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Application of Consignment to Three Stage Supply Chain

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Abstract

Purpose – The study investigates the impact of consignment on the economic performance in the supply chain with three stages. Through the analysis on distinct forms of consignment application, this study intends to answer to the question of how the consignment should be used in the multi-stage supply chain.

Research design, data, and methodology – The proposed mathematical model represents the supply chain system with a manufacturer, a wholesaler, and a retailer. Three different forms of consignment application are considered depending on which stages adapt the consignment, and their system profits are compared with the traditional non-consignment system in numerical examples.

Results – The numerical examples show that the serial consignment application performs better than any other forms of consignment as well as the non-consignment system. The additional analysis indicates that the system profit is significantly sensitive to the consignment rate.

Conclusions – The outcome of this study implies the potential of consignment to improve the system performance even in the multi-stage supply chain system. Meanwhile, each supply chain member's preference to the specific form of consignment application could be different depending on which stage he has. All the supply chain members should jointly determine the appropriate consignment rates to obtain the best system performance.

Keywords: Supply Chain Collaboration, Consignment, Optimization Model.

JEL Classifications: M11, M19, M21, M29.

1. Introduction

Consignment has been used in various industries for a long time in history. Even in these days, this special form of business contracts receives heavy attention from both business managers and academic researchers because of its potential to be one of supply collaboration initiatives.

In spite of its capacity to improve overall supply chain operations, most researchers focus on the dyadic relationship between two supply chain members in their studies and they examine only the case that the consignment is used in the simple supply chain system with two stages. Due to the conventional perception on the consignment as a normal business contract made between two business traders – buyer and seller, only a few studies look for the opportunity that the consignment is used at more than two stages in the supply chain system, just like any other supply chain collaboration programs such as VMI (Vendor-Managed Inventory) and CPFR(Collaborative Planning, Forecasting, and Replenishment).

This study intends to find out how the consignment affects the system performance in the supply chain with more than two echelons. Three forms of consignment application are considered depending on where the consignment is used in the supply chain system, and they are compared with the traditional non-consignment system to find out how the consignment should be used to get the best possible outcome in the multi-stage supply chain system.

The proposed mathematical model represents three stage supply chain system with a manufacturer, a wholesaler, and a retailer, and the economic performance of consignment application is evaluated in numerical examples. The numerical analysis indicates the possibility that the consignment improves the system performance if it is used

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in the entire supply chain. Since some supply chain members still get the economic damage from the consignment, it is necessary to prepare the well-designed incentive scheme to compensate their losses and sustain the supply chain collaboration. The further analysis on the numerical examples points out that the proper levels of consignment rates should be agreed by all supply chain members to obtain the best possible performance from the consignment.

There are certain reasons that it is necessary for this study to investigate the application of consignment to three-stage supply chain system. First, the researchers should have a definite theoretical background for searching the true nature of the consignment beyond the dyadic relationship when they investigate the consignment as the supply chain collaboration program. While quite a lot of studies already see the potential of the consignment to be a collaboration program that affects the entire supply chain system, most of them are still limited to examine its performance in two stage system, and it is still recognized as merely a form of contracts in the academic research area. By examining the consignment in three stage supply chain system, this study builds a fundamental basis for researchers to test the true value of consignment and they are expected to develop strong theories supporting that the consignment is one of the prominent collaboration programs for the whole supply chain system.

Second, the business practitioners need to know how to use the consignment in their real supply chain system. In most industries, the supply chain system is consisted of more than two stages. In particular, the current consignment should be used as a collaboration program with the aim to achieve the best supply chain performance instead of a conventional contract only for the contracting parties' benefits. This study examines the diverse types of consignment application in three stage supply chain and offer the managerial guidelines that help the business practitioners properly use the consignment to improve the supply chain operations in their real businesses.

2. Research Background

Consignment has a long history of connecting the buyer and seller in their business trades (Fenton & Sanborn, 1987), and it has still been used in various industries such as hospitals, book and canned goods retailing, part supplies in automobile and aircraft manufacturing, and paper and steel manufacturing (Ballard, 1987; de Matta et al., 2014; Gerber, 1987; Zahran et al., 2017). Recent public interest in supply chain management sheds new light on the consignment as one of collaboration programs that improve overall supply chain operations.

Consignment is generally considered to be a special form of contracts made between business traders, and it allows for the buyer to delay payment to the seller until he consumes the goods. Under the consignment contract, the seller still maintains and owns the inventories stored at buyer's warehouse until the buyer withdrawals them for use (Gerber, 1991; Harding, 1999). Consignment appears to be an efficient program that enhances the coordination between the buyer and seller by reducing buyer's inventory costs and maintaining seller's stable sales (Battini et al., 2010; Gerber, 1987; Valentini & Zavanella, 2003).

