Hindawi
Mathematical Problems in Engineering
Volume 2018, Article ID 4686531, 13 pages
https://doi.org/10.1155/2018/4686531

*Research Article*

# Supply Chain Coordination under Inventory Inaccuracy with RFID Technology

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Received 2 February 2018; Revised 9 September 2018; Accepted 1 October 2018; Published 22 October 2018

Academic Editor: Ibrahim Zeid



In this paper we consider a two-echelon supply chain under price-dependent demand market and we use RFID to eliminate the effect of inventory inaccuracy. Models are built to evaluate the economic viability and coordination conditions. We analyze two scenarios in which the supply chain is defined, the integrated one and the decentralized one, respectively. For the integrated, we compare the different supply chain revenue with and without RFID technology and then determine the optimal inventory decisions. For the decentralized, we mainly focus on the coordination mechanism by revenue sharing contract under Stackelberg game. By seeking appropriate contract parameters, the supply chain can finally be coordinated while all partners are better off. Furthermore, numerical examples are given to verify our proposition.

## 1. Introduction

Inventory inaccuracy can be considered as the difference between the inventory level in information systems and the real physical inventory level [1]. This gap can deeply affect the performance of companies. About 65% of the inventory records in retail stores were reported to be inaccurate, based on a survey about 370,000 inventory records of 37 stores [2]. Transaction malfunction, misplacement, shelf, or scan errors are some of the common reasons causing inventory inaccuracy. For example, to simplify the payment process, the cashier may scan the different items with the same price together instead of one by one, which may lead to inventory errors for all the items. Misplacement directly makes the products unavailable for sale. Even though they can be found finally, they may not yield profit, because of the seasonal products or the food with limited expiry date. A study shows that the misplaced items reduce profit by 25% [3].

For resolving the above inventory inaccuracy, radio frequency identification (RFID) technology has emerged as one of the most popular technologies in supply chain management today. By providing a real-time communication with numerous objects at the same time at a distance without contact or direct line of sigh, this technology can improve the product traceability and visibility in a supply chain [4]. The Economist eulogized RFID as one of the best things since the barcode. Companies, especially the manufacture and retail industry, have anticipated about the magic RFID tags and the economic effect they can bring. For example, Wal-Mart requests their top suppliers to ship selective cases and pallets equipped with RFID tag to their distribution centers since 2005, and other retailers like TESCO, Target, and the Department of Defense have also made similar claims [5]. A labor cost reduction in some retail stores is estimated about 17% and a 10% to 30% inventory reduction occurred in the supply chain from an Accenture study [6, 7]. Shrinkage and out-of-stock reduction can also be observed. After the deployment of RFID, Procter & Gamble and Wal-Mart have gain an inventory level reduction by 70% and an improved service level from 96% to 99% [8].

When considering whether to implement the RFID technology, many companies may hesitate due to the expensive previous investment and the high market uncertainty. The game among supply chain partners is also complicated. The tagging process occurs in the producing process; i.e., the supplier should make the previous investment, but retailer stores are usually the ones benefiting more from the technology. The supply chain members may primarily concern their own profit and choose not to cooperate on the investment [9]. One of the most effective ways to coordinate the supply chain and avoid the suboptimization is the contract mechanism.

The revenue sharing contract has been proved to be effective in prevent providing suboptimization caused by the distribution of decision power over the various members. The earliest adoption of revenue sharing was in 1999, when Blockbuster, a video rental store, agreed to allocate part of his revenue to several major suppliers and was reported to see a 90% improvement on revenue [10]. And Google adopts revenue sharing contracts with most of its partners on advertise income on its website, while 80% of the e-commerce websites have put this contract mechanism into practice [11].

Like most literatures, the basic model in this paper is Newspaper Vendor Problem (NVP). From the perspective of incentive and newsvendor theories, we address the preceding research questions by analyzing a stylized a two-echelon supply chain consisting of a manufacturer and a retailer in a single-period model with price-dependent demand; that is, the market demand is price dependent and has a random component.

Firstly, in an integrated supply chain, we focus on figuring out for this one-supplier-one-retailer supply chain system and how the exogenous elements (inaccuracy degree, the tag price) affect the incentive. We consider two different scenarios. In the first non-RFID scenario, the supply chain optimizes its operations by only taking into account the inventory shrinkage problems. We find if the commodity availability can be improved, an integrated supply chain without the RFID technology will be better off. In the second scenario, films improve the inventory system by deploying RFID. We also propose an analytical critical tag price which makes the deployment of RFID cost effective.

Secondly, in decentralized supply chain, we mainly study whether can we coordinate the supply chain by RFID technology through revenue sharing contract. By seeking appropriate contract parameters under Stackelberg game, the supply chain can finally be coordinated while all partners are better off.

This paper is organized as follows: in the following section, we present an overview of the academic research of RFID adoption in supply chain management and the development of revenue sharing contracts. In Section 3 we give the description and assumption of our model. Next in Section 4 we have an appropriate condition to make the investment profitable in an integrated supply chain. Then Section 5 compares the uncoordinated and revenue sharing contract supply chain and gets the coordinate condition. We present some numerical examples in Section 6 to make our propositions more clear. Finally, in Section 7 we summarize our results and discuss the possible future research.

## 2. Literature Review

RFID application and inventory inaccuracy were researched long time ago but mostly separately. With the development of RFID technology, it is used to eliminate the inaccuracy in supply chain, and some research has been done on reducing the effect of inventory inaccuracy by developing RFID and obtaining the supply chain coordination.

The first paper considering inventory inaccuracy is Iglehart and Morey [12]. They explored the impact of inventory inaccuracy and its causes. The four main causes are transaction errors, shrinkage errors, inaccessible inventory, and supply errors. Since then, many researchers started to look for the effective solutions to reduce the inaccuracy. The early application of RFID was created during the second war to tell friendly planes from enemy planes [13]. Then the RFID technology has been used in many areas like inventory management, retail, healthcare, textile, automotive, and luxury goods industries [14]. Here we mainly consider the ROI (return on investment) analysis and its use in supply chain with inventory inaccuracy. RFID technology is one of the most anticipated technologies [15]. Note that none of the above empirical works have a uniform and reasonable model, nor do they give the company some effective operational advice.

Rekik et al. [16] analyzed the associated costs and profits if a company decided to implement RFID under the wholesale contract. And they discovered the sufficient condition to invest it when no fixed investment was concerned. Heese [17] compared the different optimal decisions in a decentralized supply chain with those in an integrated one and found that by assuming RFID technology could eliminate the inventory inaccuracy, they determined the cost thresholds at which RFID adoption became profitable. Camderelia and Swaminathan [15] considered a supply chain under misplacement of inventory subject to uncertain demand, studied both centralized and decentralized cases, and identified the conditions to coordinate the supply chain under implementation of RFID.

Fan and Chang [18] added a new parameter in the traditional model of RFID's application in supply chain with inventory inaccuracy. They considered the situation of a retailer stemming from shrinkage problems. The analysis of inventory shrinkage problems was to optimize the order quantities and the expected profits in consideration with the effect of the available rate of ordering quantity, RFID read rate improvement, and the tag price, respectively. Their results show that whether the retailer to deploy RFID depended on the relative value of the available rate of ordering quantity and RFID read rate improvement. They also presented a formulation of the threshold value of tag cost which makes the deployment of RFID cost effective. Xu and Jiang [19] tried to get optimal order decision of a single newsvendor model in four inventory inaccuracy cases including (1) the retailer ignores the inventory error; (2) the retailer estimates the inventory error; (3) the retailer shares the inventory information with the manufacture; and (4) RFID is used to reduce or eliminate the error. They discussed the profitability of RFID adoption as well as derive the critical RFID tag price for RFID investment. The above literatures either illustrate the conditions for coordinating the supply chain or consider the RFID cost thresholds that make the supply chain profitable, but seldom literatures combine these two important parts.

Qin et al. [20] attempted to compare the inventory inaccuracy impact on bullwhip effect in terms of order variance amplification and supply chain performance. In particular, the incentive of sharing information in supply chain is also provided by comparing the cost of two supply chain settings. Besides, readers who are interested in RFID's profitability can also refer to De Kok and Van Donselaar [21] which analyzed break-even of RFID technology for inventory sensitive to shrinkage or Özden Engin Çakıcı and Groenevelt [22] which emphasized the RFID's usage in pharmaceutical inventory to optimal system and control shrinkage.

