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The impact of credit risk on cash-bullwhip in supply chain

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ABSTRACT

Because cash flow is a critical issue for companies, it is important to effectively operate cash flow to mitigate liquidity risks. However, compared with research on the bullwhip effect, few studies have analyzed the effects and causes of the cash-flow bullwhip in the supply chain. None has considered the influence of credit risk on the cash-flow bullwhip effect from downstream to upstream throughout the supply chain. Thus, this study develops a mathematical model to investigate the influence of credit risk on the cash-flow bullwhip. To achieve this, it analyzes the variability of each member's account receivable, account payable, and cash level along with three financial performance measures: account receivable turnover, account payable turnover, and cash conversion cycle. The excessive inventory level created by the bullwhip effect is known to cause the cash-bullwhip effect, which leads to supply chain members experiencing liquidity problems. However, the results of this study demonstrate that a consideration of credit risk increases the amounts of account receivable, account payable, and cash from downstream members to upstream members. In addition, this study demonstrates that when considering the credit risk, the account receivable turnover index accurately illustrates the cash-bullwhip effect of each member throughout the supply chain.

1. Introduction

Supply chain management controls material, information, and cash flows to efficiently convert raw materials from upstream into products to downstream through the supply chain. Because supply chain management is considered essential for companies wishing to achieve a sustainable business operation, the management of material, information, and cash is deemed important in the contemporary business environment. To improve the efficiency of the supply chain, most companies have strived to identify and solve the problems occurring from the flows of material, information, and cash through the entire supply chain. However, compared with the efforts companies expend on the management of material and information flows, there has been little focus on the cash flow of the supply chain as a means of improving efficiency.

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One of the critical problems in the supply chain is a bullwhip effect, which refers to an increasing inventory fluctuation moving from downstream members to upstream members in response to distorted information on customer demand. Distorted demand results in an inefficient production and excess inventory which exacerbates the liquidity problems of supply chain members. In other words, the bullwhip effect further leads to a cash-bullwhip effect, which is defined as an increase in the variance of a cash conversion cycle from downstream to upstream through the supply chain that corresponds to inventory fluctuation (Tangsucheeva & Prabhu, 2013). Like the bullwhip effect, the cash-bullwhip effect is important for companies wishing to achieve sustainable business operations through the efficient and effective management of production and inventory. To mitigate the effects of the cash-bullwhip effect, a prerequisite is to identify its causes and impacts on all members of the supply chain.

Despite its importance, few studies have investigated the causes and impacts of the cash-bullwhip effect on supply chain management (Goodarzi et al., 2017). Among these, most have focused on identifying the causes of the cash-bullwhip effect and presenting various supply chain strategies to mitigate its impacts (Badakhshan et al., 2020). To the best of our knowledge, most studies have not considered the impacts of the credit risks of each member on the cash-bullwhip effect in terms of the probability of making payments to suppliers. To fully understand the cash-bullwhip phenomenon, it is necessary to examine the amount of cash collected and paid off by each member in a given period in terms of an account receivable and an account payable through an entire supply chain.

For these reasons, this study develops a mathematical model of a cash-bullwhip effect to analyze its causes and effects from downstream members to upstream members in the supply chain. In addition, it utilizes key performance measures—account payable turnover, account receivable turnover, and cash conversion cycle—to measure the cash-bullwhip effect throughout the supply chain. Because the inflows and outflows of cash directly affect the account receivable and account payable of each supply chain member, this study further investigates how the payment probability of each member's account payable influences the cash-bullwhip effect from downstream members to upstream members. Its contribution is to consider the impacts of the credit risk of each member on the cash-bullwhip effect throughout an entire supply chain.

2. Literature review

Because the concept of the cash-bullwhip effect is a relatively new research area in literature on the supply chain, few studies have been conducted, compared with other topics in this area (Lamzaouek et al., 2021). For this reason, this study first reviews research investigating the impacts of cash flow risks on supply chain members. A number of studies present several supply chain strategies to mitigate cash flow risks in a supply chain network. For instance, Zhao et al. (2015) found that demand forecasting techniques along with customer demand information can reduce the demand uncertainty and cash flow risk in a dual-channel supply chain network.

In addition, Tsai (2008) investigated the cash inflows and outflows of supply chain members to identify the time related factors influencing cash flow risks. Their results indicated that offering an early payment discount improves supply chain members' cash conversion cycles and further reduces cash flow risks in supply chain networks. Another study by Tsai (2017) demonstrated that changes in a cost structure, production lead time, and credit terms mitigate the cash risk in the domain of new production technology. Their results suggested that the reduction of a cost ratio and lead time improves the financial status of the company.

Kroes and Andrew (2014) employed longitudinal sample data to analyze the relationship between cash flow measures and a company's financial performance. Their results concluded that a reduction in the account receivables and inventory level directly improves the company's financial performance. A study by Chen et al. (2013) considered corporate bond yield spreads to investigate the impacts of financial bullwhip effects on the internal liquidity risks of both suppliers and customers. The results indicated that the internal liquidity risks become larger from downstream members to upstream members through the supply chain due to a financial bullwhip effect.

Other researchers have investigated the impact of credit rating on cash flow in a supply chain. For instance, Kouvelis and Zhao (2018) used a modified newsvendor Stackelberg game to examine the relationships between supplier selection and credit rating in an early payment discount contract. Through consideration of wholesale prices, a trade credit rate, a bank loan, and order quantity, their study demonstrated that there is a supplier's credit rating threshold for the capital-constrained retailer in the processes of supplier selection and financing selection. In addition, Lee et al. (2018) analyzed the impact of a trade credit on the performance of the supplier and buyer in terms of various completion types. The results illustrated that trade credit generally enhances the performance of the supply chain member. However, an excess trade credit negatively affects the buyer's performance. In addition, the researchers found that a supplier with weak market power prefers to use the trade credit as a competition benefit.

Yang and Birge (2018) examined the risk-sharing role of trade credit on supply chain efficiency in the condition of partial risk sharing of demand. Their study empirically demonstrated that the supplier experiences difficulty in managing default risk, which leads to the use of trade credit to finance the supply chain, the results also indicated that risk-sharing improves the benefit to the supplier in terms of financing the cost of trade credit default, while the retailer's internal capital is not restricted. A later study by Nigro et al. (2021) developed the supplier-based financing model to assess the impacts of a retailer's effort and trade credit conditions on the working capital level between themselves and the supplier. The results suggested that an early payment with discount policy allows a low rating supplier to achieve higher profit under the managerial support of a retailer with sufficient working capital.

Several studies have considered the credit risk issues in the supply chain. Using a variational inequality model, Liu and Cruz (2012) analyzed the impacts of financial risk on the supply chain network under conditions of economic uncertainty. They demonstrated that suppliers prefer lower margins with lower financial risk to higher margins with higher financial risk. Conversely, using a machine learning approach, Zhu et al. (2019) forecast the supply chain finance risk of small and medium-sized enterprises in terms of credit risk. They highlighted the importance of profit margin in a company's financing ability under certain payment conditions.

Another study by Zhang et al. (2014) utilized the Newsvendor problem to investigate supply chain coordination by considering the trade credit and credit risk in the relationship between a retailer and a manufacturer. The results elucidated the importance of the payment term in the retailer's operational decisions and supply chain performance in a risk averse case. Qian and Zhou (2016) then used the Stackelberg game to assess two types of credit risks—the bank loan risk and the commercial credit risk—in the two-echelon supply chain. Their results identified a positive relationship between credit risk and trade credit risk under capital constraints. Wu et al. (2017) also utilized a supplier Stackelberg game to develop a retailer-supplier uncooperative replenishment model with trade credit and default risk. Their results showed that the trade credit of default risk influenced the order quantity of the retailer under a trade credit period dependent demand.