Consignment has been a main research topic in the business area, and most early studies on the consignment focus on inventory management and examine its impact on the inventory policy (Braglia & Zavanella, 2003; Corbett, 2001; Hill, 1999; Lee & Whang, 1999; Valentini & Zavanella, 2003). The revenue sharing scheme under the consignment contract is another issue that many researchers address in their studies and they evaluate its performance under diverse situations (Gerchak & Khmelnitsky, 2003; Hackett, 1993; Wang et al., 2004).

Escaping from the conventional perception about the consignment merely as one of contracts, one group of the recent studies considers it to be an innovative program for realizing supply chain collaboration (Zahran et al., 2015). In particular, some researchers consider the new form of consignment combined with VMI (Vendor-Managed Inventory), one of the existing collaboration initiatives and they evaluate its impact on the supply chain performance (Alfares & Attia, 2017; Chen, 2017; Ferretti et al., 2017; Hariga & Al-Ahmari, 2013). Another group of studies expands their investigations on the consignment to the area of distribution after production and proposes the algorithms for solving the complicated consignment problems (Braglia et al., 2013; Bylka, 2013; Bylka & Górny, 2015; Hariga et al., 2013; Jemai et al., 2013). There have been numerous attempts to examine the impact of consignment under the special situations, such as the online market (Chen, 2013, 2014; Wang et al., 2018), third-party manufacturing (Ferretti et al., 2017), environment protection (Hariga et al., 2017; Zanoni et al., 2014), quality control (Bazan et al., 2014; Giri et al., 2017; Hu et al., 2014), and reverse logistics (Jaber et al., 2014). <Table 1> shows the selected studies that evaluate the performance of consignment, and it compares them in terms of compared systems, supply chain structure, research methodology, and performance evaluation.

<Table 1> Selected Studies on Consignment Performance

Authors (Year)	Compared Systems	Supply Chain Structure (Participants)	Mathematical Model and Analysis	Performance Measurement
Ben-Daya et al. (2013)	No partnership, VMI & consignment, centralized supply chain	2 stages (a vendor, multiple buyers)	Economic production quantity model, numerical examples	Buyers' cost, vendor's cost, total cost
Chen (2013)	Consignment, VMI with consignment contract in traditional and electronic markets	2 stages (a supplier, a retailer)	Retailer-led Stackelberg game model, numerical examples	Retailer's profit, supplier's profit, total channel-wide profit
Hariga & Al-Ahmari (2013)	No-partnership, VMI-consignment partnership	2 stages (a supplier, a retailer)	EOQ-based mode for lot sizing and retail space allocation, numerical examples	Retailer's profit, supplier's profit, supply chain profit
Choudhary et al. (2014)	Retailer Managed Inventory (RMI), retailer-managed consignment, VMI	2 stages (a supplier, a retailer)	Extended EOQ model, numerical examples	System-wide cost saving, inventory reduction, replenishment frequency
Lee & Cho (2014)	RMI, VMI contract with consignment stock	2 stages (a supplier, a retailer)	Continuous review (Q, r) inventory model, numerical examples	Retailer's cost, supplier's cost, supply chain cost
de Matta et al. (2014)	Consignment, wholesale price markup policies	2 stages (a supplier, a retailer)	Non-linear programming model for pricing and stocking, numerical examples	Supper's profit, retailer's profit
Zanoni et al. (2014)	Traditional system, VMI with consignment stock	2 stages (a vendor, a buyer)	Joint economic lot size model, numerical examples	Vendor's cost, buyer's cost, system cost
Xu et al. (2016)	Stockout recovery without consignment, with consignment	2 stages (a manufacturer, a retailer)	Modified newsvendor model, numerical examples	Manufacturer's profit, retailer's profit, supply chain profit
Alfares & Attia (2017)	Traditional, VMI-consignment, integrated systems	2 stages (a vendor, two buyers)	Economic production quantity model, numerical examples	Buyers' cost, vendor's cost, total supply chain cost
Chen (2017)	RMI with price-only contract, VMI with consignment contract	2 stages (a supplier, a retailer)	Dynamic programming for pricing and replenishment, numerical examples	Supplier's profit, retailer's profit, total channel-wide profit, service level
Ferretti et al. (2017)	Traditional system, centralized VMI policy with consignment agreement	2 stages (a vendor, a third party manufacturer, a buyer)	Joint economic lot size model, numerical examples	Total supply chain cost
Hemmati et al. (2017)	Non-coordinated system, VMI with consignment agreement	2 stages (a vendor, a buyer)	Joint economic lot size model, numerical examples	Total system profit
Islam et al. (2017)	Traditional policy, manufacturer managed consignment policy	3 stages (a supplier, a manufacturer, multiple retailers)	Stochastic optimization model for pricing and lot sizing, numerical examples	Supplier's profit, manufacturer's profit, retailer's profit, total system profit
Zahran et al. (2017)	Four combinations of traditional and consignment policies	3 stages (a supplier, a vendor, a buyer)	Joint economic lot size model, numerical examples	Supplier's profit, vendor's profit, buyer's profit, total system profit
Wang et al. (2018)	Direct sales channel, third-party consignment channel	2 stages (a manufacturer, multiple customers)	Game theoretic model, numerical examples	Manufacturer's profit, customer's profit