Cui et al. [23] explored the different effectiveness of RFID in decreasing the inventory inaccuracies in a supply chain containing one retailer and two suppliers, and they indicate that RFID can not only decrease inventory inaccuracies, but also strengthen the supply chain coordination. Zhang and Li [24] investigated RFID adoption strategies in a decentralized supply chain with one manufacturer and two competing retailers both of whom face inventory misplacement problems. These two papers examined how RFID can be applied to inventory inaccuracy in the supply chain of multiple suppliers and retailers.

Different from the above literature, in our model, the most distinct contribution is the supply chain coordination under inventory inaccuracy with price-dependent demand. Most literatures including the paper above simulate the demand realization as simple distribution. However, in our model, price-dependent demand is more realistic and detailed by comparison. We apply the price-dependent demand in the model with the aid by the paper [25], which examined an extension of the newsvendor problem in which stocking quantity and selling price were set simultaneously. The newsvendor model was affected by price, in additive case. In this market setting, at the one hand, we evaluate the RFID system installation incentive when the supply chain is integrated. By comparing two scenarios (non-RFID and RFID), we find out the condition of inventory inaccuracy degree, the tag price, and corresponding optimal actions. On the other hand, we analyze the decentralized supply chain, in which retailer and supplier share the tag cost and benefit offered by RFID. By the revenue sharing contract, the supply chain can be coordinated.

## 3. Model Introduction

We consider a two-echelon supply chain consisting of a manufacturer and a retailer in a single-period model with price-dependent demand. The order decision should be made before selling season, and after the season two things may happen: for the demand the retailer does not satisfy, a goodwill penalty cost occurs; for the unsold products, the retailer suffers a holding cost. The demand contains a stochastic component.

Inventory inaccuracy exists in this supply chain. We assume the inventory inaccuracy occurs immediately on the delivery. Once the inventory level is decided part of the order gets misplaced in the store and not all the order is available to the end customers during the selling season. Inventory can be misplaced due to various reasons. Customers or employees may put the items on the wrong floor or these goods are misplaced in storage areas. In reality, the inventory inaccuracy happens gradually over time. For convenience, we assume that all the inaccuracy completes instantly and the demand occurs right after that. The proportion of the right inventory is $\theta$. By the fact that most of the goods are in the right place, we assume $0.5 \leq \theta < 1$.

Once the supply chain implements the RFID system, every single item can be tracked exactly through the RFID tag. For the goods that the customers cannot get, the retailer can ensure them immediately back to the right shelf via checking and monitoring. Hence, the commodity availability always keeps $100\%(\theta = 1)$. The supply chain investing RFID system incurs a fixed cost and a variable tag cost per unit. For conveniently we set the final total tag cost at $t > 0$ per unit.

The demand in this paper is follows: an additive fashion $D(p,\varepsilon) = y(p) + \varepsilon$, where $y(p)$ is a decreasing function that captures the dependency between demand and price and $\varepsilon$ is a random variable larger than 0. The exponential distribution has no memory and can be used to represent the interval at which individual random events occur. So, we assume that $\varepsilon$ follows an exponential distribution with parameter $\lambda$; the mean $\mu = 1/\lambda$. We let $y(p) = a - bp > 0$ $(a > 0, b > 0)$. $b$ is a parameter to the demand sensitivity.

At the beginning of the selling season, $\boldsymbol{Q}$ units are produced at a unit cost $\boldsymbol{c}$. In RFID system, an item-level tag is attached on every product and another cost $\boldsymbol{t}$ occurs in the same time. The retailer purchases these products at a wholesale price $\boldsymbol{w}$ from the manufacturer and sells them out at a price $\boldsymbol{p}$. If the demand during the season does not exceed $\boldsymbol{Q}$, the leftover is held at the unit cost $\boldsymbol{h}$. Alternatively, if the demand exceeds $\boldsymbol{Q}$, each of the shortage is assessed the per-unit penalty cost $\boldsymbol{g}$.

Other notations used in our model are as follows:

$\theta$: the commodity availability (in RFID system, $\theta = 1$ otherwise $0.5 \leq \theta < 1$).

$\alpha$: the fraction of RFID tag cost the retailer pays.

$\varphi$: the fraction of the revenue the retailer gives to the manufacturer.

For the calculation simplicity, we add a constraint $\mu < b(p + g + h)$.

## 4. Integrated Supply Chain

In an integrated supply chain, the manufacturer and the retailer belong to the same company and jointly deal with the demand uncertainty of the custom market. No wholesale and order flows exit. We attempt to compare the best performance before and after the system adopting the RFID technology and in this way discuss the incentive mechanism. Define $\Pi_i(t,\theta,p)$ as the expected profit of the supply chain, where $i \in \{RF, NRF\}$, representing the RFID condition and non-RFID condition.

The supply chain's profit can be written as

$$\pi(z,p) = p\min(Q,D) - h(Q-D)^{+} - g(D-Q)^{+} - cQ \tag{1}$$

We set $z = Q - y(p)$; order quantity can be expressed as $Q = y(p) + z$, while the profit is

$$\begin{aligned}\pi(z,p) &= p\min(y(p)+z, y(p)+\varepsilon) \\ &\quad - h(y(p)+z-(y(p)+\varepsilon))^{+} \\ &\quad - g(y(p)+\varepsilon-(y(p)+z))^{+} \\ &\quad - c(y(p)+z) \\ &= p(y(p)+\min(\varepsilon,z)) - h(z-\varepsilon)^{+} \\ &\quad - g(\varepsilon-z)^{+} - c(y(p)+z)\end{aligned} \tag{2}$$

This transformation of variables was first designed in the work of Petruzzi and Dada [25]. It provides an alternative interpretation of production decisions: if the choice of $\boldsymbol{z}$ is larger than the relative value of $\varepsilon$ and the leftover occurs, we have to bear overstock cost. Conversely, the shortages cost occurs. All the deciders need to do is to find an optimal price p$*$ and an optimal production factor z$*$ that maximize the expected profit. Then the corresponding production quantity is $Q* = y(p*) + z*$.

*4.1. Non-RFID Scenario.* In a non-RFID system, the inventory inaccuracy exists with $0.5 \leq \theta < 1$. The true inventory is Q, but this is not the effective inventory that the retail shelf can get: $100(1-\theta)\%$ of the inventory is assumed to disappear due to inventory inaccuracy; thus the effective inventory is $100\theta\%$ of true number of products, that is, $\theta Q$. We can express the partner's expected profit in the following way:

$$\begin{aligned}\Pi^{\theta}_{NRF}(\mathrm{Q},\mathrm{p}) &= \int_{0}^{\theta Q}(\mathrm{p}D - h(\theta Q - D))\,f(D)\,dD \\ &\quad + \int_{\theta Q}^{\infty}(p\theta Q - g(D-\theta Q))\,f(D)\,dD \\ &\quad - cQ\end{aligned} \tag{3}$$

The profit function consists of three parts. The first is the sales revenue and the stock cost when overstocked. The second part indicates the retailer's revenue and penalty when the custom demand only partly satisfied. The last is the production cost.

