Hindawi
Discrete Dynamics in Nature and Society
Volume 2019, Article ID 4695654, 13 pages
https://doi.org/10.1155/2019/4695654

Research Article

Strategic Information Sharing in a Dynamic Supply Chain with a Carrier under Complex Uncertainty

Heng Du [1] **and Ye Jiang** [1,2]

[1] *School of Management and Engineering, Nanjing University, Nanjing 210093, China*
[2] *School of Business, Jiangsu Open University, Nanjing 210011, China*

Correspondence should be addressed to Heng Du; 18795898791@163.com

Received 10 January 2019; Accepted 13 May 2019; Published 2 June 2019

Academic Editor: Manuel De la Sen

Whether to use an information sharing mechanism is investigated in a dynamic supply chain, where one manufacturer, one carrier, and one retailer are faced with uncertain yield, demand, and lead time during multiple periods. Each member is modeled as an adaptive agent based on multiagent technique, and their decisions can be adjusted timely to adapt to external environment. There are two choices for the whole supply chain to deal with uncertain risks: information sharing *(IS)* or no information sharing *(NS)*. Under strategy *IS*, the information about market demand and the retailer's inventory can be shared within the supply chain. For each strategy, the effects of yield, demand, and lead time uncertainties on costs of the supply chain and channel members are studied. It is found that (i) it is rewarding for the upstream manufacturer to use a retailer's shared information under uncertain yield or demand; (ii) however, information sharing (*IS)* strategy sometimes should be abandoned for other members and the whole supply chain; (iii) counterintuitively, the increase of transportation time uncertainty benefits the retailer.

1. Introduction

Information sharing is regarded as a prevalent business strategy to improve operations performance of the supply chain, which has been successfully used in many industries. It is widely acknowledged that information sharing can simultaneously benefit the whole supply chain and each member [1]. A classic case is Nestle and Tesco [2]. By means of sharing sales data between partners, Tesco sharply simplifies the organization procedures and Nestle also reduces the inventory cost. Traditional information sharing focuses on the relationship between sellers and buyers. But with the deepening of labor division, more and more intermediate carriers emerge and are authorized to delivery materials instead of upstream shipper firms. The carrier, a transport service provider, plays a significant role across the supply chain [3]. For instance, Fedex (a third party logistics in America) collaborates with computer manufacturers (such as Apple, Dell, and IBM) and retailers in Taiwan. Some real-time information is shared among them, so that the profit of each member is raised [4]. However, it is not always the case for all firms. As an example of Yingte (a pharmaceutical company in China), it ever failed to decrease cost by sharing information with a carrier and partners. Consequently, strategic information sharing should be used in the actual situation. Strategic information sharing, a flexible strategy, is defined as two choices: information sharing or not. Namely, it is not always necessary to utilize information sharing strategy; sometimes sharing information should be adopted in the supply chain, but it should not be selected at other times. Thus, motivated by these practical observations, it is one of our goals to understand whether information in a multilevel supply chain with a carrier should be shared.

Information sharing decision is usually directly affected by external complex uncertainty [5]. Uncertain market demand and stock information are shared by many companies to mitigate the bullwhip effect, for instance, P&G, Wal-Mart, and Cisco [6]. To cater for time-sensitive consumers, L&TT in Hong Kong presents own production data to upstream suppliers to eliminate the impact of uncertain lead-time risk [7]. Nevertheless, there are also some companies not willing to provide information to others due to environmental uncertainties. After all, they are afraid that the simple information sharing behavior may not cope with the complex uncertainties [5]. Given the different attitudes toward the information sharing under an uncertain situation, this paper explores how multiple external uncertainties influence information sharing strategy for a supply chain, such as uncertain demand, supply, and lead time.

The actual supply chain is proved to be a dynamic system [8]. The complex dynamics are mainly reflected in two aspects. On the one hand, the supply chain exists in an extremely uncertain environment, where almost all external elements vary all the time. On the other hand, the members in the supply chain are autonomous individuals. Sometimes they adjust own decisions to adapt the dynamic exterior circumstance. We refer to this supply chain as a dynamic supply chain. To the best of our knowledge, the static optimal decision is mainly concentrated on in conventional supply chain studies, which are difficult to reflect the dynamic characteristic of the supply chain. Hence, unlike most researches, the supply chain dynamics in a changing market that consists of multiple periods, however, is the focus of this paper.

An information sharing strategy is investigated in a three-level supply chain, where one manufacturer, one carrier, and one retailer are faced with uncertain demand, yield and lead time. There are two choices for the supply chain to manage external uncertainties: information sharing (denoted by *IS*) or not (denoted by *NS*). Based on the method of multiagent modelling, we compare the total cost of the supply chain and each member in two cases, to address the following issues. (1) Can the information sharing be beneficial to the whole supply chain and each member in a dynamic environment, simultaneously? (2) What are the impacts of some uncertain risk factors on the information sharing decisions? We obtain meaningful management implications. For instance, it is rewarding for the upstream manufacturer to use the retailer's shared information under uncertain yield or demand, whereas information sharing strategy may be abandoned for the whole supply chain and other channel members, and the retailer can obtain more benefits with the increase of transportation time uncertainty.

2. Literature Review

This paper is related to the information sharing in the supply chain and multiagent modeling.

From the perspective of participants in the supply chain, the information sharing literature can be classified into two streams. The partnership between sellers and buyers is widely discussed in the first stream. For example, Cachon and Fisher [9], Lee et al. [6], and Teunter et al. [10] studied the value of information sharing between upstream and downstream firms. It is concluded that sharing information is beneficial to both parties only under certain conditions. Dejonckheere et al. [11], Chatfield et al. [12], Ma and Ma [13], and Zhao et al. [14] analyzed the impacts of many factors on the well-known bullwhip effect. Aviv [15], Fildes and Kingsman [16], Trapero et al. [17], and Sanders and Wan [18] focused on how forecast errors affect the information sharing, whereas, our paper is different from these researches in that a carrier is regarded as a key supply chain member here. Particularly, we consider the impact of a carrier on the information sharing in a multilevel supply chain. The second stream is about the collaboration with the third party logistics. The typical studies are few. For instance, Wen [19] explored how to forecast shipment of the carrier based on shared information. However, our work places emphasis on identifying complex uncertain factors influencing the information sharing strategy. Tyan et al. [4] and Wen [3] qualitatively described the framework and competitive advantage of collaborative transportation management (CTM). To be different, quantitative study on information sharing behavior for a supply chain with a carrier is conducted in our paper. Chan and Zhang [20] and Li and Chan [21] investigated the benefits of CTM in the mode of make-to-order (MTO), which is somewhat similar to ours. It is found that CTM lowers the total cost and risk for the whole supply chain. Yet the cost of each member is not discussed. As a matter of fact, it is necessary to guarantee each member's benefit in the case of information sharing. In contrast with [20, 21], our differences are mainly displayed in four aspects: (1) not only total cost of the whole supply chain, but also that of each individual is examined as well; (2) the manufacturer, exogenous in their researches, is served as an adaptive agent here, which is more in line with practical cases; (3) the supply chain here is a make-to-stock (MTS) production system rather than the MTO system; namely, the manufacturer's order is based on forecast; (4) the effects of multiple uncertain risks are taken into account.