While the past studies address diverse issues and examine various ways to apply the consignment to the practices, most of them use the simple form of supply chain system with only two stages. Some of them focus on the simple relationship between one seller and one buyer (Chen, 2017; Choudhary et al., 2014; Ferretti et al., 2017; Hemmati et al., 2017; Lee & Cho, 2014; Xu et al., 2016), and the others assume a more complex situation where more than one buyers exist with a single seller (Alfares & Attia, 2017; Ben-Daya et al., 2013; Wang et al., 2018). Even when the consignment is regarded as one of the collaboration program improving supply chain operations, most of the past studies still rely on its conventional definition as merely a form of contract made between two business traders.

Meanwhile, there has been some researchers who raise the question whether it is sufficient to examine the supply chain collaboration simply based on the dyadic relationship between two supply chain members. In the case study of a pharmaceutical and healthcare company, Danese et al.(2004) claim that VMI, which is one of well-known collaboration programs, need to be employed to the whole supply chain system rather than the dyadic relationship between the seller and buyer. In general, it is commonly known that any collaboration programs can be fully beneficial to the supply

chain system only if everyone in the system is coordinated (Chopra & Meindl, 2010). By implication, the true value of consignment as one of collaboration programs can be measured by the studies that examine the case that the consignment is applied to more than two stage supply chain system.

Only a few studies conduct research on the consignment in the supply chain with more than two echelons. Islam et al.'s study (2017) investigates the consignment in three stage supply chain system with a supplier, a manufacturer, and multiple retailers. They propose a manufacturer-managed consignment policy, and under this special type of consignment agreements, the manufacturer keeps the ownership of products stored at retailers' warehouses just like any typical consignment contracts. This contract is special, because both the supplier and retailers earn the revenue only through the commissions provided by the manufacturer. Their numeral analysis shows that the proposed three-tier consignment policy outperforms the two-tier consignment policy as well as the non-consignment system.

Zahran et al. (2017) examine the impact of consignment application on the system performance in the supply chain system where a supplier, a vendor, and a buyer exist. In particular, their study compares four different combinations of non-consignment and consignment in three stage supply chain system, and it is similar to this study that considers three forms of consignment application. While the system profit is used to evaluate the performance of consignment in their study, they assume the constant demand in the proposed supply chain models and still examine the potential benefit from the consignment in terms of cost-saving.

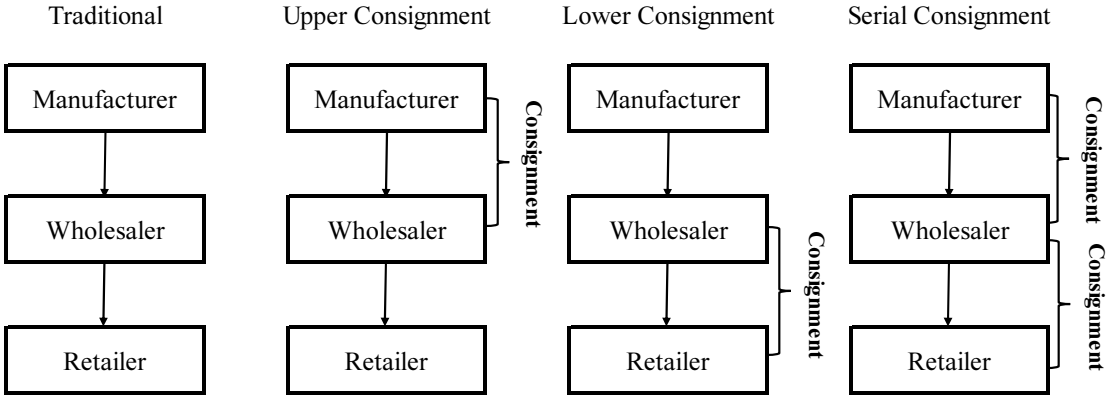
Distinct from numerous studies that configure the consignment merely as a dyadic contract, this study considers it to be one of the innovative initiatives that realize collaboration in the entire supply chain system, and investigates its application under three stage supply chain system. Furthermore, in the accordance with the previous studies showing that the consignment significantly increases throughput in the entire supply chain system (Ryu, 2007), this study looks for its true benefit in profit increase rather than cost saving by utilizing the price-dependent demand in the proposed supply chain model.

