DEVELOPMENT OF BUY-BACK AND OPTION CONTRACTS TO DEAL WITH PARTIAL SUPPLY DISRUPTION

by

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AUTHOR'S DECLARATION

I, Thongchai Shiesathanakun, declare that the research work carried out for this thesis was in accordance with the regulations of the Asian Institute of Technology. The work presented in it are my own and has been generated by me as the result of my own original research, and if external sources were used, such sources have been cited. It is original and has not been submitted to any other institution to obtain another degree or qualification. This is a true copy of the thesis, including final revisions.

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ABSTRACT

In this research, we study coordination mechanism by using supply contract between single retailer and dual suppliers. The profit functions of each member are developed under the presence of partial supply disruption. Specifically, concept of backup supplier is introduced to deal with the disrupted supplier in order to maximize the supply chain profit by using option contract. After developing the mathematical models, effect of the input parameters to the decision variables analyzed using MATLAB program. Furthermore, sensitivity analysis and coordination efficiency are conducted to examine the behavior of the profit functions and the effectiveness of the coordination of the supply chain.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

1.1. Background of the Study

The decision to build a supply chain network is the cornerstone of supply chain management, and it has a significant effect on the company's return on investment provides a competitive advantage (Zokaee et al., 2014; Farahani et al., 2014). Supply chain networks have been designed for years and are absolutely essential. It must be strong in dealing with uncertainty in the future. Tang (2006) distinguishes outsourcing risks to be the two principal categories. There is operational risk which represent daily operation in supply system and disruption risk. Operational risk arises from natural disruptions such as unpredictability of consumer demand, unpredictability of manufacturing capability, and unpredictability of purchasing costs. Severe incidents such as natural and man-made disasters, also including earthquakes, flooding, terrorist attacks, explosions, and so on, increase the risk of disruption.

In 2014, Esmaeilikia et al. provides a similar description and categorizes the risks of supply chains in the event of significant disruptions (frequent occurrence, but less detrimental) and demand/supply interruption. Excess supply and product shortage became important issues in management, which will reduce the profitability of the supply chain and affect the enthusiasm of the members of the supply chain. Therefore, reduce the impact of fluctuations and share the risk that members face in supply chains are important topics in supply chain management.

Many companies admit that they control just a minor element of the supply chain and lack coordination between them. As a result, they realize that collaboration between departments can lead to better efficiency for all partners in the supply chain. Supply chain coordination is a hot issue in research of supply chain management. Supply chain contracts are contractual arrangements that control costs and the sharing of products or services between individual supply chain participants. A well-drafted purchasing contract is an efficient way to exchange supply and demand uncertainties. It is generally acknowledged that coordination will help suppliers and retailers while also contributing to the improvement of the whole supply chain.

There are several well-known contract forms, such as repurchase, revenue sharing, volume flexibility, sales discounts, and volume discounts, demonstrate supply chain coordination. In this research, a study is conducted with two suppliers and one retailer experiencing supply disruption during the production phase. Two different contracts for the two suppliers that are able to coordinate the supply chain with supply disruptions will be utilized. The normal supplier who is under buy-back contract is the one who is subjected to disruption with low wholesale price, and the back-up supplier who is signed with option contract is the other one who is reliable but offers the higher price of product.

Even if a back-up supplier is used, coordination within the supply chain system is still needed to achieve greater profitability for all members of the supply chain. For many operational modifications performed by multiple companies, coordination plays a key role in contrast to pricing and effort models. Cachon (2003) studied coordination within the supply chain system that strong coordination is important in regulating downstream competition. It is also true that in almost all situations, a centralized system is more efficient than a decentralized system in terms of supply chain profitability (Chen et al., 2017).

The effect of interruption of supply can be improved through contractual agreements, and it is better for the retailer to have a long-term relationship with their suppliers. Contracting with suppliers can help buyers reserve capacity in advance to reduce ineffective costs. The use of the procurement contract is an incentive to the members involved. In addition, the centralized system makes everyone having more profit. It is necessary to mitigate risks within the supply chain by using supply contracts to achieve greater profits for members of the supply chain. The reason for the use of contract is to allow the decentralized system to work as if it was a centralized system. In other words, the procurement contract will encourage each member of the supply chain to maximize profits, which creates a mutually beneficial situation in which the members are willing to compromise.

In summary, the contracts can be used in the supply chain to help reduce the negative impact on the efficiency of the supply chain as a result of disruption in supply. The focus is on helping all members of the supply chain benefit from the coordination of the supply chain in the time of risk of disruption.

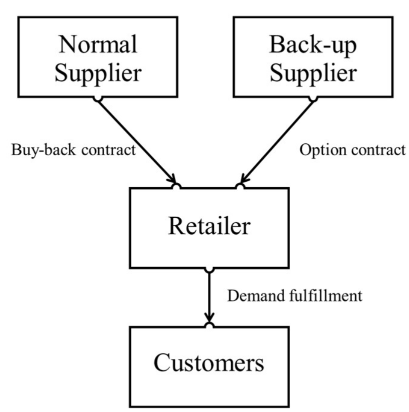
1.2. Statement of the Problem

In the past few years, a number of unforeseen events have occurred. In fact, it somehow has a negative impact on the performance of many industries. For examples, shortage and delay can lead to the lack in delivering process. As a consequence, the companies become more interested in bringing flexibility to their supply chain. Therefore, finding the reliable suppliers are the idea which can reduce the supply chain risks. However, better coordination between members is required to make the flexibility in the supply chain. Supply risk management and coordination mechanisms are the popular topics which are interested nowadays such as supply contracts that have recently grown in global markets (Hou & Zhao, 2012). However, most supply contract studies has concentrated on supply chains with perfect supply (Cachon, 2003). This is not always true. The market is often faced with unforeseen events and contributes to supply disruptions.

In this research, we address a coordinating mechanism to enhance supply chain performance. We mainly focus on the mitigating strategy of the retailer under supply disruption. The supply chain structure includes a retailer who is facing stochastic demand, a normal supplier who offer a cheaper wholesale price but he is prone to disruption, and a back-up supplier who offer a higher wholesale price but also very reliable. To investigate the impact of supply disruption under the supply contract arrangement, we mainly consider the supply chain contracts which are buy-back contract and option contract, as illustrated in Figure 1.1