A study by Yan et al. (2016) analyzed the uncertainty of market demand with the quantity discount contract based on a combination of risk compensation and quantity discount in the two-stage supply chain. Their results suggested voluntary coordination is achievable when the seller's funds are dependent on the amount available. In addition, Vandana and Kaur (2019) considered two levels of trade credit policy to obtain a distribution-free optimal order quantity of the retailer and the optimal credit period of the supplier with the objective of profit maximization. The results indicated that default risk is the critical factor in determining the compound interest for the retailer in the two-echelon supply chain.

Using fuzzy preference theory, Gu et al. (2017) evaluated the spontaneous and contagious credit risk in supply chain enterprises. They found that related exchanges among the enterprise cause the contagion effects of the associated credit risk throughout the supply chain. Wu and Liao (2020) then employed a utility-based hybrid fuzzy axiomatic design to make finance decisions that consider credit risk in supply chain finance. A study by Xie et al. (2020) also investigated the contagion effect of credit risk in a two-echelon supply chain using the Stackelberg game. By comparing the single trade credit financing mechanism with the dual channel trade credit financing mechanism, the researchers provided a selection of financing methods and risk control mechanisms for supply chain enterprises.

As the first study of the cash-bullwhip effect in the supply chain, Tangsucheeva and Prabhu (2013) utilized the financial performance index and cash conversion cycle to measure a cash-bullwhip effect, while identifying lead time as the most critical factor in the cash-bullwhip effect under an order up to replenishment policy. In addition, the study of Sim and Prabhu (2017) analyzed the impacts of the credit risk on the cash-flow bullwhip effect in micro-credit finance. A later study by Patil and Prabhu (2021) empirically investigated the influences of various firm-level variables on the level of working capital in terms of the cash-flow bullwhip effect in the supply chain. Their results demonstrated that large companies with a conservative payment policy and high liquidity ratio experience a small cash-flow bullwhip effect, while a large lead time and high demand autocorrelation increases the cash-flow bullwhip effect of companies.

A study by Goodarzi et al. (2017) utilized a system dynamics methodology to identify the critical causes of the cash-bullwhip effect in centralized and decentralized supply chains. The results suggested that rationing and shortage gaming exert a stronger influence on a cash-bullwhip effect than factors such as lead time and demand forecast. To mitigate the effects of the cash-bullwhip effect in the supply chain, Badakhshan et al. (2020) integrated system dynamics and genetic algorithm methods to determine the optimal parameter values of inventory, supply line, and financial performance. Their findings concluded that optimal parameter values improve the efficiency of liquidity management and cost management, further decreasing the impact of the cash-bullwhip effect in supply chain management.

Compared with other research studies on the supply chain, few studies have been conducted to analyze the causes and impacts of a cash-flow bullwhip effect in a supply chain. Furthermore, no studies have considered the impacts of credit risk on a cash-flow bullwhip effect from downstream members to upstream members. To address this gap, this study investigates how the credit risks of supply chain members influence the cash-flow bullwhip effect in terms of financial performance measures.

3. Methodology

To examine the impacts of the cash-bullwhip effect with customer credit risk in the supply chain, this study develops a mathematical model of the cash-bullwhip effect that describes how the credit risk of each member influences this effect from downstream to upstream of the supply chain in terms of inventory level, cash level, account receivable, and account payable. In addition, it employs financial performance measures—account receivable turnover, account payable turnover, and cash conversion cycle—to measure the impacts of the cash-bullwhip effect on each member in the supply chain.

3.1. Account receivable and payable processes

Key assumptions made in this study are that the sales term is credit sales, in which the customer makes a payment at a later date, and that the payment term is Net 30, in which the customer should make a payment 30 days after the date of the invoice. In other words, the buyer should pay off the invoice to the seller 30 days after receiving it. With respect to the account receivable, after receiving orders from the customer, the company documents the order and ships the product to the customer. At this time, the company issues the invoice and sends it to the customer for payment, while creating an account receivable account in the finance system. After the payment is received, the invoice is marked as received in the finance system. With respect to account payable, after receiving the invoice from the seller, the account payable account is created in the finance system. After the product is delivered, the company approves the invoice for payment and sends the payment to the seller, while the invoice is marked as paid in the finance system.

3.2. Customer payment probability

To calculate the payment probability of the customer, this study utilizes the method proposed by Corcoran which used account receivable aging to calculate the transition probabilities of the Markov chain for a cash flow forecast (1978). Because account

Table 1. The account receivable aging process.

Year	Month	(State 0)	(State 1)	(State 2)	(State 3)
2011	December	Sum of invoices sent out in December 2011			
⋮	⋮	⋮	⋮	⋮	⋮
2012	March	Sum of invoices sent out in March 2012	Sum of invoices sent out in February 2012, not paid by March 2012	Sum of invoices sent out in January 2012, not paid by March 2012	Sum of invoices sent out before January 2012, not paid by March 2012

receivable aging is a periodic report that displays the outstanding invoice balance, it is a useful tool with which to forecast the payment probability of the customer. The account receivable typically has four states—0–30 days as state 0, 31–60 days as state 1, 61–90 days as state 2, and over 90 days as state 3.

Based on the account receiving aging information, the account receivable aging matrix, R matrix, is calculated as follows. As illustrated in Table 1, if the current time is March 2012, state 0 denotes the total amount of invoices sent in that month. State 1 denotes the total amount of invoices sent out one month prior to this in February 2012 that were not paid by the current time. Similarly, state 2 denotes the total amount of invoices sent out two months prior to this in January 2012 that were not paid by the current time, March 2012. Finally state 3 denotes the total amount of invoices sent out before January 2012 that were not paid by the current time.

According to Corcoran (1978), the account receivable aging is converted into the account receivable aging matrix as shown in Eq. (1). In the account receivable aging matrix, r_{ji} represents the amount of the account receivable aging in period j at state i and r_{jB} represents the amount of bad debt in period j.

$$R = \begin{bmatrix} r_{10} & r_{11} & r_{12} & \cdots & r_{1n} & r_{1B} \\ r_{20} & r_{21} & r_{22} & \cdots & r_{2n} & r_{2B} \\ r_{30} & r_{31} & r_{32} & \cdots & r_{3n} & r_{3B} \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ r_{j0} & r_{j1} & r_{j2} & \cdots & r_{j4} & r_{jB} \end{bmatrix} \tag{1}$$

To forecast the payment probabilities of the customer, the transient states and absorbing states of the Markov chain need to be determined. Using the account receivable aging, the transition states are defined as $S_t = [0,\ 1,\ 2,\ \cdots,\ n]$, where n is the account receivable aging state while the absorbing states are defined as $S_a = [P,\ B]$, where P is the paid state and B is the bad debt state. The absorbing state is a state that can be reached from any state, but is impossible to leave once entered.

The Markov chain state transition diagram is illustrated in Figure 1. The invoice process begins with a current state, state 0, indicating the invoices are sent out in the current month. If the invoice is not paid, the invoice is transferred to the next month with the probability of p_{01}. However, if the invoice is paid off in the current month, then the invoice is moved to state p with the probability of p_{0p}. This process continues to the absorbing state—paid state or bad debt state.

