Information Sharing on the Bullwhip Effect in a Four-Level Supply Chain

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Abstract. In a global supply chain structure, market demand changes dynamically. To conquer the dynamics, information sharing has been applied in enterprises to reduce inventory costs. Thus, the enterprises' competitiveness can be maintained. To investigate the issue of information sharing, most scholars build a two-level supply chain model to simplify the analysis. However, the two-level models do not fit with the supply chains in the real world, which consist of more than three levels. By mathematical derivation, this study proposes the analytic model to analyze the four-level supply chain and verifies the value of information sharing for each tier enterprise of the supply chain. This study assumes that the market demand follows AR (1) model which was also used in many studies of the literature and the lead time of each tier is also considered. At first, the bullwhip effect of each tier is verified in a four-level supply chain. Then, by analyzing total inventory of each tier, the benefit of information sharing for each tier is quantified. The results of this study show that the bullwhip effect still exists in the supplier and the raw material supplier even though demand information is shared. Inventory variation raises rapidly as self-correlation coefficients ρ increases and standard deviation (volatility) σ increases. The effects of lead time on inventory among enterprises interact with one another. Information sharing brings much more significant benefit for the supplier and for the raw material supplier. Under the condition of the volatile market dynamics and the condition that the downstream manufacturer is highly associated with the market demand, the raw material supplier can reduce up to 35% of inventory by information sharing.

Keywords: Information Sharing, Supply Chain, Bullwhip effect, Inventory Model, Order-Up-To policy

1. INTRODUCTION

In the past, most studies concerning analyzing the ben efit of information sharing are the two-level supply ch ain in the literature; however, the supply chain of alm ost each real-world industry has more than 2 levels. B ased on the derivation of Lee et al. (2000) where the two level supply chain was also considered, this study analyzes the bullwhip effect for the four-level supply chain by deriving the variances of inventory for each tier. Our objective is to quantify the benefit of each tire by information sharing.

The goals of this study are listed below:

1. Summarize the related studies regarding the bullwhip effect and information sharing in the literature to understand the gap in the research field.
2. Based on the AR(1) model for the demand market, derive the bullwhip effect for each tier in the four-level supple chain.

3. Determine the inventory deduction of each tier with infor mation sharing.

The rest of this paper is organized as follows. Se ction 2 outlines the related studies in the literature. Th e detailed supply chain model is provided in Section 3; this section also analyzes the model without informatio n. Section 4 derives the bullwhip effect and quantifies the benefit of each tier enterprise with information sharing. Finally, the summary and conclusions are presented in Section 5.

2. LITERATURE REVIEW

2.1 DEMAND MODEL AND INVENTORY OF SUPPLY CHAIN

Each enterprise develops its own model to forecast eit her market demand or the demand of its downstream enterprise to balance demand and supply. Box and Jen kins developed the well-known forecasting model, ARI MA (Autoregressive Integrated-Moving Average Model), in 1970. There are 3 parameters in ARIMA(p, d, q) where p is the number of terms for autoregressions, d is the number of times of computing differences in time series, and q is the number of terms of moving averages. The fundamental condition of using ARIMA is stationary which means that the values should be random without any trend (either increasing or decreasing). In case there exits an evident trend, the smoothing process of taking the differences should be applied.

There are two types of inventory planning, dependent planning and independent planning. Independent planning is for finished products or for maintenance parts (Hillier & Lieberman, 1995), and dependent planning is for the rest of materials and is according to independent planning of finished products by MRP. To simplify the analysis, this study only considers independent planning. Silver et al. (1998) classified the inventory policy into 2 systems: the continuous review system and the periodic system. The popular system used in the literature, the Order-Point, Order-Up-To-Level system, belongs to the continuous review system.

2.2 BULLWHIP EFFECT

Bayraktar et al. (2008) proposed the following measures to evaluate the performance of the supply chain: 1. total cost, 2. service level, 3. average inventory level, and 4. bullwhip effect. This study focuses on the bullwhip effect of the supply chain which is the key to the management of the supply chain. The bullwhip effect is the phenomenon of enlarging variance of demand along the upstream enterprises of the supply chain. The bullwhip effect can be significantly observed in the developing market where the market demand increases dramatically. These industries include telecommunication manufacturing, computer parts manufacturing, food, retailers, cars, and clothes (Hugos, 2011).