We set $D = a - bp + \varepsilon$, and let $T = \theta Q - (a - bp)$; the profit is

$$\begin{aligned}&\Pi^{\theta}_{NRF}(\mathrm{Q},\mathrm{p}) \\ &= \int_{0}^{T}(\mathrm{p}(a-bp+\varepsilon) - h(\theta Q - (a-bp+\varepsilon)))\,f(\varepsilon)\,d\varepsilon \\ &\quad + \int_{T}^{\infty}(p\theta Q - g((a-bp+\varepsilon)-\theta Q))\,f(\varepsilon)\,d\varepsilon - cQ\end{aligned} \tag{4}$$

Then, we can rewrite it as follows:

$$\begin{aligned}\Pi^{\theta}_{NRF}(Q,p) &= (p+g)\bullet\theta Q\bullet\overline{F}(T) + (p+h) \\ &\quad \bullet(a-bp)\bullet F(T) \\ &\quad + (p+h)\int_{0}^{T}uf(u)\,du - h\bullet\theta Q \\ &\quad \bullet F(T) - g\bullet(a-bp)\bullet\overline{F}(T) \\ &\quad - g\int_{T}^{\infty}uf(u)\,du - cQ\end{aligned} \tag{5}$$

Our goal is to maximize $\Pi^{\theta}_{NRF}(Q,p)$ and discover the optimal action of the system. The first and second partial derivatives of $\Pi^{\theta}_{NRF}(Q,p)$ with respect to $\boldsymbol{Q}$ and $\boldsymbol{p}$ are

$$\frac{\partial\Pi^{\theta}_{NRF}(Q,p)}{\partial Q} = (p+g)\bullet\theta\overline{F}(T) - h\bullet\theta F(T) - c \tag{6}$$

$$\frac{\partial^2\Pi^{\theta}_{NRF}(Q,p)}{\partial Q^2} = -\theta^2(p+g+h)\bullet f(T) < 0 \tag{7}$$

$$\begin{aligned}\frac{\partial\Pi^{\theta}_{NRF}(Q,p)}{\partial P} &= (a-2bp-bh)F(T) \\ &\quad + (\theta Q + gb)\overline{F}(T) + \int_{0}^{T}uf(u)\,du\end{aligned} \tag{8}$$

$$\begin{aligned}\frac{\partial^2\Pi^{\theta}_{NRF}(Q,p)}{\partial p^2} &= -b^2(p+g+h)\bullet f(T) - 2b\bullet F(T) \\ &< 0\end{aligned} \tag{9}$$

The Hessian matrix of $\Pi^{\theta}_{NRF}(Q,p)$ in this situation is

$$\begin{aligned}H_{\Pi^{\theta}_{NRF}(Q,p)} &= \begin{bmatrix}\dfrac{\partial^2\Pi^{\theta}_{NRF}(Q,p)}{\partial Q^2} & \dfrac{\partial^2\Pi^{\theta}_{NRF}(Q,p)}{\partial Q\partial p} \\ \dfrac{\partial^2\Pi^{\theta}_{NRF}(Q,p)}{\partial p\partial Q} & \dfrac{\partial^2\Pi^{\theta}_{NRF}(Q,p)}{\partial p^2}\end{bmatrix} \\ &= \begin{bmatrix}-\theta^2(p+g+h)\bullet f(T) & \theta\overline{F}(T) - \theta bf(T)(p+g+h) \\ \theta\overline{F}(T) - \theta bf(T)(p+g+h) & -b^2(p+g+h)\bullet f(T) - 2b\bullet F(T)\end{bmatrix}\end{aligned} \tag{10}$$

With the parameter setting all positive, the first leading principle minor is $-\theta^2(p+g+h)\bullet f(T) < 0$. And the second leading principle minor is $\theta^2 e^{-\lambda T}[-e^{-\lambda T} + 2b\lambda\bullet(p+g+h)\bullet(1 - b\lambda(p+g+h)e^{-\lambda T})]$.

Then we consider the situation under $a - bp > \theta Q$; thus $e^{-\lambda(\theta Q-(a-bp))} > 1$. As assumed $\mu < \mathrm{b}(\mathrm{p}+\mathrm{g}+\mathrm{h})$, so $b\lambda(p+g+h)e^{-\lambda T} > 1$. Then we have $\theta^2 e^{-\lambda T}[-e^{-\lambda T} + 2b\lambda \bullet (p+g+h) \bullet (1 - b\lambda(p+g+h)e^{-\lambda T})] < 0$. There is a single extreme point $(\mathbf{Q}*, \boldsymbol{p}*)$ for $\Pi^{\theta}_{NRF}(Q, p)$.

We can have the conclusion that there is a unique sale price $p_{NRF}*$ and order quantity $Q_{NRF}{}^*$ that maximize the supply chain's profit, which means $\Pi^{\theta}_{NRF}(Q^*, p^*)$ is a global maximum. They can easily be archived by letting (6) and (8) equal 0, respectively.

$$\begin{aligned}&(a - 2bp^* - bh) F(T) + (\theta Q + gb)\overline{F}(T) \\ &\quad + \int_0^T uf(u)\,du = 0 \\ &F(T) = \frac{(p^* + g)\theta - c}{\theta(p^* + g + h)}\end{aligned} \tag{11}$$

The following propositions summarize the above discussion.

**Proposition 1.** *For an integrated supply chain with inventory inaccuracy, the optimal decision to maximize the total profit satisfies the following equations:*

$$\begin{aligned}&\left(a - 2bp^* + \frac{bc}{\theta}\right) + \frac{(p+g)\theta - c}{\lambda\theta(p^* + g + h)} = 0 \\ &Q^* = \frac{a - bp^*}{\theta} - \frac{1}{\lambda\theta}\ln\frac{c + h\theta}{\theta(p^* + g + h)}\end{aligned} \tag{12}$$

*Proof.* Substituting $f(T) = \lambda e^{-\lambda T}$, $F(T) = 1 - e^{-\lambda T}$ into (11), we can get $\int_0^T uf(u)du = TF(T) - T - (1/\lambda)e^{-\lambda T} + 1/\lambda$. Thus

$$\begin{aligned}&(a - 2bp^* - bh)\bullet\left(1 - e^{-\lambda T}\right) + (\theta Q + gb)e^{-\lambda T} \\ &\quad + TF(T) - T - \frac{1}{\lambda}e^{-\lambda T} + \frac{1}{\lambda} = 0 \\ &1 - e^{-\lambda T} = \frac{(p^* + g)\theta - c}{\theta(p^* + g + h)}\end{aligned} \tag{13}$$

So the optimal decision $(Q^*, p^*)$ is given by

$$\begin{aligned}&\left(a - 2bp^* + \frac{bc}{\theta}\right) + \frac{(p+g)\theta - c}{\lambda\theta(p^* + g + h)} = 0 \\ &Q^* = \frac{a - bp^*}{\theta} - \frac{1}{\lambda\theta}\ln\frac{c + h\theta}{\theta(p^* + g + h)}\end{aligned} \tag{14}$$

□

**Proposition 2.** *The optimal price $p_{NRF}{}^*$ decrease in $\boldsymbol{\theta}$. The total profit $\Pi^{\theta}_{NRF}(Q, p)$ increases when commodity availability $\boldsymbol{\theta}$'s increase while $\boldsymbol{p}$ and $\mathbf{Q}$ are fixed.*

*Proof.*

*Part 1.* To prove $\mathrm{d}p^*/\mathrm{d}\theta < 0$, we define $\mathrm{G}(p^*, \theta) = (a - 2bp^* + bc/\theta) + ((p+g)\theta - c)/\lambda\theta(p^* + g + h)$. Hence, we obtain

$$\begin{aligned}\frac{\mathrm{dG}(p^*, \theta)}{\mathrm{d}p^*} &= -2b + \frac{c + h\theta}{\lambda\theta(p + g + h)^2} \\ \frac{\mathrm{dG}(p^*, \theta)}{\mathrm{d}\theta} &= -\frac{bc}{\theta^2} + \frac{c}{\lambda\theta^2(p + g + h)}\end{aligned} \tag{15}$$

Moreover, we have $\mu = 1/\lambda < \mathrm{b}(p + g + h)$ and $0.5 < \theta < 1$; thus $\mathrm{dG}(p^*, \theta)/dp^* < 0$, and $\mathrm{dG}(p^*, \theta)/\mathrm{d}\theta < 0$. By using the implicit function theorem, we can get

$$\begin{aligned}\frac{dp^*}{d\theta} &= -\frac{dG(p^*, \theta)/d\theta}{dG(p^*, \theta)/dp^*} \\ &= -\frac{-bc/\theta^2 + c/\lambda\theta^2(p + g + h)}{-2b + (c + h\theta)/\lambda\theta(p + g + h)^2} < 0\end{aligned} \tag{16}$$

The optimal price is decreasing in commodity availability ($\boldsymbol{\theta}$).

*Part 2.* For a fixed $\boldsymbol{p}$ and $\mathbf{Q}$

$$\frac{\mathrm{d}\Pi^{\theta}_{NRF}}{\mathrm{d}\theta} = (p + g)\bullet Q \bullet \overline{F}(T) + s \bullet Q \bullet F(T) \tag{17}$$

$\overline{F}(T) > 0$, $F(T) > 0$, so we get $d\Pi^{\theta}{}_{NRF}/d\theta > 0$.

In Petruzzi and Dada [25], there was a series of optimal stocking and pricing policies for different demand cases but they did not go through every case. Here in our model, we assume the demand by setting it follows an exponential distribution and get a direct expression of the order quantity and pricing.

