Effect of Trade Promotion in Centralized and Decentralized Supply Chain: Wholesale Price Experiment

Phattarasaya Tantiwattanakul and Aussadavut Dumrongsiri

***Abstract*—This research studies and compares behavior of centralized and decentralized supply chain. A two level supply chain with a single manufacturer supplying a single product to a single retailer is considered. The mathematical models were developed in centralized and decentralized to find the minimum cost in multiple time periods. The effects of demand quantity, parameter, and wholesale price on centralized and decentralized supply chain were explored. The numerical results show how the parameters affect supply chain performance. Moreover, we analyze the effect of trade promotion on decentralized supply chain. From the experiment, we can use trade promotion such as wholesale price discount to reduce the supply chain cost.**

***Index Terms*—Centralized and decentralized supply chain, trade promotion, wholesale price.**

I. Introduction

Supply chain management plays an important role for any firms to reduce their operation cost and enhance their competitive advantage. Supply chain members cannot compete as independent members. They depend on each other for resources and information [1], [2]. One of the major problems in managing supply chain networks is the lack of collaboration among the different entities including suppliers, manufacturers, warehouses, and retailers. Supply chain members have not make decision by considering entire supply chain network, and in addition they usually operate under different objective functions [3]. Decision making in a supply chain network can be performed in centralized or decentralized way. In centralized structure, there is a single decision maker who tries to optimize the overall supply chain, whereas in a decentralized structure the individual supply chain members can make their own decisions. In practice no supply chain can be completely centralized or decentralized and both approaches have their advantages and disadvantages [4], [5].

There are relatively many papers in different supply chain problem that using centralized and decentralized optimization strategies providing a comparison of these two approaches. Reference [6] presented three cases studies; linear programming, mixed integer linear programming, and stochastic supply chain where centralized and decentralized optimization is applied and qualitative results are given. Reference [7] studied multi-item replenishment problem in a two-echelon supply chain. Both centralized and decentralized decision models were proposed to determine the best solution to minimize costs. From the result, a centralized replenishment policy is superior to the decentralized replenishment policy in terms of cost reduction, especially when setup costs were high. Reference [8] developed centralized and decentralized models for a capacitated supply chain inventory system. The interactions between capacity constraint, control strategy, and demand were analyzed. Moreover, they evaluate the supply chain performance in more details from different angles to provide some useful managerial insights. Reference [9] modeled a 2-stage supply chain consisted of multiple suppliers and a manufacturer with limited production capacities as a queuing system. They developed both decentralized and centralized capacitated supply chains models and examined three different transfer payment contracts for the coordination of the supply chain. Their study focuses on the supplier side. Reference [10] investigated the decentralized operation of a capacitated supplier-retailer supply chain using stationary base stock policies for inventory control. They focus on understanding the causes of the inefficiency in the decentralized system and then study a set of simple linear contracts for improve the efficiency of decentralized system.

Mostly researches show that centralized supply chain is more efficient than decentralized supply chain. There are many studies to improve the efficiency of decentralized supply chain. Supply chain members can coordinate by using contracts for better management of supplier buyer relationship and risk management. Reference [11] developed a two period contract model for a two-echelon assembly system. They show that contract operating under a decentralized control mode can be coordinated by adjusting both wholesale and buyback prices. Reference [12] presented the coordination of purchasing and production functions in three-level supply chain. They show decentralized supply chain gives same results as centralized supply chain if quantity discounts are considered at both upstream and downstream interfaces. Moreover, trade promotion can be used as the manufacturer's tools to maximize company's profit. Reference [13] stated that trade promotions constitute a growing category of manufacturer incentives directed to channel members and wholesale and retail distributors rather than to consumers. A manufacturer can use trade promotion to motivate retailers to increase the order size. For example, manufacturer offer wholesale price discount to retailer to change ordering decision that can make manufacturer have increasing profit. Reference [14] analyzed the options available to a buyer and developed profit functions for different combinations of sales period and replenishment time and present optimal ordering policies. In this paper they

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relaxed the constant demand assumption made in most studies of inventory systems with price changes. The paper also presents a procedure to include any relationship between price and demand to determine the combined optimal price and optimal order quantity. Reference [15] analyzed the impacts of price promotions on profit levels in a two-stage supply chain consist of supplier and retailer. They considered how promotions affect forward buying and increased consumption from brand switchers. Even though, trade promotion leads to the bullwhip effect but the benefits of promotions can outweigh the negative operations cost impacts.