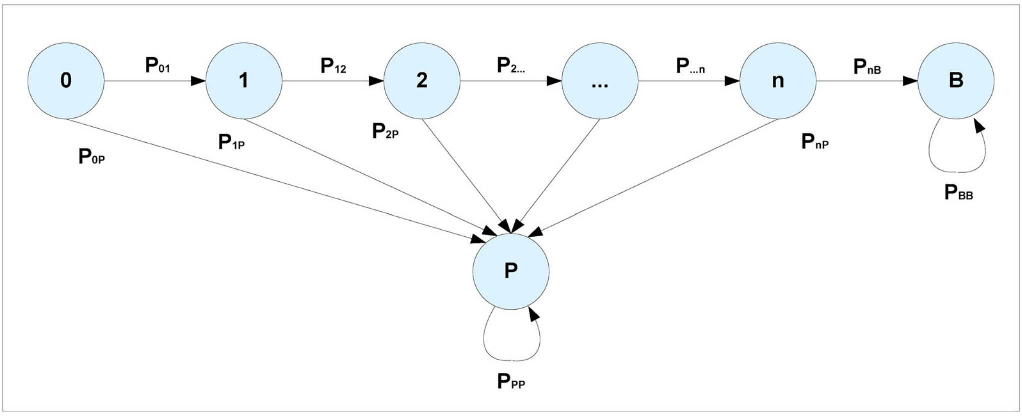

Figure 1. The Markov chain state transition diagram.

Using the account receivable aging matrix, the payment probability of the customer, $p'_{p,}$ is calculated using Eq. (2). In Eq. (2), p'_p is defined as the payment probability from state i to state P and p'_{nB} is the transition probability from state n to state B.

$$p'_p = \begin{bmatrix} p'_{0p} & 0 \\ p'_{1p} & 0 \\ \vdots & \vdots \\ p'_{ip} & 0 \\ \vdots & \vdots \\ p'_{np} & p'_{nB} \end{bmatrix} \tag{2}$$

Where

$$p'_{ip} = \frac{(r_{ji} - r_{j+1i+1})}{r_{ji}} \tag{3}$$

$$p'_{nB} = \frac{r_{jB}}{r_{j-1n}} \tag{4}$$

3.3. Financial performance indicator

Because financial performance indicators are important metrics for measuring and analyzing the financial status of the company, this study utilizes three key indicators—account receivable turnover, account payable turnover, and cash conversion cycle—to assess the impacts of the cash-bullwhip effect on each member from downstream to upstream in the supply chain. The account receivable turnover ratio is an efficiency ratio that gives the efficiency with which a company collects the outstanding debt over a given period. A higher account receivable turnover ratio means the company efficiently collects its credit from its customers. In addition, the account receivable turnover ratio is calculated by measuring total credit sales over the average account receivable in a given period. The account payable turnover ratio is a liquidity ratio that gives the speed with which the company pays the outstanding debt over a given period. A higher account payable turnover ratio means the company quickly pay its debt to its creditor. The account payable turnover is calculated using the average account payable in a given period.

The cash conversion cycle is an efficiency ratio that gives the time required by the company to transform the inventory investment into cash over a given period. A shorter cycle means the company quickly recovers its inventory investment from the inventory sales. The cash conversion cycle is obtained by adding the days of inventory outstanding, days of sales outstanding, and days of payable outstanding, as shown in Eq. (5). The days of inventory outstanding is the length of time taken to sell inventory in storage, the days of sales outstanding is the length of time to collect cash from the sales, and the days of payable outstanding is the length of time taken to pay off purchases from the supplier.

$$\begin{aligned} Cash\ conversion\ cycle = \ & Days\ of\ inventory\ outstanding + Days\ sales\ outstanding \\ & - Days\ payable\ outstanding \end{aligned} \tag{5}$$

3.4. Cash-bullwhip effect mathematical model

To analyze the cash-flow bullwhip effect, this study develops a mathematical model of the cash-flow bullwhip effect in the supply chain as follows. An assumption is made that there are four supply chain components—customer, retailer, distributor, and manufacturer—from the downstream to the upstream of the supply chain. The data on customer demand are obtained from the study conducted by Tangsucheeva and Prabhu (2013). Based on this, it is assumed that the order data for the other three members can be determined by each member's inventory status. In this study, the order of each member to its upstream member is determined using the order-up-to policy through the entire supply chain. The demand of each supply chain member is exactly equal to the order placed by its downstream member. For instance, the retailer's order amount is equal to the customer demand and the manufacturer's production amount is equal to the distributor's order amount.

In this study, it is assumed that each supply chain member uses different prices of the product for markup consideration. For instance, the price is $2, $1.75, and $1.5 for the retailer, the distributor, and the manufacturer respectively, while it is assumed that all supply chain members have the same lead time of five days. In addition, this study assumes that the production cost for the manufacturer and the cost of goods sold for the retailer and the distributor is 25% of the revenue, while the inventory holding cost is 15% of the revenue. With respect to lead time, the manufacturer has both a manufacturing lead time and a delivery lead time, while the retailer and the distributor have only a delivery lead time. However, because this study mainly focuses on the impact of the delivery lead time on the cash-flow bullwhip effect in the supply chain, it does not consider the manufacturing lead time.

In this study, index j denotes the supply chain member. From the perspective of the distributor, index j indicates the distributor, index j-1 indicates the downstream member, namely the retailer, and index $j+1$ indicates the upstream member, namely the manufacturer. This study uses two specific members, the distributor as a supplier and the retailer as a buyer, to clearly explain several mathematical equations.

The inventory of stocks is the finished product that is ready for sale to the customer. The inventory $(INVI_{j,t})$ is equal to the addition of the inventory $(INV_{j,t-1})$ in a previous unit of time and the product $(ORD_{j,t-L})$ received from the distributor as a supplier in a lead time by subtracting the product $(ORD_{j-1,t})$ shipped to the retailer as a buyer in a previous unit of time and the back order $(BO_{j,t-1})$ in a previous unit of time, as shown in Eq. (6). In addition, the backlog is the amount that is not yet fulfilled to the buyer's order in the downstream. The backlog $(B_{j,t})$ is equal to the shortage amount of the inventory required for demand fulfillment at the current time.

$$INV_{j,t} = INV_{j,t-1} + ORD_{j,t-L} - ORD_{j-1,t} - BO_{j,t-1} \quad \forall\ i,t \tag{6}$$

In this study, the order of each member to its upstream member is determined using the order-up-to policy through the entire supply chain. The order-up-to policy reviews the inventory position and places an order to bring the inventory position up to a required inventory level. The demand of each supply chain member is exactly equal to the order placed by its downstream member. For instance, the retailer's order amount is equal to the customer demand and the manufacturer's production amount is equal to the distributor's order amount. In addition, the forecast consumption is calculated using the moving average method.

The order amount $(ORD_{j,t})$ denotes the order quantity made from the downstream retailer to the upstream distributor to fulfill the buyer's expected order. Conversely, the order amount $(ORD_{j-1,t})$ is the amount of finished product delivered from the upstream distributor to the downstream retailer to satisfy the retailer's order. In addition, the forecast consumption $(FC_{j,t})$ is the forecast order demand, which is calculated using a nine units of time moving average method.