3. Three forms of Consignment Application

This study uses the mathematical model to investigate how the consignment affects the supply chain performance. The proposed model represents three-stage supply chain system, where a manufacturer, a wholesaler, and a retailer trade a single product item. The manufacturer produces and sells the product to the wholesaler. The wholesaler places orders of the products to the manufacturer and buy the products from him. In addition, the wholesaler processes and sells the products to the retailer. The retailer's role is to place orders to the wholesaler and buy the products from him.

In this study, four different supply chain systems are compared – traditional, upper consignment, lower consignment, and serial consignment, and they are different in terms of where the consignment is applied in the supply chain, as shown in <Figure 1>.

The traditional system indicates the supply chain system where no consignment is applied at all, and it is used as the base case for comparison with the other systems. In the upper consignment, the consignment is applied at the upper portion of the supply chain system, and the manufacturer and wholesaler hold the consignment contract. Lower consignment represents the case that the consignment stands up between the wholesaler and retailer, which is the lower part of the supply chain system. The serial consignment is the combination of upper and lower consignment cases. In this last system, all the supply chain members involve in the consignment and the consignment contracts are maintained between the manufacturer and wholesaler and between the wholesaler and retailer.



<Figure 1> Four Supply Chain Systems compared in Analysis

<Table 2> Notations used in Mathematical Model

Manufacturer		Wholesaler		Retailer	
π_M	Profit	π_W	Profit	π_R	Profit
p_M	Unit price	p_W	Unit price	p_R	Unit price
x_M	Production rate	x_W	Processing rate	q_R	Order quantity
S_M	Setup cost per wholesaler's order	q_W	Oder quantity	O_R	Ordering cost
α_M	Unit inventory cost per price	S_W	Setup cost per retailer's order	D_R	Retail market demand
v_M	Unit production cost	O_W	Ordering cost	k_R	Potential market size
τ_M	Unit transportation cost per price	ω_W	Profit margin	d_R	Price sensitivity parameter
ω_M	Profit margin	v_W	Unit processing cost	α_R	Unit inventory holding cost per price
		τ_W	Unit transportation cost per price	α_R^F	Unit inventory financing cost per price
		α_W	Unit inventory holding cost per price	α_R^S	Unit inventory stocking cost per price
		α_W^F	Unit inventory financing cost per price		
		α_W^S	Unit inventory stocking cost per price		

The series of optimization models are formulated to describe the decision making problems for the manufacturer, wholesaler, and retailer in three-stage supply chain system. <Table 2> explains about the notations used in the mathematical models.

In the mathematical models, the original joint economic lot size model (Banerjee, 1986) is modified to meet the condition of three-stage supply chain system (Ryu, 2017). In particular, the following models represent the case of serial consignment application.

Manufacturer

$$\max_{p_M, x_M} \pi_M = x_W \cdot p_M - \frac{S_M \cdot x_W}{q_W} - \frac{\alpha_M \cdot p_M \cdot q_W \cdot x_W}{2 \cdot x_M} - v_M \cdot x_M - \tau_M \cdot p_M \cdot x_W - - \frac{\alpha_W^F \cdot p_M \cdot q_W}{2} \quad (1)$$

subject to

$$x_M \geq x_W \quad (2)$$

$$p_M, x_M \geq 0 \quad (3)$$

Wholesaler

$$\max_{p_W, x_W, q_W} \pi_W = D_R \cdot p_W - x_W \cdot p_M - \frac{o_W \cdot x_W}{q_w} - \frac{\alpha_W^S \cdot p_M \cdot q_W}{2} - \frac{S_W \cdot D_W}{q_R} - \frac{\alpha_W \cdot p_W \cdot q_R \cdot D_R}{2 \cdot x_W} - v_W \cdot x_W - \tau_W \cdot p_W \cdot D_R - \frac{\alpha_R^F \cdot p_W \cdot q_R}{2} \quad (4)$$