In this paper, we study and compare the behavior of supply chain in centralized and decentralized. The mathematical models were developed to find the minimum total supply chain cost in multiple time periods. The effects of demand quantity, parameters, and trade promotion on centralized and decentralized supply chain were explored. This paper is organized as follows: Section II describes the assumption and notation. Mathematical models were formulated both centralized and decentralized in Section III and IV. Section V presents the numerical analysis. Section VI and VII summarize the conclusion and further research, respectively.

II. Assumptions and Notation

A. Assumptions

We consider a two stage supply chain that consists of a single manufacturer and a single retailer. The assumptions are summarized as follows:

- Manufacturer produces single product.
- Demand of each period is independent and known.
- Replenishment lead time is zero.
- The initial inventory level is zero.
- Inventory holding cost is known and constant.
- Transportation cost is included in the wholesale price.

B. Notation

Parameters:

T	Set of time period $\{1,...,T\}$
p	Production cost per unit
Sc	Production setup cost
Rc	Fixed reorder cost
w	Wholesale price
h_r	Inventory holding cost per period at retailer
h_{wh}	Inventory holding cost per period at warehouse

Variables:

X_t	Production quantity in period t
$Pr_t = 1$	if product is produced by manufacturer in period t; 0 otherwise.
Q_t	Quantity of product ordered by retailer in period t
$Or_t = 1$	if product is ordered by retailer in period t; 0 otherwise
Iwh_t	Inventory at warehouse at the end of period t
Ir_t	Inventory at retailer at the end of period t
D_t	Retailer's demand in period t

III. Centralized Model

The model is formulated under consideration that manufacturer and retailer belong to the same enterprise. Centralized decisions are made to minimize the overall supply chain cost that consists of production cost, setup cost, reorder cost, and inventory holding cost at both manufacturer and retailer.

Minimize Total Supply Chain Cost Z_{SC}

$$= \sum_{t=1}^{T} p \times X_t + \sum_{t=1}^{T} Sc \times Pr_t + \sum_{t=1}^{T} Rc \times Or_t + \sum_{t=1}^{T} h_{wh} \times Iwh_t + \sum_{t=1}^{T} h_r \times Ir_t$$

Subject to

$$Iwh_t = Iwh_{t-1} + X_t - Q_t \qquad \forall\ t \in T$$
$$Ir_t = Ir_{t-1} + Q_t - D_t \qquad \forall\ t \in T$$
$$Iwh_0 = Iwh_T = Ir_0 = Ir_T = 0$$
$$X_t \le \mathrm{Pr}_t \times M \qquad \forall\ t \in T$$
$$Q_t \le Or_t \times M \qquad \forall\ t \in T$$
$$Iwh_t, Ir_t, X_t, Q_t, D_t \ge 0 \qquad \forall\ t \in T$$
$$Pr_t, Or_t \in \{0,1\} \qquad \forall\ t \in T$$

IV. Decentralized Model

In decentralized, supply chain members are treated as individual company. They make their decisions based on their local information independently and aim to minimize their own cost regardless of the system cost. We develop two linear mathematical models. The first model optimizes the production plan of manufacturer and the second model optimizes the ordering plan of retailer.

A. Manufacturer Model

The objective of manufacturer model is to minimize manufacturer cost that consist of production cost, and inventory holding cost at warehouse minus the revenue from selling product.

Minimize Manufacturer Cost Z_m

$$= \sum_{t=1}^{T} p \times X_t + \sum_{t=1}^{T} Sc \times Pr_t + \sum_{t=1}^{T} h_{wh} \times Iwh_t - \sum_{t=1}^{T} w_t \times Q_t$$

Subject to

$$Iwh_t = Iwh_{t-1} + X_t - Q_t \qquad \forall\ t \in T$$
$$Iwh_0 = Iwh_T = 0$$
$$X_t \le Pr_t \times M \qquad \forall\ t \in T$$
$$Iwh_t, X_t, Q_t \ge 0 \qquad \forall\ t \in T$$
$$Pr_t \in \{0,1\} \qquad \forall\ t \in T$$

B. Retailer Model

The objective of retailer model is to minimize retailer cost that consist of product cost (wholesale price), reorder cost, and inventory holding cost at retailer.