Under this circumstance, we can totally get the idea that an integrated supply chain without the RFID technology will be better off if the commodity availability can be improved. That is to say, perfecting the inventory visualization can raise the income substantially. □

*4.2. RFID Scenario.* After the system implements the RFID technology, the commodity availability becomes *1*, but every unit has an extra cost-tag cost $\boldsymbol{t}$. Then the expected profit of the integrated system is given as follows:

$$\begin{aligned}&\Pi_{RF}(t, z, p) \\ &\quad = \int_0^z (p[y(p) + u] - h[z - u]) f(u)\,du \\ &\qquad + \int_z^{\infty} (p[y(p) + z] - g(u - z)) f(u)\,du \\ &\qquad - (c + t)[y(p) + z]\end{aligned} \tag{18}$$

The expression of $\Pi_{RF}(t, z, p)$ consists of three parts as well. The first and second parts are the profit the supply chain can get when the demand excesses order quantity and when the shortage happens. The last part is the production cost including tag cost. This profit function was also used in the work of Petruzzi and Dada [25] and many other studies based on the newsvendor model. Define

$$\Lambda(z) = \int_0^z (z-u) f(u)\,du,$$
$$\Theta(z) = \int_z^{\infty} (u-z) f(u)\,du. \tag{19}$$

Transform (18) in the same way above; we can write

$$\Pi_{RF}(t,z,p) = (p-c-t)(y(p)+\mu) - [(c+h+t)\Lambda(z) + (p+g-c-t)\Theta(z)] \tag{20}$$

Then we get Propositions 3 and 4.

**Proposition 3.** *If an integrated supply chain invests the RFID technology, the inventory inaccuracy will be removed. The optimal profit of the system can satisfy the following equation:*

$$p_{RF}* - \frac{a+(c+t)b+\mu}{2b} + \frac{1}{2b\lambda}\cdot\frac{(c+t)+h}{p_{RF}*+g+h} = 0$$
$$z_{RF}* = -\frac{1}{\lambda}\ln\frac{c+t+h}{p+g+h} \tag{21}$$

**Proposition 4.** *The optimal price $p_{RF}*$ also increases in $\boldsymbol{t}$ while the optimal production quantity $Q_{RF}* = a - bp_{RF}* + z_{RF}*$ decreases with $\boldsymbol{t}$. $\Pi_{RF}(z,p)$ decreases with the tag price $\boldsymbol{t}$ for the fixed $\boldsymbol{p}$ and $\boldsymbol{z}$*

*Proof.*

*Part 1.* By changing the expression of the optimal price, it becomes $2bp = a + (c+t)b + \mu - \mu(c+t+h)/(p+g+h)$. Differentiating both side with respect to $\boldsymbol{t}$ comes $dp/dt = (b-\mu/(p+g+h))/(2b-\mu(c+t+h)/(p+g+h)^2)$. Applying $\mu < b(c+h)$, we have $b-\mu/(p+g+h) > 0$; most industry, we have $\boldsymbol{c}+\boldsymbol{t} < \boldsymbol{p}$; hence $2b-\mu(c+t+h)/(p+g+h)^2 > 0$, $dp/dt > 0$.

*Part 2.* $Q* = a - bp* + z* = a - bp* - (1/\lambda)\ln((c+t+h)/(p+g+h))$; the derivative with respect to tag price $\boldsymbol{t}$ is $dQ/dt = (-b+\mu/(p+g+h))(dp/dt) - \mu/(c+t+h)$. Applying $\mu < b(c+h)$ and $dp/dt > 0$, we have $dQ/dt < (-b + b(c+h)/(p+g+h))(dp/dt) - \mu/(c+t+h) < 0$, then the optimal production quantity decreases with the tag price $\boldsymbol{t}$.

*Part 3.* For a fixed $\boldsymbol{p}$ and $\boldsymbol{z}$, $d\Pi^t{}_{RF}/dt = -(y(p)+\mu) - \Lambda(z) + \Theta(z) = -y(p) - z < 0$.

Here we define $\Delta\Pi(t,\theta) = \Pi^t{}_{RF} - \Pi^\theta{}_{NRF}$ as the incentive of adopting RFID technology for an integrated system. This kind of evaluation can be also found in Gaukler and Seifert [26]. In the same way, we examine the effect the commodity availability and the tag price have on the incentive. Because $\Pi^t{}_{RF}$ decreases with the tag price t and $\Pi^\theta{}_{NRF}$ increases with the commodity availability, we can easily find that the incentive of investing RFID system is decreasing with the tag price $\boldsymbol{t}$ and the commodity availability $\boldsymbol{\theta}$. This is straightforward that, for a company with high inventory inaccuracy or facing an expensive tag, it is not willing to adopt RFID system. □

**Proposition 5.** *A supply will be profitable only when $t \le \bar{t}$ and $\theta \le \bar{\theta}$ with RFID, where $\bar{t}$ and $\bar{\theta}$ satisfy the following equation: $\Delta\Pi(\bar{t},\bar{\theta}) = \Pi^t{}_{RF} - \Pi^\theta{}_{NRF} = 0$.*

*Since the convexity, for every $\boldsymbol{\theta}$, there exists a unique tag price $\bar{t}$ such that there is a positive incentive of RFID for the integrated supply chain for all $t \le \bar{t}$. The $\bar{t}$ can be called the break-even point. This applies to the tag price, too.*

## 5. Decentralized Supply Chain with RFID

*5.1. Manufacturer as a Stackelberg Leader.* In a decentralized system, we first consider the case that the manufacturer holds prominent power and acts as a leader in a two-echelon Stackelberg game. Its profit will be maximized. The game is described as follows.

The retailer faces the newsvendor's problem. The retailer must choose an order quantity $\boldsymbol{Q}$ at a wholesale price $\boldsymbol{w}$ before the start of a single selling season with a stochastic demand. The demand is price dependent. Retailer has the right to decide sale price $\boldsymbol{p}$. The demand is price dependent and can be molded in an additive fashion $D(p,\varepsilon) = y(p) + \varepsilon$, where $y(p) = a - bp$, $a > 0, b > 0$. After the season, the retailer may suffer a goodwill lost for unsatisfied demand or a host cost for surplus commodities. Because of the manufacturer's leader position, he will have the retailer to pay for a fraction $\boldsymbol{\alpha}$ of the tag price.

We use $\Pi_i^D$ to express the individual profit in the uncoordinated condition $i \in \{M,R,SC\}$, standing for the manufacturer, the retailer, and the supply chain, respectively.

The retailer's expected profit is

$$\begin{aligned}\Pi_R^D(z,p) &= p\min(Q,D) - h(Q-D)^+ - g(D-Q)^+ \\ &\quad - (w+\alpha t)Q \\ &= p(y(p)+\min(\varepsilon,z)) - h(z-\varepsilon)^+ \\ &\quad - g(\varepsilon-z)^+ - (w+\alpha t)(y(p)+z)\end{aligned} \tag{22}$$

In this scenario, the retailer's profit consists of the following four parts. The first is the sales revenue. The second and the third parts are inventory cost and goodwill penalty cost, where only one cost happens in each scenario. The last part is the purchasing cost and the partial tag cost retailer should take.

In the same way, we let $z = Q - y(p)$: (22) can be transformed to

$$\Pi_R^D(z,p) = \int_0^z (p[y(p)+u] - h[z-u]) f(u)\,du$$

$$+\int_{z}^{+\infty}\left(p\left[y\left(p\right)+z\right]-g\left(u-z\right)\right)f\left(u\right)du$$
$$-\left(w+\alpha t\right)\left[y\left(p\right)+z\right] \tag{23}$$

The expected profit of the manufacturer is

$$\Pi_M^D\left(w\right)=\left[w-c-\left(1-\alpha\right)t\right]\left[y\left(p\right)+z\right] \tag{24}$$

We can get $\Pi_R^D(z,p) = (p-w-\alpha t)(y(p)+\mu)-(w+\alpha t+h)\Lambda(z)-(p+g-w-\alpha t)\Theta(z)$.