The bullwhip effect influences the supply chain in many ways and results in the following problems: 1. excessive inventory of the supply chain, 2. deficit or excessive productivity, 3. product unavailability, 4. increasing the total cost of the supply chain, 5. sales loss, 6. incorrect production planning (Sun & Ren, 2005). Therefore, the bullwhip effect leads to the bad effect for many enterprises.

2.3 INFORMATION SHARING

Lee et al. (2000) utilized AR(1) demand model to analyze the 2-level supply chains without information sharing and with information sharing which contains one manu facture and one retailer. For the manufacturer, both the inventory and the cost with information sharing were reduced compared those without information sharing.

Yu et al. (2002) used demand model AR(1) to analy ze three types of information sharing: distributed contr ol, collaborative control, and central control. The result demonstrated that information sharing helped the man ufacturer reduce inventory.

Zhang (2004) proposed that market demand model ARMA could be transferred in the supply chain; besi des, for the manufacturer, the lead time, inventory poli cy, market demand, and historical orders have to be sh ared to forecast its future demand.

Based on market demand model AR(1), Liu et al. (2013) proposed to analyze the 3-level supply chain. In addition, information is shared to tier 1 and tier 2 enterprises, and the results showed that it would bring benefit to tier 2 enterprise with information sharing when the value of autocorrelation coefficient ρ is from -1 to 1.

Ganesh et al. (2014) proposed to analyze the multiple-level supply chain but lead time was not considered in their study. Huang et al. (2015) considered the 2-tier supply chain with multiple suppliers.

Deficits of information transparence and of coordination lead to the bullwhip effect, and the partners among the supply chain are short of mutual understanding to one another. That results in misunderstanding in current market demand (Bhattacharya & Bandyopadhyay, 2011). Hence, this study proposes the key factor to solve the bullwhip effect is through information sharing in the supply chain. That is, it can reduce excessive inventory significantly. Besides, unlike most studies which only considered 2-level, this study proposes to analyze the multiple-level supply chain which is more practical in the real world. The positive lead time is also considered in this study. The main goal of this study is to verify information sharing can alleviate the bullwhip effect and reduce the inventory in the four-level supply chain.

3. ANALYZING THE FOUR-LEVEL SUPPLY CHAIN WITHOUT INFORMATION SHARIN G

3.1 MODEL DESCRIPTIONS AND ASSUMPTIONS

Based on Lee et al. (2000), this study extends to derive the demand and the inventory for each tier enterprise in the four-level supply chain without information sharing. With the derivations provided in this section, the bullwhip effect and the benefit of each tier enterprise can be further derived in the next section. This study considers the four-level supply chain which consists of one retailer, one manufacturer, one supplier, and one raw material supplier. The structure of the supply chain in this study is depicted in Fig. 1. The detailed supply chain model considered in this study is described below. Only one product is considered. After the retailer receives market demand at each planning period, it will place the purchase order to the manufacturer. The similar situation applies to the manufacturer, the supplier and the raw material supplier. Backorder is allowed for each tier enterprise.

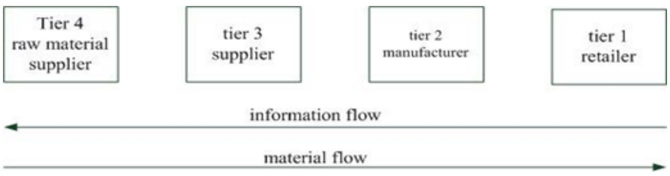

Fig. 1 The structure of the four-level supply chain

The following notations are used to describe and analyze the model:

d = average market demand for each planning period

ρ = autocorrelation coefficient of the market demand

ε_t = error term at planning period t and has i.i.d. $N(0,\sigma^2)$ distributions

$D_t^{(i)}$ = demand of tier i enterprise at planning period t; i=1, 2, 3, 4

$Y_t^{(i)}$ = (purchasing) order quantity of tier i enterprise at planning period t; i=1, 2, 3, 4

$m_t^{(i)}$ = the expected value of the total demand in the lead time for tier i enterprise at planning period t; i=1, 2, 3, 4

$v_t^{(i)}$ = the variance of the total demand in the lead time for tier i enterprise at planning period t; i=1, 2, 3, 4

