Impact of Wholesale Price Contracts in Two-echelon Supply Chains Under Production Disruptions

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Abstract

In this study, we analyze a two-echelon supply chain consisting of a manufacturer and a retailer operating in a monopolistic market under production disruptions due to pandemic workforce restrictions. In this work, the production disruptions occur at the manufacturer, which is transmitted to the retailer. The objective of this study is to analyze supply chain performance in uncoordinated and coordinated situations. Our results show that a coordinated situation, where coordination is achieved through a wholesale price contract, has a higher optimal order quantity compared to an uncoordinated situation.

Keywords
Production Disruption, Supply chain Coordination, Optimal Order quantity, Wholesale Price

Introduction
As the world moves through decades to centuries of development, it faces challenges, disasters, disruptions, and risks, and so do the modern world's supply chains (SC). Supply chains face many challenges and disruptions (Kapoor et al., 2021). Production disruptions are generally events that affect the manufacturing company processes. This paper mainly focuses on production disruptions due to pandemic workforce restrictions. The disruptions caused by the COVID -19 pandemic have caused major upheavals in manufacturing and have had serious impacts on production and its operations. (Cachon 2003) defines that a contract between two partners is called a *coordinating contract* if it ensures the maximization of the sum of the partners' profit in such a way that the total profit of a non-coordinated supply chain is equal to the profit of a supply chain with a single decision maker. We succeed in showing that coordination under disturbances can be achieved if the contracting parties agree on a wholesale price that lies between the calculated bounds.

Manufacturing has encountered significant disruptions on previous occasions.; natural disasters, trade wars, political risks, and other infectious diseases have already put the industry at risk (Okorie et al. 2020). Nevertheless, COVID - 19 precedes all as it wreaks havoc on the global economy (Handfield et al. 2020). For example, during the pandemic, industrial production in the United States experienced the sharpest monthly decline since World War II (Rapaccini et al., 2020); manufacturing in the United Kingdom is still experiencing massive economic shocks after years of impending Brexit and deindustrialization (Harris et al. 2020). Even before the pandemic, the manufacturing sector in 2019 was experiencing a global economic life of its own, which has now turned into a global economic crisis with COVID -19 (Teng et al. 2021). Despite past disasters, lessons have not been sufficiently learned for the manufacturing sector to successfully overcome the challenges of the pandemic (Handfield et al. 2020; Javaid et al.,2020). Manufacturers are constantly struggling with liquidity and profitability issues, and now COVID - 19 they are becoming even more vulnerable to economic shocks (Juergensen et al. 2020). Now, in the midst of an economic storm, manufacturing faces difficulties stemming from cancelled orders, weak revenues, and falling stock prices. In this study, we assume production disruptions at the manufacturer, which can spread to both the manufacturer and the retailer. Moreover, in this study, we attempt to model the disruption in two scenarios based on coordination and non-coordination.

1.1 Objectives
The objectives of our study are as follows.

1. Analyze supply chain performance in profit and order quantity in both uncoordinated and coordinated situations.

2. Develop wholesale price contracts for supply chain coordination.
3. Determine the expected profit and optimal order quantity for two-echelon supply chains.

2.Literature Review

With this said, many authors have tried to model the uncertainty in terms of demand (Chen and Xiao, 2013); they consider a supply chain consisting of one risk-neutral manufacturer and one lose-averse retailer and develop three models of ordering strategies' decisions. Through comparing the models, we can find that a second ordering opportunity can lead most better. (Vipin and Amit 2021) Their research studies the effect of behavioral issues in a supply chain with the risk-neutral supplier and behavioral retailer on the supply chain performance under wholesale price and buyback contracts. They investigate that wholesale price contracts can coordinate the supply chain and outperform than buyback (Zhang and Cheng 2005). This paper analyzes a supply chain model in which a single Supplier Sells a single product to a single retailer who faces a newsvendor problem where the retailer is loss averse.