To maximize $\Pi_R(z,p)$ and get the optimal actions of the retailer, we obtain the first and second partial derivatives to $\boldsymbol{z}$ and $\boldsymbol{p}$:

$$\begin{aligned}\frac{\partial\Pi_R^D\left(z,p\right)}{\partial z}&=\left(p+g-w-\alpha t\right)-\left[p+g+h\right]F\left(z\right)\\&=\left(p+g+h\right)\overline{F}\left(z\right)-\left(w+\alpha t+h\right)\end{aligned} \tag{25}$$

$$\frac{\partial^2\Pi_R^D\left(z,p\right)}{\partial z^2}=-\left(p+g+h\right)f\left(z\right)<0 \tag{26}$$

$$\begin{aligned}\frac{\partial\Pi_R^D\left(z,p\right)}{\partial p}&=\left(y\left(p\right)+\mu\right)+\left(p-w-\alpha t\right)\left(-b\right)\\&\quad-\Theta\left(z\right)\end{aligned} \tag{27}$$

$$\frac{\partial^2\Pi_R^D\left(z,p\right)}{\partial p^2}=-2b<0 \tag{28}$$

By the same way we did in the precious section, we here can also see that the $\boldsymbol{p}*$ and $\boldsymbol{z}*$ with (25) and (27) equal to 0 are the optimal decisions maximizing $\Pi_R(z,p)$. The following demonstrates the optimal solution to the retailer.

The retailer's optimal price $\boldsymbol{p}*$ and order factor $\boldsymbol{z}*$ satisfy the following equation:

$$\begin{aligned}&p^D*-\frac{a+\left(w+\alpha t\right)b+\mu}{2b}+\frac{1}{2\lambda b}\frac{w+\alpha t+h}{p^D*+g+h}=0\\&z^D*=-\frac{1}{\lambda}\ln\frac{w+\alpha t+h}{p+g+h}\end{aligned} \tag{29}$$

Because we assume both the manufacturer and the retailer have complete information, when the contract parameters are given, the manufacturer can surely know the retailer's action. Consequently, he needs to decide a best wholesale $\boldsymbol{w}*$ to maximize own his profit. We can rewrite the retailer's solution as a function of $\boldsymbol{w}$, namely, $\boldsymbol{p}*(\boldsymbol{w})$ and $\boldsymbol{z}*(\boldsymbol{w})$.

The manufacturer's expected profit is $\Pi_M^D(w) = [w-c-(1-\alpha)t]Q*$. Substituting $p*(w)$ and $z*(w)$ into it, we get (30). What the manufacture needs to do is maximize the following expression:

$$\begin{aligned}\Pi_M^D\left(w\right)=\left[w-c-\left(1-\alpha\right)t\right]&\left(\frac{a-\left(w+\alpha t\right)b-\mu}{2}\right.\\&\left.+\frac{1}{2\lambda}\cdot\frac{w+\alpha t+h}{p+g+h}-\frac{1}{\lambda}\ln\frac{w+\alpha t+h}{p+g+h}\right)\end{aligned} \tag{30}$$

and in the vertically competition of the game, if manufacturer wants to make a profit, i.e., $w > c+(1-\alpha)t$, the retailer's order quantity and price cannot reach the sets of system-wide optimal. The supply chain is not coordinated.

*5.2. Retailer as a Stackelberg Leader.* Then we discuss the situation that the retailer plays the role as a leader. Powerful retailers like Wal-Mart usually dictate the contract terms. In such cases, the demand market keeps is the same as before but the retailer decide how much he should pay for the RFID tag price.

$$\begin{aligned}\Pi_M^D\left(w\right)&=\left[w-c-\left(1-\alpha\right)t\right]\left[y\left(p\right)+z\right]\\\Pi_R^D\left(z,p\right)&=\left(p-w-\alpha t\right)\left(y\left(p\right)+\mu\right)\\&\quad-\left(w+\alpha t+h\right)\Lambda\left(z\right)\\&\quad-\left(p+g-w-\alpha t\right)\Theta\left(z\right)\end{aligned} \tag{31}$$

Using the first-order optimality conditions for the retailer's problem, we have

$$\begin{aligned}\frac{\partial\Pi_R^D\left(z,p\right)}{\partial z}&=\left(p+g-w-\alpha t\right)-\left[p+g+h\right]\overline{F}\left(z\right)\\&=\left(p+g+h\right)\overline{F}\left(z\right)-\left(w+\alpha t+h\right)\end{aligned} \tag{32}$$

Thus we find the maximum wholesale price, $w^M = p+g-\alpha t$, so that if $w < w^M$, the best retailer's response is determined by

$$F\left(z\right)=\frac{p+g-w-\alpha t}{p+g+h} \tag{33}$$

As the retailer being a leader, the follower will act first to maximize his profit under the assumptions that the leader has given the action (p, $z$, and $\alpha$). We can see the manufacture's profit is an increasing function of the wholesale price w. So she will choose the max wholesale price $w^M$ to earn a biggest profit. Substituting manufacture's best response to the retailer's action $p^D*$ and $z^D*$, we get $\overline{p} = (a+bg)/b, \overline{z} = 0$, but $a-b\overline{p} < 0$, so we need to adjust as $\overline{p} = a/b$.

Compared with the manufacture leading the supply chain, the retailer's leading makes the calculation more simple; the best response of each partner is as follows.

For the manufacturer, $\overline{w} = p+g-\alpha t$, and for the retailer $\overline{p} = a/b, \overline{z} = 0$.

Let us look back on the supply chain performance; the order quantities $\overline{q} = a-b\overline{p}+\overline{z} = 0, \Pi_M^D = 0$, and $\Pi_R^D = -\mu g$. Both partners can not earn a positive profit; thus the supply chain is not coordinated.

*5.3. Revenue Sharing Contract under Stackelberg Game.* In this section, we aim to seek a set of actions which coordinates the supply chain with a revenue sharing contract in Stackelberg game. The retailer agrees to give part of his revenue to his manufacturer, then he can get a lower wholesale price less than the production cost. This contract often generates a larger order quantity and a better custom service [9]. We try to get the condition under which the retailer's optimal ordering quantity equals the supply chain's optimal ordering quantity. We often call them reach at a coordination status.

Contract parameters $(w, \varphi)$ are set to reach an agreement between the partners before the order flow. Let $\varphi$ be the fraction of the revenue the manufacturer earns, so $(1-\varphi)$ is the fraction the retailer keeps. Assume all revenue is shared (i.e., holding cost and goodwill penalty are also shared among companies firms). We want to coordinate the supply chain through this contract.

Coordination is a condition where the retailer's optimal decisions (i.e., order size and sale price) bring into correspondence with the supply chain's optimal action (production quantity and sale price). Also, both the retailer and the manufacturer can be better off after the coordination. When a contract coordinates a supply chain, the following three conditions are satisfied: First, the set of supply chain optimal action is supply chain equilibrium; i.e., no firm has a profitable unilateral deviation from the set of supply chain optimal actions. In our model the action to coordinate is the retailer's order size and sale price. Second, there is sufficient flexibility to allow for any division of the supply chain's profit among the firms. If the profit can be allocated arbitrarily, then there always exists a contract that Pareto dominates a noncoordinating contract; i.e., each firm's profit is no worse off and at least one firm is strictly better off. Third, although coordination and flexible profit allocation are desirable features, administer tends to be costly [9].

$\Pi_i^{RS}$ is in token of the partner's expected profit with a RFID system and a revenue sharing contract. $i \in \{M, R, SC\}$, standing for the manufacturer, the retailer, and the supply chain, respectively.

$$\begin{aligned}\Pi_R^{RS}(z,p) &= \int_0^z \left(p\left[y(p)+u\right]-h\left[z-u\right]\right) f(u)\,du \\ &\quad + \int_z^\infty \left(p\left[y(p)+z\right]-g(u-z)\right) f(u)\,du \\ &\quad - (w+\alpha t)\left[y(p)+z\right]-T\end{aligned} \tag{34}$$

$$\Pi_M^{RS}(w) = \left[w-c-(1-\alpha)t\right]\left[y(p)+z\right]+T \tag{35}$$

$$\begin{aligned}\Pi_{SC}^{RS}(z,p) &= \int_0^z \left(p\left[y(p)+u\right]-h\left[z-u\right]\right) f(u)\,du \\ &\quad + \int_z^\infty \left(p\left[y(p)+z\right]-g(u-z)\right) f(u)\,du \\ &\quad - (c+t)\left[y(p)+z\right]\end{aligned} \tag{36}$$

where $T = \varphi\{\int_0^z (p[y(p)+u)]-h[z-u])f(u)du+\int_z^\infty (p[y(p)+z]-g(u-z))f(u)du\}$.