Multiagent modeling is also correlated with our work. The traditional approaches about operations optimization are widely adopted in the supply chain management, which attempts seeking the optimal decision. Instead, this static optimal behavior is usually not in line with practical cases. After all, the supply chain is a complex adaptive system, where each member has to be confronted with an uncertain situation. In addition, practical members across the supply chain are bounded rational [22], who are hard to acquire complete information and find the best decision due to the own ability. In most cases, adaptive learning through past experience is the common method to make decisions. Multiagent modeling (MAM) is a powerful and popular tool to solve the complex dynamic problem owing to the distinct strengths [23]. Consequently, MAM is introduced to depict the dynamic and autonomous features that we primarily focus on. There have been representative literatures on MAM. For example, Swaminathan [23], Long [24], and Yu and Wong [25] construct a framework to explore the supply chain network dynamics. Dogan and Guner [26] and He et al. [27] discuss pricing and ordering policies under demand uncertainty. In addition, some other problems, such as inventory strategies [28], products management [29], and scheduling [30, 31] are examined by many scholars as well.

To sum up, this paper contributes to the literature in several aspects. First, unlike many literatures, the carrier is considered as a crucial member in a supply chain. The issue of whether to share information with an intermediary carrier in a supply chain is investigated. Each party's cost especially is studied in detail. Second, we further explore the motivation

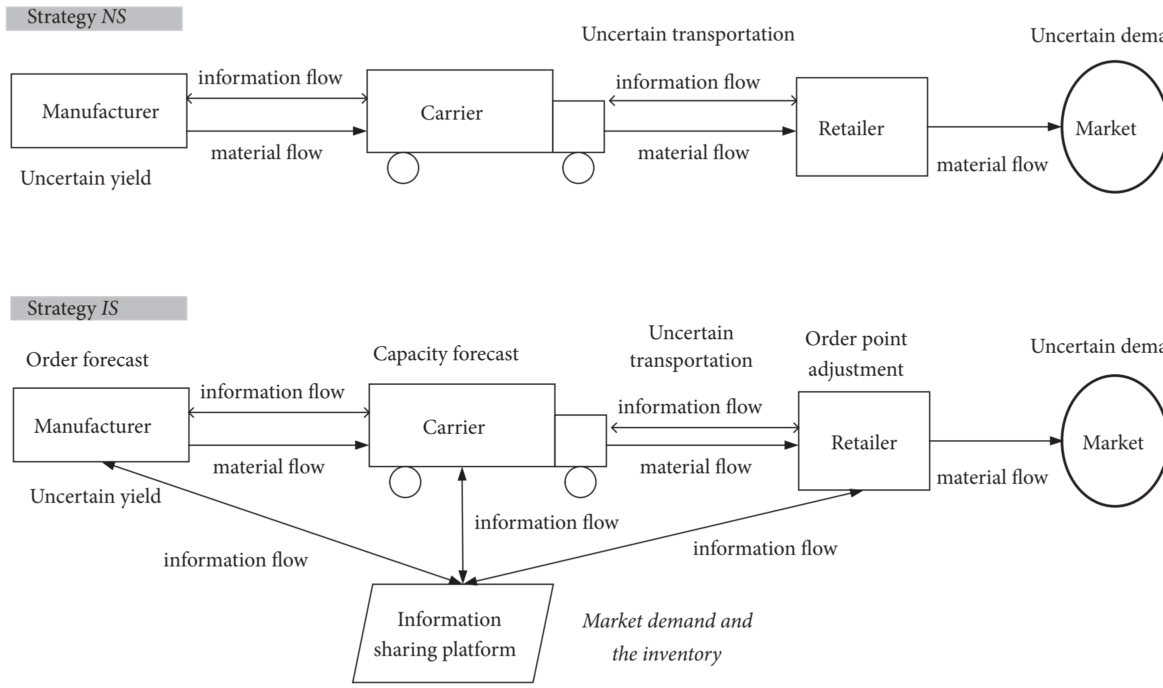

Figure 1: Two strategies: *IS* and *NS*.

to share information under external uncertainties. To be specific, the impacts of uncertain demand, yield, and lead time on information sharing are discussed. Lastly, the complex supply chain's dynamic and adaptive natures are captured in this paper. In particular, each member is capable of altering own decisions in a dynamic environment.

3. The Model

3.1. The Overall Structure and Problem Description. Consider a supply chain with one manufacturer, one retailer, and one carrier in the presence of complex uncertainties. It is assumed that demand, D_t, follows a normal distribution; i.e., $D_t \sim N(\mu_1, \sigma_1^2)$. And the upstream manufacturer's yield is unstable. There are two methods (strategies) for the whole supply chain to cope with uncertain risks: information sharing (*IS*) or not (*NS*). Under strategy *IS*, real-time information on market demand and the retailer's inventory is shared among all members. Therefore, the valuable information can be used by each member to adjust own decision to adapt to the external environment. However, demand and inventory information is not shared under strategy *NS*, where it is difficult to make dynamic decisions for some members. The detailed channel structures under two strategies are showed in Figure 1. The whole event of our model is dynamic, which includes two stages.

Stage 1. The whole supply chain jointly decides whether to share information among all members: *IS* or *NS*.

Stage 2. Under the given strategy, the second stage is made up of multiple periods. During each period, the sequence of events is as follows:

(1) At the beginning of each period, the manufacturer forecasts an order in advance and completes production.

(2) The demand is realized.

(3) The retailer firstly meets the back orders and market demand through available inventory in hand. Then, the order point is adjusted through sharing information under strategy *IS*; but it is constant under strategy *NS*. Lastly, whether to place an order upstream is decided. Unmet demand will be delayed to next period if the inventory is enough.

(4) The transportation capability is forecasted in advance by the carrier with shared information under strategy *IS*; but it is constant under strategy *NS*.

(5) If the manufacturer accepts the retailer's order, the order is transported to the retailer by the carrier (when yield is not enough, insufficient orders are delayed until the next period); otherwise, go to (6).

(6) Inventories of the manufacturer and the retailer are checked, and the leftovers will be still sold in next periods.

(7) All members compute the total cost to prepare for the next period.

The parameters and variables used throughout the paper are defined in Table 1.

3.2. The Retailer Agent

3.2.1. Retailer's Behavior under Strategy NS. Under strategy *NS*, four tasks are completed in turn according to the

Table 1: The decision variables and parameters in the model.

Decision variables			
Notation	*Description*	*Notation*	*Description*
k_t	Transportation capacity	y_t	Manufacturer's order forecast
s_t	Order point		
Parameters			
Notation	*Description*	*Notation*	*Description*
t	Period	π_{sc}	Supply chain's total cost
π_R	Retailer's total cost	π_M	Manufacturer's total cost
MH	Retailer's in-transit inventory	RE_t	Retailer's remaining inventory
MR	Order received by the retailer	$punish_{trans}$	Total delayed penalty cost of the carrier
ML	Retailer's in-transit inventory	λ	Yield risk factor
I	Retailer's initial inventory	BO_M	Manufacturer's back order
IE	Retailer's ending inventory	H	Manufacturer's unit inventory holding cost
IP	Retailer's current inventory	B	Manufacturer's unit short cost
BO_R	Retailer's back order	I_Mend	Manufacturer's ending inventory
LT_R	Order process time	I_Mstart	Manufacturer's initial inventory
S	*The* maximum inventory level	$sale$	Delivered order quantity of the manufacturer
δ	The safety factor on inventory	$punish_M$	Total penalty cost of the manufacturer
Q	Retailer's order quantity	f	The cost of maintaining the transportation capacity
h	Retailer's unit inventory holding cost	b	Retailer's unit short cost
π_{trans}	Carrier's total cost	D	The actual market demand
LT_{trans}	Transportation time	α, β	System parameters
c_{trans}	Unit transportation cost	μ_1	Mean of uncertain market demand
c_p	Unit penalty cost due to transportation delay	σ_1	Standard deviation of uncertain market demand
μ_3	Mean of order process time	σ_2	Standard deviation of uncertain yield
σ_3	Standard deviation of order process time	σ_4	Standard deviation of transportation time
μ_4	Mean of transportation time	O_M	Fixed order cost of the manufacturer
O_R	Fixed order cost of the retailer		

time sequence during each period: inventory check, demand fulfillment, inventory management, and cost compute.