$T_t^{(i)}$ = the target inventory level for tier i enterprise at planning period t; i=1, 2, 3, 4

l = lead time of purchasing for the retailer

L= lead time of purchasing for the manufacturer

L^S = lead time of purchasing for the supplier

L^Z = lead time of procurement for the raw material supplier

3.2 ANALYZING THE SUPPLY CHAIN WITHOUT INFORMATION SHARING

Following most studies in the literature, the time series model is utilized to represent real market demand. This study follows Kahn (1987) to use AR(1) model to forecast future market demand below

$$D^{(1)}{}_t = d + \rho D^{(1)}{}_{t-1} + \varepsilon_t \, . \tag{1}$$

The above AR(1) is also the demand for the retailer. This study assumes that each tier enterprise adopts order-up-to level inventory policy. After each enterprise receives the current demand, it will then determine its target inventory level below

$$\mathrm{T}_t^{(i)} = m_t^{(i)} + k\sqrt{v_t^{(i)}} \tag{2}$$

Lee et al. (2000) had derived the purchasing order quantity and target inventory level for tier 1 and 2 ent erprises. This study exploits similar reasoning to derive the decisions for tier 3 and 4 enterprise. For tier 3 e nterprise (supplier), $D_t^{(3)}$ and $T_t^{(3)}$ can be derived as f ollows:

$$\begin{aligned} D^{(3)}{}_t &= d + \rho D^{(3)}{}_{t-1} + \frac{(1-\rho^{l+2})(1-\rho^{L+2})}{(1-\rho)^2}\,\varepsilon_t \\ &+ \frac{\rho(1-\rho^{L+1})[2\rho^{l+2}-\rho-1] - \rho(1-\rho^{l+1})(1-\rho)}{(1-\rho)^2}\varepsilon_{t-1} \\ &+ \frac{\rho^2(1-\rho^{L+1})(1-\rho^{l+1})}{(1-\rho)^2}\varepsilon_{t-2} \end{aligned} \tag{3}$$

and

$$\begin{aligned} \mathrm{T}^{(3)}{}_t &= \frac{d}{1-\rho}\left\{(L^s+1) - \frac{\rho\ (1-\rho^{L^s+1})}{1-\rho})\right\} \\ &+ \frac{\rho\ (1-\rho^{L^s+1})}{1-\rho} D^{(3)}{}_t + \\ &+ k\sigma\sqrt{\left\{\begin{array}{l} \dfrac{\{(1-\rho^{l+2})\ [\rho(1-\rho^{L+1})+1-\rho]\}^2}{(1-\rho)^4} + \\ \dfrac{1}{(1-\rho)^2}\displaystyle\sum_{i=1}^{L^s}(1-\rho^{L^s+2\text{-}i})^2\,\dfrac{\{(1-\rho^{l+2})[\rho(1-\rho^{L+1})+1-\rho]\}^2}{(1-\rho)^4} \\ + \dfrac{1}{(1-\rho)^2}\displaystyle\sum_{i=1}^{L^s+1}(1-\rho^{L^s+2\text{-}i})^2 \\ \dfrac{\{\rho(1-\rho^{L+1})[2\rho^{l+2}-\rho-1]\}^2 - \{\rho(1-\rho^{l+1})(1-\rho)\}^2}{(1-\rho)^4} \\ + \dfrac{1}{(1-\rho)^2}\displaystyle\sum_{i=1}^{L^s}(1-\rho^{L^s+1\text{-}i})^2\left\{\dfrac{\rho^2(1-\rho^{L+1})(1-\rho^{l+1})}{(1-\rho)^2}\right\}^2 \\ + \dfrac{(1-\rho^{L^s+1})^2}{(1-\rho)^2}\left\{\dfrac{\rho^2(1-\rho^{L+1})(1-\rho^{l+1})}{(1-\rho)^2}\right\}^2 \end{array}\right\}} \end{aligned} \tag{4}$$