Figure 1.1

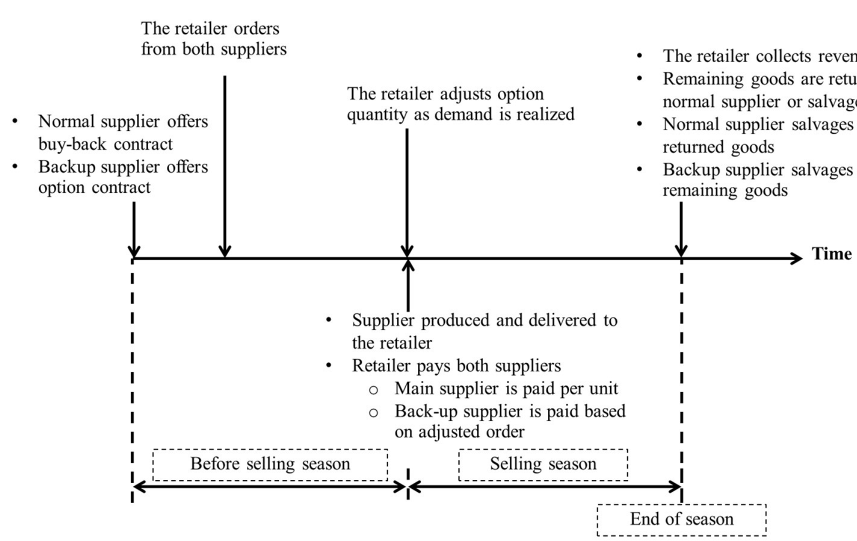
Supply Chain Structure



There is a chance that a supply disruption will occur with the probability P_d. For example, the normal supplier is unable to fulfill the promised order quantity of the retailer. When the normal supplier faces the supply disruption problem, a penalty cost per unit has to paid ordered quantity that cannot supplied to the retailer (Li et al., 2013). The supplier will sign the contracts with the back-up supplier who is the alternate option used to meet the requirement. Supposed that the back-up supplier is the perfect supplier who always available to deliver the retailer's order. When a supply disruption happens with the normal supplier, by using a special arrangement for supply, including option contract, the manufacturer shall transfer orders to the backup supplier. In this research, the aim is to study the best combination of parameters in the buy-back and option contracts in order to mitigate the effect of partial-supply disruption which normal can deliver some among of full initial order quantity to the retailer during disruption period. In this research, the single period problem will be considered for a product having short lifecycle. The general sequence of events in supply contract arrangement between the retailer and the both suppliers (i.e., normal supplier and back-up supplier) is shown in Figure 1-2 below.

Figure 1.2

The Sequence of Events within Supplier-Retailer Relation



In this research, supply disruption can exist in two forms: (a) failure due to a natural cause, and (b) failure due to a supplier. Supply disruption is described as the abrupt cessation of supply due to the occurrence of some unexpected events. As a result, the entire supply chain has been significantly impacted. In addition, based on the product's supply volatility, the normal supplier may be in two different states: (i) without supply disruption and (ii) with supply disruption. In the without supply disruption state, the normal suppliers can successfully supply the order quantity to the retailer on the promised time. On the other hand, in with supply disruption state of a normal supplier, limited capacity can be used to fulfil the order of the retailer. So, in our present study, supply disruption does not mean absolute failure to deliver the item to the retailer, but it means the supplier still can deliver some part of the whole order of the retailer. Back-up supplier is the alternative source to fulfill the demand and always available, but with higher wholesale price. Both suppliers are assumed to have the same product quality. The research question addressed in this paper is how the retailer can get the maximum profit under the occurrence of supply disruption at normal supplier.

1.3. Objectives of the Study

The objective of this research is to develop a contractual model for a supply chain with single-retailer and dual-suppliers, one normal supplier and one back-up supplier, by using two types of contract which are buy-back contract and option contract. The buy-back contract will be used for normal supplier while the option contract will be used for the back-up supplier.

1.4. Scope and Limitation

The following characteristics of the supply chain structure will be studied in the research;

- The supply chain structure is composed of a retailer from dual-supplier (i.e., one normal supplier and one back-up supplier).
- This research takes only a single selling period into account.
- Supply disruption occurs only at the normal supplier while the back-up supplier is always reliable.
- The retailer signs buy-back contract with normal supplier but signs option contract with back-up supplier.
- When supply disruption occurs, the supplier still can deliver some products to the retailer and this amount is a random variable.

CHAPTER 2
LITERATURE REVIEW

Supply chain disruption has been proven that it has both a short-term and long-term negative impact on company earnings and shareholder value. Companies are becoming more vulnerable to disruption risks as they extend their supply chains worldwide. Therefore, it is critical that they first analyze and comprehend these risks before developing solutions to mitigate their impacts. Certainly, proper design and implementation can play an important role in risk management and disruptions in various operational settings. In this direction, there has been an increase in the literature on the joint management of rewards and risk management over the last decade.

2.1. Supply Disruption Management

A big variety of products or services that are manufactured, delivered or stored in several locations are frequently included in supply chains. As a consequence, it adds to the difficulty in supply chain management. While management fights everyday risks including shortages and volatility, complexity may limit productivity, and it can increase the risk of disruption, as dependencies between goods can bring everything to a halt. Controlling complexity can result in better cost efficiency and lower risk, which is a win-win situation.

The topic of research on disruption management is a modern discipline in supply chain management studies, and researchers have been paying great attention in recent years. Parlar and Berkin (1991) conducted experimental work in the classical EOQ (economic order quantity) model on the supply interruption. Berk and Arreola-Risa (1994) then suggested a cost function that corrected Parlar and Berkin's cost function (1991). Similarly, Snyder (2005) suggested a basic but near approximation to the model proposed by Berk and Arreola-Risa (1994). Then, Yu et al. (2008) also proposed a dual-sourcing model for placing orders with inexpensive suppliers or costly efficient suppliers.

The most of the literature focusing on supply disruption consists of a single supplier. However, in today's dynamic market world, stock-outs or lost-sales situations can happen due to yield uncertainty, and this will create an opportunity for the other competitors. Therefore, in order to mitigate demand uncertainties, firms are now having one or more secondary sources on hand as an emergency source of supply. As a result, this back-up supplier leads to reducing the risk of stock-outs and mitigating the negative impacts of supply disruption. For example, in August 2005, when Hurricane Katrina struck the Gulf Coast of the United States, Wal-Mart was able to respond quickly to supply disruptions and mitigate the effects of supply shortages by using its backup sourcing strategy (Fortune Magazine, 2005). The March 2011 earthquake and tsunami in Japan is another relevant real-life case. The Japan disasters had impacted a lot of automotive products. Xirallic pigments is in particular one of the first car products to be influenced by this, the only plant in the world that makes them. The temporary shutdown of this plant impacted many of the world's automakers, including Ford, Chrysler, Volkswagen, BMW, Toyota, and GM (The Truth About Cars, 2011). Furthermore, as a result of the Japanese disasters, Toyota, the world's largest automaker, was knocked offline for months due to a lack of dual sourcing policy (Automotive News, 2016) and subsequently Toyota's January–March profit slid to 25.4 billion dollars from 112.2 billion dollar a year earlier (Associated Press, 2011). Recently on January 8, 2016, an explosion at Toyota supplier Aichi Steel Corporation caused it to suspend production at its Chita factory. As a result of this, Toyota, the world's largest automaker, is facing a steel shortage. However, by using the emergency backup sourcing strategy, Toyota was able to recover from its recall crisis in just 7 days (Reuters, 2016). As a result, it is normally valuable to buyers (e.g. retailer) to have more than one supplier of similar products to reduce the supply disruption risks. Chopra, Reinhardt, and Mohan (2007) investigated a two-supplier model of dual sourcing in the case of single period of both supply disruptions and yield uncertainty. many researchers suggest the same approach in their supply chain models to minimize supply disruption. In our present article, we also consider a related approach to mitigate the negative impacts of supply disruption.