(1) Inventory Check. Before demand is realized in each period, the order quantity from upstream is ensured by the retailer.

$$MR_t = MH_{t-LT} + MH_{t-LT-1} \tag{1}$$

where MR_t is the retailer's order received from upstream in period t; MH_{t-LT} (MH_{t-LT-1}) is the retailer's order quantity in period *t-LT (t-LT -1)*.

Then, the initial inventory and in-transit inventory are, respectively, updated.

$$I_t = IE_{t-1} + MR_t \tag{2}$$

$$ML_t = ML_{t-1} - MR_t \tag{3}$$

where I_t is the retailer's initial inventory at the beginning of period t; IE_{t-1} is the ending inventory in the last period *t-1;* ML_t is the total in-transit inventory in period t.

(2) Demand Fulfillment. The former back orders and market demand are met through available inventory.

$$RE_t = \begin{cases} I_t - BO_{R,t-1} - D_t, & I_t > BO_{R,t-1} + D_t \\ 0, & I_t \leq BO_{R,t-1} + D_t \end{cases} \tag{4}$$

where RE_t is the remaining inventory in period t; $BO_{R,t-1}$ is the retailer's total delayed order in the last period *t-1.*

(3) Inventory Management. It is assumed that famous (s_t, S) inventory policy is used. Similar to Axsater [32],

$$s_0 = \mu_1 \cdot \overline{LT} + \delta \cdot \sqrt{\overline{LT}} \cdot \sigma_1 \tag{5}$$

$$\delta = \varphi^{-1}\left(\frac{b}{b+h}\right) \tag{6}$$

$$S = s_0 + \sqrt{\frac{2\mu_1 \cdot O_R \cdot (b+h)}{b \cdot h}} \tag{7}$$

where s_t is the order point; s_0 is the initial value of s_t, and it is a constant under strategy *IS*, s_t $(t = 1, 2, \ldots.) = s_0$; S is the maximum inventory level, and the initial inventory in the first period $I_1 = S$; δ is the safety factor on inventory; b is the retailer's unit delayed cost; h is the unit inventory holding cost; O_R is the retailer's ordering cost; LT_R and LT_{trans} are, respectively, the lead time of the order process time and transportation time, which are random variables following normal distribution, $LT_R \sim N(\mu_3, \sigma_3^2)$, $LT_{trans} \sim N(\mu_4, \sigma_4^2)$, and $\overline{LT} = \mu_3 + \mu_4$.

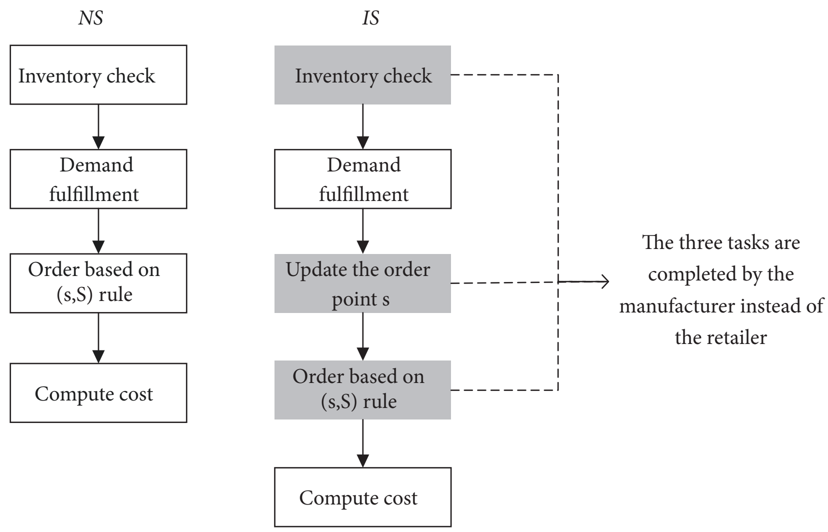

Figure 2: The retailer's behavior under two strategies.

The current inventory level IP_t is

$$IP_t = RE_t + ML_t \tag{8}$$

The order quantity in this period is

$$Q_t = \begin{cases} S - IP_t, & IP_t < S \\ 0, & IP_t \geq S \end{cases} \tag{9}$$

In-transit inventory is updated:

$$ML_{t+1} = ML_t - MR_t + Q_t \tag{10}$$

The back order is checked:

$$BO_{R,t} = \begin{cases} D_t + BO_{R,t-1} - I_t, & I_t \leq D_t + BO_{R,t-1} \\ 0, & I_t > D_t + BO_{R,t-1} \end{cases} \tag{11}$$

(4) Cost. Retailer's total cost is

$$\begin{aligned} \pi_{R,t}^{NS(IS)} &= h \cdot (IP_t - ML_t) + b \cdot BO_{R,t} - punish_{trans,t} \\ &\quad - punish_{M,t} + O_R \end{aligned} \tag{12}$$

where $\pi_{R,t}^{NS(IS)}$ is the retailer's total cost under strategy *NS (IS)* in period t; the first term is the total inventory holding cost; the second term is the total delayed cost due to unmet demand; the third term is the total carrier's punishment cost; the fourth term is the total manufacturer's punishment cost; and the last term is the fixed order cost.

3.2.2. Retailer's Behavior under Strategy IS. Under strategy *IS*, inventory check and management are accomplished by the manufacturer in lieu of the retailer. The detail is presented in Section 3.3.2. Other behaviors are the same as those under strategy *NS*. The retailer's behavior under two cases is shown in Figure 2.

3.3. The Manufacturer Agent

3.3.1. Manufacturer's Behavior under Strategy NS. Under strategy *NS*, the work of forecast and production, demand fulfillment, inventory management, and cost computation are conducted in turn.

(1) Forecast and Production. Because of a long lead time for many products, forecast and production must be finished before the selling season in order to respond to consumers rapidly. Hence, the mode of make-to-stock is adopted by the manufacturer.

In most cases, the manufacturer cannot know the market demand information clearly under strategy *NS*. After all, there is a retailer between the manufacturer and consumers market. Further, it is often hard and costly to obtain complete information on uncertain market for a manufacturer. Thus, production quantity is forecasted based on orders from the downstream retailer [6, 10].

Similar to Teunter et al. [10], the common moving average method is utilized to forecast the order quantity after N periods. The forecast is based on historical order quantities Q_j ($j = t-1, t-2, \ldots, 1$) from the retailer. y_t is the forecast value in period t. y_t is a constant y_o when $t < N$.

$$y_t = \begin{cases} y_0 & t < N \\ \dfrac{1}{N} \displaystyle\sum_{j=t-N}^{t-1} Q_j & t \geq N \end{cases} \tag{13}$$

Then, the production is competed. It is assumed that the manufacturer is subjected to yield risk due to the uncertain production process. The actual yield is λy_t. The common proportion model is used here to describe this random phenomenon. λ, a multiplication factor, is set to be a random variable following normal distribution, $\lambda \sim N(1, \sigma_2^2)$ [33].

(2) Demand Fulfillment. First, initial inventory is updated in accord with yield and the ending inventory in last period.

$$I\_Mstart_t = I\_Mend_{t-1} + \lambda y_t \quad (14)$$

I_Mstart_t is the manufacturer's initial inventory in period t; I_Mend_{t-1} is the ending inventory in the last period t-1.

