decentralized case: We use backward induction method to solve the model under decentralized decision. $\pi_{r,b}^N$ is concave in $p_{r,b}^N$. Taking the partial derivative of $p_{r,b}^N$ and setting $\partial\pi_{r,b}^N/\partial p_{r,b}^N=0$, we obtained retail price $p_{r,b}^{N*}=\frac{a}{2}+\frac{\beta p_{m,b}^N}{2}+\frac{w_b^N}{2(1-\alpha_r)}$. Substituting $p_{r,b}^{N*}$ into $\pi_{r,b}^N$, a Hessen matrix for $\pi_{m,b}^N(p_{m,b}^N,w_b^N)$ can be calculated as $H_b^N=\begin{vmatrix}\partial^2\pi_{m,b}^N/\partial^2 p_{m,b}^N & \partial^2\pi_{m,b}^N/\partial p_{m,b}^N\partial w_b^N\\ \partial^2\pi_{m,b}^N/\partial w_b^N\partial p_{m,b}^N & \partial^2\pi_{m,b}^N/\partial^2 w_b^N\end{vmatrix}=\frac{2-\beta^2}{(1-\alpha_r)^2}>0$. We have $\partial^2\pi_{m,b}^N/\partial^2 p_{m,b}^N=-(2-\beta^2)<0$. Solving $\partial\pi_{r,b}^N/\partial w_{r,b}^N=0$ and $\partial\pi_{m,b}^N/\partial p_{m,b}^N=0$, we obtain the optimal wholesale price is $w_b^{N*}=\frac{1}{2}\left(\frac{a(1-\alpha_r)}{1-\beta}+\frac{c_m}{1-\alpha_m}\right)$ and the optimal direct selling price is $p_{m,b}^{N*}=\frac{1}{2}(\frac{a}{1-\beta}+\frac{c_m}{1-\alpha_m})$. In turn, the optimal profits $\pi_{r,b}^{N*}$ of Dual-channel supply chain members in the N scenario are obtained.

(ii) Centralized case: Taking the partial derivative of $p_{C,m,b}^N$ and $p_{C,r,b}^N$ for $\pi_{C,b}^N$ and get the corresponding Hessen matrix $H_{C,b}^N=\begin{vmatrix}\partial^2\pi_{C,b}^N/\partial^2 p_{C,m,b}^N & \partial^2\pi_{C,b}^N/\partial p_{C,m,b}^N\partial p_{C,r,b}^N\\ \partial^2\pi_{C,b}^N/\partial p_{C,r,b}^N\partial p_{C,m,b}^N & \partial^2\pi_{C,b}^N/\partial^2 p_{C,r,b}^N\end{vmatrix}=4(1-\beta^2)>0$, which means $\pi_{C,b}^N$ is joint concave in $p_{C,m,b}^N$ and $p_{C,r,b}^N$. Setting $\partial\pi_{C,b}^N/\partial p_{C,m,b}^N=0$ and $\partial\pi_{C,b}^N/\partial p_{C,r,b}^N=0$, we obtain the direct selling price $p_{C,m,b}^{N*}$ and the retail price $p_{C,r,b}^{N*}$. Substituting $p_{C,m,b}^{N*}$ and $p_{C,r,b}^{N*}$ into $\pi_{C,b}^N$, thus we get the Dual-channel supply chain optimal profit under centralized decision making.

Cournot competition: (i) Decentralized case: the second derivative of $q_{m,g}^N$ is solved for $\pi_{m,g}^N$ to obtain the result $\partial^2\pi_{m,g}^N/\partial^2 q_{m,g}^N<0$. Setting $\partial\pi_{m,g}^N/\partial q_{m,g}^N=0$, we get the direct selling quantity $q_{m,g}^{N*}=\frac{1}{2}\left(a-\beta(1-\alpha_r)q_{r,g}^N-\frac{c_m}{1-\alpha_m}\right)$. $\pi_{r,b}^N$ is concave in $p_{r,b}^N$, thus the retail order quantity is $q_{r,g}^{N*}=\frac{(2-\beta)a+\beta c_m}{2[1-\beta(1-\alpha_r)]}-\frac{w_g^N}{(1-\alpha_r)[1-\beta(1-\alpha_r)]}$. Substituting $q_{m,g}^{N*}$ and $q_{r,g}^{N*}$ into $\pi_{r,g}^N$, we can get the wholesale price

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$w_g^{N*}=\frac{(1-\alpha_r)(1-\alpha_m)(8-6\beta^2+\beta^3)a+[8-4\beta^2+\beta^3(1-\alpha_r)]c_m}{2(1-\alpha_m)(8-5\beta^2)}$. Then we obtain the optimal profits of the Dual-channel supply chain partners.