Minimize Retailer Cost Z_r

$$= \sum_{t=1}^{T} w_t \times Q_t + \sum_{t=1}^{T} h_r \times Ir_t + \sum_{t=1}^{T} Rc \times Or_t$$

Subject to

$$Ir_t = Ir_{t-1} + Q_t - D_t \qquad \forall\, t \in T$$
$$Ir_0 = Ir_T = 0$$
$$Q_t \le Or_t \times M \qquad \forall\, t \in T$$
$$Ir_t, Q_t, D_t \ge 0 \qquad \forall\, t \in T$$
$$Or_t \in \{0,1\} \qquad \forall\, t \in T$$

V. Numerical Analysis

We consider the operating in 8 periods. Parameter values and demand used in the example are provided in Table I.

TABLE I: Parameter Values and Demand

	Values
Setup cost	1000
Reorder cost	500
Inventory holding cost at:	
- Warehouse	2
- Retailer	5
Production cost per unit	10
Wholesale price	20
Retailer's demand (units)	{100, 110, 55, 50, 80, 120, 65, 40}

A. Centralized VS Decentralized Results

The optimal decision of centralized supply chain shows in Table II. Manufacturer produced product in period 1 and 5. Product was ordered by retailer in period 1, 2, 5, and 6. This decision makes supply chain have total cost equal to 12,580.

TABLE II: Optimal Decision of Centralized Model

	Time period							
	1	2	3	4	5	6	7	8
Produced quantity	**315**	0	0	0	**305**	0	0	0
W/H's inventory	215	0	0	0	225	0	0	0
Ordered quantity	**100**	**215**	0	0	**80**	**225**	0	0
Retailer's inventory	0	105	50	0	0	105	40	0
Retailer's demand	100	110	55	50	80	120	65	40

Table III shows the optimal decision of decentralized retailer and manufacturer. Retailer ordered product in period 1, 2, 4, 6, and 7. The ordering decision of retailer causes manufacturer produced product in period 1 and 6. This decision makes supply chain have total cost equal to 12,895.

TABLE III: Optimal Decision of Decentralized Model

	Time period							
	1	2	3	4	5	6	7	8
Produced quantity	**395**	0	0	0	0	**225**	0	0
W/H's inventory	295	130	130	0	0	105	0	0
Ordered quantity	**100**	**165**	0	**130**	0	**120**	**105**	0
Retailer's inventory	0	55	0	80	0	0	40	0
Retailer's demand	100	110	55	50	80	120	65	40

From the results, we found that optimal decision of decentralized retailer is different from centralized. Retailer has order product frequently in decentralized model. The changing of retailer's ordering periods cause the produced periods of manufacturer changed. Fig. 1 shows total supply chain cost in centralized is lower than decentralized. The centralized manufacturer has lower cost than decentralized while centralized retailer has a little bit higher cost than decentralized. So, we can conclude that the performance of centralized supply chain is better than decentralized supply chain.

Fig. 1. Cost comparison between centralized and decentralized.

B. Demand Analysis

We study the effect of demand quantity on supply chain cost. The different average demands in 8 periods were used in this analysis. The result shows total supply chain cost of centralized model is lower than decentralized model for all average demand. Fig. 2 shows the increasing of average demand causes the increasing of supply chain cost but percentage of delta cost between centralized and decentralized is decrease. That means the centralized model has high performance than decentralized model especially in low average demand.

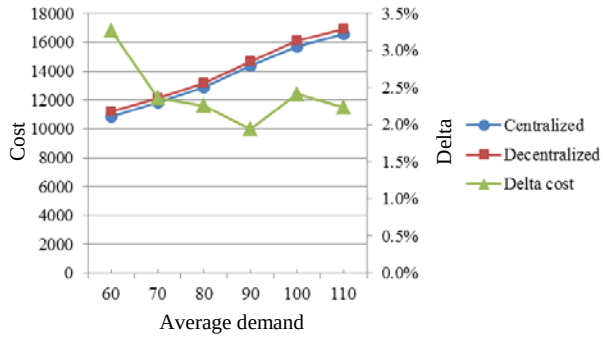


Fig. 2. Supply Chain Cost with difference average demand.