The analysis shows that the optimal production quantity with decentralized decision-making with a wholesale price contract is less than that with centralized decision-making. (Cachon 2003) His paper discusses multiple contracts that achieve coordination and manage incentive disagreements. They investigate several varieties of supply chain contracts with coordination in detail.(Qi and Bard 2003) Their paper represents the first attempt to introduce demand disruptions in analyzing one Supplier and one retailer supply chain. A supply chain can be coordinated under certain wholesale Quantity discount policies. (Wang and Webster 2007)They analyzed a supply chain composed of a risk-neutral manufacturer selling a perishable product to a loss-averse retailer. They find that the independence between parameters and market demand breaks down in a buyback contract retailer is loss averse. They establish a GLB (Gain, Loss, Buyback) contracts, which sets the buyback credit to the value that would be offered in a buyback contract to a risk (Hoi and koo 2022). This study considers a two-stage neutral retailer supply chain consisting of a single supplier and a manufacturer with capacity cost-sharing contracts (Mei and Qian 2022) and examines the impact of adverting cooperation on the decisions of dual channel Supply chain consisting of a manufacturer and a retailer (Martin 2021). In his paper studies revenue-sharing contracts in a general supply chain model with revenues determined by Each retailer's purchase quantity and price (Wang and Lin 2021). This paper researches the effects of revenue-sharing contracts, direct channel price contracts and retail channel price discount contracts(Say and Lovejoy 2022). Analyses the quantity flexibility (QF) contract is a method for coordinating materials and information flows in supply chains operating under rolling planning (Zhao and Zhang 2022). They consider a supply chain Consisting of a manufacturer and a retailer, where the unit product cost is uncertain when the firms sign a procurement contract.

3.Methodology

The supply chain consists of a two-echelon supply chain having a manufacturer (M) and a retailer (R) where production disruptions occurred due to pandemic workforce restrictions. Let p represent the probability of normal functioning of the supply chain, s represents the selling price of the product, the manufacturing cost per unit m, order quantity Q. Cost of purchasing per unit C, the fraction of quantity ordered γ when production disruption occurred, (1- p) represents the probability that disruption will occur.

Quantity received by the retailer, $Q_{rec} = \begin{cases} Q, \text{with probability } p \\ \gamma Q, \text{with probability } 1-p \end{cases}$

Profit for retailer is represented by the equation
π_R = s×min (Q_{rec}, X) – cQ_{rec}

Assumption 1

It is assumed that selling price is greater than manufacturing cost $(\gamma s > m)$
Depending on the realization of demand, we have the following expression for profit for retailer

$$\pi_R = \begin{cases} sX - CQ \quad X \le Q \text{ with probability p} \\ sQ - CQ \quad X > Q \text{ with probability p} \\ sX - C\gamma Q \quad X \le \gamma Q \text{ with probability } 1 - \text{p} \\ s\gamma Q - C\gamma Q \quad X > \gamma Q \text{ with probability } 1 - \text{p} \end{cases}$$

Similarly, profit for Manufacturer

$$\pi_m = \begin{cases} CQ_{rec} - mQ_{rec} \text{with probability p} \\ C\,Q_{rec} - m\gamma Q_{rec} \text{with probability } 1 - \text{p} \end{cases}$$

We are considering integration and it is solved by integration by parts.finally we have,
Expected Profit function for retailer

$E(\pi_R) = pQ(s\text{-}C) - ps\int_0^Q F(x)dx + (1-p)[\gamma Q(s-C)] + (1-p)s\int_0^{\gamma Q} F(x)dx$

Expected profit function for manufacturer
$E(\pi_m) = CQ[(p+\gamma)(1\text{-}p)] - m\gamma Q$
We analyze two scenarios under this production disruptions;1.Non-coordination 2.coordination.

3.1 Non-coordination Scenario
In this scenario of non-coordination both the manufacturer and retailer would try to maximize their individual profits without considering the maximization of supply profit.

Assumption 2
It is assumed that X follows a uniform distribution between the limits 0 and D i.e., X ~uniform $[0, D]$
Decision of retailer is to maximize expected profit.
In this situation , wholesale price should not exceed the selling price of the product.

Maximize E (π_R)
s.t $Q \geq 0$
Differentiating the equation of profit for retailer with respect to Q
Upon solving the problem, we get $\hat{Q} = D\left(\frac{p+\gamma\,(1-p)}{p+\gamma^2\,(1-p)}\right)\left(\frac{s-c}{s}\right)$

$\hat{Q}$ = optimal order quantity under non coordination condition
Similarly decision of manufacturer is to maximize expected profit subject to the restriction that the wholesale price should not exceed the selling price of the product
Maximize E (π_m)
s.t $C \leq s$

Differentiating the equation for manufacturer with respect to C
Upon solving the problem, we get $\hat{c} = \frac{\gamma m}{2}\frac{1}{(p+\gamma(1-p))} + \frac{s}{2}$

Where $\hat{c}$ = optimal order quantity under non-coordination.