The order amount is calculated by subtracting the addition of the inventory- $(INV_{j,t-1})$ in a previous unit of time, the order amount $(ORD_{j,t-L})$ shipped from the distributor as a supplier in a lead time, and the in-transit-inventory $(OINV_{j,t})$ at the current time, from the addition of the forecast consumption $(FC_{j,t})$ during lead time (L) at the current time, the product $(ORD_{j-1,t})$ shipped to the retailer as a buyer in a previous unit of time, and the back order $(BO_{j,t-1})$ in a previous unit of time as shown in Eq. (7).

$$ORD_{j,t} = FC_{j,t} \cdot L - (INV_{j,t-1} + ORD_{j,t-L} + OINV_{j,t} - ORD_{j-1,t} - BO_{j,t-1}) \quad \forall\ i,t \tag{7}$$

The in-transit-inventory denotes that the previous order that has not been delivered to the retailer as a buyer at the current time. The in-transit-inventory $(OINV_{j,t})$ is calculated by the addition of the in-transit-inventory $(OINV_{j,t-1})$ in a previous unit of time and the product $(ORD_{j,t-1})$ received from the distributor as a supplier in a previous unit of time, as shown in Eq. (8).

$$OINV_{j,t} = OINV_{j,t-1} + ORD_{j,t-1} \quad \forall\ i,t \tag{8}$$

Account receivable denotes the current asset account that is expected to collect the payments from the downstream retailer for products sold on credit sales. The accounts receivable $(AR_{j,t})$ is equal to the addition of the payment $(ARC_{j,t})$ collected from the account receivable in a previous time ($AR_{j,t-1}$) and the invoices ($BPB_{j,t}$) sent at the current time by subtracting the payment ($ARC_{j,t}$) collected at the current time, as shown in Eq. (9).

$$AR_{j,t} = AR_{j,t-1} + BPB_{j,t} - CR_{j,t} \cdot ARC_{j,t} \quad \forall\ i,t \tag{9}$$

In Eq. (9), the newly issued invoices ($BPB_{j,t}$) are calculated by multiplying the corresponding product price ($P_{j,t}$) by the order placed by its downstream member, a retailer, ($ORD_{j-1,t}$), as shown in Eq. (10).

$$BPB_{j,t} = P_{j,t} \cdot ORD_{j-1,t} \quad \forall\ i,t \tag{10}$$

Collection ratio is the likelihood of collecting the payments from the downstream retailer for the orders delivered on credit. According to Liu (2011), the collection ratio ($CR_{j,t}$) for the retailer is equal to the payment ratio of the retailer ($PR_{j-1,t}$) divided by the sales amount, as shown in Eq. (11). Because this study assumes two units of time are taken to collect payments from the retailer, the sales amount is equal to the multiplication of the order amount placed by the retailer ($O_{j-1,t-2}$) by the unit price of a specific product (P_j).

$$CR_{j,t} = \frac{PR_{j-1,t}}{P_j \cdot O_{j-1,t-2}} \quad \forall\ i,t \tag{11}$$

Account payable is the current liability account expected to make the payments to the upstream distributor for product orders on credit sales. The accounts payable ($AP_{j,t}$) is equal to the addition of the accounts payable in a previous unit of time ($AP_{j,t-1}$) and the new payment ($APP_{j,t}$) issued at the current time by subtracting the payment ($APG_{j,t}$) made at the current time, as shown in Eq. (12).

$$AP_{j,t} = AP_{j,t-1} + APP_{j,t} - PR_{j,t} \cdot APG_{j,t} \quad \forall\ i,t \tag{12}$$

In Eq. (12), the new payment ($APP_{j,t}$) is calculated by multiplying the corresponding product price ($P_{j+1,t}$) by the order placed for its upstream member, a distributor, ($ORD_{j,t}$), as shown in Eq. (13).

$$APP_{j,t} = P_{j+1,t} \cdot ORD_{j,t} \quad \forall\ i,t \tag{13}$$

Payment ratio is the probability of making the payment to the upstream member in the supply chain. According to Liu (2011), the next payment ratio ($PR_{j,t+1}$) for the distributor is estimated by multiplying the forecast collection ratio ($CRF_{j-1,t}$) of its downstream member, a retailer, by the sales amount for its downstream member, a retailer, as demonstrated in Eq. (14). In this study, the payment ratio to a retailer by a customer is obtained using the Corcoran method which utilizes both the account receivable aging and the transition probabilities of the Markov chain (Corcoran, 1978).

$$PR_{j,t} = CRF_{j-1,t} \cdot P_j \cdot ORD_{j-1,t-2} \quad \forall\ i,t \tag{14}$$

Using the exponential smoothing method, this study calculates the forecast collection ratio (CRF_{jt}) which assumes recent account receivable aging data is more important in the forecasting process. With a smoothing factor (α), the forecast collection ratio is calculated by the simple weighted average of the current collection ratio ($CR_{j,t}$) and the previous smoothed forecast collection ratio ($CRF_{j,t-1}$), as shown in Eq. (15).

$$\mathrm{CRF}_{j,t} = \alpha \cdot \mathrm{CR}_{j,t} + (1-\alpha) \cdot \mathrm{CRF}_{j,t-1} \quad \forall\ i,t \tag{15}$$

The cash level is the amount of money the supply chain member as available. The cash level $(\mathrm{CASH}_{j,t})$ at the current time is calculated by subtracting the cash outflow at the current time from the addition of the cash level in a previous time $(\mathrm{CASH}_{j,t})$ and the cash inflow at the current time, as shown in Eq. (16).

$$\mathrm{CASH}_{j,t} = \mathrm{CASH}_{j,t-1} + (\ \mathrm{BPB}_{j,t} - \quad \mathrm{CR}_{j,t} \ \cdot \mathrm{ARC}_{j,t}) \\ - (\ \mathrm{APP}_{j,t} - \quad \mathrm{PR}_{j,t} \ \cdot \mathrm{APG}_{j,t}) \quad \forall\ i,t \tag{16}$$

4. Results and discussion

Using the developed mathematical model of cash-bullwhip effect, this study analyzes the impacts of the credit risk and uncertain order of the customer on supply chain members from downstream to upstream in the supply chain in terms of account receivable, account payable, and cash level. To illustrate the impact of the credit risk on the cash-bullwhip effect, this study also compares the changes in an account receivable turnover, an account receivable turnover, and cash conversion cycle both with and without credit risk consideration. In addition, it investigates how the lead time influences the cash-bullwhip effect through the supply chain.

4.1. Credit risk

To investigate the impact of the credit risk of the customer on the cash-bullwhip effect, the credit risk of the customers is calculated in terms of payment probability based on the method proposed by Corcoran (1978). Using the account receivable aging matrix and the Markov chain, the Corcoran method forecasts the payment probability of the customer. As illustrated in Figure 2, the account receivable aging matrix is calculated from the example of account receivable aging data, as presented in Table 2. The account receivable aging data are obtained from the customer's account receivable aging data used by Tangsucheeva and Prabhu (2013). For instance, the account receivable aging data depicts each customer's unpaid invoice balances according to the duration for which an invoice has been outstanding.

As demonstrated in Figure 2, the account receivable aging matrix is calculated from the account receivable aging data using Eq. (1). The average values of the account receivable aging matrix are 608,207.2 for the current time (State 0), 217.554.7 for 31–60 days past due (State 1), 36,948.6 for 61–90 days past due (State 2), and 1,334.6 for over 90 days past due (State 3) respectively.