Many existing researches efforts differ from each other in their definitions and points of view on supply chain risk and disruption. However, they all agree that one of the most critical questions about supply chain management is supply chain disruptions, and the most pressing challenge is to formulate the appropriate solutions for mitigating the effects of supply chain disruption. Since sourcing is closely linked to supply chain disruptions and may be used to mitigate disruption risks, analyzing and designing an effective sourcing approach in the presence of supply chain disruptions is becoming one of the hot topics in recent research efforts. The below table shows studies based on supply disruption management, and this mainly focus on dual-sourcing method.

Table 2.1

Recent Studies Based on Supply Disruption Management

Paper	Supply Chain Structure	Key finding
Yu et al., (2008)	Single retailer – Single supplier, Single retailer – Dual supplier	This research found that either single or dual sourcing can be efficient. However, the dual sourcing being preferable when the probability of disruption is high enough (normal supplier and back-up suppler sign wholesale price contract)
Jian Li et al., (2010)	Single retailer – Dual supplier	Absolute coordination is difficult to accomplish by wholesale-price-only contracts. When the two vendors cooperate, the net benefit of the whole supply chain is smaller than when they are competitive. This suggests that supplier coordination does not always result in supply chain efficiency. (normal supplier and back-up suppler sign wholesale price contract)
Konsue, (2018)	Single retailer – Dual supplier	The result show that dual sourcing is more profitable than single sourcing when normal supplier cannot deliver any products during supply disruptive period. (normal supplier signs buy-

Paper	Supply Chain Structure	Key finding
		back contract, and back-up suppler signs option contract)
Salgado, (2019)	Single retailer – Dual supplier	When the retailer orders from both vendors in order to increase his benefit, the model is most useful. (normal supplier signs quantity flexibility contract, and back-up suppler signs option contract)
Gangaw, (2019)	Single retailer – Dual supplier	Having a backup source in place while the main supplier is expected to experience supply disruption would benefit the retailer's profit as well as the whole supply chain's profit. (normal supplier signs buy-back contract, and back-up suppler signs option contract)
Tulika et al., (2019)	Single retailer – Dual supplier	In the face of supply disruption, even with lower disrupting probabilities, the manufacturer will still choose to take advantage of a back-up supplier, and the optimum reserve quantity of back-up supplier rises with disruption probabilities. However, the survey from companies show that suppliers tend to cooperate together wherever possible. (normal supplier signs buy-back contract, and back-up suppler signs option contract)

Paper	Supply Chain Structure	Key finding
Varun et al., (2020)	Single retailer – Dual supplier	If a disruption happens before orders are received, the supplier that is not disrupted will still charge the highest wholesale price. (normal supplier and back-up suppler sign wholesale price contract)

2.1.1 Partial Supply Disruption

Supply disruption is described as "disturbance or problems that interrupt an activity, event, or process" in the dictionary. Thus, a supply chain disruption is described as a breakdown in the distribution of products from manufacturing to consumers. In complex supply chain, there is a possible case that the main supplier cannot deliver the whole order quantity to the buyer, and the buyer also accepts the available quantity which can be shipped from his's supplier. This risk situation is called "Partial Supply Disruption". Supplier can't always ship an entire order at once, and he prefers to ship items separately to ensure they arrive on-time. To deal with a partial disruption case, it must be agreed upon by the specific contract agreement between retailer and supplier.

2.2. Contracts Agreement

In today's competitive supply chain, a manager must account for many supply chain risks while developing appropriate mitigation strategies. Many successful supply chains rely on coordination mechanisms. To maximize the competitive advantage, the companies needs to develop a matched system with its boundaries (Dyer & Singh, 1998). The key point to get the success in the supply chain management has to deal with complexity in the system. Contract flexibility is needed to improve processes in the face of changing market conditions. That is the coordination of individual firms. An inhibited mechanism can result from a lack of cooperation among all members. Lee et al. (1997) has shown that unorganized configuration in a system has impact to supply chain. Firstly, it can result in additional losses as a result of a lack of inventory. Additionally, it takes time, and transportation is costly. Moreover, the loss status would be serious, and customer service would be inefficient.

We know that many successful supply chains depend on coordination mechanisms. In principle, the structure of self-sufficient profit-maximizing companies (decentralized system) receives a lower profit than the integrated (centralized) system. However, in practice, a decentralized supply chain strategy in which each member of the chain is a decision maker is easy to implement, having different targets by achieving their own objectives, which could be conflicting and contribute to system inefficiency. As a result, only appropriate strategies for coordination will adjust the incentives of various channel stakeholders. Therefore, the supply chain's total profit is maximized. For an outstanding presentation and summary of coordination management, Lariviere (1999), Tsay, Nahmias, and Agarwal (1999) and Cachon (2003) are recommended to readers. Contract mechanisms can help to improve coordination in supply chain. Arshinder et al. has proposed the objectives of adopting contract in 2008, they are represented as follows;

1. To optimize the profitability of the total supply chain.
2. To minimizing inventory levels relative to total costs (i.e., inventory and storage).
3. To manage the risk-sharing between members of the supply chain.

Nowadays, there are various kinds of supply contract such as contracts which describe the way of revenue sharing between members (revenue sharing contracts), contracts provide more flexibility on order quantities (quantity flexibility contracts), contracts which offer a discount on order quantities (quantity discount contracts), contracts which agree on buy-backs (buy-back contracts) and option contract.

Most of the supply contracts in the previous classical studies has focused more on two-echelon supply chains and the smoot supply along the supply chain system (Cachon, 2003). by Xiao et al. (2010) has been studied the supply chain system includes buy-back policies. Donohue (2000) is the researcher who has studied the supply coordination in supply chain with buy-back contract and customizing forecast for demand info of the short-life products. Bernstein and Federgruen (2005) investigated the reliability behavior of a decentralized supply chain structure under uncertain demand in the consideration of two-echelon supply chains. They also design the contractual arrangements between members in the supply chain. Arcelus et al. (2008)

has revealed the coordination with in a single retailer and a single supplier when the demand is fluctuating.

Furthermore, as the global economy progresses and new technology is widely applied in today's market environment, the ways in which companies compete with each other become rivalry among channel members in supply chain management in supply chain management. Many researchers developed models that took into account either upstream competition (Cachon & Kok, 2010; Chakraborty, Chauhan, & Vidyarthi, 2015) or downstream competition (Cachon, 2003; Yao, Leung, & Lai, 2008). In 1996, Choi considered a model that takes into account both upstream and downstream competition.

2.3. Coordination Mechanism: Buy-back and Option Contract

We know that many successful supply chains depend on coordination mechanisms. In principle, the structure of self-sufficient profit-maximizing companies (decentralized system) receives a lower profit than the integrated (centralized) system. However, in practice, a decentralized supply chain strategy in which each member of the chain is a decision maker is easy to implement, having different targets by achieving their own objectives, which could be conflicting and contribute to system inefficiency. As a result, only appropriate strategies for coordination will adjust the incentives of various channel stakeholders. Therefore, the supply chain's total profit is maximized. For an outstanding presentation and summary of coordination management, Lariviere (1999), Tsay, Nahmias, and Agarwal (1999) and Cachon (2003) are recommended to readers. Contract mechanisms can help to improve coordination in supply chain. Price contracts or wholesale price (WP) contracts alone are used as a benchmark for assessing the anticipated contract performance. The retailers carry the full responsibility on all unsold units under a WP contract.