Similarly, for tier 4 enterprise (raw supplier), $D_t^{(4)}$ and $T_t^{(4)}$ can be derived below:

$$
\begin{aligned}
D^{(4)}{}_t &= d+\rho[D^{(4)}{}_{t-1}]+\Big[\frac{(1-\rho^{l+2})(1-\rho^{L+2})(1-\rho^{L^s+2})}{(1-\rho)^3}\Big]\varepsilon_t \\
&+\Big\{\frac{\rho\,(1-\rho^{L^s+1})}{1-\rho}\Big[\frac{\rho(1-\rho^{L+1})[2\rho^{l+2}-\rho-1]-\rho(1-\rho^{l+1})(1-\rho)}{(1-\rho)^2} \\
&-\frac{(1-\rho^{l+2})(1-\rho^{L+2})}{(1-\rho)^2}\Big]+ \\
&\frac{\rho(1-\rho^{L+1})[2\rho^{l+2}-\rho-1]-\rho(1-\rho^{l+1})(1-\rho)}{(1-\rho)^2}\Big\}\varepsilon_{t-1} \\
&+\Big\{\frac{\rho\,(1-\rho^{L^s+1})}{1-\rho}\Big[\frac{\rho^2(1-\rho^{L+1})(1-\rho^{l+1})}{(1-\rho)^2}- \\
&\frac{\rho(1-\rho^{L+1})[2\rho^{l+2}-\rho-1]-\rho(1-\rho^{l+1})(1-\rho)}{(1-\rho)^2}\Big] \\
&+\frac{\rho^2(1-\rho^{L+1})(1-\rho^{l+1})}{(1-\rho)^2}\Big\}\varepsilon_{t-2}+ \\
&\Big[-\frac{\rho^3(1-\rho^{L^s+1})(1-\rho^{L+1})(1-\rho^{l+1})}{(1-\rho)^3}\Big]\varepsilon_{t-3}
\end{aligned}
\tag{5}
$$

and

$$
\mathrm{T}^{(4)}{}_t=\frac{d}{1-\rho}\left\{(L^z+1)-\frac{\rho\,(1-\rho^{L^z+1})}{1-\rho}\right\}+\frac{\rho\,(1-\rho^{L^z+1})}{1-\rho}D^{(4)}{}_t
+k\sigma\sqrt{\left\{\begin{aligned}
&h^2+\Big[\frac{1}{1-\rho}\sum_{i=1}^{L^z}(1-\rho^{L^z+2-i})h\Big]^2+\\
&\Big[\frac{1}{1-\rho}\sum_{i=1}^{L^z+1}(1-\rho^{L^z+2-i})e\Big]^2+\Big[\frac{1}{1-\rho}\sum_{i=1}^{L^z+1}(1-\rho^{L^z+2-i})f\Big]^2\\
&+\Big[\frac{1}{1-\rho}\sum_{i=1}^{L^z}(1-\rho^{L^z+1-i})\{g\}\Big]^2+\Big[\frac{(1-\rho^{L^z+1})}{1-\rho}\{g\}\Big]^2
\end{aligned}\right\}}
\tag{6}
$$

where

$$a=\frac{(1-\rho^{l+2})(1-\rho^{L+2})}{(1-\rho)^2},$$

$$b=\frac{\rho(1-\rho^{L+1})[2\rho^{l+2}-\rho-1]-\rho(1-\rho^{l+1})(1-\rho)}{(1-\rho)^2},$$

$$c=\frac{\rho^2(1-\rho^{L+1})(1-\rho^{l+1})}{(1-\rho)^2},$$

$$h=\frac{(1-\rho^{l+2})(1-\rho^{L+2})(1-\rho^{L^s+2})}{(1-\rho)^3},$$

$$
\begin{aligned}
e=\Big\{&\frac{\rho\,(1-\rho^{L^s+1})}{1-\rho}\\
&\Big[\frac{\rho(1-\rho^{L+1})[2\rho^{l+2}-\rho-1]-\rho(1-\rho^{l+1})(1-\rho)}{(1-\rho)^2}\\
&-\frac{(1-\rho^{l+2})(1-\rho^{L+2})}{(1-\rho)^2}\Big]\\
&+\frac{\rho(1-\rho^{L+1})[2\rho^{l+2}-\rho-1]-\rho(1-\rho^{l+1})(1-\rho)}{(1-\rho)^2}\Big\},
\end{aligned}
$$

$$
\begin{aligned}
f=\Big\{&\frac{\rho\,(1-\rho^{L^s+1})}{1-\rho}\Big[\frac{\rho^2(1-\rho^{L+1})(1-\rho^{l+1})}{(1-\rho)^2}\\
&-\frac{\rho(1-\rho^{L+1})[2\rho^{l+2}-\rho-1]-\rho(1-\rho^{l+1})(1-\rho)}{(1-\rho)^2}\Big],\\
&+\frac{\rho^2(1-\rho^{L+1})(1-\rho^{l+1})}{(1-\rho)^2}\Big\}
\end{aligned}
$$

and

$$g=-\frac{\rho^3(1-\rho^{L^s+1})(1-\rho^{L+1})(1-\rho^{l+1})}{(1-\rho)^3}.$$

The above equations (3-6) can be validated by Ganesh et al. (2014) with lead time set to 0.