As illustrated in Figure 3, the average values of the account receivable aging matrix decrease from state 0 to state 3 with a 63.23% decrease for state 1, a 83.02% decrease

$$R = \begin{bmatrix} 702{,}560 & 623{,}810 & 101{,}470 & 163{,}565 & 16{,}270 \\ 1{,}418{,}250 & 530{,}080 & 528{,}400 & 179{,}165 & 12{,}328 \\ 896{,}140 & 505{,}465 & 669{,}020 & 216{,}445 & 4{,}556 \\ 829{,}995 & 586{,}160 & 450{,}745 & 174{,}065 & 13{,}590 \end{bmatrix}$$

Figure 2. The account receivable aging matrix.

Table 2. Account receivable aging.

Month (Period j)	Total	Current (State 0)	**31–60 days** (State 1)	61–90 days (State 2)	Over 90 days (State 3)	Bad debt (State B)
December (12)	1,609,405	702,560	623,810	101,470	163,565	16,270
January (1)	2,655,895	1,418,250	530,480	110,220	179,165	12,328
February (2)	2,287,070	896,140	505,465	669,020	216,445	4,556
March (3)	2,109, 595	829,995	586,160	450,745	174,065	13,590

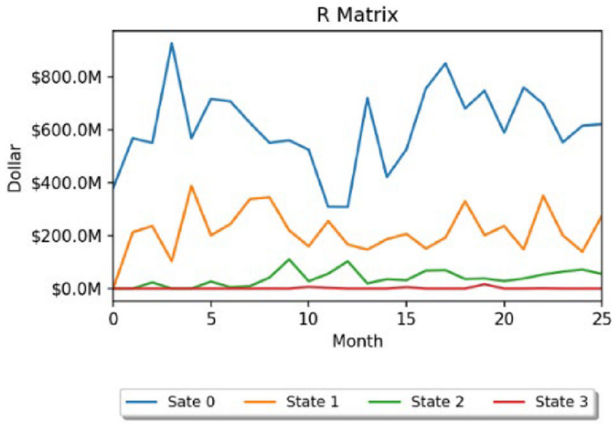

Figure 3. The R matrix.

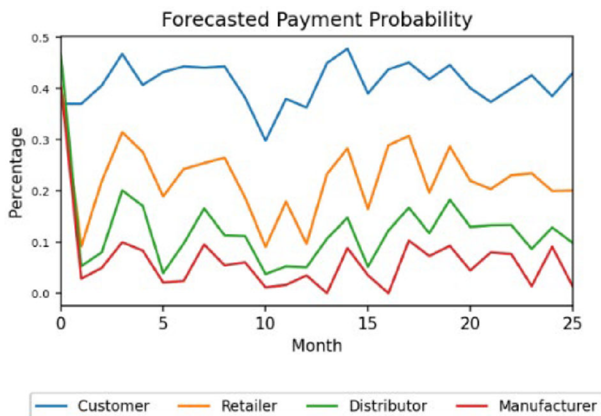

Figure 4. The Forecasted payment probability.

for state 2, and a 96.39% decrease for state 3 compared with state 0, state 1, and state 2, respectively. The decrease values of the account receivable indicate that the uncollectable receivables amount reduces in line with the duration of time an invoice has been outstanding.

Then, using the account receivable aging matrix and Markov chain, the payment probability of each customer is calculated. The payment probability of each member decreases from downstream members to upstream members, as illustrated in Figure 4. The payment probability values of the distributor, the manufacturer, and the supplier decrease by 45.34%, 47.66%, and 52.50%, compared with the retailer, the distributor,

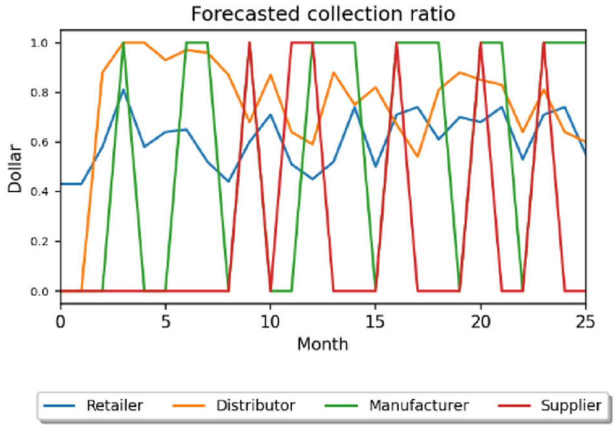

Figure 5. The Forecasted collection ratio.

and the manufacturer, respectively. The decreased payment probability values indicate that the cash-bullwhip effect is amplified as it moves further upstream of the supply chain.

Based on the payment probability of each member in the supply chain, the collecting ratio value of each member is estimated according to the study conducted by Liu (2011) in Eq. (11). As Figure 5 indicates, the forecast collection ratio for each supply chain member is estimated using the exponential smoothing method. The average credit scores are 0.61 for the retailer, 0.74 for the distributor, 0.51 for the manufacturer, and 0.25 for the supplier. The reduced credit ratios indicate that the impact of the cash-bullwhip effect is amplified from the downstream to the upstream along the supply chain.

4.2. Bullwhip effect

Because the bullwhip effect is known to be one of the most critical issues affecting the efficiency of the supply chain, this study first investigates the bullwhip effect in terms of an inventory level through the supply chain. The order data are obtained from the study performed by Tangsucheeva and Prabhu (2013), as illustrated in Figure 6. As shown, the order amounts generally increase from the customer of downstream to the manufacturer of upstream in the supply chain. For instance, compared with customer demand, the order amount increases by an average of 2.15% and 10.16% for the manufacturer and the supplier, respectively, compared with that of the retailer for a given period.

It is known that uncertain customer demand is the main cause of the bullwhip effect, which amplifies the inventory level of supply chain members as an order moves further along the supply chain. To validate the developed mathematical model of the bullwhip effect, this study investigates whether the inventory levels fluctuate in respond to customer order from downstream to upstream through the supply chain using Eq. (6). As indicated in Figure 7, the inventory levels fluctuate as they move up the supply chain. For example, the inventory level of the distributor is on average 11.53% larger than that of the retailer, while the inventory levels of the manufacturer and supplier are on average 39.82% and 49.50% larger than those of the distributor and the manufacturer.

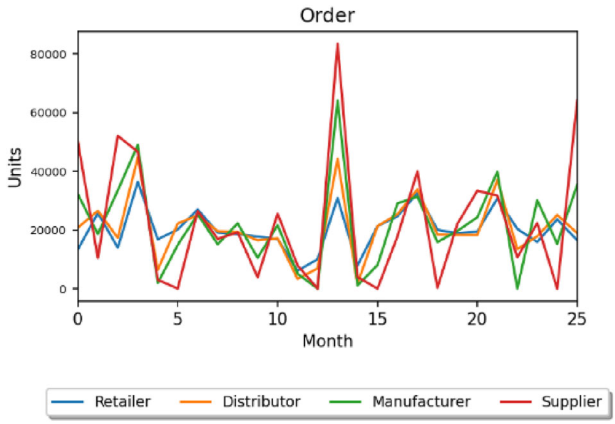

Figure 6. The order amount.

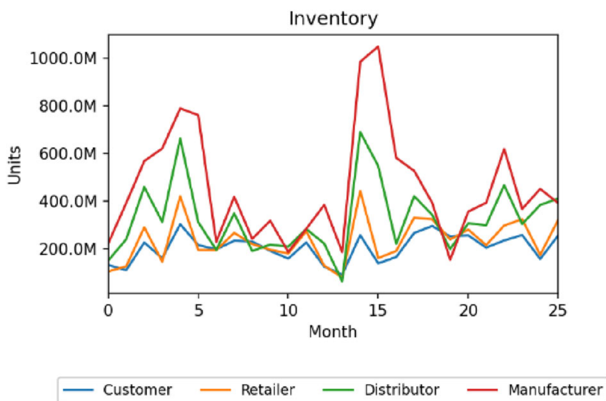

Figure 7. The inventory level.