Then, the demand is met.

$$sale_t = \min\left(I\_Mstart_t, BO_{M,t-1} + Q_t\right) \quad (15)$$

$sale_t$ is the actual fulfillment quantity in period t; BO_{t-1}^{M} is the manufacturer's total short order in the last period t-1.

(3) Inventory Management. The ending inventory and back order are checked.

$$I\_Mend_t = \begin{cases} 0, & I\_Mstart_t \le BO_{M,t-1} + Q_t \\ I\_Mstart_t - BO_{M,t-1} - Q_t, & I\_Mstart_t > BO_{M,t-1} + Q_t \end{cases} \quad (16)$$

$$BO_{M,t} = \begin{cases} BO_{M,t-1} + Q_t - I\_Mstart_t, & I\_Mstart_t \le BO_{M,t-1} + Q_t \\ 0, & I\_Mstart_t > BO_{M,t-1} + Q_t \end{cases} \quad (17)$$

I_Mend_t are regarded as remaining inventories to be sold in next periods, and short orders $BO_{M,t}$ are delayed to fulfill in next periods.

(4) Cost. The total cost of the manufacturer in each period is

$$\begin{aligned} \pi_{M,t}^{NS(IS)} &= H \cdot I\_Mend_t + punish_{M,t} + O_M \\ &= H \cdot I\_Mend_t + BO_{M,t} \cdot B + O_M \end{aligned} \quad (18)$$

where $\pi_{M,t}^{NS(IS)}$ is the manufacturer's total cost under strategy *IS (NS)* in period t; H is unit inventory holding cost; B is the manufacturer's unit short cost. Hence, the first term is the total inventory holding cost; the second term is the total short cost; the last term is the fixed order cost.

3.3.2. Manufacturer's Behavior under Strategy IS. Under strategy *IS*, two behaviors are different from those under strategy *NS*.

Firstly, the order forecast is dependent on shared market demand data rather than the historical order quantities after N periods. Likewise, y_t is a constant y_o as $t < N$.

$$y_t = \begin{cases} y_0 & t < N \\ \dfrac{1}{N} \displaystyle\sum_{j=t-N}^{t-1} D_j & t \ge N \end{cases} \quad (19)$$

Market demand information can be shared by the retailer under strategy *IS*, when the manufacturer's production can be forecasted in light of direct market demand rather than a retailer's orders. As a result of the famous bullwhip effect [11], market demand information is more accurate for a manufacturer compared with the information on a retailer' orders.

Secondly, the retailer's inventory is specially managed by the manufacturer. (s_t, S) policy is still adopted under strategy *IS*. Due to the shared information of market demand and inventory, on the one hand, the retailer's order process time is removed; i.e., $LT_R = 0$. Thus, the initial value of the order point $s_0 = \mu_1 \cdot \mu_3 + \delta \cdot \mu_3 \cdot \sigma_1$. On the other hand, the order point s_t can be adjusted dynamically after N periods to decrease operations cost; $s_t = s_0$ if $t < N$. The decision rule is as below, which is dependent on historical experience [21].

$$s_t = \begin{cases} s_0 & t < N \\ \dfrac{1}{N} \displaystyle\sum_{j=t-N}^{t-1} \left(D_j \cdot \mu_3 + \delta \cdot \sqrt{\mu_3} \cdot \sigma_1\right) & t \ge N \end{cases} \quad (20)$$

$$\Delta s = s_t - s_{t-1} \quad (21)$$

Only if $|\Delta s| \ge \alpha \cdot s_{t-1}$ $(0 < \alpha < 1)$, s_t replaces s_{t-1}. α is a constant coefficient.

The manufacturer's behavior under two cases is shown in Figure 3.

3.4. The Carrier Agent. The manufacturer's products are transported by the carrier. The delivery lead time is LT_{trans}, which is assumed to follow the normal distribution, $LT_{trans} \sim N(\mu_3, \sigma_3^2)$. The transportation capacity, k_t, is reserved before each delivery, which is a constant k_0 under strategy *NS*. The cost of maintaining the transportation capacity is $f = \beta k_t$ $(0 < \beta < 1)$; β is the maintaining cost of unit capacity. If the freight volume is less than k_t, the delivery time is LT_{trans}; otherwise, the delivery time is $LT_{trans} + 1$ [4], and the delayed punishment cost is

$$punish_{trans,t} = \begin{cases} sale_t \cdot c_p & sale_t > k_t \\ 0 & sale_t \le k_t \end{cases} \quad (22)$$

However, the capacity k_t is a dynamic decision variable under strategy *IS*. k_t can be determined dynamically in light of some shared information after N periods [21].

$$k_t = \begin{cases} k_0 & t < N \\ k_{t-1} + \Delta s, & t \ge N \text{ and } \left|\left(\mu_1 - \dfrac{1}{N}\displaystyle\sum_{t=i-N}^{i-1} D_t\right) \cdot \mu_3\right| \ge \alpha s \\ k_{t-1}, & t \ge N \text{ and } \left|\left(\mu_1 - \dfrac{1}{N}\displaystyle\sum_{t=i-N}^{i-1} D_t\right) \cdot \mu_3\right| < \alpha s \end{cases} \quad (23)$$

After each delivery, the total cost of the carrier is computed.

$$\pi_{trans,t}^{NS(IS)} = punish_{trans,t} + f + c_{trans} \cdot sale_t \quad (24)$$

where $\pi_{trans,t}^{NS(IS)}$ is the carrier's total cost under strategy *NS (IS)* in period t; the first term is delayed punishment cost; the

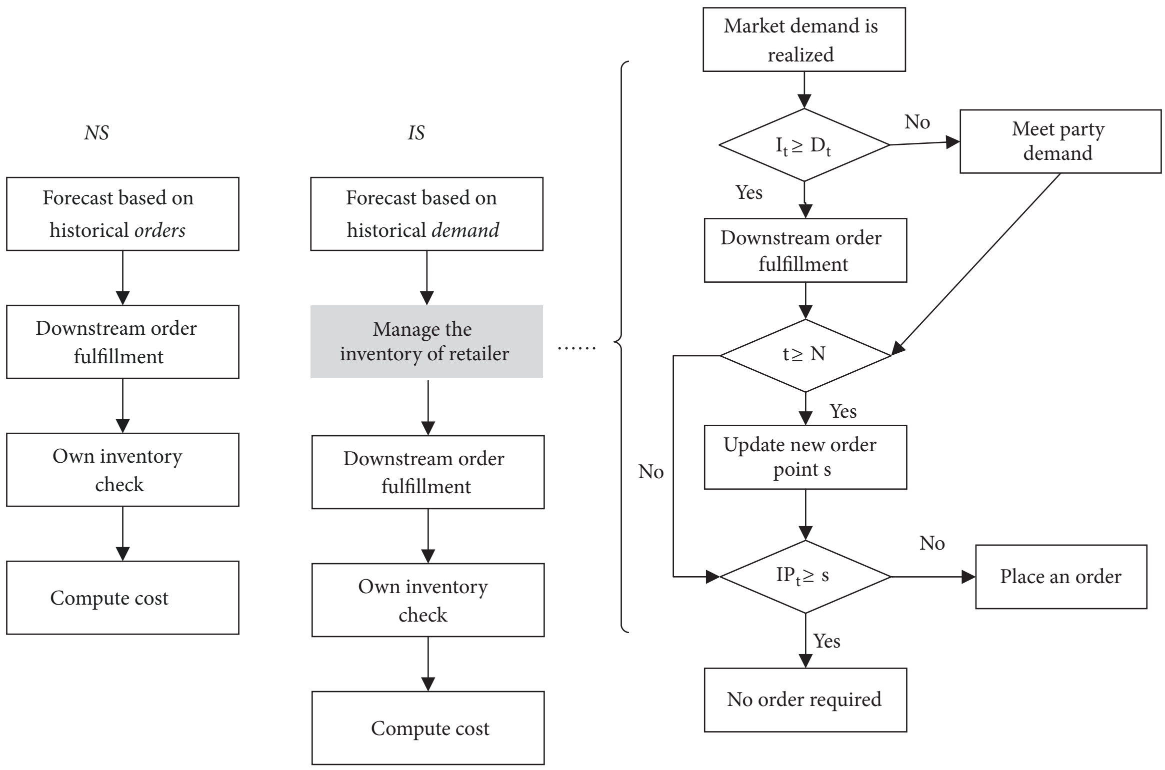

Figure 3: The manufacturer's behavior under two strategies.

second term is capacity maintaining cost; the third term is the delivery cost.