4. ANALYZING THE EFFECT ON BULLWHIP AND THE BENEFIT OF INFORMATION SHARING

4.1 EFFECT ON BULLWHIP

Based on the derivations in the previous section, each tier enterprise forecasts future demand and then decide s the inventory decision. Therefore, the inventory decis ion is affected by the forecasting demand. The excessi ve forecasting demand leads to increasing the inventor y cost; on the contrary, the insufficient forecasting de mand results in lost sales. The incorrect forecasting de mand is enlarged with the bullwhip effect.

Therefore, this study proposes that information sh aring is exploited to alleviate the bullwhip effect. At fi rst, the bullwhip effect of the supply chain without inf ormation sharing is measured at each tier enterprise. T he bullwhip of tier 1 enterprise, the retailer, is verified below:

$$
\begin{aligned}
&Var(Y^{(1)}{}_t) \\
&= Var(D^{(1)}{}_t) + \left(\frac{\rho(1-\rho^{l+1})}{1-\rho}\right)^2 \cdot Var(D^{(1)}{}_t - D^{(1)}{}_{t-1}) \\
&\quad + 2\frac{\rho(1-\rho^{l+1})}{1-\rho} \cdot \operatorname{cov}(D^{(1)}{}_t - D^{(1)}{}_{t-1}, D^{(1)}{}_t) \\
&= Var(D^{(1)}{}_t) + \frac{2\rho(1-\rho^{l+1})(1-\rho^{l+2})}{(1+\rho)(1-\rho)^2}\sigma^2 \\
&= Var(D^{(1)}{}_t) + P > Var(D^{(1)}{}_t)
\end{aligned} \quad . \tag{7}
$$

As for tier 2-4 enterprises, the results are just too messy to present so the simplified presentations are given as follows:

$$Var(Y^{(2)}{}_t) = Var(D^{(2)}{}_t) + Q > Var(D^{(2)}{}_t), \tag{8}$$

$$Var(Y^{(3)}{}_t) = Var(D^{(3)}{}_t) + R > Var(D^{(3)}{}_t), \tag{9}$$

and

$$Var(Y^{(4)}{}_t) = Var(D^{(4)}{}_t) + S > Var(D^{(4)}{}_t), \tag{10}$$

where Q, R, and S are functions of ρ and σ^2. It can be shown that Q, R, and S are always positive; hence, the bullwhip effects at tier 2 to 4 enterprises can also be verified. Equations (7-10) with lead time = 0 and with ρ = 0.1 are plotted in Figs. 2 and 3, respectively. The effect of each factor, ρ, σ^2, l, L, L^s, and L^Z, on the bullwhip effect can be observed in these two figures. Note that $l = L = L^s = L^z$ is assumed in Fig. 3. The bullwhip effect is pronounced as ρ is close to 1 and σ^2 is increased. As for the lead time of each tier enterprise, when the lead time is not long, the longer lead time is, the stronger bullwhip effect is. However, as the lead time is bigger than some threshold value, lead time will not affect the bullwhip effect any more.

Based on Equations (7-10), the inventory level at each tier enterprise can be determined, but the results are not provided to simplify the presentation.