subject to

$$x_W \geq D_R \quad (5)$$

$$p_w, x_w, q_w \geq 0 \quad (6)$$

Retailer

$$\max_{p_R, q_R} \pi_R = D_R \cdot (p_R - p_W) - \frac{O_R \cdot D_R}{q_R} - \frac{\alpha_R^S \cdot p_W \cdot q_R}{2 \cdot x_M} \quad (7)$$

subject to

$$p_R, q_R \geq 0 \quad (8)$$

Equation (1) describes that the manufacturer decides his price and production rate to maximize his profit including the sales revenue, setup cost, inventory holding cost, ordering cost, production cost, and transportation cost. Both annual inventory holding cost and unit transportation cost is proportion to the value of the product ($h = \alpha \cdot p,\ t = \beta \cdot p,$ t). When the consignment is used, the annual inventory holding cost is separated into stocking cost and financing cost ($h = h^S + h^F,$ where $h^S = \alpha_s \cdot p,\quad h^F = \alpha_F \cdot p$). Since the consignment contract is made between the manufacturer and wholesaler, the manufacturer is responsible for paying additional financing cost for holding inventories at wholesaler's warehouse (Valentini & Zavanella, 2003). In the constraint, the manufacturer's production rate should be at least the wholesaler's processing rate (Equation (2)), and the price and production rate cannot be negative values (Equation (3)).

The wholesaler determines his price, processing rate, and order quantity to maximize his profit (Equation (4)). The wholesaler's profit is comprised of the sale revenue, purchasing cost, ordering cost, setup cost, processing cost, and transportation cost. Since the wholesaler has the consignment contracts with both the manufacturer and retailer, he should pay the financing cost for holding inventories at the retailer's warehouse, while he need to pay only the stocking cost for holding his own inventories. Equation (5) indicates that the wholesaler should process the sufficient amount of products to cover the retail market demand. Equation (6) is non-negativity constraint for wholesaler's decision values.

The retailer maximizes his profit by properly deciding his price and order quantity as shown in Equation (7). His profit contains the sales revenue, purchasing cost, and ordering cost. Due to the consignment contract with the wholesaler, the retailer has to pay only the stocking cost for holding his own inventories. It is assumed that the retail market demand is sensitive to the retail price ($D = k - d \cdot p$). Equation (8) describes that the retailer price and lot size should be greater than or equal to zero.

4. Analysis on Numerical Examples

This study examines the impact of consignment on the system performance in three-stage supply chain system. The numerical examples of the proposed mathematical models are used to compare four forms of consignment application. The specific values of parameters used in the bases case of numerical examples are arbitrarily determined as shown in <Table 3>.

<Table 3> Parameters in Base Case

k = 2,000	d = 6	v_M = 30	v_W = 10	
S_M = 500	S_W = 300	O_W = 70	O_R = 75	
α_M = 0.05	α_W = 0.06	α_R = 0.07	τ_M = 0.05	τ_W = 0.05
α_W^F = 0.04	α_W^S = 0.02	α_R^F = 0.047	α_R^S = 0.023	

This study designs diverse conditions of the supply chain system to figure out the overall performance of each form of consignment application in the numerical examples. The values of four parameters including the potential market size, unit setup cost, unit ordering cost, and unit inventory holding cost per price are varied in seven levels, and total 2,401 cases are considered for each supply chain system ($7^4 = 2,401$).

4.1. Performances of four supply chain systems

The detailed performances of four supply chain systems from the numerical examples are measured on average as <Table 4> shows.