In the revenue sharing contract, if the retailer is as the Stackelberg leader, the manufacturer will be unprofitable. So like most situations, in this paper, manufacturer is the leader and retailer is the follower. The set of supply chain optimal actions is a Stackelberg equilibrium under a specific condition, which also coordinates the supply chain. We use the following proposition to characterize the strategy.

**Proposition 6.** *The supply chain can be coordinated when $w+\alpha t-(1-\varphi)(c+t)=0$.*

$$\begin{aligned}\Pi_R^{RS} &= (1-\varphi)\,\Pi_{SC}^{RS} \\ \Pi_M^{RS} &= \varphi\Pi_{SC}^{RS}.\end{aligned} \tag{37}$$

*At the same time, supply chain's profit can be allocated arbitrarily.*

*Proof.* We can rewrite the retailer and manufacturer's profit function as follows:

$$\begin{aligned}\Pi_R^{RS} &= (1-\varphi)\,\Pi_{SC}^{RS} + \left[(1-\varphi)(c+t)-(w+at)\right] \\ &\quad \bullet \left[y(p)+z\right] \\ \Pi_M^{RS} &= \varphi\Pi_{SC}^{RS} + \left[(w+at)-(1-\varphi)(c+t)\right] \\ &\quad \bullet \left[y(p)+z\right]\end{aligned} \tag{38}$$

When $w+\alpha t-(1-\varphi)(c+t)=0$, we can get

$$\begin{aligned}\Pi_R^{RS} &= (1-\varphi)\,\Pi_{SC}^{RS} \\ \Pi_M^{RS} &= \varphi\Pi_{SC}^{RS}\end{aligned} \tag{39}$$

By manufacturer as a Stackelberg leader, to maximize $\Pi_R^{RS}$ and get the optimal actions of the retailer, we obtain the first and second partial derivatives to $\boldsymbol{z}$ and $\boldsymbol{p}$:

$$\begin{aligned}&\frac{\partial \Pi_z^{RS}(z,p)}{\partial \mathrm{z}} \\ &\quad = (1-\varphi)\left\{(p+h+s)(1-F(z))-(c+t+h)\right\} \\ &\frac{\partial^2 \Pi_z^{RS}(z,p)}{\partial z^2} = -(1-\varphi)(p+h+s)\,f(z)<0 \\ &\frac{\partial \Pi_z^{RS}(z,p)}{\partial \mathrm{p}} \\ &\quad = (1-\varphi)\left\{a-2bp+\mu+b(c+t)-\Theta(z)\right\} \\ &\frac{\partial^2 \Pi_z^{RS}(z,p)}{\partial p^2} = -2b<0\end{aligned} \tag{40}$$

By the same way we did in the precious section, the retailer's optimal price $p_R^{RS*}$ and order factor $z_R^{RS*}$ satisfy the following equation:

$$\begin{aligned}p_R^{RS*} &= \frac{a+(c+t)b+\mu}{2b} - \frac{\Theta(z)}{2b} = p_{SC(RS)}^* \\ F\left(z_R^{RS*}\right) &= 1-\frac{c+t+h}{p+g+h} = F\left(z_{SC(RS)}^*\right)\end{aligned} \tag{41}$$

Substituting $p_R^{RS*}$ and $z_R^{RS*}$ into the manufacturer's expected profit, obviously, the set of supply chain optimal

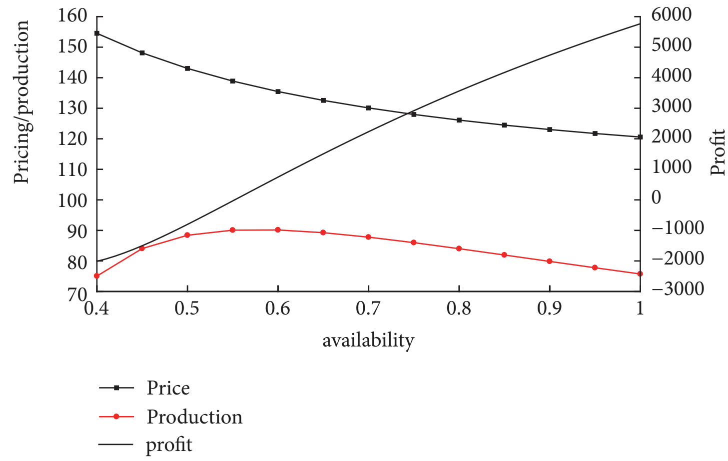


FIGURE 1: Retail price, production quantity, and profit versus commodity availability.

actions is an equilibrium; i.e., neither the retailer nor the manufacturer has a profitable unilateral deviation from the set of supply chain optimal actions.

Notice that $w^0 = (1-\varphi)(c+t) - \alpha t < c+t$. That means the retailer pays less than the commodity cost, but it does not affect the fact that the manufacturer can earn a positive profit, that is, because he can get more through the revenue sharing. □

## 6. Numerical Examples

To verify our above propositions and offer a direct picture of these results, we hereby simulate a supply chain environment where several scenarios are considered and all parameters are set in certain value. Our numerical examples mainly focus on the performance of both RFID technology and revenue sharing contract and also verify what effect we will have on supply chain decisions by different outside factors. We take three kinds of factors into consideration: the business environment factors (i.e., commodity availability $\theta$ and tag price $\boldsymbol{t}$), the demand factors (i.e., demand sensitivity $\boldsymbol{b}$), and the contract factors (tag cost share proportion $\boldsymbol{\alpha}$ and revenue sharing proportion $\boldsymbol{\varphi}$). We study their effects on the performance, respectively.

For business environment factor, we can find what situation is suitable for investing RFID and what effect inventory inaccuracy may have on supply chain decisions. For introducing different level of demand uncertainty, we want to verify that whether revenue sharing contract can bring stabilization to both partners and improve their competitiveness. At last, if a supply chain would like to adopt revenue sharing contract, how their profit will be affected by contract game.

*6.1. Effect of Business Environment.* We examine the effect of the tag price $\boldsymbol{t}$ and the commodity availability $\boldsymbol{\theta}$ (we summarize them as business environment) on the optimal production size and profit in an integrated system in the Figures 1 and 2. The former is with non-RFID system while the latter is in the RFID system. First, on the premise of satisfying the assumptions, the basic parameters are assumed to be valued as shown in Table 1.

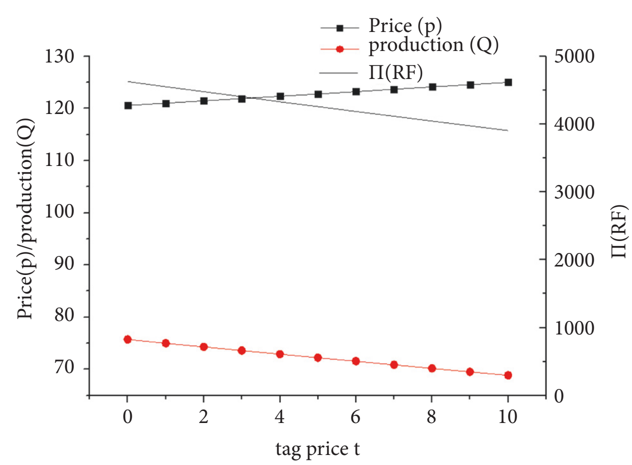


FIGURE 2: Retail price, production quantity, and profit versus tag price.

TABLE 1

| $a$ | $b$ | $\mu$ | $c$ | $h$ | $g$ | $K$ |
|---|---|---|---|---|---|---|
| 180 | 1 | 20 | 50 | 10 | 5 | 0 |

These two examples shown in Figures 1 and 2 illustrate Propositions 2 and 4.