4.2 BENEFIT OF INFORMATION SHARING

The bullwhip effect is verified at each tier enterprise in the previous subsection and is more pronounced with higher tier enterprise. It will lead to inaccurate demand forecasted and poor decision on inventory. This research suggests information sharing is adopted in the supply chain to alleviate the bullwhip effect. The inventory levels of tier 2-4 enterprises can be derived below:

$$
\begin{aligned}
\mathrm{T_{full}}^{(2)}{}_t &= \frac{d}{1-\rho}\left\{(L+1) - \frac{\rho\,(1-\rho^{L+1})}{1-\rho})\right\} \\
&+ \frac{\rho\,(1-\rho^{L+1})}{1-\rho}D^{(2)}{}_t - \frac{\rho\,(1-\rho^{L+1})(1-\rho^{l+1})}{(1-\rho)^2}\varepsilon_t \\
&+ k\sigma\sqrt{\frac{(1-\rho^{l+2})^2}{(1-\rho)^2} + \frac{1}{(1-\rho)^2}\sum_{i=1}^{L}(1-\rho^{L+l+3-i})^2}
\end{aligned} \quad , \tag{11}
$$

$$
\begin{aligned}
\mathrm{T_{full}}^{(3)}{}_t &= \frac{d}{1-\rho}\left\{(L^s+1) - \frac{\rho\,(1-\rho^{L^s+1})}{1-\rho})\right\} + \frac{\rho\,(1-\rho^{L^s+1})}{1-\rho}D^{(3)}{}_t \\
&+ \frac{1}{(1-\rho)}(1-\rho^{L^s+1}) \\
&\frac{\{\rho(1-\rho^{L+1})[2\rho^{l+2}-\rho-1]\} - \{\rho(1-\rho^{l+1})(1-\rho)\}}{(1-\rho)^2}\varepsilon_t \\
&+ \frac{1}{(1-\rho)}(1-\rho^{L^s})\left\{\frac{\rho^2(1-\rho^{L+1})(1-\rho^{l+1})}{(1-\rho)^2}\right\}\varepsilon_t \\
&+ \frac{(1-\rho^{L^s+1})}{(1-\rho)}\left\{\frac{\rho^2(1-\rho^{L+1})(1-\rho^{l+1})}{(1-\rho)^2}\right\}\varepsilon_{t-1} \\
&+ k\sigma\sqrt{\left\{\begin{aligned}
&\frac{\{(1-\rho^{l+2})\,[\rho(1-\rho^{L+1})+1-\rho]\}^2}{(1-\rho)^4} \\
&+\frac{1}{(1-\rho)^2}\sum_{i=1}^{L^s}(1-\rho^{L^s+2\text{-}i})^2\frac{\{(1-\rho^{l+2})[\rho(1-\rho^{L+1})+1-\rho]\}^2}{(1-\rho)^4} \\
&+\frac{1}{(1-\rho)^2}\sum_{i=2}^{L^s+1}(1-\rho^{L^s+2\text{-}i})^2 \\
&\frac{\{\rho(1-\rho^{L+1})[2\rho^{l+2}-\rho-1]\}^2 - \{\rho(1-\rho^{l+1})(1-\rho)\}^2}{(1-\rho)^4} \\
&+\frac{1}{(1-\rho)^2}\sum_{i=2}^{L^s}(1-\rho^{L^s+1\text{-}i})^2\left\{\frac{\rho^2(1-\rho^{L+1})(1-\rho^{l+1})}{(1-\rho)^2}\right\}^2
\end{aligned}\right\}}
\end{aligned} \tag{12}
$$

and

$$
\begin{aligned}
\mathrm{T_{full}}^{(4)}{}_t &= \frac{d}{1-\rho}\left\{(L^z+1) - \frac{\rho\,(1-\rho^{L^z+1})}{1-\rho})\right\} + \frac{\rho\,(1-\rho^{L^z+1})}{1-\rho}D^{(4)}{}_t \\
&+ \frac{1}{1-\rho}(1-\rho^{L^z+1})e\varepsilon_t + \frac{1}{1-\rho}\sum_{i=1}^{2}(1-\rho^{L^z+2\text{-}i})f\,\varepsilon_{t+i\text{-}2} \\
&+ \frac{1}{1-\rho}\sum_{i=1}^{2}(1-\rho^{L^z+1\text{-}i})\{g\}\,\varepsilon_{t+i\text{-}2} + \frac{(1-\rho^{L^z+1})}{1-\rho}\{g\}\,\varepsilon_{t-2} \\
&+ k\sigma\sqrt{\left\{\begin{aligned}
&h^2 + [\frac{1}{1-\rho}\sum_{i=1}^{L^z}(1-\rho^{L^z+2\text{-}i})h]^2 + [\frac{1}{1-\rho}\sum_{i=2}^{L^z+1}(1-\rho^{L^z+2\text{-}i})e]^2 \\
&+[\frac{1}{1-\rho}\sum_{i=3}^{L^z+1}(1-\rho^{L^z+2\text{-}i})f\,]^2 + [\frac{1}{1-\rho}\sum_{i=3}^{L^z}(1-\rho^{L^z+1\text{-}i})\{g\}\,]^2 \\
&+[\frac{(1-\rho^{L^z+1})}{1-\rho}\{g\}\,]^2
\end{aligned}\right\}}
\end{aligned} \quad .
$$