<Table 4> Performances of Four Supply Chain Systems

			Traditional	Upper Consign	Lower Consign	Serial Consign
Market demand			384.41	385.06	385.30	385.82
Manufacturer	Price		125.96	126.02	125.96	126.02
	Production Rate		940.37	939.77	940.37	939.77
	Costs	Setup	1,762.77	1,523.28	2,146.36	1,955.75
		Inventory Holding	205.58	865.80	167.72	671.04
		Production	28,211.19	28,193.05	28,211.19	28,193.05
		Transportation	2,975.58	2,987.79	2,965.22	2,975.22
		Total	33,155.12	33,569.92	33,490.48	33,795.05
	Revenue		59,511.54	59,755.83	59,304.36	59,504.47
	Profit		26,356.42	26,185.91	25,813.88	25,709.42
Wholesaler	Price		204.02	203.81	204.23	204.06
	Order Quantity		133.35	155.11	108.95	119.98
	Processing Rate		467.84	469.55	466.19	467.55
	Costs	Purchasing	59,511.54	59,755.83	59,304.36	59,504.47
		Ordering	246.57	213.08	300.23	273.57
		Inventory Holding (Before Processing)	497.50	191.19	407.18	148.48
		Setup	1,822.26	1,822.85	1,042.61	1,042.88
		Inventory Holding (After Processing)	317.41	316.88	1,094.86	1,094.24
		Processing	4,678.37	4,695.55	4,661.86	4,675.54
		Transportation	3,962.90	3,965.39	3,976.00	3,977.96
		Total	71,036.56	70,960.76	70,787.11	70,717.13
	Revenue		79,258.02	79,307.75	79,519.99	79,559.23
	Profit		8,221.46	8,347.00	8,732.88	8,842.10
Retailer	Price		269.27	269.16	269.12	269.03
	Order Quantity		63.79	63.88	112.58	112.71
	Costs	Purchasing	79,258.02	79,307.75	79,519.99	79,559.23
		Ordering	451.44	451.59	258.30	258.37
		Inventory Holding	451.45	451.59	258.30	258.36
		Total	80,160.91	80,210.94	80,036.59	80,075.96
	Revenue		104,704.42	104,837.44	104,888.26	104,993.70
	Profit		24,543.52	24,626.51	24,851.67	24,917.74
Supply Chain System	Cost		184,352.58	184741.61	184314.18	184588.13
	Revenue		243,473.98	243,901.03	243,712.61	244,057.39
	Profit		59,121.40	59,159.41	59,398.44	59,469.26

The numerical examples indicate that the serial consignment achieves the greatest profit among all four systems. The lower consignment outperforms the upper consignment in terms of system profit, and the traditional non-consignment results in the lowest system profit. The difference in system profit among these systems is due to their distinct demand volumes. In the serial consignment, both the wholesaler and retailer receives the benefits of reduced inventory holding cost, and they afford more inventories and demand by decreasing their prices. After all, the increased demand caused by the decreased price enables the serial consignment to obtain higher system profit than any other systems.

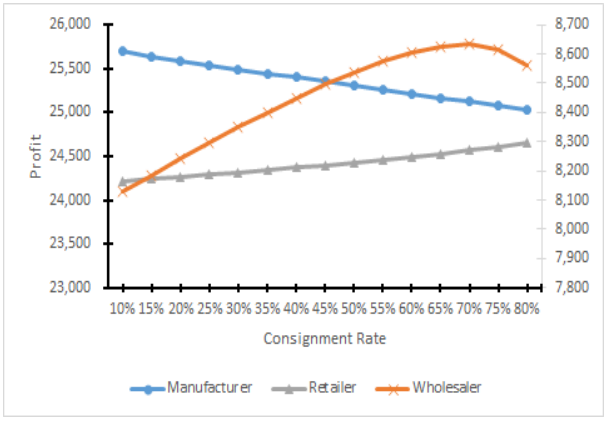
While both upper and lower consignment systems install the consignment at one place of the supply chain, the lower consignment leads to greater system profit than upper consignment. The consignment contract between the wholesaler and retailer makes a direct impact on the way that the retailer determines his price in the lower consignment. Meanwhile, the consignment contract between the manufacturer and wholesaler also indirectly affects the retail price in upper consignment, but its impact is smaller than the case of lower consignment. The traditional system does not receive any benefit from the increased demand without any consignment contract.

When the profit is measured for each individual supply chain member, the orders from the largest to smallest profit for the wholesaler and retailer among four systems are identical to the one for the system profit. However, the rank in manufacturer's profit is exactly opposite to the other profits, and all the cases of consignment application underperform the traditional non-consignment system. In both upper and serial consignment systems, the manufacturer has to pay additional cost for financing wholesaler's inventories due to the consignment contract. Even in the lower consignment where the manufacturer does not belong to the consignment, his cost increases due to the increased retail demand size from the lower stage of supply chain system, but he hardly receives any benefit from it.

4.2. Impact of consignment rate on supply chain performance

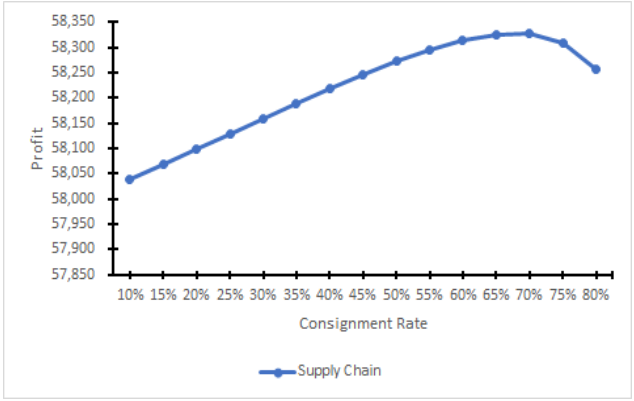
The additional analysis on the numerical examples is conducted to figure out how the consignment rate affects the performance of consignment. The consignment rate indicates the ratio of financing and stocking costs for holding inventories under the consignment contract, and it is particularly represented as a portion of financing cost over entire inventory holding cost ($\frac{\alpha_F}{\alpha_F+\alpha_S}$) in the mathematical models. In the numerical examples, this study focuses on only the serial consignment, which results in the best performance, and observes its profit changes as the consignment rate is varied.