Over the years, numerous scholars have suggested different coordination structures for supply chain contracts, depending on the existence of the parameters of the supply chain. In our study, the buy-back and option contracts are considered for the coordination of our theoretical supply chain.

2.3.1 Buy-back Contract

Buy-back contract is one type of coordination mechanism for supply chain management. It is commonly used for businesses. In essence, a buyback deal is a credit back system in which manufacturers buy back unsold products from consumers at partial or full purchase prices. This system not only compensates suppliers for taking the risk of excess inventories, but it also protects suppliers' brands, especially when consumer demand for their goods is uncertain.

2.3.2 Option Contract

An option contract is one in which the retailer buys a certain number of products and has the option to change his order if appropriate. This ordered amount can be modified in any way (it can be larger or smaller than the original order) by ordering an option premium in advance from the supplier. This paper investigates the situation of an option contract in which prices remain stable but the retailer is required to pay an option premium to the supplier.

2.4. Review of Previous Studies Conducted on Supply Contract Agreement under Supply Disruption

With the widespread use of contracts in the supply chains, the study of contracts and design problems in the supply chain management is very interesting, and many studies have led to a number of solutions to the issues involved in the past few years. Despite the abundance of literature, modern research is imperative in the face of new issues that are changing with developments in the manufacturing environment. The previous studies as research shows below are mainly focus on effective of supply chain when a retailer has contracts with retailers.

Yu et al. (2008) investigates the complexities of sourcing decisions in the face of supply chain disruptions. The probability of disruption lead to effectiveness of single sourcing vs dual sourcing. The dual sourcing was preferred when the probability of supply disruption is high enough.

Jian Li et al. (2010) examine a retailer's procurement policy and the price practices of two vendors in a supply chain in the face of supply disruption. The two suppliers have signed wholesale price contract with the supplier. One of both suppliers which is called main supplier has lower unit price than other one but he subjects to disruption. They discovered that using wholesale-price-only contracts makes it impossible to reach maximum cooperation. The net benefit of the whole supply chain is smaller when the two vendors cooperate than when they compete. This suggests that supplier coordination does not always result in supply chain efficiency.

Konsue (2018) studied the supply chain disruption with single retailer and dual supplier. Under existing disruptions to supply, the profit functions of any member of the supply chain are established. Furthermore, the idea of supply disruption is adopted in order to increase the overall profit of the supply chain. The retailer signs an option contract with the supplier, and the normal supplier signs buy-back contract. The result shows that dual-sourcing is more profitable than single-sourcing when normal supplier cannot deliver any products during supply disruption period.

Tulika et al. (2019) consider a supply chain structure of two suppliers and one retailer supply chain, and the demand pattern is price-dependent stochastic demand with suppliers that are susceptible to disruption. The findings show that in the presence of a supply disruption, even though the probability is poor, the manufacturer will still choose to take advantage of a back-up supplier, and the optimum reserve amount of a back-up supplier increases with the probability of the disruption. However, the survey from companies show that suppliers would always prefer to cooperate with each other (normal supplier signs buy-back contract, and back-up suppler signs option contract).

Salgado (2019) have develop the mathematical model of this system was derived in order to determine optimal order quantities the retailer should place to the two suppliers in order to maximize a retailer profit. During disruption period, a normal supplier is signed with option contract, and back-up supplier is signed with quantity flexibility contract. The findings show that the model is the most efficient way to maximize his benefit when retailer order all suppliers.

Gangaw (2019) study a mechanism to deal with supply disruption in a supply chain with single supplier and dual retailers by use of two different types of supply contract (i.e., buy-back contract and range contract). In the examined supply chain, the buy-back contract is signed with a normal supplier who is subjected to disruption, and the range contract is signed with a back-up supplier who is reliable but offers the product at higher price. The findings indicate that the provider is in a system when supply disruptions are expected to occur to the main provider, the retailer's earnings and the total profit of the supply chain would rise.

Varun et al. (2020) conduct conducts an observational analysis to investigate the impact of production capability interruption timing on price decisions for replacement goods in a two-supplier with one-retailer. They found that price leadership affects the quantity of orders from the disturbed supplier and seems to increase when the non-disrupted supplier is the leader. If a disruption happens before orders are received, the non-disrupted provider will still charge the highest wholesale price. This emphasizes the importance of order timing. The findings will assist operations management in properly designing risk avoidance ordering plans and redesigning procurement contracts in the event of product replacement due to supply disruptions.

Table 2.2

Supply Contract Agreement under Supply Disruption

Author	Demand form	Supply Contracts	Controlled factors	Supply chain structure
Yu et al., (2008)	Stochastic	Wholesale price contract	Order quantity, Wholesale price, Demand price, Penalty cost	Single retailer – Single supplier, and Single retailer – Dual supplier
Jian Li et al., (2010)	Stochastic	Wholesale price contract	Order quantity, Wholesale price, Delivery cost, Demand price, Penalty cost	Single retailer – Single supplier,
Konsue, (2018)	Stochastic	Buy-back and Option contract	Order quantity, Unit prices, Salvage value, Penalty cost, Demand price	Single retailer – Dual supplier
Salgado, (2019)	Stochastic	Option and Quantity	Order quantity, Unit prices,	Single retailer – Dual supplier

Author	Demand form	Supply Contracts	Controlled factors	Supply chain structure
		flexibility contracts	Penalty cost, Demand price	
Gangaw, (2019)	Stochastic	Buy-back contract and Bidirectional option contract	Order quantity, Unit prices, Salvage value, Penalty cost	Single retailer – Dual supplier
Tulika et al., (2019)	Stochastic	Buy-back and Option contract	Order quantity, Unit prices, Salvage value, Penalty cost, Demand price	Single retailer – Multiple supplier
Varun et al., (2020)	Deterministic	Wholesale price contract	Order quantity, Unit prices, Penalty cost, Demand price, Supply capacity	Single retailer – Dual supplier

The exciting studies have studied the different combination of the contracts between retailers and suppliers to deal with supply disruption. The dual sourcing is preferable when the probability of disruption is high enough (Yu et al., 2008). Konsue (2018) have shown that when a supplier has signed two different types of supply, using the combination of buy-back and option contract has very high coordination efficiency (on average 99.61%). However, he only focuses on simple situation of the disrupted supplier. When disruption occur with the main supplier, the supplier completely cannot deliver any product to the retailer. Penalty costs have been paid by disrupted supplier because of late or shortage deliveries. It is a huge loss which has to be reduced. Supply chain model can become complexity because of decisions from suppliers. The supplier who face with the supply problems will try to reduce the loss of his advantages. In this study, we will develop the mathematical model for single retailer – dual sourcing to meet with the actual situation that the disrupted supplier still has a probability to deliver some products when supply disruption occurs.