(12)

Inventory reductions of tier 2-4 enterprises between without information sharing (in Subsection 4.1) and with information sharing (Equations 10-12) can be computed. This study uses inventory reduction computed to quantify the value of information sharing at each tier enterprise. The inventory reductions at tier 2-4 enterprises are plotted in Fig. 5. From Fig. 5, important results can be observed below:

1. Information sharing helps upstream enterprises reduce holding inventory. Inventory reduction increases as the tier of the enterprise increases.
2. The value of information sharing increases as the standard deviation of error term in the market demand model increases.
3. The value of information sharing increases as the autocorrelation coefficient increases.
4. When lead time is positive, autocorrelation coefficient and the standard deviation have interactions to affect inventory

5. SUMMARY AND CONCLUSIONS

This study first proposes the structure of the 4-level supply chain and then quantifies the bullwhip effect at each tier enterprise. Based on the derived results, the critical factors to affect the bullwhip effect can be determined. This research further proposes information sharing is adopted to alleviate the bullwhip effect and determine whether information sharing can reduce inventory level at each tier enterprise or not.

Our results shows that bullwhip effect significantly influences higher tier enterprises. Furthermore, it can be observed that the factors to significantly affect the bullwhip effect are autocorrelation coefficient, ρ, standard deviation, σ, and the lead time of each tier enterprise, l, L, L^s, L^z. Information sharing indeed helps reduce invention level, and this was also verified in some studies in the literature. However, the new and important finding in this study is that the higher tier of the enterprise is, the more value of information sharing will obtain. When the market demand is very volatile, the inventory reduction can be up to 35% for the raw material supplier.

Past studies on information sharing of the supply chain almost discussed 2-level structure. This study shows that information sharing benefits the upstream enterprises most (supplier and raw material supplier in this study). Hence, this study suggests that the manufacture should develop as the ODM (Original Design Manufacturer) so the number of tiers as well as the total cost in the supply chain can be reduced. It can therefore share more profit to the retailer and that further motivate the retailer to share the demand to the manufactures. In sum, the win-win situation can be obtained in the supply chain.

ACKNOWLEDGMENTS

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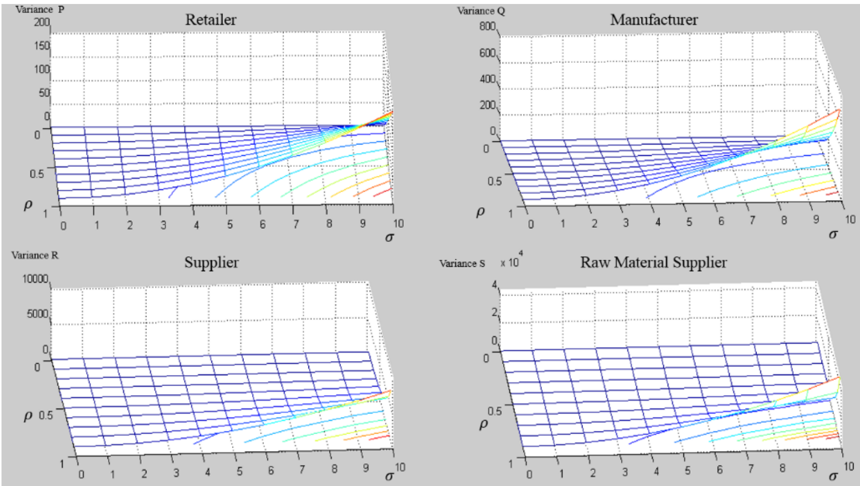