4.3. Cash-bullwhip effect

This study investigates the changes in three important ledger accounts—an account receivable, an account payable, and a cash level—to analyze the changes in cash amount along the supply chain using Eqs. (9), (12), and (16), respectively. An account receivable is the cash amount that is expected to be collected from the buyer for their purchase on the invoice due date. As demonstrated in Figure 8(a), the account receivable amounts of each supply chain member are reduced from the downstream to the upstream through the supply chain. In terms of an account receivable, the distributor, the manufacturer, and the supplier undergo a 15.80%, 26.64% and 32.59% decrease, respectively, compared with the retailer.

In Figure 8(b), with credit risk consideration, the account receivable amount increases by 36.67% for the retailer, 22.23% for the distributor, 26.34% for the manufacturer, and 47.40% for the supplier, respectively, compared with noncredit consideration. Because the account receivable amounts for each member increase, the results indicate that credit risk consideration allows each member to order more products while paying for their purchase on credit.

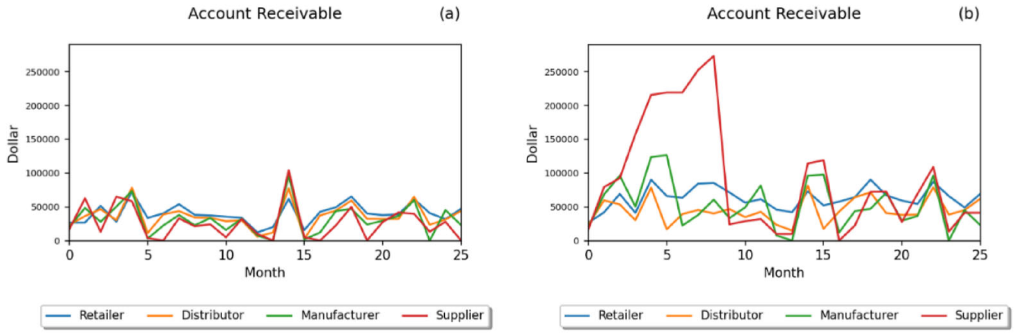

Figure 8. The comparison of account receivable amount.

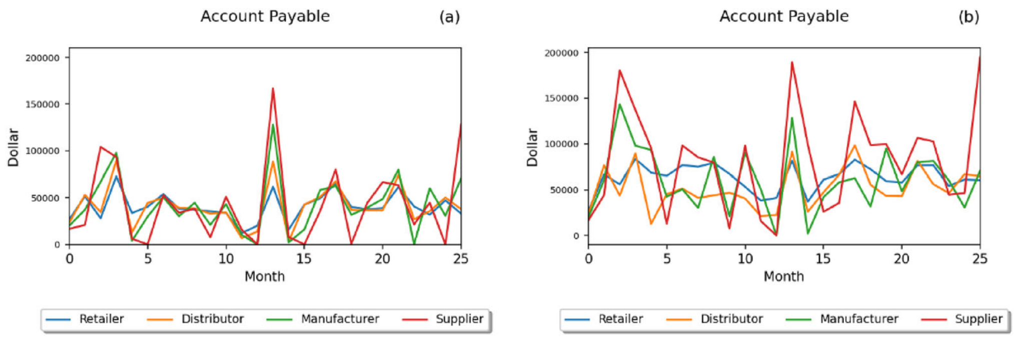

Figure 9. The comparison of account payable amount.

The second ledger account is an account payable, which is the cash amount that is expected to be paid to the seller on the invoice due date. As illustrated in Figure 9(a), the changes of the account receivable become relatively smaller as it moves from the downstream to the upstream in the supply chain. For example, with respect to the retailer's account payable, the account payable of the distributor, the manufacturer, and the supplier decrease by 5.86%, 5.12%, and 3.24%, respectively. With credit risk consideration, the account payable amounts of the retailer, the distributor, the manufacturer, and the supplier increase by 37.11%, 22.06%, 25.70%, and 43.46%, respectively, compared with noncredit consideration, as illustrated in Figure 9(b). The results indicate that the credit risk consideration motivates each member to buy more products on credit from the seller.

To investigate the impact of cash level on the cash-bullwhip effect through the supply chain, this study examines the level of cash that is mainly influenced by both the cash inflows and the cash outflows using Eq. (16). From downstream to upstream through the supply chain, the cash level decreases in the case of noncredit risk consideration, as shown in Figure 10(a), but increases in the case of credit risk consideration, as illustrated in Figure 10(b). With credit risk consideration, the cash levels of the retailer, the distributor, the manufacturer, and the supplier increase by 3.25%, 19.30%, 8.34%, and 38.04%, respectively, compared with noncredit risk consideration. Because cash-bullwhip effects reduce the cash level of each member in the supply chain, it is reasonable to conclude that the credit risk consideration mitigates the cash-bullwhip effect through the supply chain.

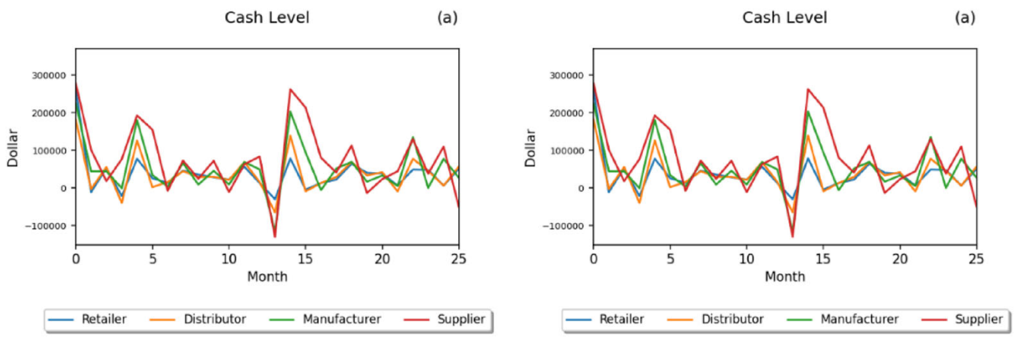

Figure 10. The comparison of cash level.

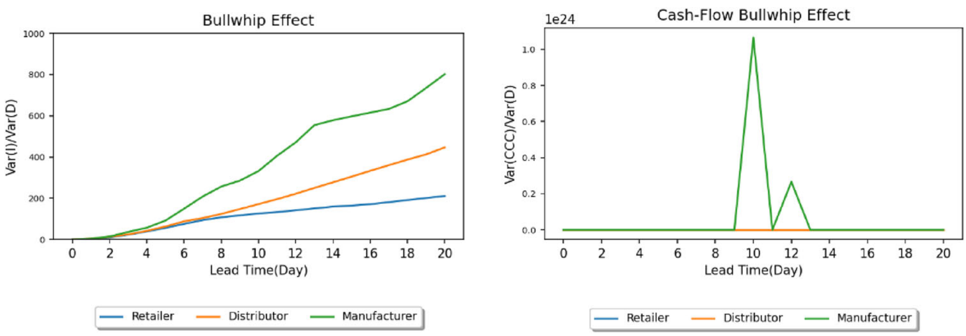

Figure 11. The bullwhip effect and cash-flow bullwhip effect.