CHAPTER 3
MATHEMATICAL MODEL DEVELOPMENT

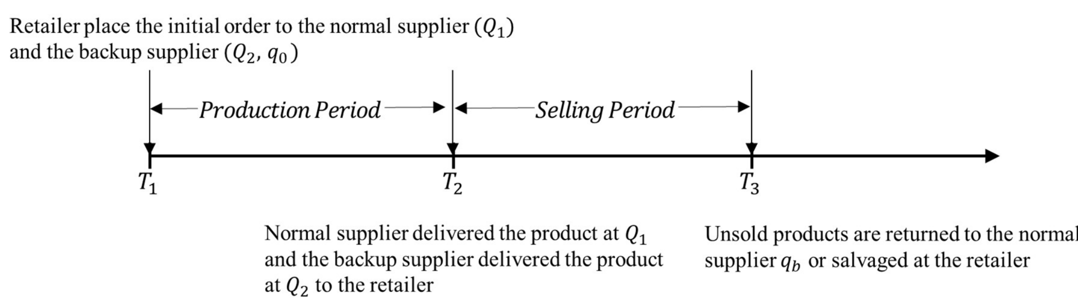
3.1 Notations and Assumptions

In this chapter, the problem cases will be derived to be the mathematical model based on the following assumptions. This research considers a single period problem in supply chain. The retailer has dual-sourcing. First supplier is call main supplier who has low product cost but less reliable, and the other supplier is call back-up supplier who is more expensive than the normal supplier but perfectly reliable. However, we suppose that the both suppliers produce the same product quality.

The general sequence of the retailer-suppliers decision in single period problem is designed as figure below:

Figure 3.1

The Sequence of Events of Retailer-Suppliers Decision



In the situation that without the occurrence of supply disruption, the retailer orders the initial quantity Q_1 to the normal supplier by using buy-back contract with the wholesale price w. Unsold products which cannot be sale at the end of selling period can be returned to the normal supplier. The retailer can transfer unsold quantity up to the full amount Q_1 with the buy-back price b.

Moreover, the supplier also places the order to the back-up supplier by using option contract. At time T_1 (beginning of production period), the retailer orders the initial quantity Q_2 to the back-up supplier with the wholesale price w'. Additionally, the supplier can order the option quantity q_o with the unit price w_{ep} for put option and w_{ec}

for call option at this point of times. At the time T_2 (beginning of selling period), the profit functions are analyzed based on the actual demand, the retailer has two options to places the additional order to the back-up supplier. They are call option and put option. If the call option is presented, the retailer has to pay w_{ec} for each exercised quantity up to the full quantity q_o. On the other hand, if the put option is presented, the retailer can transfer back with w_{ep} for each exercised quantity up to the full of quantity q_o.

However, the normal supplier has the probability that the partial-supply disruption will occur with the probability P_d. It means that the normal supplier is unable to deliver the full product among due to the supply disruption, and thus the retailer increases in the initial order quantity (Q_2) from the back-up supplier. We also assume that demand pattern is a random variable which can be derive as distribution function $F(.)$ and density function $f(x)$.

There are two periods of horizontal time which are production period and selling period;

At the beginning of production period (T_1), retailer orders to the normal supplier with initial quantity (Q_1), and he also order to the back-up supplier with initial quantity (Q_2). The retailer can order more using put/call option quantities (q_o) to the back-up supplier in advance. It helps the supply chain more flexibility when disrupted-supplier presents. After that, all suppliers decide on the output quantity and deliver products to the retailer depending on the order quantity placed by the retailer.

At the beginning of selling period (T_2), the retailer's decision to place the order quantities is based on the normal supplier's supply disruption situation and the actual demand. The retailer may decide to return unsold units (q_b) to the normal supplier and/or exercises the option quantities (q_e) to the back-up supplier. If the normal supplier faces partial-supply disruption occurs, the retailer will order the exercised option quantity to back-up supplier because the normal supplier cannot provide the full initial order quantity (Q_1).

However, it should be mentioned that the mathematical model develop throughout this research is subject to $w_{ep} < b < w_{ec}$ which indicates that unsold units should always be returned to the normal supplier.

To define the models, the notations described below will be used in this research.

Q_1	=	Initial order quantity to the normal supplier
Q_2	=	Initial order quantity to the back-up supplier
$Q_1{}'$	=	Delivered order quantity from the normal supplier
q_o	=	Option quantity
q_b	=	Buy-back quantity
w	=	Wholesale price of the normal supplier
w'	=	Wholesale price of the back-up supplier
r_p	=	Retail price
b	=	Buy-back price
w_o	=	Unit option premium price
w_{ep}	=	Unit put option price
w_{ec}	=	Unit call option price
s	=	Unit shortage cost
v	=	Salvage value
c_1	=	Production cost per unit of the normal supplier
c_2	=	Production cost per unit of the back-up supplier
p	=	Penalty cost per unit of the normal supplier
P_d	=	Probability of supply disruption
$1 - P_d$	=	Probability of no supply disruption
R	=	Ratio between the delivered order quantity $Q_1{}'$ and initial order quantity Q_1
$f_X(.)$	=	Probability density function (p.d.f.) of average demand X
$F_X(.)$	=	Cumulative density function (c.d.f.) of average demand X
$f_{\frac{D}{x}}(.)$	=	Conditional probability density function of demand given the average demand $X = x$
$F_{\frac{D}{x}}(.)$	=	Conditional cumulative density function of demand given the average demand $X = x$

In this research, we consider that the demand is randomness which is considered to follow uniform distribution. At the beginning of the selling season, demand (x) follows uniform distribution over the range [γ - n, γ + n]. It is also assumed that $\gamma > n + m$ to ensure that the demand always positive.

$$f_X(x) = \frac{1}{2n}, x \in [\gamma - n, \gamma + n],$$

$$F_x(x) = \frac{1}{2n}(x - \gamma - n), x \in [\gamma - n, \gamma + n],$$

3.2 Without Supply Disruption Situation

Since the normal supplier who signs the buy-back contract allows the retailer to return the unsold product and pays the retailer with buy-back price b per remaining unit at the end of selling season. In addition, the back-up supplier who signs the option contract allows the retailer to adjust the exercised quantity after demand quantity is actual. Therefore, the profit functions can be derived as following states.

1) Profit Function of Each Member at First Stage (T_1)

In the "no supply disruption" case, the retailer orders from both suppliers with initial orders Q_1 and Q_2. The following equations are the profit functions of each member of the supply chain.