<Figure 2> shows each supply chain member's profit changes with different consignment rates. As the consignment rate becomes higher, manufacturer's profit decreases due to the increased financing cost for holding inventories under the consignment contract. With higher consignment rate, however, the retailer pays less stocking cost and his profit becomes greater. Meanwhile, the profit of the wholesaler, who pay both financing and stocking costs under the serial consignment contract, increases in the beginning and then decreases later as the consignment rate increases.



<Figure 2> Impact of Consignment Rate on Supply Chain Member's Profit

After all, the change of the supply chain profit with the increasing consignment rate shows the almost same pattern with wholesaler's profit. As the consignment rate increases, the supply chain profit begins to increase and then decreases later. According to this particular numerical examples, the maximal supply chain profit is realized at 70% of consignment rate.



<Figure 3> Impact of Consignment Rate on System Profit

For the further investigation on how the consignment rate

affects the system performance, the another set of numerical examples are prepared by differentiating the consignment rate between the manufacturer and wholesaler (upper consignment rate) and one between the wholesaler and retailer (lower consignment rate) in the serial consignment system. <Table 5> shows that individual profits become smallest and largest among the cases considered with the particular combinations of upper and lower consignment rates in the range of consignment rate between 10 and 80%.

<Table 5> Impact of Upper and Lower Consignment Rate on Profits

Profit	Smallest		Largest	
Manufacturer's	Upper rate	80%	Upper rate	10%
	Lower rate	80%	Lower rate	10%
Wholesaler's	Upper rate	10%	Upper rate	80%
	Lower rate	10%	Lower rate	65%
Retailer's	Upper rate	10%	Upper rate	80%
	Lower rate	10%	Lower rate	80%
System's	Upper rate	10%	Upper rate	80%
	Lower rate	10%	Lower rate	65%

As both upper and lower consignment rates increase, the manufacturer's profit decreases but the retailer's profit increases. Meanwhile, wholesaler obtains the largest profit when lower consignment rate is neither lowest nor highest (65%). After all, the total system profit becomes largest when the lower consignment rate is between the lowest and highest ones just like the wholesaler's profit, but it is different from the upper consignment rate. This result implies that independently determined consignment rates could result in only less-than-best outcome and all the consignment contracts in the serial consignment system need to be synchronized to achieve the real best performance.

5. Discussion

The experimental study on the consignment in three stage supply chain system provides the following managerial implications to the business practitioners. First, the supply chain system can achieve the best performance when the consignment contract is used at its every stage. The comparison among three different forms of consignment application indicates that the serial consignment, which applies the consignment contracts to both upper and lower stages of supply chain system, outperforms the other forms employing the consignment at only a part of the supply chain. This result implies that all the supply chain members need to involve in the consignment contracts to obtain the best outcome from the consignment.

Second, the consignment improves the supply chain performance, mainly because it increases the overall throughput of the entire supply chain system. The numerical analyses show that the inventory holding cost saving due to the consignment allows the retailer and wholesaler to maintain the increased demand, and the enlarged system demand size enables the consignment system to obtain greater system profit than the non-consignment system. This result enlightens the unique perspective on how the consignment improves the supply chain operations. Traditionally, most studies focus on cost saving as the key benefit of consignment, when it is researched as a plain form of contracts made between two business traders. Meanwhile, the outcome of this study implies that the real value of consignment to the supply chain system, where is beyond the simple dyadic relationship, can be found as revenue enlargement rather than cost saving. This proposition may explain the reason that the past study comparing different consignment forms ends with somewhat mixed outcomes (Zahran et al., 2017).

Third, the consignment results in better system performance if it is used at the downstream rather than the upstream of the supply chain system. In general, the inventory becomes more expensive as it moves toward the downstream of the supply chain system, and the positive impact of the consignment on the system performance is greater when the downstream utilizes the consignment contract than the case that the consignment is used at the upstream.