(ii) Centralized case: Taking the partial derivative of $q_{C,m,g}^N$ and $q_{C,r,g}^N$ for $\pi_{C,g}^N$ and get the corresponding Hessen matrix $H_{C,b}^N=\begin{vmatrix}\partial^2\pi_{C,g}^N/\partial^2 q_{C,m,g}^N & \partial^2\pi_{C,g}^N/\partial q_{C,m,g}^N\partial q_{C,r,g}^N \\ \partial^2\pi_{C,g}^N/\partial q_{C,r,g}^N\partial q_{C,m,g}^N & \partial^2\pi_{C,g}^N/\partial^2 q_{C,r,g}^N\end{vmatrix}=4(1-\alpha_r)^2(1-\beta^2)>0$, which indicates $\pi_{C,g}^N$ is joint concave in $q_{C,m,g}^N$ and $q_{C,r,g}^N$. Setting $\partial\pi_{C,g}^N/\partial q_{C,m,g}^N=0$ and $\partial\pi_{C,g}^N/\partial q_{C,r,g}^N=0$, we obtain the optimal direct selling quantity $q_{C,m,g}^{N*}$ and the optimal retail order quantity $q_{C,r,g}^{N*}$. Substituting $q_{C,m,g}^{N*}$ and $q_{C,r,g}^{N*}$ into $\pi_{C,g}^{N*}$., we get the Dual-channel supply chain optimal profit under centralized case.

<u>Proof of Proposition 2:</u>

Through the revenue sharing contract, the manufacturer charges a lower wholesale price $\hat{w}_i^N$ for each product and receives a portion $\hat{\varphi}_i^N$ of the retailer's profit.

Bertrand competition: the retailer's response function is $p_{r,b}^N=\frac{w_b^N}{2(1-\varphi)(1-\alpha_r)}+\frac{a+\beta p_{m,b}^N}{2}$. In order to satisfy that the profit of Dual-channel supply chain under centralized decision is equal to decentralized decision (i.e. $\pi_{r,b}^{N*}+\pi_{m,b}^{N*}=\pi_{C,b}^{N*}$). So $p_{C,m,b}^{N*}=p_{m,b}^N=\frac{1}{2}(\frac{a}{1-\beta}+\frac{c_m}{1-\alpha_m})$ and $p_{C,r,b}^{N*}=p_{r,b}^N=\frac{1}{2}[\frac{a}{1-\beta}+\frac{c_m}{(1-\alpha_m)(1-\alpha_r)}]$ must be met. Solving these two equations, we get the coordinated wholesale price as $\hat{w}_b^{N*}=2(1-\hat{\varphi}_b^{N*})(1-\alpha_r)\{\frac{a\beta}{4(1-\beta)}+\frac{c_m[2-\beta(1-\alpha_r)]}{4(1-\alpha_m)(1-\alpha_r)}\}$. In addition, $\hat{\pi}_{r,b}^{N*}>\pi_{r,b}^{N*}$ and $\hat{\pi}_{m,b}^{N*}>\pi_{m,b}^{N*}$ must be met to achieve Pareto improvement of supply chain members. The result of solving the revenue sharing coefficient is $\varphi\in(1/2,3/4)$. The coordination methods under Cournot competition are similar to that under Bertrand competition.

<u>Proof of Proposition 3:</u>

Bertrand competition: (i) Decentralized case: We use backward induction method to solve the model under decentralized decision. $\pi_{r,b}^R$ is concave in $p_{r,b}^R$. Taking the partial derivative of $p_{r,b}^R$ and setting $\partial\pi_{r,b}^R/\partial p_{r,b}^R=0$, we obtained retail price $p_{r,b}^{R*}=\frac{1}{2}(a-a\beta+c_t+\beta p_{m,b}^R+w_b^R)$. Solving $\partial\pi_{r,b}^R/\partial w_{r,b}^R=0$ and $\partial\pi_{m,b}^R/\partial p_{m,b}^R=0$, we obtain the optimal wholesale price is $w_b^{R*}=\frac{1}{2}(\frac{a}{1-\beta}+\frac{c_m}{1-\alpha_m}-c_t)$ and the optimal direct selling price is $p_{m,b}^{R*}=\frac{1}{2}\left(\frac{a}{1-\beta}+\frac{c_m}{1-\alpha_m}\right)$. In turn, the optimal profits $\pi_{r,b}^{R*}$ of Dual-channel supply chain members in the R scenario are obtained.