- The retailer's profit function = -Initial purchasing cost from the normal supplier – Initial purchasing cost from the back-up supplier – Purchasing cost for option quantity

$$\pi_r^{T_1}(Q_1, Q_2, q_o) = -Q_1 w - Q_2 w' - q_o w_o$$

- The normal supplier's profit function = Revenue from the initial order quantity - Production cost of the normal supplier

$$\pi_{S1}^{T_1}(Q_1, Q_2, q_o) = Q_1(w - c_1)$$

- The back-up supplier's profit function = Revenue from the initial order quantity - Production cost of the back-up supplier

$$\pi_{S2}^{T_1}(Q_1, Q_2, q_o) = (Q_2 w' + q_o w_o) - (Q_2 + q_o)c_2$$

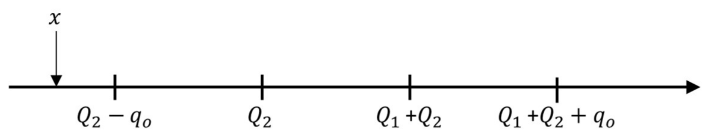
2) Profit Function of Each Member at Second Stage (T_2)

As the demand (x) is actual during this time, the retailer decides the buy-back quantity (q_b) and the exercised option quantity (q_e). Based on the actual demand, there are five scenarios need to be considered. They can be examined separately in the following cases:

Case I: $x < Q_2 - q_o$

Figure 3.2

Actual Demand is less than $Q_2 - q_o$



x is less than $Q_2 - q_o$ in this scenario. As a result, the retailer will transfer the unsold unit back to the normal supplier with the full buy-back quantity $q_b = Q_1$, and exercise the maximum put option, and then, he can receive full refunds of option quantity $q_e = -q_o$. The excess inventory is faced at both suppliers and retailer which can be sold as salvage.

• The retailer's profit function = Revenue from selling products + Income from buy-back quantity + Income from exercised put option + Salvage value

$$\pi_r^{T_2}(Q_1, Q_2, q_b, q_o, q_e) = x(r_p) + Q_1 b + w_{ep} q_o + v(Q_2 - q_o - x)$$

• The normal supplier's profit function = - Cost of buy back quantity + Salvage value

$$\pi_{S1}^{T_2}(Q_1, Q_2, q_b, q_o, q_e) = -Q_1 b + vQ_1$$

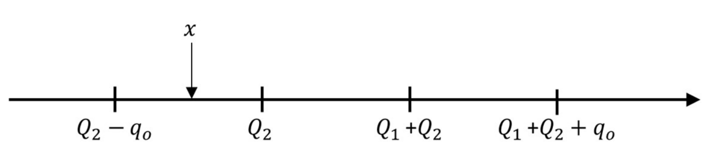
• The back-up supplier's profit function = - Cost of exercised put option + Salvage value

$$\pi_{S2}^{T_2}(Q_1, Q_2, q_b, q_o, q_e) = -w_{ep} q_o + v(2q_o)$$

Case II: $Q_2 - q_o < x < Q_2$

Figure 3.3

Actual Demand is between $Q_2 - q_o$ *and* Q_2



In this scenario, the actual demand is greater than or equal to $Q_2 - q_o$ but it is also less than Q_2. As a result, the retailer will transfer the unsold product back to the normal supplier at full buy-back quantity $q_b = Q_1$, and exercise put option at quantity $q_e = -(Q_2 - x)$. The excess inventory is faced at both suppliers which can be sold as salvage.

- The retailer's profit function = Revenue from selling products + Income from buy back quantity + Income from exercised put option

$$\pi_r^{T_2}(Q_1, Q_2, q_b, q_o, q_e) = x(r_p) + Q_1 b + w_{ep}(Q_2 - x)$$

- The normal supplier's profit function = - Cost of buy back quantity + Salvage value

$$\pi_{S1}^{T_2}(Q_1, Q_2, q_b, q_o, q_e) = -Q_1 b + vQ_1$$

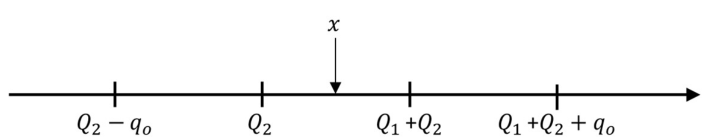
- The back-up supplier's profit function = - Cost of exercised put option + Salvage value

$$\pi_{S2}^{T_2}(Q_1, Q_2, q_b, q_o, q_e) = -w_{ep}(Q_2 - x) + v(Q_2 + q_o - x)$$

Case III: $Q_2 \leq x \leq Q_1 + Q_2$

Figure 3.4

Actual Demand is between Q_2 *and* $Q_1 + Q_2$



In this scenario, the actual demand is greater than or equal to Q_2 but it is also less than $Q_1 + Q_2$. As a result, the retailer will transfer the unsold product back to the normal supplier at quantity $q_b = Q_1 + Q_2 - x$. However, the retailer no need to order the exercise option quantity from back-up supplier ($q_e = 0$), because only initial orders from both suppliers are sufficient to meet demand. Therefore, there is no excess inventory for the retailer.

- The retailer's profit function = Revenue from selling products + Income from buy-back quantity

$$\pi_r^{T_2}(Q_1, Q_2, q_b, q_o, q_e) = x(r_p) + (Q_1 + Q_2 - x)b$$

•	The normal supplier's profit function = - Cost of buy back quantity + Salvage value

$$\pi_{S1}^{T_2}(Q_1, Q_2, q_b, q_o, q_e) = -(Q_1 + Q_2 - \mathrm{x})b + v(Q_1 + Q_2 - \mathrm{x})$$

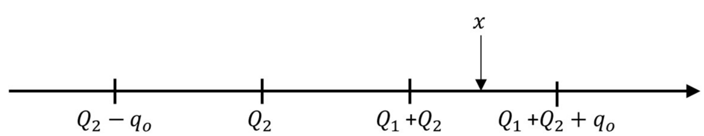
•	The back-up supplier's profit function = Salvage value

$$\pi_{S2}^{T_2}(Q_1, Q_2, q_b, q_o, q_e) = v(q_o)$$

Case IV: $Q_1 + Q_2 \leq x \leq Q_1 + Q_2 + q_o$

Figure 3.5

Actual Demand is between $Q_1 + Q_2$ *and* $Q_1 + Q_2 + q_o$



In this scenario, the actual demand is greater than or equal to $Q_1 + Q_2$ but it is also still less than $Q_1 + Q_2 + q_o$. As a result, the retailer will not transfer the unsold product back to the normal supplier since the demand is greater than the total initial orders and thus, q_b=0. In addition, the retailer must exercise call option at a quality $q_e = x - (Q_1 + Q_2)$. Therefore, there is no excess inventory for retailer.

•	The retailer's profit function = Revenue from selling products - Cost of exercised call option quantity

$$\pi_r^{T_2}(Q_1, Q_2, q_b, q_o, q_e) = x(r_p) - w_{ec}(x - (Q_1 + Q_2))$$

•	The normal supplier's profit function = 0

$$\pi_{S1}^{T_2}(Q_1, Q_2, q_b, q_o, q_e) = 0$$

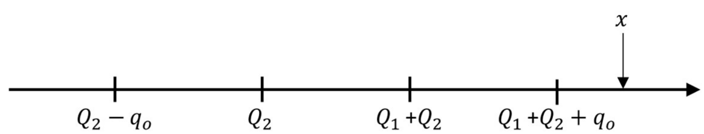
•	The back-up supplier's profit function = Income from exercised call option + Salvage value

$$\pi_{S2}^{T_2}(Q_1, Q_2, q_b, q_o, q_e) = w_{ec}(x - (Q_1 + Q_2)) + v\{q_o - [x - (Q_1 + Q_2)]\}$$

Case V: $x > Q_1 + Q_2 + q_o$

Figure 3.6

Actual Demand is greater than $Q_1 + Q_2 + q_o$



In this scenario, the actual demand is greater than $Q_1 + Q_2 + q_o$. As a result, the retailer will not transfer any product back to the normal supplier $q_b = 0$. In addition, the retailer must exercise call option quantity as full quantity $q_e = q_o$. Since demand is more than $Q_1 + Q_2 + q_o$, the retailer must pay the penalty cost due to the shortage quantity presents in this case.