The best price, order quantity, and profit as a function of availability are shown in Figure 1. It shows that the profit without RFID technology becomes larger as the availability increases, which can be easily explained. With lower inventory inaccuracy, customer can get better purchasing experience, and more existing commodity can be transferred into profit. Because the first derivation function of best price with respect to the availability is nonpositive, the best price in this scenario is decreasing with the availability. Also we can do the same analyses for RFID scenario, a higher tag cost

Table 2

| Wholesale Price system ($\alpha$ = 0.3) | | | | | | |
|---|---|---|---|---|---|---|
| **Optimal solution** | $p$ | 142.57 | $w$ | 124.43 | $z$ | 3.132 |
| **Profit** | **M** | 2990.5 | **R** | 723.63 | **SC** | 3714 |
| **Revenue Sharing system ($\varphi$ = 0.65, $\alpha$ = 0.3)** | | | | | | |
| **Optimal solution** | $p$ | 109.67 | $z$ | 14.296 | | |
| **Profit** | **M** | 3475.5 | **R** | 1489.5 | **SC** | 4965 |

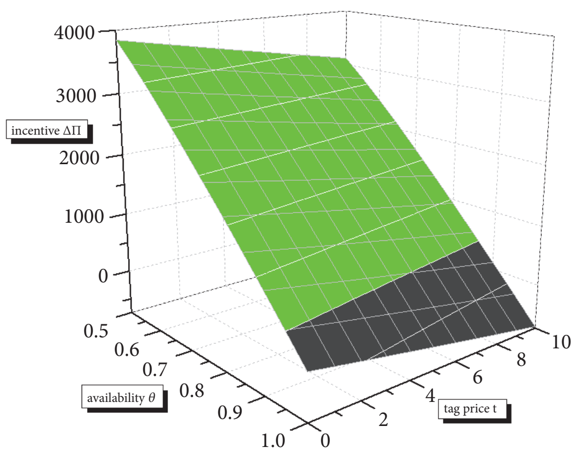


Figure 3: Incentive versus availability and tag price.

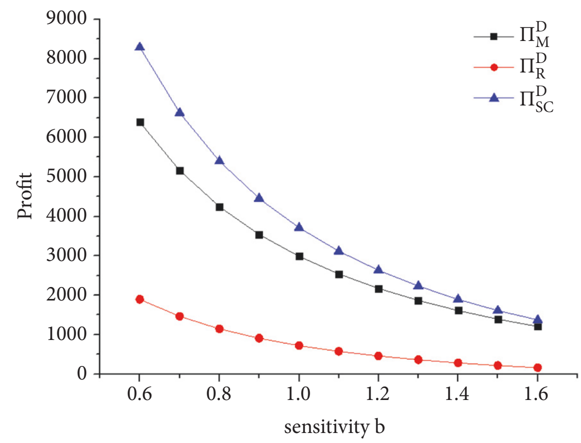


Figure 4: Individual profit in uncoordinated scenario versus demand sensitivity.

will surely lead to a lower profit, so in Figure 2, the profit decreases directly with respect to tag cost. From the proof of Proposition 4, we can easily get that the best price p∗ increases and order quantity Q∗ decreases when a RFID tag becomes more expensive.

Figure 3 shows that the incentive declines in $\boldsymbol{\theta}$ and $\boldsymbol{t}$. This is aligned with real business environment, where companies are willing to invest RFID when tag price is lower or bad commodity availability.

According to this incentive mechanism, companies can make an appropriate decision whether to invest RFID.

*6.2. Effect of Demand Factors.* In this section, we first discover the optimal decisions of price-only condition (the wholesale price condition) and the revenue sharing condition respectively. When the retailer acts as the leader, the supply chain is obviously nonprofitable. So we only assume the manufacturer as the Stackelberg leader and dominates the supply chain. According to Sections 5.1 and 5.3, the optimal solutions of p, w, z (or p, z) and the profits of retailer, supplier, and supply chain are shown in Table 2 for both uncoordinated and revenue sharing systems, with the assumption of $\alpha = 0.3$ and $\varphi = 0.65$.

We can see that, in the same setting of tag price sharing parameter ($\alpha = 0.3$), the supply chain under the revenue sharing is more profitable. The whole profit increases from 3714 to 4965. Even though the retailer's profit share is less than 50% which means he offers 65% of his earning to the manufacturer and his profit is much larger than the one under the uncoordinated condition. All the parties are better off after the coordination.

In this case, the retail's optimal order quantity equals the supply chain's optimal production quantity. Both of the partners act like an entirety and are not worse off, and the profit can be allocated arbitrarily by the profit sharing parameter $\varphi$; we can see the supply chain has been coordinated and has a better performance than the decentralized scenario.

We give a series of figures here to explain the effect of the demand sensitivity on these performance indicators (profit, optimal price, and optimal order quantity). Figure 4 shows that when the demand sensitivity $\boldsymbol{b}$ increases, all the profits, including the manufacture's profit, the retailer's profit, and the supply chain's profit, reduce in the uncoordinated condition. In Figure 5, first we can see that the participants will choose the revenue sharing contract because the supply chain's profit is always larger. Then we can find the market with a revenue sharing contract is relatively insensitive to the price compared to the uncoordinated scenario. We also exam the effect of $b$ on the optimal price and production quantity in the two scenarios. Meanwhile we see that both profit and the improvement decline with $\boldsymbol{b}$ (see Figures 6 and 7). The following four show a downward sloping with the demand sensitivity $\boldsymbol{b}$. The price in the uncoordinated scenario is higher than the revenue sharing scenario, while the opposite happens for the optimal production quantity. After the supply chain adopta this contract, the market is better satisfied.

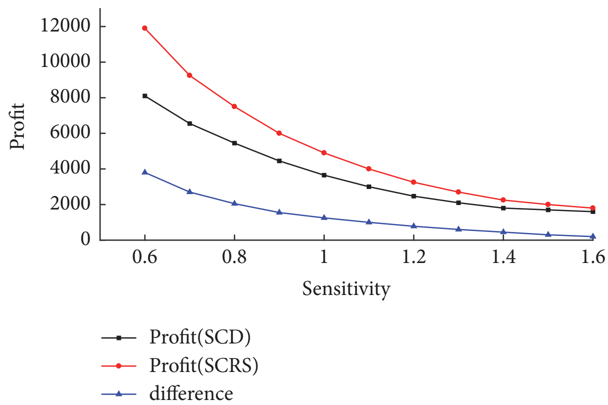


Figure 5: Profit in 2 scenarios versus demand sensitivity.

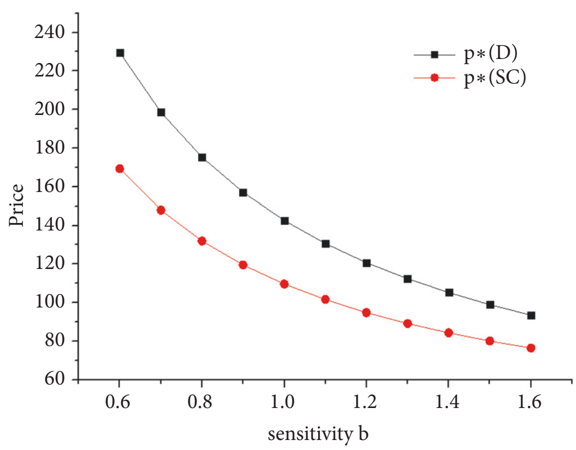


Figure 6: Optimal price in 2 scenarios versus demand sensitivity.

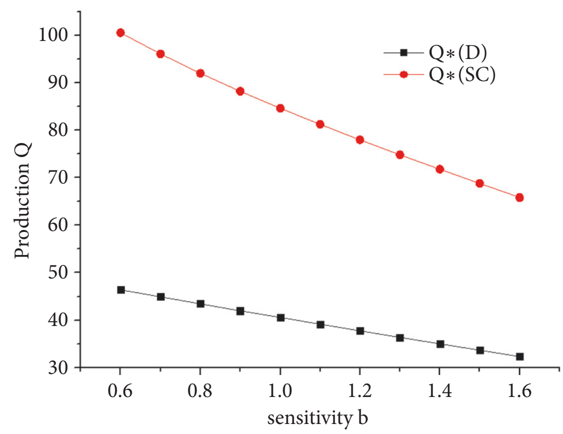


Figure 7: Optimal production quantity in 2 scenarios versus demand sensitivity.