The carrier's behavior under two cases is presented in Figure 4.

Finally, the supply chain's total cost is examined, which is the cost sum of three members.

$$\pi_{sc,t}^{NS(IS)} = \pi_{trans,t}^{NS(IS)} + \pi_{M,t}^{NS(IS)} + \pi_{R,t}^{NS(IS)} \tag{25}$$

where $\pi_{sc,t}^{NS(IS)}$ is the supply chain's total cost under strategy *NS (IS)* in period t.

3.5. Algorithm

Step 1. $t \longleftarrow 1$.

Step 2. Decision variables s_0, y_0, k_0 and all exogenous parameters are initialized.

Step 3. The manufacturer determines an order y_t based on forecast.

Step 4. Market demand D_t is randomly realized.

Step 5. The retailer firstly fulfills the former back orders and market demand. Then, the order point s_t is updated according to formulas (20) and (21) under strategy *IS*; however, $s_t = s_0$ under strategy *NS*. Lastly, the retailer computes the order quantity Q_t.

Step 6. The transportation capability k_t is adjusted according to formula (23) under strategy *IS*; otherwise, $k_t = k_0$ under strategy *NS*.

Step 7. The products are transported to the retailer by the carrier.

Step 8. The total costs $\pi_{sc,t}^{NS(IS)}$, $\pi_{trans,t}^{NS(IS)}$, $\pi_{M,t}^{NS(IS)}$, $\pi_{R,t}^{NS(IS)}$ are computed.

Step 9. Enter next period ($t \longleftarrow t+1$) and go to Step 3 until termination.

Step 10. Compare the average cost of each member and the whole supply chain under cases *IS* and *NS*.

4. Simulation Experiments and Analysis

In this section, the simulation experiments are firstly designed. Then the effects of uncertain risks on the costs of supply chain members and information sharing strategy are studied.

Parameters of the experiments are set as Table 2. Simulation experiments are conducted on the Eclipse platform

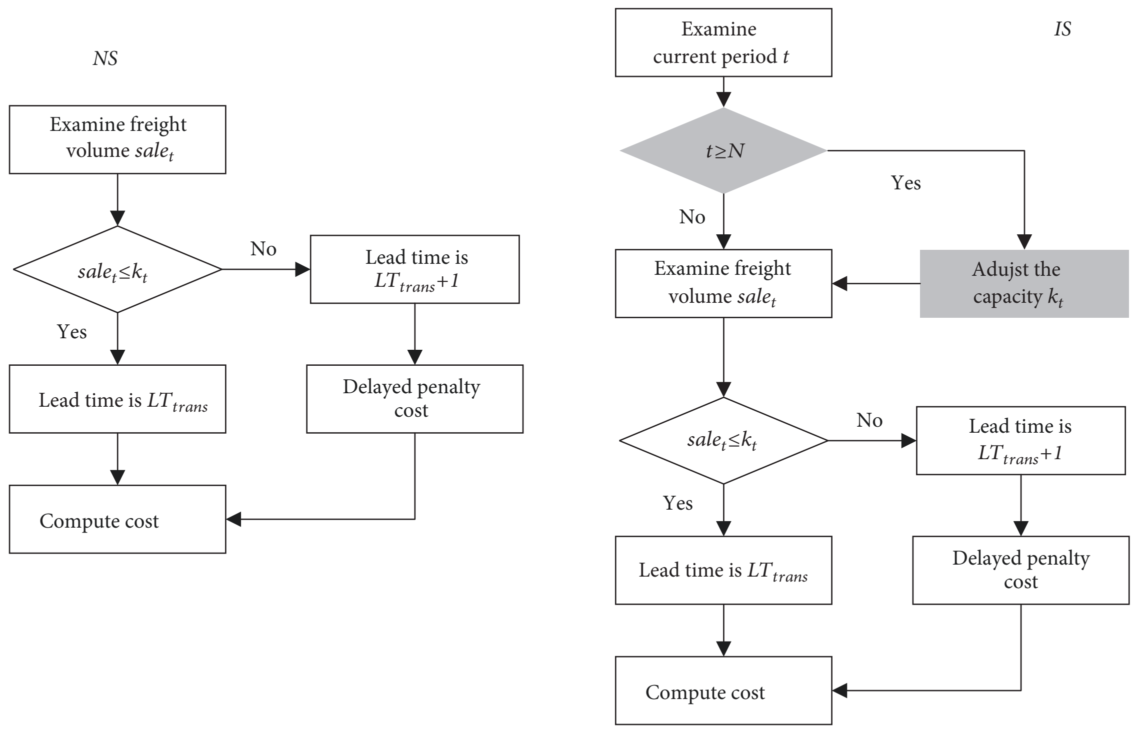

Figure 4: The carrier's behavior under two strategies.

Table 2: Thevalues of important parameters in experiments.

Parameters	Value
μ_1	80,90,100,110,120
σ_1	10,15,20,25,30
σ_2	0.1,0.15,0.2,0.25,0.3
μ_3	1,2,3,4,5
σ_3	1,3,5,7,9
μ_4	1,2,3,4,5
σ_4	1,3,5,7,9
H	3,5,7,9,11
B	1,3,5,7,9
h	3,5,7,9,11
b	1,3,5,7,9
c_{trans}	1,3,5,7,9
c_p	4,6,8,10,12
k_0	40,50,60,70,80
y_0	40,50,60,70,80
N	5,10,15,20,25

with Java codes. Experiments are carried out considering all parameters with multiple values. This combination method is used in the literature [34, 35]. The results in following figures are shown on *average*. Each simulation is run 100 times with different random seeds, and each time lasts for 500 periods to give each agent abundant time to learn historical experiences.

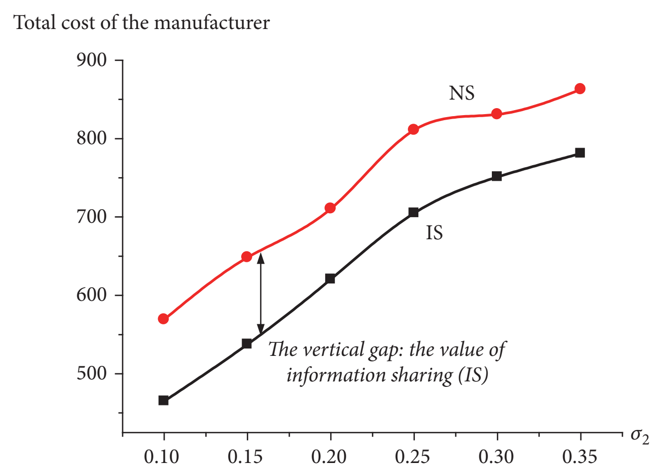

Figure 5: Yield uncertainty versus the manufacturer's costs under two cases.