- The retailer's profit function = Revenue from selling products - Cost of exercised call option quantity - Shortage cost

$$\pi_r^{T_2}(Q_1, Q_2, q_b, q_o, q_e) = (Q_1 + Q_2 + q_o)(r_p) - w_{ec}q_o$$
$$-s\big(x - (Q_1 + Q_2 + q_o)\big)$$

- The normal supplier's profit function = 0

$$\pi_{S1}^{T_2}(Q_1, Q_2, q_b, q_o, q_e) = 0$$

- The back-up supplier's profit function = Income from exercised maximum call option

$$\pi_{S2}^{T_2}(Q_1, Q_2, q_b, q_o, q_e) = w_{ec}q_o$$

3.2.1 The Full Expressions for Profits of All Members

The addition of profit in the first stage and the expected profit in the second stage generates the full expressions for profits of all stakeholders of the no-disruption situation. To cope with stochastic demand, the demand is supposed to be uniformly distributed all over the range $[\gamma - n, \gamma + n]$. In details, we have:

- Retailer's profit function

The retailer's expected profit can be derived as follows.

$\pi_R^N(Q_1, Q_2, q_o) =$ Profit function at first stage + Expected profit function at second stage

$$\pi_R^N(Q_1, Q_2, q_o) = [-Q_1 w - Q_2 w' - q_o w_o] + E\left[\pi_r^{T_2}(Q_1, Q_2, q_b, q_o, q_e)\right]$$

The expression of retailer's profit function in the second stage with no disruption can be determined as:

$$\begin{aligned}E\left[\pi_r^{T_2}(Q_1, Q_2, q_b, q_o, q_e)\right] = &\int_{\gamma-n}^{Q_2-q_o} \pi_r^{T_2}(Q_1, Q_2, q_b, q_o, q_e) f(x)dx \\ &+ \int_{Q_2-q_o}^{Q_2} \pi_r^{T_2}(Q_1, Q_2, q_b, q_o, q_e) f(x)dx \\ &+ \int_{Q_2}^{Q_1+Q_2} \pi_r^{T_2}(Q_1, Q_2, q_b, q_o, q_e) f(x)dx \\ &+ \int_{Q_1+Q_2}^{Q_1+Q_2+q_o} \pi_r^{T_2}(Q_1, Q_2, q_b, q_o, q_e) f(x)dx \\ &+ \int_{Q_1+Q_2+q_o}^{\gamma+n} \pi_r^{T_2}(Q_1, Q_2, q_b, q_o, q_e) f(x)dx\end{aligned}$$

The detailed expression of the retailer's expected profit function can then be derived as:

$$\begin{aligned}\pi_R^N(Q_1, Q_2, q_o) = &[-Q_1 w - Q_2 w' - q_o w_o] \\ &+ \left\{\frac{1}{2n}\left[\left[r_p \frac{(Q_2 - q_o)^2}{2} - r_p \frac{(\gamma - n)^2}{2}\right] + [Q_1 b(Q_2 - q_o) - Q_1 b(\gamma - n)]\right.\right. \\ &+ \left[w_{ep} q_o (Q_2 - q_o) - w_{ep} q_o (\gamma - n)\right] \\ &+ \left[v\left(Q_2(Q_2 - q_o) - q_o(Q_2 - q_o) - \frac{(Q_2 - q_o)^2}{2}\right)\right. \\ &\left.\left.\left. - v\left(Q_2(\gamma - n) - q_o(\gamma - n) - \frac{(\gamma - n)^2}{2}\right)\right]\right]\right\} \\ &+ \left\{\frac{1}{2n}\left[\left[r_p \frac{(Q_2)^2}{2} - r_p \frac{(Q_2 - q_o)^2}{2}\right] + [Q_1 b(Q_2) - Q_1 b(Q_2 - q_o)]\right.\right. \\ &+ \left[\left(w_{ep} Q_2 (Q_2) - w_{ep} \frac{(Q_2)^2}{2}\right)\right. \\ &\left.\left.\left. - \left(w_{ep} Q_2 (Q_2 - q_o) - w_{ep} \frac{(Q_2 - q_o)^2}{2}\right)\right]\right]\right\}\end{aligned}$$

$$+\left\{\frac{1}{2n}\left[\left[r_p\frac{(Q_1+Q_2)^2}{2}-r_p\frac{(Q_2)^2}{2}\right]\right.\right.$$

$$+\left[\left(bQ_1(Q_1+Q_2)+bQ_2(Q_1+Q_2)-b\frac{(Q_1+Q_2)^2}{2}\right)\right.$$

$$\left.\left.\left.-\left(bQ_1(Q_2)+bQ_2(Q_2)-b\frac{(Q_2)^2}{2}\right)\right]\right]\right\}$$

$$+\left\{\frac{1}{2n}\left[\left[r_p\frac{(Q_1+Q_2+q_o)^2}{2}-r_p\frac{(Q_1+Q_2)}{2}\right]\right.\right.$$

$$-\left[\left(w_{ec}\frac{(Q_1+Q_2+q_o)^2}{2}-w_{ec}Q_1(Q_1+Q_2+q_o)\right.\right.$$

$$\left.-w_{ec}Q_2(Q_1+Q_2+q_o)\right)$$

$$-\left(w_{ec}\frac{(Q_1+Q_2)^2}{2}-w_{ec}Q_1(Q_1+Q_2)\right.$$

$$\left.\left.\left.\left.-w_{ec}Q_2(Q_1+Q_2)\right)\right]\right]\right\}$$

$$+\left\{\frac{1}{2n}\left[\left[\left(Q_1r_p(\gamma+n)+Q_2r_p(\gamma+n)+q_or_p(\gamma+n)\right)\right.\right.\right.$$

$$-\left(Q_1r_p(Q_1+Q_2+q_o)+Q_2r_p(Q_1+Q_2+q_o)\right.$$

$$\left.\left.+q_or_p(Q_1+Q_2+q_o)\right)\right]$$

$$-[w_{ec}q_o(\gamma+n)-w_{ec}q_o(Q_1+Q_2+q_o)]$$

$$-\left[\left(s\frac{(\gamma+n)^2}{2}-sQ_1(\gamma+n)-sQ_2(\gamma+n)-sq_o(\gamma+n)\right)\right.$$

$$-\left(s\frac{(Q_1+Q_2+q_o)^2}{2}-sQ_1'(Q_1+Q_2+q_o)\right.$$

$$\left.\left.\left.\left.-sQ_2(Q_1+Q_2+q_o)-sq_o(Q_1+Q_2+q_o)\right)\right]\right]\right\}$$

After simplifying.