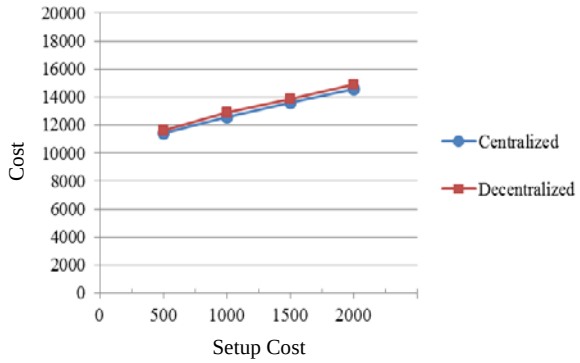
C. Parameter Analysis

The effect of setup cost and reorder cost on centralized and decentralized model was analyzed. We use retailer's demand in Table I. We vary one parameter while others are constant. The values of parameter are listed in Table IV.

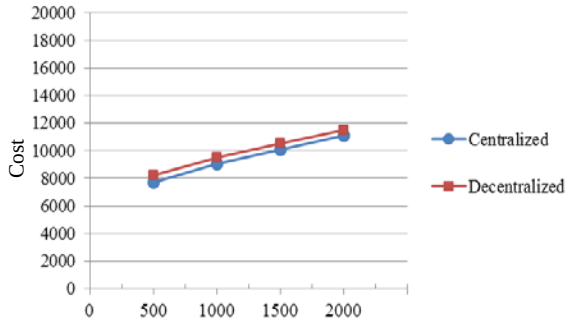
TABLE IV: Parameter Setting

Test Parameter	Values
Setup cost	500, 1000, 1500, 2000
Reorder cost	200, 600, 1000, 1400

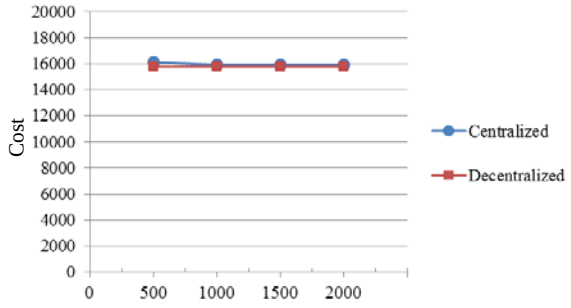
Fig. 3 shows the increasing of setup cost affect manufacturer's cost but has no affect to decentralized retailer's cost. Decentralized model have total supply chain cost higher than centralized model and the difference of cost is increase when setup cost increased.



(a) Total supply chain's cost.



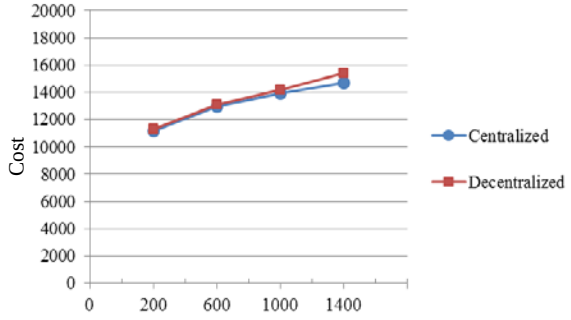
(b) Manufacturer's cost.



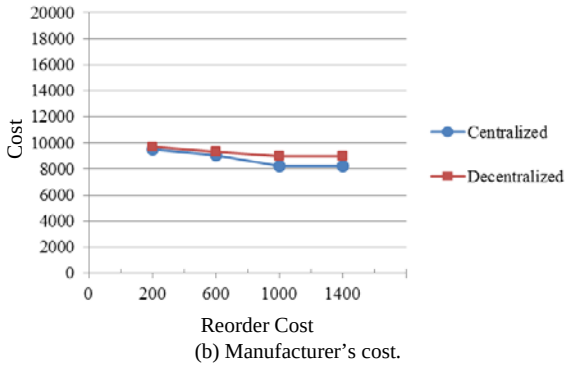
(c) Retailer's cost.

Fig. 3. Cost with difference setup cost.