(ii) Centralized case: Taking the partial derivative of $p_{C,m,b}^R$ and $p_{C,r,b}^R$. $\pi_{C,b}^R$ is joint concave in $p_{C,m,b}^R$ and $p_{C,r,b}^R$. Setting $\partial\pi_{C,b}^R/\partial p_{C,m,b}^R=0$ and $\partial\pi_{C,b}^R/\partial p_{C,r,b}^R=0$, we obtain the direct selling price $p_{C,m,b}^{R*}$ and the retail price $p_{C,r,b}^{R*}$. Substituting $p_{C,m,b}^{R*}$ and $p_{C,r,b}^{R*}$ into $\pi_{C,b}^R$, thus we get the Dual-channel supply chain optimal profit under centralized decision making.

Cournot competition: (i) Decentralized case: the second derivative of $q_{m,g}^R$ is solved for $\pi_{m,g}^R$ to obtain the result $\partial^2\pi_{m,g}^R/\partial^2 q_{m,g}^R<0$. Setting $\partial\pi_{m,g}^R/\partial q_{m,g}^R=0$, we get the direct selling quantity $q_{m,g}^{R*}=\frac{1}{2}\left(a-\beta q_{r,g}^R-\frac{c_m}{1-\alpha_m}\right)$. $\pi_{r,b}^R$ is concave in $p_{r,b}^R$, thus the retail order quantity is $q_{r,g}^{R*}=\left[\frac{1}{2}a(2-\beta)-c_t+\frac{\beta c_m}{2-2\alpha_m}-w_g^R\right]/(2-\beta^2)$. Substituting $q_{m,g}^{R*}$ and $q_{r,g}^{R*}$ into $\pi_{r,g}^R$, we can get the wholesale price $w_g^{R*}=\frac{(\beta^3-6\beta^2+8)(1-\alpha_m)a+(8-4\beta^2-\beta^3)c_m-(1-\alpha_m)(8-6\beta^2)c_t}{2(1-\alpha_m)(8-5\beta^2)}$. Then we obtain the optimal profits of the Dual-channel supply chain partners.

(ii) Centralized case: Taking the partial derivative of $q_{C,m,g}^{R}$ and $q_{C,r,g}^{R}$. $\pi_{C,g}^{R}$ is joint concave in $q_{C,m,g}^{R}$ and $q_{C,r,g}^{R}$. Setting $\partial\pi_{C,g}^{R}/\partial q_{C,m,g}^{R}=0$ and $\partial\pi_{C,g}^{R}/\partial q_{C,r,g}^{R}=0$, we obtain the optimal direct selling quantity $q_{C,m,g}^{R*}$ and the optimal retail order quantity $q_{C,r,g}^{R*}$. Substituting $q_{C,m,g}^{R*}$ and $q_{C,r,g}^{R*}$ into $\pi_{C,g}^{R*}$., we get the Dual-channel supply chain optimal profit under centralized case.

Proof of Proposition 4:

Through the revenue sharing contract, the manufacturer charges a lower wholesale price $\hat{w}_i^R$ for each product and receives a portion $\hat{\varphi}_i^R$ of the retailer's profit.

Bertrand competition: the retailer's response function is $p_{r,b}^{R}=\frac{c_t+2(1-\varphi)[a(1-\beta)+\beta p_{m,b}^{R}]+w_b^R}{2(1-\varphi)}$. In order to satisfy that the profit of Dual-channel supply chain under centralized decision is equal to decentralized decision (i.e. $\pi_{r,b}^{R*}+\pi_{m,b}^{R*}=\pi_{C,b}^{R*}$). So $p_{C,m,b}^{R*}=p_{m,b}^{R}=\frac{a}{2(1-\beta)}+\frac{c_m}{2(1-\alpha_m)}$ and $p_{C,r,b}^{R*}=p_{r,b}^{R}=\frac{a}{2(1-\beta)}+\frac{c_m}{2(1-\alpha_m)}+\frac{c_t}{2}$ must be met. Solving these two equations, we get the coordinated wholesale price as $\hat{w}_b^{R*}=(1-\hat{\varphi}_b^R)[\frac{a\beta}{2(1-\beta)}+\frac{(2-\beta)c_m}{2(1-\alpha_m)}-\frac{\hat{\varphi}_b^R c_t}{1-\hat{\varphi}_b^R}]$. In addition, $\hat{\pi}_{r,b}^{R*}>\pi_{r,b}^{R*}$ and $\hat{\pi}_{m,b}^{R*}>\pi_{m,b}^{R*}$ must be met to achieve Pareto improvement of supply chain members. The result of solving the revenue sharing coefficient is $\varphi\in(1/2,3/4)$. The coordination methods under Cournot competition are similar to that under Bertrand competition.