To investigate the changes in cash flow in the supply chain, this study analyzes the bullwhip effect and the cash-flow bullwhip effect, as shown in Figure 11. The bullwhip effect is represented as Var(I)/Var(D) and the cash-flow bullwhip effect is represented as Var(CCC)/Var(D) (Tangsucheeva & Prabhu, 2013). As depicted in Figure 11, the bullwhip effect is amplified as it moves from the retailer to the manufacturer in the supply chain. For instance, the distributor's bullwhip effect increases by 68.78%, compared with that of the retailer, while the manufacturer's bullwhip effect increases by 88.98%, compared with that of the distributor.

By contrast, because the variance of the demand amount is too large compared with the variance of the cash conversion cycle value, the cash-bullwhip effect increases in the case of the manufacturer, as indicated in Figure 11. This implies that the manufacturer does not collect the outstanding payment quickly enough and needs to improve its management of working capital. In addition, the results suggest that the large variance in demand does not accurately represent the cash-bullwhip effect.

4.4. Financial performance

This study employs three financial performance indicators to measure the financial status of each supply chain member, which express the impacts of the cash-bullwhip effect along the supply chain. The account receivable turnover is the index that indicates the company's efficiency in collecting any amount of money from its customer at a given period. The account receivable turnover ratios for each member are illustrated in Figure 12.

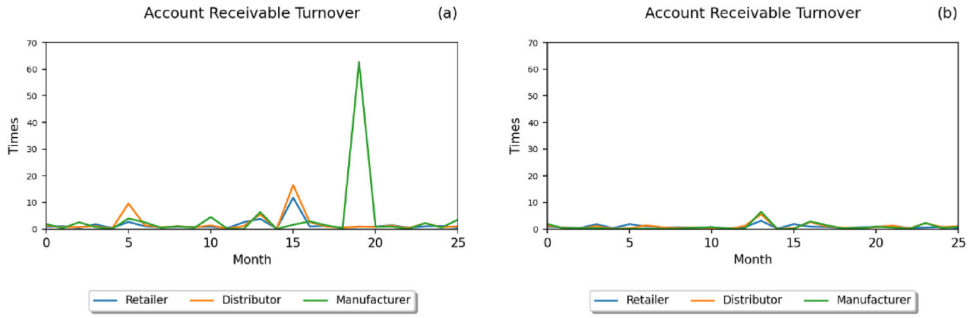

Figure 12. The comparison of account receivable turnover.

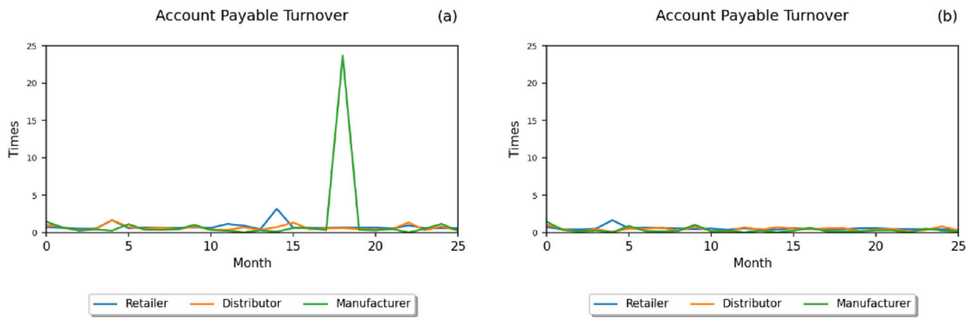

Figure 13. The comparison of account payable turnover.

For instance, in terms of the account receivable turnover, the ratios of the retailer, the distributor, and the manufacturer are on average 1.56, 2.15, and 4.10, respectively. With credit risk consideration, the average ratios are 0.88 for the retailer, 0.95 for the distributor, and 0.83 for the manufacturer. It is known that a low ratio of account receivable turnover indicates that the cash liquidity of each member increases by reducing working capital investment. Because the values of the account receivable turnover decrease with credit risk consideration, it is reasonable to assert that credit risk consideration mitigates the cash-bullwhip effect from the downstream to the upstream through the supply chain.

The account payable turnover is an index that denotes the speed with which the company is able to pay off any amount of money owed to its supplier at a given period. Figure 13 presents the account payable turnover values for each member. For example, with respect to the account payable turnover, the values for the retailer, the distributor, the manufacturer, and the supplier are 0.80, 0.65, and 1.42 respectively. With credit risk consideration, the ratios are 0.55 for the retailer, 0.43 for the distributor, and 0.32 for the manufacturer for the supplier. A higher account payable turnover expresses the financial health of each member in fulfilling its financial obligations to its creditor. However, the results indicate that the account payable turnover values of each member decrease with credit risk consideration compared to noncredit risk consideration. Consequently, it is difficult to infer that credit risk consideration decreases the cash-bullwhip effect along the supply chain.

The cash conversion cycle is an index that indicates the efficiency with which a company is able to convert inventory investments into cash flows. As indicated in

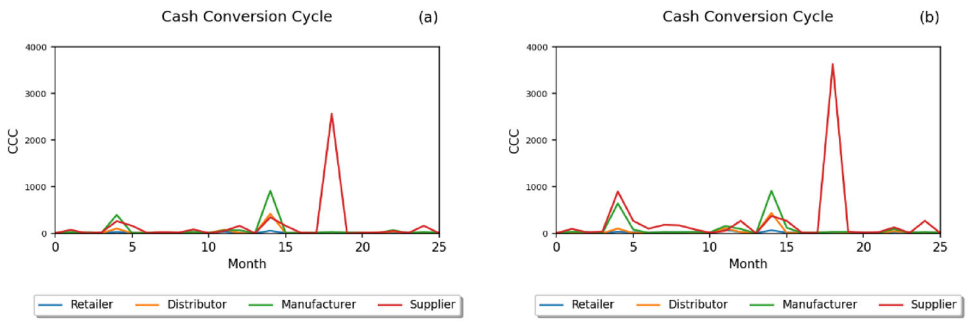

Figure 14. The comparison of cash conversion cycle.

Figure 14(a), the cash conversion cycle values are 16.8 for the retailer, 36.6 for the distributor, 72.8 for the manufacturer, and 169.2 for the supplier. With credit risk consideration, the cash conversion cycle values for the retailer, the distributor, the manufacturer, and the supplier are 26.0, 42.1, 100.7, and 279.8, respectively, as presented in Figure 14(b). The low cash conversion cycle values indicate that the cash-bullwhip effect can be mitigated by decreasing the inventory investment of each member. However, because the values of the cash conversion cycle increase for each member in the case of credit risk consideration, it can be concluded that credit risk consideration does not mitigate the cash-bullwhip effect along the supply chain.

4.5. Sensitivity analysis

Because the lead time is one of the critical factors that causes the bullwhip effect in the supply chain, a sensitivity analysis is conducted to analyze the impact of the lead time on the cash-bullwhip effect in terms of the inventory level and the cash level. With a lead time of 5 days as a basis, the inventory levels are investigated by changing the lead time from 10 days to 30 days with a 10 day increase rate in the case of credit risk consideration.

As indicated in Figure 15, the inventory levels of all supply chain members rapidly increase as the lead time rapidly increases. For instance, the inventory levels of the manufacturer increase 3 times, 18 times, and 79 times with an increase in lead time from 10 days to 30 days with a 10 day increase rate. With the change in lead time, the bullwhip effect becomes amplified from downstream to upstream along the supply chain in terms of inventory level.