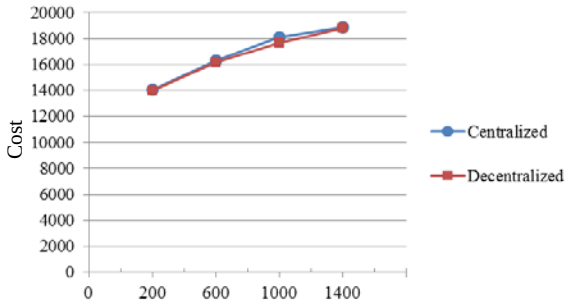
Fig. 4 shows the increasing of reorder cost affect retailer's decision. Retailer's costs increase correspond to reorder cost both centralized and decentralized model. The changed retailer's decision may affect to manufacturer's cost. Decentralized model have total supply chain cost higher than centralized model and the difference of cost is increase when reorder cost increased.



(a) Total supply chain's cost.



(b) Manufacturer's cost.



(c) Retailer's cost.

Fig. 4. Cost with difference reorder cost.

D. *Effect of Trade Promotion*

In this session, we analyze the effect of trade promotion on supply chain. Wholesale price discount is one of trade promotion technique. For example, manufacturer offer discount to induce retailer to increase order. In this experiment, we determine the set of wholesale price that called "controlled wholesale price". We analyze the decentralized supply chain by using controlled wholesale prices. How the optimal decision and total supply chain cost changed if manufacturer offers discount in some periods to retailer?

We use $w_t = \{20, 20, 21, 21, 18, 18, 20, 20\}$ as controlled wholesale price instead of constant wholesale price, then solve decentralized model. The optimal decision of decentralized model with controlled wholesale price shows in Table V. Both retailer and manufacturer make decision same as centralized model in Table II. Total supply chain cost equal to 12,580 that is lower than decentralized supply chain cost with constant wholesale price.

TABLE V: OPTIMAL DECISION OF DECENTRALIZED MODEL WITH CONTROLLED WHOLESALE PRICE

	Time period							
	1	2	3	4	5	6	7	8
Produced quantity	**315**	0	0	0	**305**	0	0	0
W/H's inventory	215	0	0	0	225	0	0	0
Ordered quantity	**100**	**215**	0	0	**80**	**225**	0	0
Retailer's inventory	0	105	50	0	0	105	40	0
Retailer's demand	100	110	55	50	80	120	65	40
Wholesale Price	20	20	**21**	**21**	**18**	**18**	20	20

From the experiment, retailer change decentralized ordering decision form period 1, 2, 4, 6, 7 (as shown in Table III) to be 1, 2, 5, and 6. That occurs because wholesale price is changed in some periods. Table VI shows cost comparison

of each model. The controlled wholesale price can help both decentralized manufacturer and retailer to reduce cost while total supply chain cost of decentralized model with controlled wholesale price is equal to centralized model. We call this situation is Pareto improvement.

TABLE VI: SUPPLY CHAIN COST COMPARISON

Model	Cost		
	Supply chain	Manufacturer	Retailer
Centralized	12,580	9,080	15,900
Decentralized with:			
- Constant wholesale price	12,895	9,520	15,775
- Controlled wholesale price	12,580	9,080	15,290

Next, we set experiment by using 5 sets of different demand and determine controlled wholesale price for each demand as shown in Table VII. Centralized and decentralized model were solved for optimal decision. Result shows in Table VIII.

TABLE VII: SET OF DEMAND AND CONTROLLED WHOLESALE PRICE

Demand	Controlled wholesale price
D1 = {100, 110, 55, 50, 80, 120, 65, 40}	{20, 20, 21, 21, 18, 18, 20, 20}
D2 = {60, 55, 45, 70, 55, 80, 65, 50}	{18, 20, 20, 20, 20, 18, 20, 20}
D3 = {80, 100, 55, 45, 70, 110, 55, 45}	{18, 20, 20, 20, 20, 18, 20, 20}
D4 = {100, 120, 60, 50, 80, 120, 70, 40}	{20, 18, 20, 20, 18, 18, 20, 20}
D5 = {95, 105, 90, 85, 80, 90, 100, 75}	{18, 20, 20, 20, 20, 20, 18, 20}