Proof of Proposition 5:

Bertrand competition: (i) Decentralized case: We use backward induction method to solve the model under decentralized decision. $\pi_{r,b}^{M}$ is concave in $p_{r,b}^{M}$. Taking the partial derivative of $p_{r,b}^{M}$ and setting $\partial\pi_{r,b}^{M}/\partial p_{r,b}^{M}=0$, we obtained retail price $p_{r,b}^{M*}=[a+c_t\theta+\beta p_{m,b}^{M}+w_b^M]/2$. Substituting $p_{r,b}^{M*}$ into $\pi_{r,b}^{M}$. $\pi_{m,b}^{M}$ is joint concave in $p_{m,b}^{M}$ and w_b^M Solving $\partial\pi_{r,b}^{M}/\partial w_{r,b}^{M}=0$ and $\partial\pi_{m,b}^{M}/\partial p_{m,b}^{M}=0$, we obtain the optimal wholesale price is $w_b^{M*}=\frac{1}{2}[\frac{a}{1-\beta}+c_m+(1-2\theta)c_t]$ and the optimal direct selling price is $p_{m,b}^{M*}=\frac{1}{2}(\frac{a}{1-\beta}+c_m+c_t)$. In turn, the optimal profits $\pi_{r,b}^{M*}$ of Dual-channel supply chain members in the M scenario are obtained.

(ii) Centralized case: Taking the partial derivative of $p_{C,m,b}^{M}$ and $p_{C,r,b}^{M}$ for $\pi_{C,b}^{M}$. $\pi_{C,b}^{M}$ is joint concave in $p_{C,m,b}^{M}$ and $p_{C,r,b}^{M}$. Setting $\partial\pi_{C,b}^{M}/\partial p_{C,m,b}^{M}=0$ and $\partial\pi_{C,b}^{M}/\partial p_{C,r,b}^{M}=0$, we obtain the direct selling price $p_{C,m,b}^{M*}$ and the retail price $p_{C,r,b}^{M*}$. Substituting $p_{C,m,b}^{M*}$ and $p_{C,r,b}^{M*}$ into $\pi_{C,b}^{M}$, thus we get the Dual-channel supply chain optimal profit under centralized decision making.

Cournot competition: (i) Decentralized case: the second derivative of $q_{m,g}^{R}$ is solved for $\pi_{m,g}^{M}$ to obtain the result $\partial^2\pi_{m,g}^{M}/\partial^2 q_{m,g}^{M}<0$. Setting $\partial\pi_{m,g}^{M}/\partial q_{m,g}^{M}=0$, we get the direct selling quantity $q_{m,g}^{M*}=\frac{1}{2}(a-c_m-c_t-\beta q_{r,g}^{M})$. $\pi_{r,b}^{M}$ is concave in $p_{r,b}^{M}$, thus the retail order quantity is $q_{r,g}^{M*}=\frac{a(2-\beta)+\beta(c_m+c_t)-2(c_t\theta+w_g^M)}{2(2-\beta^2)}$. Substituting $q_{m,g}^{M*}$ and $q_{r,g}^{M*}$ into $\pi_{r,g}^{M}$, we can get the wholesale price $w_g^{M*}=\frac{(\beta^3-6\beta^2+8)a-(\beta^3+4\beta^2-8)(c_m+c_t)}{(16-10\beta^2)}$. Then we obtain the optimal profits of the Dual-channel supply chain partners.

(ii) Centralized case: Taking the partial derivative of $q_{C,m,g}^{M}$ and $q_{C,r,g}^{M}$ for $\pi_{C,g}^{M}$. $\pi_{C,g}^{M}$ is joint concave in $q_{C,m,g}^{M}$ and $q_{C,r,g}^{M}$. Setting $\partial\pi_{C,g}^{M}/\partial q_{C,m,g}^{M}=0$ and $\partial\pi_{C,g}^{M}/\partial q_{C,r,g}^{M}=0$, we obtain the optimal direct selling quantity $q_{C,m,g}^{M*}$ and the optimal retail order quantity $q_{C,r,g}^{M*}$. Substituting $q_{C,m,g}^{M*}$ and $q_{C,r,g}^{M*}$ into $\pi_{C,g}^{M*}$., we get the Dual-channel supply chain optimal profit under centralized case.