Forth, the consignment contract needs to contain the additional scheme to compensate some supply chain members' loss caused by the consignment. While the serial consignment system achieves the best performance for the whole supply chain system, the numerical analysis indicates that the manufacturer obtains less profit than he does at the traditional non-consignment system. Since the consignment, as one of the supply chain collaboration programs, can be sustained only with cooperation among all the supply chain members, the additional contract terms are necessary to fairly distribute the benefit from the consignment to all members and encourage their willingness to participate in the consignment.

Finally, supply chain members should jointly decide the proper consignment rates to achieve the best possible system performance. The numerical analysis shows that the serial consignment obtains the largest system profit when the consignment rate is set at the specific level between the minimum and maximum. In particular, the best system performance requires the proper combination of different consignment rates at the upstream and downstream of supply chain. By implication, all the consignment rates at both upstream and downstream of the supply chain need to be collectively determined with all the supply chain members' agreement to obtain the best possible outcome from the consignment.

6. Conclusion

The consignment has been used in diverse industries, and, as one of the supply chain collaboration programs, it has recently attracted heavy attentions from both business practitioners and researchers. Meanwhile, the consignment has been considered to be a contract maintained only between two business traders and most researchers evaluate its performance based on the dyadic relationship of supply chain members. This study examines the impact of consignment on the system performance in the supply chain system with more than two echelons.

In order to identify the true value of consignment as the supply chain collaboration initiative, this study formulates the supply chain models that include a manufacturer, a wholesaler, and a retailer, and conducts the numerical analysis on the mathematical models. Three different forms of consignment application are proposed depending on where the consignment is used in the supply chain system, and their economic performances are compared with the traditional non-consignment case.

The numerical examples show that the serial consignment system where the consignment is applied to both the upper level between the manufacturer and wholesaler and the lower level between the wholesaler and retailer obtains the greater system profit than the cases when the consignment is used at only one level as well as the non-consignment case. The lower consignment system where the consignment is used between the wholesaler and retailer achieves higher profit than the upper consignment system where the manufacturer and wholesaler have the consignment contract. The main reason that the serial consignment outperforms any other systems is the increased throughput in the entire supply chain system. The inventory-related cost saving due to the consignment contract enables the retailer to increase the market demand by reducing the retail price and the consequent enlarged sales revenue leads to increased profits for both the wholesaler and retailer. This result implies that the consignment would make its best outcomes when all the supply chain members involve in the consignment contracts. In addition, while most past studies focus on the cost saving as the benefit of the consignment, this study shows that the true benefit from consignment can be found to be the increased system profit.

The numerical analysis indicates that the serial consignment system achieve the best outcome for the entire supply chain system, but the manufacturer performs even worse than the non-consignment case. For realizing the supply chain collaboration by using the consignment in practices, the supply chain members should prepare the incentive scheme to compensate some members' economical loss due to the consignment contract and fairly distribute its benefit to all the members.

When the consignment is used in the whole supply chain system, the supply chain members should carefully determine the consignment rates to obtain the best performance. Since it is necessary to make the specific mix of distinct consignment rates at different levels of the supply chain system, even the supply chain members who do not belong to the same consignment contract need to agree on their consignment rates to realize the best possible outcome from the consignment.

The key contributions that this study makes for the industries and academia are twofold. First, this study points out the possibility that the consignment would improve the system performance by collaborating more than two members in the supply chain system. While many studies conduct research on the consignment, most of them rely on the simple contract made between two supply chain members. By investigating the consignment application in the three stage supply chain system, this study provides the theoretical background supporting that the consignment can be applied to more than two stages of the supply chain system and improve the system performance as a collaboration program for all the supply chain members rather than a mere conventional business contract made between two business traders.

Second, this study provides the practical administrative guideline about how the consignment should be used in the supply chain system. Even though the real supply chain system has more than two stages in many industries, most of the past studies evaluate the impact of consignment on the system performance under the supply chain system with only two stages. In three stage supply chain system, this study evaluates three different forms of consignment application in terms of their economic performances and provides the specific managerial implications about where and how the consignment needs to be applied to obtain the best possible outcome.

Some limitations can be founded in this study and they can be addressed as research issues by future studies. First, this study relies on the arbitrarily determined parameters for numerical analysis, and the outcomes from it may not accurately represent the realistic business situations. Future studies can use the real data collected from the case studies in their model analyses and achieve more practical outcomes that are helpful for the business practitioners. Second, the supply chain model proposed by this study has the deterministic demand function, and it may not sufficiently represent general market conditions for examining the consignment. By using the diverse stochastic demand patterns, future researchers can obtain more generalizable results about the consignment (Islam et al., 2017).

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