TABLE VIII: NUMERICAL RESULTS WITH DIFFERENT WHOLESALE PRICE

		Centralized	Decentralized w/Constant W	Decentralized w/Controlled W
D1:	Order period	1, 2, 5, 6	1, 2, 4, 6, 7	1, 2, 5, 6
	SC's cost	12580	12895	12580 (-2.5%)
	Mfr's cost	9080	9520	9080 (-4.8%)
	R's cost	15900	15775	15290 (-3.2%)
D2:	Order period	1, 4, 6	1, 2, 4, 6, 7	1, 4, 6
	SC's cost	10875	11230	10875 (-3.3%)
	Mfr's cost	7550	7980	7550 (-5.7%)
	R's cost	12925	12850	12215 (-2.5%)
D3:	Order period	1, 3, 5, 6	1, 2, 4, 6, 7	1, 3, 5, 6
	SC's cost	11870	12150	11870 (-2.4%)
	Mfr's cost	8420	8800	8420 (-4.5%)
	R's cost	14650	14550	13870 (-4.9%)
D4:	Order period	1, 2, 5, 6	1, 2, 4, 6, 7	1, 2, 5, 6
	SC's cost	12870	13160	12870 (-2.3%)
	Mfr's cost	9320	9760	9320 (-4.7%)
	R's cost	16350	16200	15270 (-6.1%)

TABLE VIII: NUMERICAL RESULTS WITH DIFFERENT WHOLESALE PRICE

		Centralized	Decentralized w/Constant W	Decentralized w/Controlled W
D5:	Order period	1, 3, 5, 7	1, 2, 4, 6, 7	1, 3, 5, 7
	SC's cost	14375	14655	14375 (-1.9%)
	Mfr's cost	10600	10930	10600 (-3.1%)
	R's cost	18175	18125	17425 (-4%)

As shown in Table VIII, the results in each case indicate that the controlled wholesale price can use for change optimal decentralized decision to be same as centralized and also reduce both manufacturer and retailer's cost in decentralized supply chain. The minus value in bracket shows percentage of cost reduction by using controlled wholesale price compare with decentralized model with constant wholesale price. The cost of decentralized supply chain was reduced by approximately 2.5%. From the experiment, manufacturer should induce retailer by offer discount in some period to achieve potential Pareto improvements.

From theory, trade promotions and other short-term discounts offered by a manufacturer result in forward buying, by which a retailer purchases large lots during the discounting period to cover demand during future periods. Forward buying results in large orders during the promotion period followed by very small orders after that. This situation causes the increasing of variability in supply chain that leads to bullwhip effect. Even though, wholesale price discount leads to the bullwhip effect but the benefit of short-term discount is better than using constant wholesale price. The numerical result shows using controlled wholesale price have lower supply chain cost than constant wholesale price. Trade promotion has better efficiency because retailer was forced to not frequently order. Therefore, manufacturer can reduce production period lead to setup cost deduction. So, total cost of supply chain was reduced.

VI. CONCLUSION

In this paper, we consider two stage supply chain that consist of one manufacturer and one retailer. The mathematical models are developed to find the minimum total cost of supply chain in multiple time periods for both centralized and decentralized model. The performance comparison of centralized and decentralized model was showed in numerical analysis. Total supply chain cost of decentralized model is higher than centralized model. Centralized model has high performance than decentralized model especially in low average demand, in high setup cost or reorder cost. Moreover, the effect of trade promotion was analyzed in the numerical. Controlled wholesale price was used instead of constant wholesale price in decentralized. We set the experiment that manufacturer offer discount in some period. The result shows retailer has changed ordering decision by order product in the discount periods that same as decision in centralized. So both manufacturer and retailer have lower cost. Even though the discount courses bullwhip effect, the benefit from trade promotion is better than using constant wholesale price.

VII. FURTHER RESEARCH

Since the un-unified of supply chain and supply chain members act as decentralized, so supply chain has low performance. If we want to improve the supply chain performance, we have to change optimal decision of members to be same as centralized. From the experiment, we found that the discount that manufacturer offer to retailer in

some periods can make retailer changed ordering decision. So, if we found the optimal wholesale price we can improver supply chain performance.

In the future research, we will study the coordination mechanisms that can improve supply chain performance. We propose to develop a model that can give us the optimal wholesale prices which can lead to minimum supply chain cost.

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