Fig. 2 Differences on variances of each tier enterprise with lead time = 0

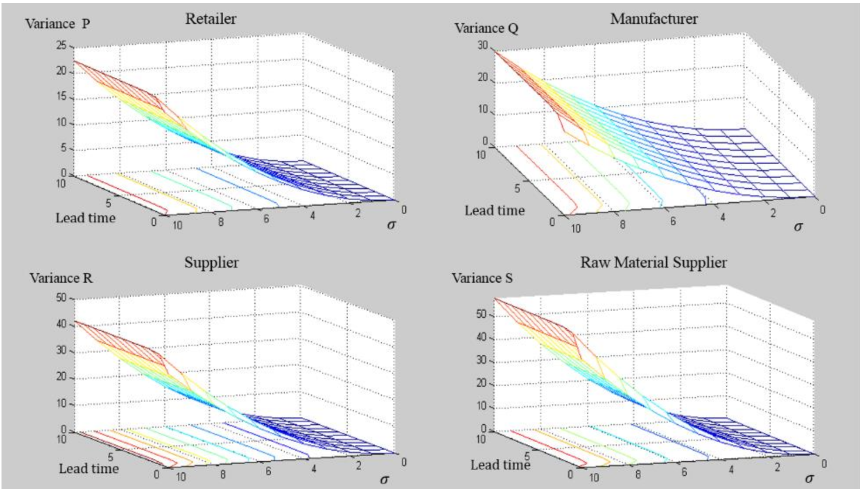

Fig. 3 Differences on variances of each tier enterprise with ρ = 0.1

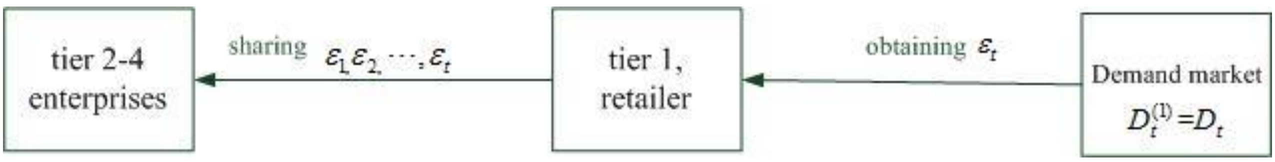

Fig. 4 Illustration of information sharing of the supply chain

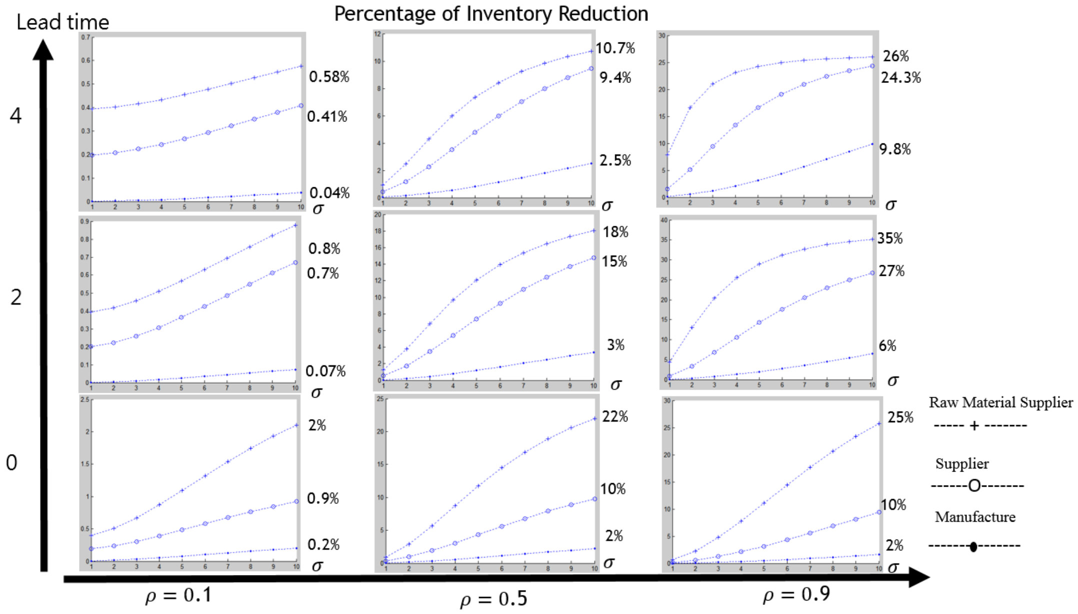

Fig. 5 Inventory reduction of tier 2-4 enterprises when information sharing is applie