Furthermore, the cash levels of all members increase except for the manufacturer. As depicted in Figure 16, the cash levels of the manufacturer rapidly decrease 16 times, 91 times, and 293 times for lead times of 10 days, 20 days, and 30 days, respectively. The results indicate that the cash-bullwhip effect strongly influences the manufacturer, which has difficulty obtaining information on customer demand.

5. Conclusion

Although the bullwhip effect and the credit risk are critical issues in material flow and cash flow throughout the supply chain, no studies have considered these two important issues simultaneously. For these reasons, this study investigated the impact of credit risk

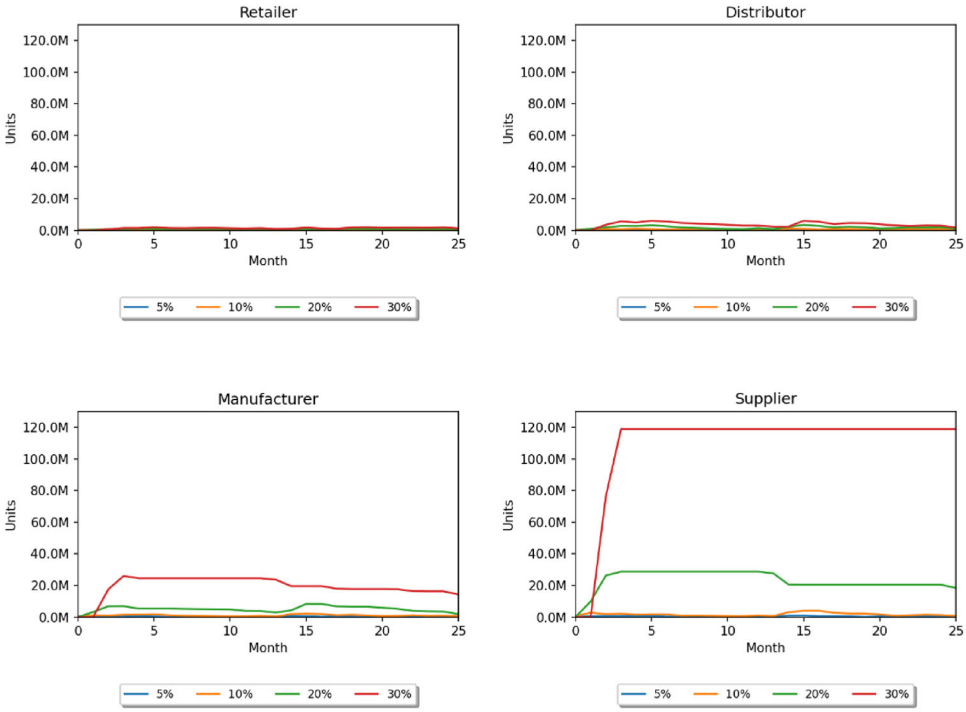

Figure 15. The sensitivity analysis of inventory level.

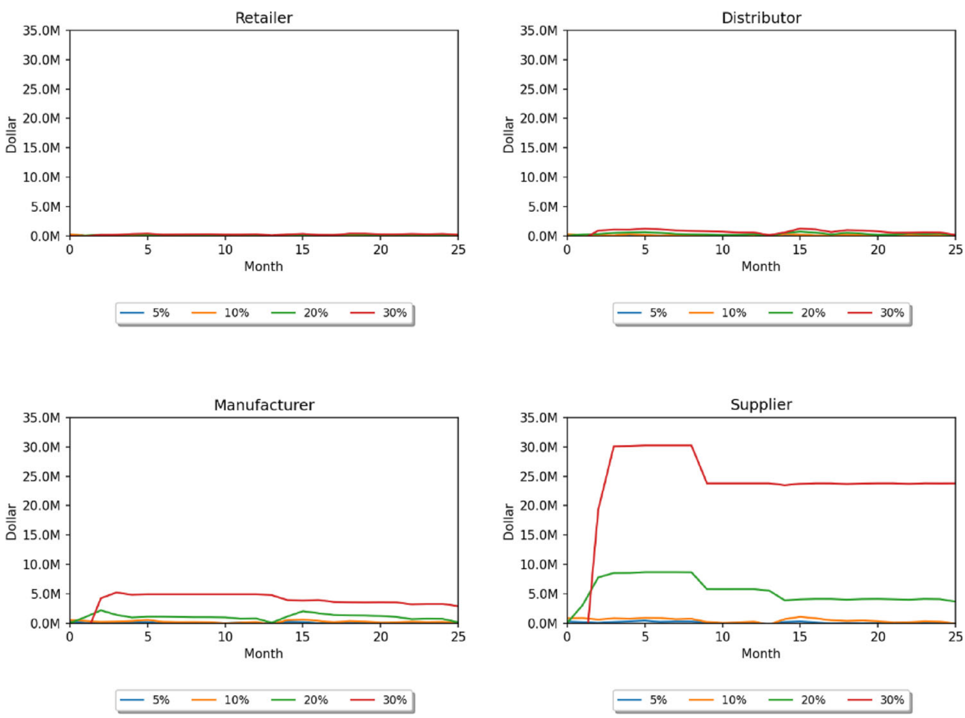

Figure 16. The sensitivity analysis of cash level.

on the cash-flow bullwhip effect from downstream members to upstream members along the supply chain in terms of account receivable, account payable, and cash. To analyze the cash-bullwhip effect, three financial performance indicators were used—account receivable turnover, account payable turnover, and cash conversion cycle.

Having applied the developed cash-bullwhip effect mathematical model, the results demonstrate that credit risk consideration improves the liquidity problems of each supply chain member by increasing the amounts of account receivable, account payable, and cash from downstream to upstream. The results also indicate that the account receivable turnover accurately indicates the cash-bullwhip effect of each member. However, the account payable turnover and the cash conversion cycle do not accurately illustrate the cash-bullwhip effect phenomenon in the case of credit risk consideration.

This study contributes to the academic literature by assessing how the credit risks of each member change the account receivable amount, account payable amount, and cash levels of other members in terms of the cash-flow bullwhip effect through the entire supply chain. In addition, it identifies the account receivable turnover as the financial performance index most effective in measuring the cash-flow bullwhip effect with credit risk consideration. However, this study used a limited amount of account payable aging data, which restricted estimates of the credit risks of each customer. Thus, to further validate the results, larger amounts of financial data need to be used to investigate the cash-bullwhip effect phenomenon while calculating each customer's credit risk more accurately.

Nomenclature

$AR_{j,t}$: The account receivable of supply chain member j at time t
$ARC_{j,t}$: The payment collected by supply chain member j at time t
$APG_{j,t}$: The payment made by supply chain member j at time t
$APP_{j,t}$: The new payment issued for supply chain member j at time t
$BO_{j,t1}$: The back order of supply chain member j at time t
$BPB_{j,t1}$: The invoice of supply chain member j at time t
$CASH_{j,t}$: The cash level of supply chain member j at time t
$CR_{j,t}$: The collection ratio of supply chain member j at time t
$CRF_{j,t}$: The forecast collection ratio of supply chain member j at time t
$FC_{j,t}$: The forecast order demand of supply chain member j at time t
$INVI_{j,t}$: The inventory of supply chain member j at time t
$OINV_{j,t}$: The order inventory of supply chain member j at time t
$ORD_{j,t}$: The order amount from supply chain member j at time t
$PR_{j,t}$: The payment probability of supply chain member j at time t

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