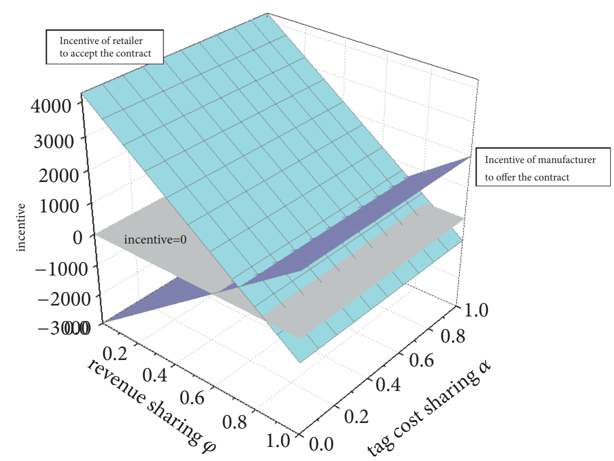


Figure 8: Incentive of manufacturer and retailer to accept the contract.

All these are easy to be explained, the demand sensitivity refers to the degree about a customer's demand changes due to price changes. When the sensitivity increases, which means that the product's substitutability increases and the necessity of the product decreases, the optimal pricing, optimal order quantity, and profit are reduced. Meanwhile, a coordinated supply chain can take a faster and more accurate action.

*6.3. Effect of Contract Parameters.* The contract parameters (tag cost bearing proportion $\boldsymbol{\alpha}$ and revenue sharing proportion $\boldsymbol{\varphi}$) have the direct bearing on the profit of each partner. This directly determines whether the contract can be accepted. It is straightforward to find out that retailer prefers a lower tag cost bearing $\alpha$ and a lower revenue paying ratio $\varphi$. But in fact, since the manufacturer is the game leader, he has the power to dominate the game and adjust some contract parameters for his own interest. So whatever one contract parameter $\alpha$ (*or* $\varphi$) changes to, she will adjust the another parameter $\varphi$ (*or* $\alpha$) to satisfy the optimal wholesale price as $w^0 = (1-\varphi)(c+t) - \alpha t < c + t$. That is to say, the effect parameter has no influence on the coordination or reaching the whole optimal profit.

But when we bring the w above into the retailer's and the manufacturer's profit function, we may find that the parameter $\alpha$ disappears, while $\varphi$ still exists, which means that $\alpha$ does not affect the profit of parties, but $\varphi$ does. It works in concert with Proposition 6 about profit allocation.

When considering the coordinated scenario, we can see that partner's profit is an affine function of the supply chain's profit when the profit sharing proposition is $1 - \varphi$. The incentive to accept revenue sharing contract between the parties is shown in Figure 8. It is easy to verify that the tag cost bearing parameter has no influence on their profit. But the income changes when $\varphi$ fluctuates. And the game leader (in this section it means the manufacturer) should ensure the follower (the retailer) a positive income even it dominates the supply chain.

## 7. Conclusion

In this paper we consider a two-echelon supply chain with inventory inaccuracy under a price-dependent demand market. We want to take the advantage of RFID to eliminate the effect of inventory inaccuracy. Models are built to evaluate the economic viability and the coordination conditions.

Unlike other works on the RFID's application in the supply chain, we use an extended NVP model which fits the real market better, and we try to coordinate the supply chain with revenue sharing contract. We analyze our model in three aspects: the business environment, the demand factors, and the contract parameters. This organization is rather clear and thorough in discussing their effect on the supply chain performance.

In the integrated supply chain, we first obtain the optimal actions for inventory inaccuracy scenario and the RFID scenario. Then we compare the difference in optimal system profit. We can find that the stock level reduces after adopting RFID technology, which is profitable for companies. For the supply chain, when the availability of products is higher by improving the inventory visualization, the profit increases greatly. Since RFID requires cost, if the tag price is controlled within a certain range, it must be a positive impact on the supply chain.

For the decentralized supply chain, our main goal is to coordinate the supply chain by revenue sharing contract and receive a Pareto improvement. In the uncoordinated scenario, the retailer should bear some tag cost. In the coordinated scenario they share the profit. Next we examine the effect by different factors on the supply chain performance, including the optimal price, order quantity, and individual profit. We can see that the revenue sharing contract can coordinate the supply chain and make all the members better off when parameters are set appropriate. The leader of the Stackelberg game, whether manufacturer or retailer, should consider using the revenue sharing contract to achieve a win-win situation if RFID is believed having an incentive effect on supply chain profits.

There are some extensions to this study. First, different price-dependent demand model can be considered while we only consider the additive from. Second, the single-period model can be extended to multiple periods while the two-echelon system can be derived into multiechelons and multimembers. Finally, besides the revenue sharing contract, there are other contracts having good properties to coordinate a supply chain. The comparison among the effect of different contracts on this supply chain may be interesting.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

## Acknowledgments

The research is supported by the National Natural Science Foundation of China (71171022 and 91546121).

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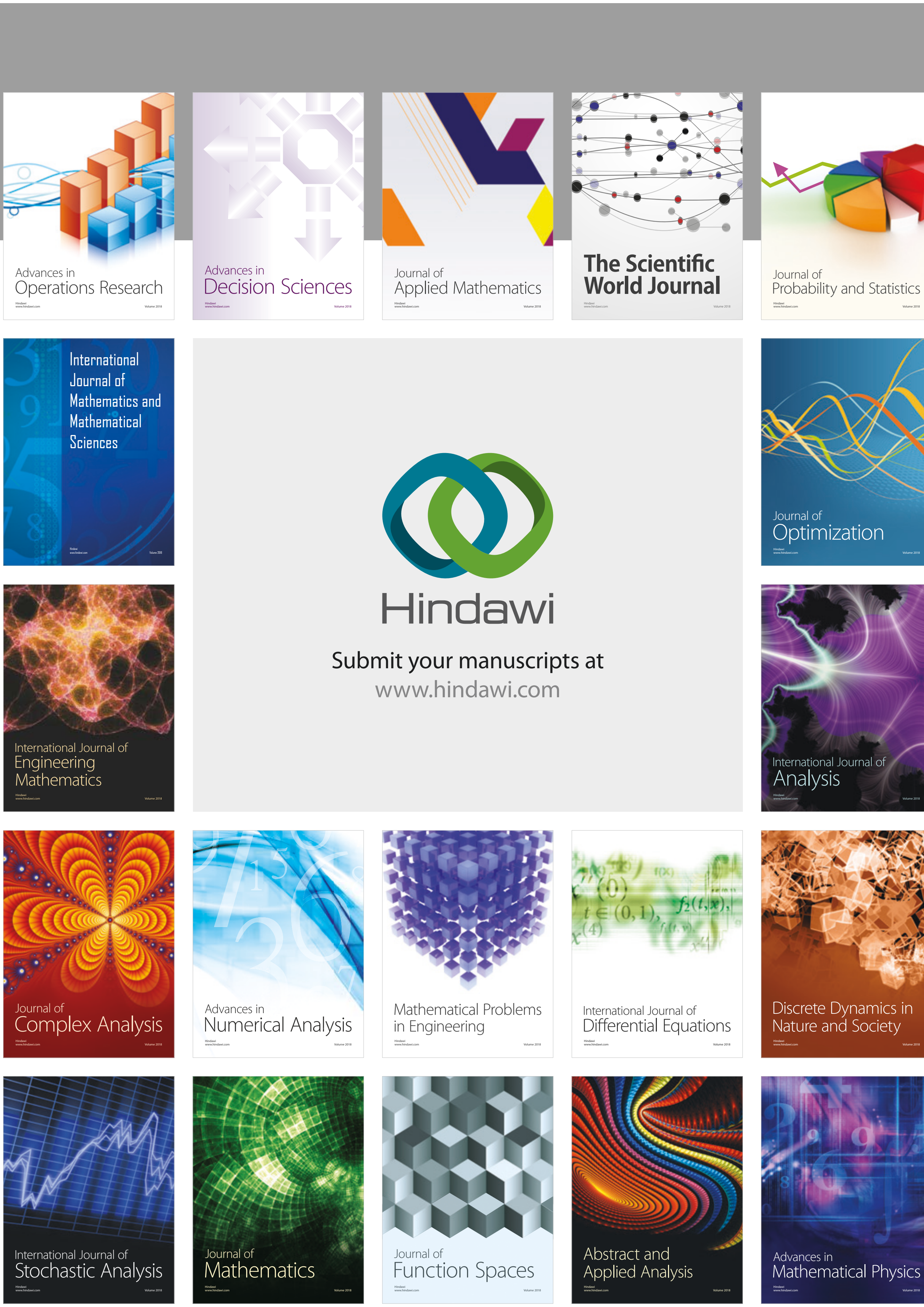
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