Proof of Proposition 6:

Through the revenue sharing contract, the manufacturer charges a lower wholesale price $\hat{w}_i^M$ for each product and receives a portion $\hat{\varphi}_i^M$ of the retailer's profit.

Bertrand competition: the retailer's response function is $p_{r,b}^{M}=\frac{\theta c_t+(1-\varphi)[a(1-\beta)+\beta p_{m,b}^{M}]+w_b^{M}}{2(1-\varphi)}$. In order to satisfy that the profit of Dual-channel supply chain under centralized decision is equal to decentralized decision (i.e. $\pi_{r,b}^{R*}+\pi_{m,b}^{R*}=\pi_{C,b}^{R*}$). So $p_{C,m,b}^{M*}=p_{m,b}^{M}=\frac{1}{2}(\frac{a}{1-\beta}+c_m+c_t)$ and $p_{C,r,b}^{M*}=p_{r,b}^{M}=\frac{1}{4}[\frac{a(3-\beta)}{1-\beta}+(1+\beta)(c_m+c_t)]$ must be met. Solving these two equations, we get the coordinated wholesale price as $\hat{w}_b^{M*}+\theta_b c_t=(1-\hat{\varphi}_b^{M})\left[\frac{a\beta}{2(1-\beta)}+\frac{(2-\beta)(c_m+c_t)}{2}\right]$. In addition, $\hat{\pi}_{r,b}^{M*}>\pi_{r,b}^{M*}$ and $\hat{\pi}_{m,b}^{M*}>\pi_{m,b}^{M*}$ must be met to achieve Pareto improvement of supply chain members. The result of solving the revenue sharing coefficient is $\varphi\in(1/2,3/4)$. The coordination methods under Cournot competition are similar to that under Bertrand competition.

Proof of Proposition 7:

Taking $\Delta_i^{M-R}=\pi_{C,i}^{M*}-\pi_{C,i}^{R*}$ as supply chain's profit variation in Models M and R. Solving $\Delta_i^{M-R}=0$, we obtain $\pi_{C,i}^{M*}\ge\pi_{C,i}^{R*}$ when $c_t\in(0,\bar{c}_{t1,i}]$, and $\pi_{C,b}^{M*}<\pi_{C,b}^{R*}$ when $c_t\in(\bar{c}_{t1,i},\bar{c}_t)$. Taking $\Delta_i^{M-N}=\pi_{C,i}^{M*}-\pi_{C,i}^{N*}$ as supply chain's profit variation in Models M and N. We obtain $\pi_{C,i}^{M*}\ge\pi_{C,i}^{N*}$ when $c_t\in(0,\bar{c}_{t2,i}]$, and $\pi_{C,i}^{M*}<\pi_{C,i}^{N*}$ when $c_t\in(\bar{c}_{t2,i},\bar{c}_t)$. Taking $\Delta_i^{R-N}=\pi_{C,i}^{R*}-\pi_{C,i}^{N*}$ as supply chain's profit variation in Models R and N. We get $\pi_{C,i}^{R*}\ge\pi_{C,i}^{N*}$ when $c_t\in(0,\bar{c}_{t3,i}]$, and $\pi_{C,i}^{R*}<\pi_{C,i}^{N*}$ when $c_t\in(\bar{c}_{t3,i},\bar{c}_t)$.