4.1. The Impacts of Uncertain Risks on the Channel Members

Observation 1. Under uncertain yield or demand, strategy *IS* is a preferable choice for the manufacturer; however, it is not always beneficial for other members to adopt *IS*.

Firstly, the effects of uncertain yield and demand on the manufacturer's costs under two strategies are explained in Figures 5 and 6, respectively. Strategy *IS* contributes to the reduction of manufacturer's cost under yield or demand uncertainty, and the value of *IS* enlarges while the yield

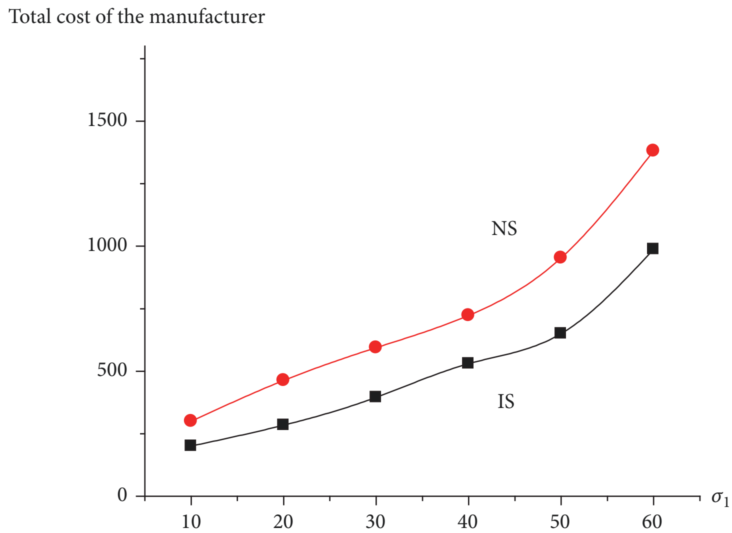

FIGURE 6: Demand uncertainty versus the manufacturer's costs under two cases.

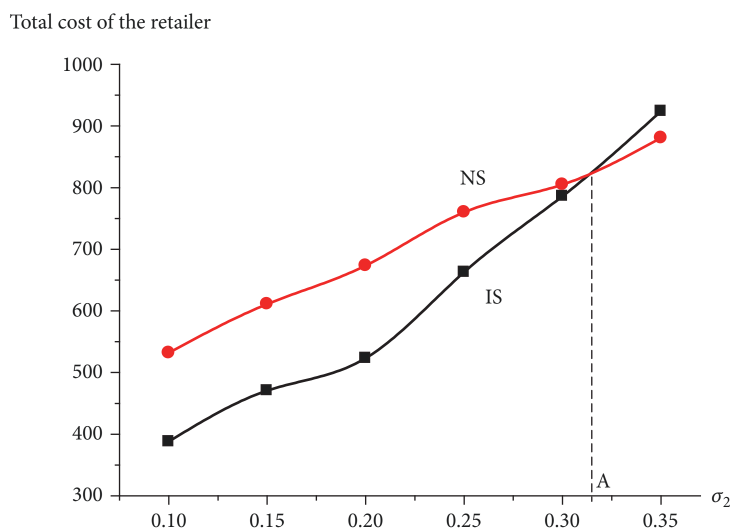

FIGURE 7: Yield uncertainty versus the retailer's costs under two cases.

(demand) uncertainty increases. The manufacturer's forecast in each period is derived from the retailer's past orders under strategy *NS*. As a result of the bullwhip effect, a crucial factor for cost, the manufacturer's forecast is larger than actual demand of the retailer. However, the retailer's stock is managed by the manufacturer under strategy *IS*, where the order process time is deleted and manufacturer's forecast is based on market demand rather than retailer's orders. Therefore, the bullwhip effect is mitigated, and inventory holding cost and short cost are cut down. Naturally, it is beneficial for the manufacturer to use the retailer's shared information. However, it is not the case for the retailer and the carrier.

Then, the impacts of uncertain yield and demand on the retailer's costs are studied. Observed from Figures 7 and 8, strategy *IS* is profitable for the retailer only when the yield or demand uncertainty is not large. But the cost gap is small when yield or demand uncertainty is large. Taking advantage of sharing information, inventory forecast accuracy can be guaranteed if yield or demand uncertainty is not great. Thus, the retailer's inventory holding cost and delayed short cost decrease. Yet forecast result is affected seriously if uncertainty value is more than a threshold ($\sigma_1 > A$ *or* $\sigma_2 > A$). It is difficult to control these unnecessary costs incurred by risks. Thus, unlike the manufacturer, strategy *IS* is not always superior to the other for the retailer. The value of *IS* is not obvious as demand or yield uncertainty is large; namely, information sharing should not be applied under the circumstance.

The impacts of yield, demand, and transportation time uncertainties on the carrier's costs are studied as well. Similar to Figures 7 and 8, forecast accuracy is considered as a significant element to trade off whether to share information. Hence, sometimes strategy *IS* is not better than *NS* for the

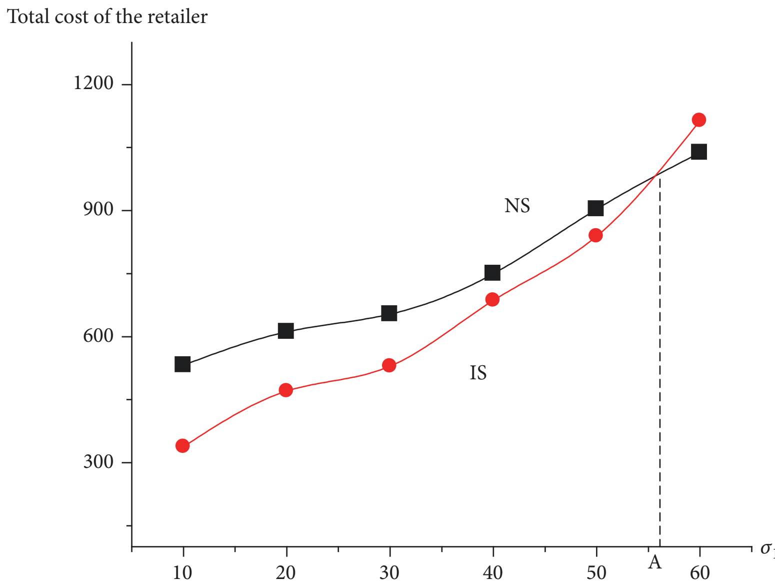

FIGURE 8: Demand uncertainty versus the retailer's costs under two cases.

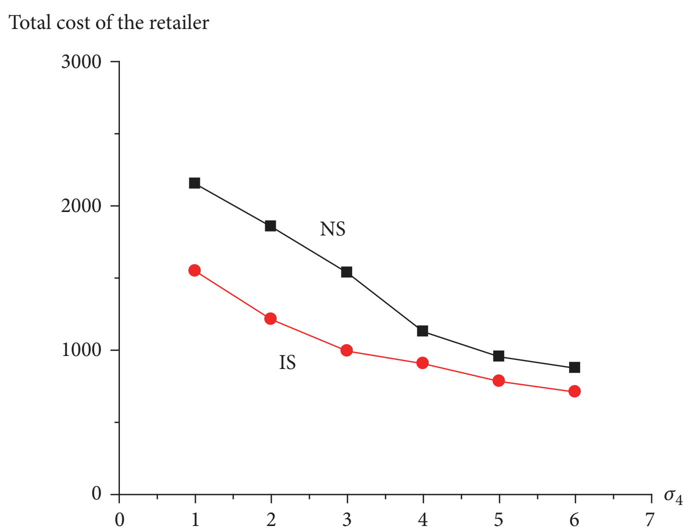

FIGURE 9: Transportation uncertainty versus the retailer's costs under two cases.

carrier. If the uncertainties are large, information sharing is not sensible. Because of the similarity, these details are omitted.