3.2 Coordination Situation
For coordination between manufacturer and retailer, the expected profit will be the sum of the individual expected profits of the manufacturer and the retailer.
For the first-order condition for optimality, we get

$$\frac{\partial(E(\pi_M)+(E(\pi_R))}{\partial Q} = 0$$

Upon solving the problem, we get

$$Q^* = D\frac{(p+\gamma(1-p))}{(p+\gamma 2(1-p))}\times(1-\frac{\gamma m}{s(p+\gamma(1-p))})$$

Where Q^* ⇒ optimal order quantity under coordination.

3.3 Conditions on Wholesale Price for Coordination
For the coordination to be possible, there should be exist a wholesale price $c*$ for manufacturer and retailer within bounds to maximizing profits . Let the condition $Q* > \hat{Q}$ which means optimal order quantity under coordination is larger than non-coordination situation.

Upon solving the problem, we get

$$C \leq \frac{3s}{8} + \frac{5m\gamma}{8(p+\gamma(1-p)} = C_H$$

Where c_H ⇒ higher bound wholesale price

$$C \geq \frac{3s}{8} + \frac{3m\gamma}{4(p+\gamma(1-p)} = C_L$$

Where $C_L \Rightarrow$ lower bound wholesale price

4. Implications

In this paper, we can derive bounds $[CL, CH]$ on wholesale price for which coordination for different partners. We compared the profits under the coordination and non-coordination situations and found that the optimal order quantity under coordination would always be larger than the optimal order quantity under non-coordination, where the wholesale price for which coordination was. From figure 1, we observe that under high disruption, a very small fraction of the quantity is supplied, and the manufacturer takes large wholesale prices to ensure coordination.

- Optimal order Quantity $\hat{Q}$ under non-coordination lies between the following bounds
  $F^{-1}(\frac{s-c}{s}) < Q^{\wedge} < \frac{1}{\gamma}\ F^{-1}(\frac{s-c}{s})$
- The retailer would agree to coordinate if the wholesale price would not exceed
  $\frac{3s}{8} + \frac{5m\gamma}{8(p+\gamma(1-p))} = C_H$
- The manufacturer would agree to coordinate if the wholesale price would exceed
  $\frac{3s}{8} + \frac{3m\gamma}{4(p+\gamma(1-p))} = C_L$
- C^* always exist $\forall$ p, $\gamma \in[0,1]$ and s, m>0, γs > mγ