In order to ensure the N scenario be the optimal RFID adoption strategy, both $\pi_{C,i}^{N*}\ge\pi_{C,i}^{M*}$ and $\pi_{C,i}^{N*}\ge\pi_{C,i}^{R*}$ must be established. Thus, it can be showed that $\pi_{C,i}^{M*}<\pi_{C,i}^{N*}$ when $c_t\in(\bar{c}_{t2,i},\bar{c}_t)$, and $\pi_{C,i}^{R*}<\pi_{C,i}^{N*}$ when $c_t\in(\bar{c}_{t3,i},\bar{c}_t)$. Further, comparing $\bar{c}_{t2,i}$ and $\bar{c}_{t3,i}$, taking $\Delta_{t,i}^{2-3}=\bar{c}_{t2,i}-\bar{c}_{t3,i}$ as the variation in $\bar{c}_{t2,i}$ and $\bar{c}_{t3,i}$. With $\Delta_{t,i}^{2-3}=0$, we get two roots $\bar{\alpha}_{m1,i}$ and $\bar{\alpha}_{m2,i}$. As $\bar{\alpha}_{m2,i}>\bar{\alpha}_m$, we give up the root $\bar{\alpha}_{m2,i}$. Setting $\bar{\alpha}_{m1,i}=\bar{\alpha}_{m,i}$, we have $\bar{c}_{t2,i}<\bar{c}_{t3,i}$ when $\alpha_m\in(0,\bar{\alpha}_{m,i}]$, and $\bar{c}_{t2,i}>\bar{c}_{t3,i}$ when $\alpha_m\in(\bar{\alpha}_{m,i},\bar{\alpha}_m)$.

In order to ensure the R scenario to be the optimal RFID strategy, both $\pi_{C,i}^{R*}\ge\pi_{C,i}^{M*}$ and $\pi_{C,i}^{R*}\ge\pi_{C,i}^{N*}$ conditions must be met. From the above, it can be seen that $\pi_{C,i}^{R*}\ge\pi_{C,i}^{N*}$ when $c_t\in(0,\bar{c}_{t3,i}]$, $\pi_{C,b}^{M*}<\pi_{C,b}^{R*}$ when $c_t\in(\bar{c}_{t1,i},\bar{c}_t)$. Taking $\Delta_{t,i}^{1-3}=\bar{c}_{t1,i}-\bar{c}_{t3,i}$ as variation in $\bar{c}_{t1,i}$ and $\bar{c}_{t3,i}$. Solving the equation with $\Delta_{t,i}^{1-3}=0$, we have $\bar{c}_{t1,i}<\bar{c}_{t3,i}$ when $\alpha_m\in(0,\bar{\alpha}_{m,i}]$, and $\bar{c}_{t1,i}>\bar{c}_{t3,i}$ when $\alpha_m\in(\bar{\alpha}_{m,i},\bar{\alpha}_m)$.

In order for the M scenario to be the optimal RFID strategy, both $\pi_{C,i}^{M*}\ge\pi_{C,i}^{N*}$ and $\pi_{C,i}^{M*}\ge\pi_{C,i}^{R*}$ must be met. It can be seen that when $c_t\in(0,\bar{c}_{t2,i}]$ then $\pi_{C,i}^{M*}\ge\pi_{C,i}^{N*}$; when $c_t\in(0,\bar{c}_{t1,i}]$, then $\pi_{C,i}^{M*}>\pi_{C,i}^{R*}$. Taking $\Delta_{t,i}^{1-2}=\bar{c}_{t1,i}-\bar{c}_{t2,i}$ as variation in $\bar{c}_{t1,i}$ and $\bar{c}_{t2,i}$. Solving the equation with $\Delta_{t,i}^{1-2}=0$, we have $\bar{c}_{t1,i}<\bar{c}_{t2,i}$ when $\alpha_m\in(0,\bar{\alpha}_{m,i}]$, and $\bar{c}_{t1,i}>\bar{c}_{t2,i}$ when $\alpha_m\in(\bar{\alpha}_{m,i},\bar{\alpha}_m)$.

After the above analysis, we get $\bar{c}_{t3,i}>\bar{c}_{t2,i}>\bar{c}_{t1,i}$ when $\alpha_m\in(0,\bar{\alpha}_{m,i}]$; $\bar{c}_{t1,i}>\bar{c}_{t2,i}>\bar{c}_{t3,i}$ when $\alpha_m\in(\bar{\alpha}_{m,i},\bar{\alpha}_m)$. Thus, we obtain the RFID adoption optimal strategy. When $\alpha_m\in(0,\bar{\alpha}_{m,i}]$: if $c_t\in(0,\bar{c}_{t1,i}]$, then M is the optimal strategy; if $c_t\in(\bar{c}_{t1,i},\bar{c}_{t3,i}]$, then R is the optimal strategy; if $c_t\in(\bar{c}_{t3,i},\bar{c}_t)$, then N is the optimal strategy. When $\alpha_m\in(\bar{\alpha}_{m,i},\bar{\alpha}_m)$: if $c_t\in(0,\bar{c}_{t2i}]$, then M is the optimal strategy; if $c_t\in(\bar{c}_{t2,i},\bar{c}_t)$, then N is the optimal strategy.