Observation 2. A higher transportation time uncertainty reduces the total cost of the retailer.

Figure 9 illustrates how the uncertainty of transportation time affects the retailer's costs. Counterintuitively, the retailer's total cost lowers with the transportation time uncertainty. The uncertain transportation time is regarded as a significant cause for the retailer's stockout crisis. Market demand fill rate decreases because of the increasing uncertainty, which further gives rise to the more delayed short cost for the retailer. However, the penalty cost of the carrier due to delayed delivery is enhanced as well while transportation time becomes more uncertain. Hence, the retailer's total cost finally decreases instead, in that the carrier's penalty cost the retailer obtains offsets increasing short cost.

4.2. The Impacts of Uncertain Risks on the Supply Chain

Observation 3. Information sharing is not always beneficial to the whole supply chain under uncertain yield (demand). Strategy *IS* should be given up when yield (demand) uncertainty is large.

The impact of yield uncertainty on the supply chain costs under two cases are presented in Figure 10. When yield uncertainty is not large, the value of strategy *IS* is evident; otherwise, strategy *IS* is worse than *NS*. Channel members use shared information to adjust decisions and

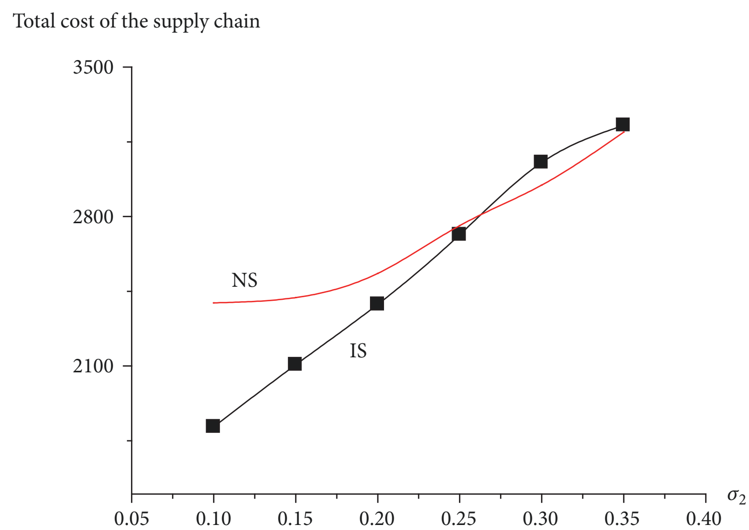

FIGURE 10: Yield uncertainty versus the supply chain's costs under two cases.

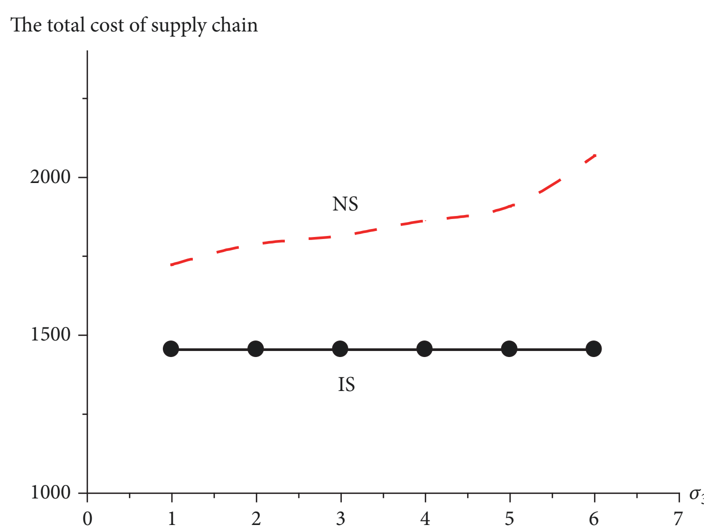

FIGURE 11: Order process uncertainty versus the supply chain's costs under two cases.

adapt to environment dynamically under strategy *IS*, which saves unnecessary costs caused by unstable yield if these uncertainties are not large. However, it is not easy to control the risk when uncertainty is large, in that forecast accuracy and quality is cut down. Naturally, the value of information sharing is gradually weakening with the increase of yield uncertainty. The result is similar to that of the demand uncertainty. Therefore, strategy *IS* should only be adopted by the supply chain when external yield (demand) uncertainty is not large. Otherwise, information sharing behavior should be avoided.

Observation 4. The cost caused by order process uncertainty can be mitigated obviously under strategy *IS*; but the advantage of strategy *IS* is not evident in terms of transportation time uncertainty.

The relationship between ordering process uncertainty and supply chain costs is showed in Figure 11. The cost under strategy *IS* is smaller than that under *NS*. Ordering process is a redundant activity under strategy *NS*, which increases the total lead time and the retailer's inventory risk. Nevertheless, the retailer's inventory is managed by the upstream manufacturer under strategy *IS*. Ordering process is omitted, so total lead time and short cost decrease. Hence, the negative impact of ordering process uncertainty can be reduced if strategy *IS* is utilized, especially under high uncertainty level. It is profitable for the whole supply chain to share information when the ordering process time exists.

The effect of transportation time uncertainty on supply chain costs is depicted in Figure 12. First, it is clear that unstable transportation time increases the supply chain's

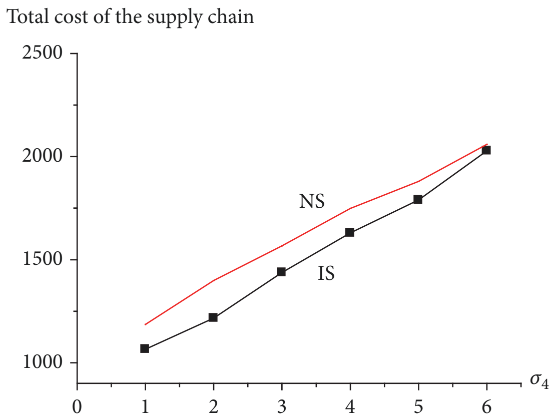

Figure 12: Transportation uncertainty versus the supply chain's costs under two cases.

operations cost owing to the internal risk. Moreover, while the cost is less for strategy *IS*, the value of *IS* is not remarkable. After all, the uncertainty in transport cannot be eliminated in the spite of shared information. Consequently, it is hard to control the risk caused by uncertain transportation.

5. Conclusions

This paper studies an information sharing strategy in a multilevel supply chain with one manufacturer, one carrier, and one retailer, where all members have to be confronted with uncertain yield, demand, and lead time in a complex multiperiod environment. Two strategies can be adopted to react to multiple uncertainties: *IS* or *NS*. Each member is regarded as an adaptive agent, where decisions can be adjusted in each period to dynamically adapt to the external situation. The costs of supply chain and channel members under two strategies are contrasted, and the effects of yield, demand, and lead time uncertainties on the two strategies are investigated. We find: (i) strategy *IS* is optimal for the upstream manufacturer under uncertain yield or demand; (ii) but for the whole supply chain, the retailer, and the carrier, strategy *IS* is not always the suitable choice; information sharing should be avoided when demand, yield, or transportation time uncertainty is large; (iii) the increase of transportation time uncertainty benefits the retailer; (iv) for the whole supply chain, the cost from ordering process uncertainty is cut down evidently through sharing information; however, it is not easy to mitigate the uncertain transportation risk with sharing information.

There are several directions for future research. First, the manufacturer's capacity is infinite. This assumption could be relaxed to study a more complex case, where the manufacturer may be faced with capacity crisis. Second, it is worth studying the impact of other decision adjustment methods on information sharing behavior. Third, market and inventory information are shared among the supply chain members in this paper, but the yield risk upstream is not shared. The factor can be further considered and studied.