5. Results

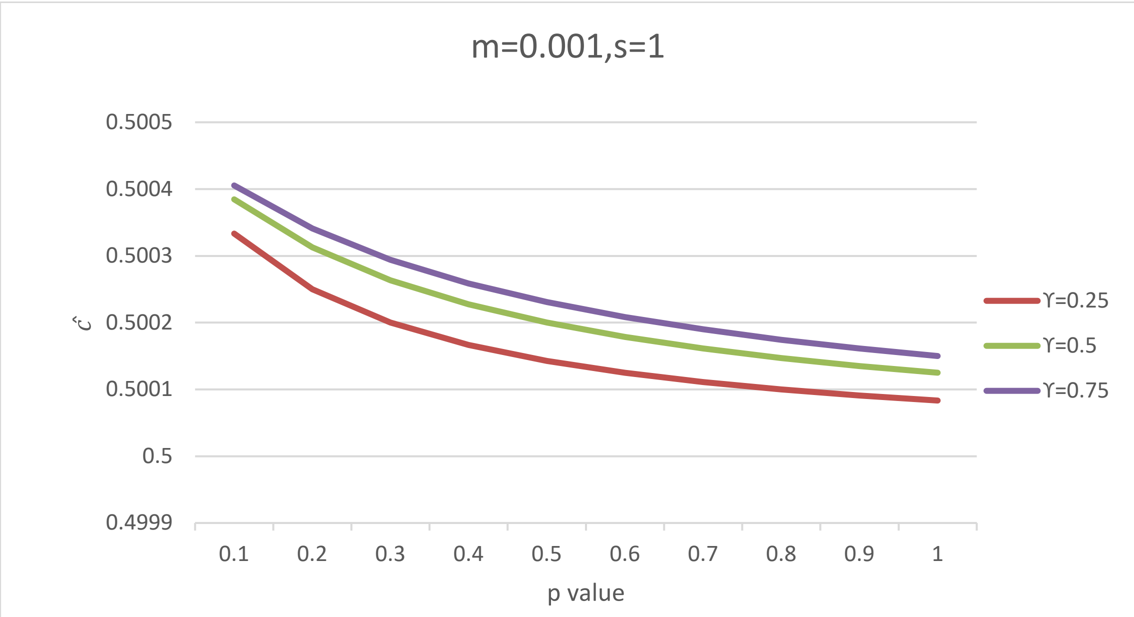

Fig 1. optimal order quantity under non-coordination

From this figure 1, We observe that under non coordination when disruption increases wholesale price also increases. This figure represents the optimal order quantity under non coordination.

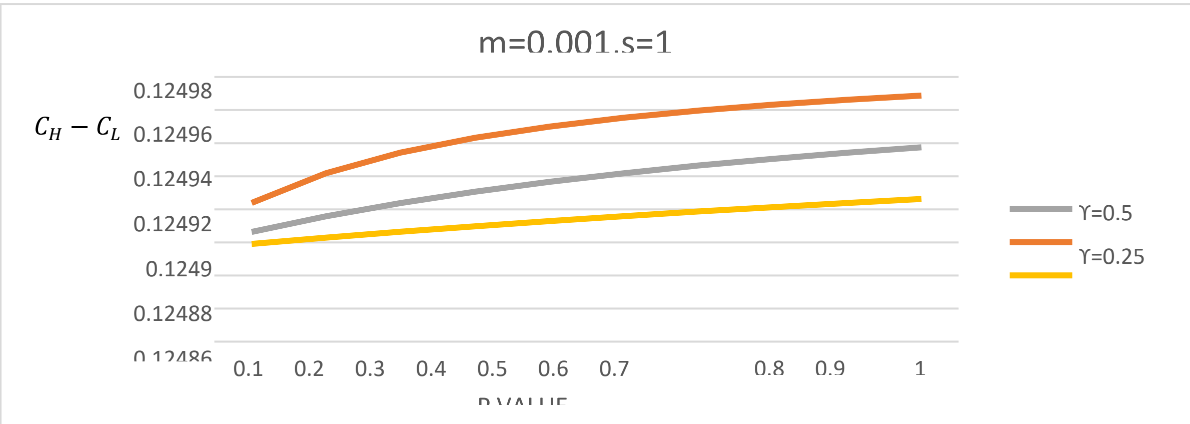

Figure 2. Under high impact disruption, a small quantity is supplied.

From Figure 2, we observe that under the high impact of disruption, i.e., γ=0.2, a very small fraction of quantity is supplied, and the manufacturer offers a larger range of possible wholesale prices to ensure coordination. This result is promising as it shows that even under disruption, a manufacturer and a retailer give themselves larger possibilities of agreeing on a price that does not harm their individual profits and ensures coordination between them. However, when the impact of disruption is low, i.e., γ= 0.9, almost all the quantity is supplied, the wholesale price contract holds strong by giving a smaller range of wholesale price to the SC partners to agree.

6. Conclusions and Future Research

This study ensures supply chain coordination using a wholesale price contract in a two-echelon supply chain with interruptions and fluctuating demand. In this analysis, order quantity is used as a decision variable, with a focus on determining a wholesale price in a no-coordination scenario and limits on the wholesale price in a coordination scenario to determine how intermittency is affected. In this study, a wholesale price contract was created, and it was shown that coordination could be achieved through this contract if the manufacturer and the retailer agree on a total sales price that falls between the calculated limits. It also compared the optimal order quantity and profits under coordinated and non-coordinated scenarios. The study concludes that the optimal order quantity under coordination is always larger than the optimal order quantity under non-coordination when the wholesale price that facilitates coordination is agreed upon. This study is limited to a two-stage serial supply chain. Future work may focus on incorporating multi-stage supply chains. This study does not include an actual case study to support its modelling. Future work may focus on the inclusion of a real enterprise supply chain.

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