Data Availability

My data is public.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] L. Li, "Information sharing in a supply chain with horizontal competition," *Management Science*, vol. 48, no. 9, pp. 1196–1212, 2002.

[2] M. A. Darwish and O. M. Odah, "Vendor managed inventory model for single-vendor multi-retailer supply chains," *European Journal of Operational Research*, vol. 204, no. 3, pp. 473–484, 2010.

[3] Y.-H. Wen, "Impact of collaborative transportation management on logistics capability and competitive advantage for the carrier," *Transportation Journal*, vol. 51, no. 4, pp. 452–473, 2012.

[4] J. C. Tyan, F. K. Wang, and T. Du, "Applying collaborative transportation management models in global third-party logistics," *International Journal of Computer Integrated Manufacturing*, vol. 16, no. 4-5, pp. 283–291, 2003.

[5] Q. Qi and Q. Zhang, "Research on information sharing risk in supply chain management," in *Proceedings of the 4th International Conference on Wireless Communications, Networking and Mobile Computing, WiCOM '08*, pp. 1–6, IEEE, 2008.

[6] H. L. Lee, K. C. So, and C. S. Tang, "Value of information sharing in a two-level supply chain," *Management Science*, vol. 46, no. 5, pp. 626–643, 2000.

[7] Z. Yu, H. Yan, and T. C. E. Cheng, "Benefits of information sharing with supply chain partnerships," *Industrial Management and Data Systems*, vol. 101, no. 3, pp. 114–121, 2001.

[8] A. Surana, S. Kumara, M. Greaves, and U. N. Raghavan, "Supply-chain networks: a complex adaptive systems perspective," *International Journal of Production Research*, vol. 43, no. 20, pp. 4235–4265, 2005.

[9] G. P. Cachon and M. Fisher, "Supply chain inventory management and the value of shared information," *Management Science*, vol. 46, no. 8, pp. 1032–1048, 2000.

[10] R. H. Teunter, M. Z. Babai, J. A. Bokhorst, and A. A. Syntetos, "Revisiting the value of information sharing in two-stage supply chains," *European Journal of Operational Research*, vol. 270, no. 3, pp. 1044–1052, 2018.

[11] J. Dejonckheere, S. M. Disney, M. R. Lambrecht, and D. R. Towill, "Measuring and avoiding the bullwhip effect: a control theoretic approach," *European Journal of Operational Research*, vol. 147, no. 3, pp. 567–590, 2003.

[12] D. C. Chatfield, J. G. Kim, T. P. Harrison, and J. C. Hayya, "The bullwhip effect—impact of stochastic lead time, information quality, and information sharing: a simulation study," *Production Engineering Research and Development*, vol. 13, no. 4, pp. 340–353, 2004.

[13] J. Ma and X. Ma, "Measure of the bullwhip effect considering the market competition between two retailers," *International Journal of Production Research*, vol. 55, no. 2, pp. 313–326, 2017.

[14] Y. Zhao, Y. Cao, H. Li et al., "Bullwhip effect mitigation of green supply chain optimization in electronics industry," *Journal of Cleaner Production*, vol. 180, pp. 888–912, 2018.

[15] Y. Aviv, "On the benefits of collaborative forecasting partnerships between retailers and manufacturers," *Management Science*, vol. 53, no. 5, pp. 777–794, 2007.

[16] R. Fildes and B. Kingsman, "Incorporating demand uncertainty and forecast error in supply chain planning models," *Journal of the Operational Research Society*, vol. 62, no. 3, pp. 483–500, 2011.

[17] J. R. Trapero, N. Kourentzes, and R. Fildes, "Impact of information exchange on supplier forecasting performance," *Omega* , vol. 40, no. 6, pp. 738–747, 2012.

[18] N. Sanders and X. Wan, "Mitigating forecast errors from product variety through information sharing," *International Journal of Production Research*, vol. 56, no. 12, pp. 1–12, 2018.

[19] Y.-H. Wen, "Shipment forecasting for supply chain collaborative transportation management using grey models with grey numbers," *Transportation Planning and Technology*, vol. 34, no. 6, pp. 605–624, 2011.

[20] F. T. S. Chan and T. Zhang, "The impact of collaborative transportation management on supply chain performance: a simulation approach," *Expert Systems with Applications*, vol. 38, no. 3, pp. 2319–2329, 2011.

[21] J. Li and F. T. S. Chan, "The impact of collaborative transportation management on demand disruption of manufacturing supply chains," *International Journal of Production Research*, vol. 50, no. 19, pp. 5635–5650, 2012.

[22] H. A. Simon, "Theories of bounded rationality," *Decision and Organization*, vol. 1, no. 1, pp. 161–176, 1972.

[23] J. M. Swaminathan, S. F. Smith, and N. M. Sadeh, "Modeling supply chain dynamics: a multiagent approach," *Decision Sciences*, vol. 29, no. 3, pp. 607–631, 1998.

[24] Q. Long, "Three-dimensional-flow model of agent-based computational experiment for complex supply network evolution," *Expert Systems with Applications*, vol. 42, no. 5, pp. 2525–2537, 2015.

[25] C. Yu and T. N. Wong, "A multi-agent architecture for multi-product supplier selection in consideration of the synergy between products," *International Journal of Production Research*, vol. 53, no. 20, pp. 6059–6082, 2015.

[26] I. Dogan and A. R. Güner, "A reinforcement learning approach to competitive ordering and pricing problem," *Expert Systems with Applications*, vol. 32, no. 1, pp. 39–48, 2015.

[27] Z. He, S. Wang, and T. C. E. Cheng, "Competition and evolution in multi-product supply chains: An agent-based retailer model," *International Journal of Production Economics*, vol. 146, no. 1, pp. 325–336, 2013.

[28] B. Ponte, E. Sierra, D. de la Fuente, and J. Lozano, "Exploring the interaction of inventory policies across the supply chain: an agent-based approach," *Computers & Operations Research*, vol. 78, pp. 335–348, 2017.

[29] I. Giannoccaro and A. Nair, "Examining the roles of product complexity and manager behavior on product design decisions: an agent-based study using NK simulation," *IEEE Transactions on Engineering Management*, vol. 63, no. 2, pp. 237–247, 2016.

[30] S. Liu, W. H. Wu, C. C. Kang et al., "A single-machine two-agent scheduling problem by a branch-and-bound and three simulated annealing algorithms," *Discrete Dynamics in Nature and Society*, vol. 2015, Article ID 681854, 8 pages, 2015.

[31] L. Wan, "Two-agent scheduling to minimize the maximum cost with position-dependent jobs," *Discrete Dynamics in Nature and Society*, vol. 2015, Article ID 932680, 4 pages, 2015.

[32] S. Axsäter, "Using the deterministic EOQ formula in stochastic inventory control," *Management Science*, vol. 42, no. 6, pp. 830–834, 1996.

[33] F. Lu, H. Xu, P. Chen, and S. X. Zhu, "Joint pricing and production decisions with yield uncertainty and downconversion," *International Journal of Production Economics*, vol. 197, pp. 52–62, 2018.

[34] Z. Liu, "Equilibrium analysis of capacity allocation with demand competition," *Naval Research Logistics (NRL)*, vol. 59, no. 3-4, pp. 254–265, 2012.

[35] K. Cattani, W. Gilland, H. S. Heese, and J. Swaminathan, "Boiling frogs: pricing strategies for a manufacturer adding a direct channel that competes with the traditional channel," *Production Engineering Research and Development*, vol. 15, no. 1, pp. 40–56, 2006.