$$\pi_R^N(Q_1, Q_2, q_o)$$

$$= [-Q_1 w - Q_2 w' - q_o w_o]$$

$$+ \left\{\frac{1}{2n}\left[\left[\frac{(\gamma-n)^2}{2}(v - r_p) + (\gamma - n)(vq_o - vQ_2 - w_{ep} - Q_1 b)\right]\right.\right.$$

$$+ \left[\frac{(Q_2 - q_o)^2}{2}(v - w_{ep})\right] + \left[\frac{(Q_2)^2}{2}(w_{eb} + b)\right] + \left[\frac{(Q_1 + Q_2)^2}{2}(b + w_{ec})\right]$$

$$+ \left[\frac{(Q_1 + Q_2 + q_o)^2}{2}(r_p - w_{ec} + s)\right.$$

$$+ (Q_1 + Q_2 + q_o)\Big(Q_1(w_{ec} - r_p - s) + Q_2(-w_{ec} - r_p - s)$$

$$\left. + q_o(r_p + w_{ec} - s)\Big)\right]$$

$$+ \left[\frac{(\gamma + n)^2}{2}(s)\right.$$

$$\left.\left.\left. + (\gamma + n)\Big(Q_1(r_p + s) + Q_2(r_p + s) + q_o(r_p - w_{ec} + s)\Big)\right]\right]\right\}$$

• Normal supplier's profit function

$\pi_{S_1}^N(Q_1, Q_2, q_o)$ = Profit function at first stage + Expected profit function at second stage

$$\pi_{S_1}^N(Q_1, Q_2, q_o) = [Q_1(w - c_1)] + E\left[\pi_{S_1}^{T_2}(Q_1, Q_2, q_b, q_o, q_e)\right]$$

The expression of normal supplier's profit function in the second stage with no disruption can be determined as:

$$E\left[\pi_{S_1}^{T_2}(Q_1, Q_2, q_b, q_o, q_e)\right] = \int_{\gamma-n}^{Q_2-q_o} \pi_{S_1}^{T_2}(Q_1, Q_2, q_b, q_o, q_e) f(x)dx$$

$$+ \int_{Q_2-q_o}^{Q_2} \pi_{S_1}^{T_2}(Q_1, Q_2, q_b, q_o, q_e) f(x)dx$$

$$+ \int_{Q_2}^{Q_1+Q_2} \pi_{S_1}^{T_2}(Q_1, Q_2, q_b, q_o, q_e) f(x)dx$$

$$+ \int_{Q_1+Q_2}^{Q_1+Q_2+q_o} \pi_{S_1}^{T_2}(Q_1, Q_2, q_b, q_o, q_e) f(x)dx$$

$$+ \int_{Q_1+Q_2+q_o}^{\gamma+n} \pi_{S_1}^{T_2}(Q_1, Q_2, q_b, q_o, q_e) f(x)dx$$

The detailed expression of the normal supplier's expected profit function can then be derived as:

$$\pi_{S_1}^{N}(Q_1, Q_2, q_o) = [Q_1(w - c_1)]$$
$$+\left\{\frac{1}{2n}\left[\left[\left(-Q_1 b(Q_2 - q_o) + Q_1 b(\gamma - n)\right)\right] + [vQ_1(Q_2 - q_o) - vQ_1(\gamma - n)]\right]\right\}$$
$$+\left\{\frac{1}{2n}\left[[-Q_1 b(Q_2) + Q_1 b(Q_2 - q_o)] + [vQ_1(Q_2) + vQ_1(Q_2 - q_o)]\right]\right\}$$
$$+\left\{\frac{1}{2n}\left[\left[\left(-bQ_1(Q_1 + Q_2) - bQ_2(Q_1 + Q_2) + b\frac{(Q_1 + Q_2)^2}{2}\right) - \left(-bQ_1(Q_2) - bQ_2(Q_2) + b\frac{(Q_2)^2}{2}\right)\right] + \left[\left(vQ_1(Q_1 + Q_2) + vQ_2(Q_1 + Q_2) - v\frac{(Q_1 + Q_2)^2}{2}\right) - \left(vQ_1(Q_2) + vQ_2(Q_2) - v\frac{(Q_2)^2}{2}\right)\right]\right]\right\}$$
$$+\left\{\frac{1}{2n}[0]\right\}$$
$$+\left\{\frac{1}{2n}[0]\right\}$$

After simplifying.

$$\pi_{S_1}^{N}(Q_1, Q_2, q_o) = [Q_1(w - c_1)]$$
$$+\left\{\frac{1}{2n}\left[\left[(\gamma - n)\left(Q_1(b - v)\right)\right] + [(Q_2 - q_o)(0)] + \left[\frac{(Q_2)^2}{2}(b - v)\right] + \left[\frac{(Q_1 + Q_2)^2}{2}(v - b)\right]\right]\right\}$$

• Back-up supplier's profit function

$\pi_{S_2}^{N}(Q_1, Q_2, q_o)$ = Profit function at first stage + Expected profit function at second stage

$$\pi_{S_2}^{N}(Q_1, Q_2, q_o) = [(Q_2 w' + q_o w_o) - (Q_2 + q_o)c_2] + E\left[\pi_{S_1}^{T_2}(Q_1, Q_2, q_b, q_o, q_e)\right]$$

The expression of back-up supplier's profit function in the second stage with no disruption can be determined as:

$$E\left[\pi_{S_2}^{T_2}(Q_1,Q_2,q_b,q_o,q_e)\right] = \int_{\gamma-n}^{Q_2-q_o} \pi_{S_2}^{T_2}(Q_1,Q_2,q_b,q_o,q_e)f(x)dx$$

$$+\int_{Q_2-q_o}^{Q_2} \pi_{S_2}^{T_2}(Q_1,Q_2,q_b,q_o,q_e)f(x)dx$$

$$+\int_{Q_2}^{Q_1+Q_2} \pi_{S_2}^{T_2}(Q_1,Q_2,q_b,q_o,q_e)f(x)dx$$

$$+\int_{Q_1+Q_2}^{Q_1+Q_2+q_o} \pi_{S_2}^{T_2}(Q_1,Q_2,q_b,q_o,q_e)f(x)dx$$

$$+\int_{Q_1+Q_2+q_o}^{\gamma+n} \pi_{S_2}^{T_2}(Q_1,Q_2,q_b,q_o,q_e)f(x)dx$$

The detailed expression of the back-up supplier's expected profit function can then be derived as:

$$\pi_{S_2}^{N}(Q_1,Q_2,q_o) = \left[(Q_2w' + q_ow_o) - (Q_2+q_o)c_2\right]$$

$$+\left\{\frac{1}{2n}\left[\left(-w_{ep}q_o(Q_2-q_o) + 2vq_o(Q_2-q_o)\right) - \left(-w_{ep}(\gamma-n) + 2vq_o(\gamma-n)\right)\right]\right\}$$

$$+\left\{\frac{1}{2n}\left[\left[\left(-w_{ep}Q_2(Q_2) + w_{ep}\frac{(Q_2)^2}{2}\right) - \left(-w_{ep}Q_2(Q_2-q_o) + w_{ep}\frac{(Q_2-q_o)^2}{2}\right)\right] + \left[\left(vQ_2(Q_2) + vq_o(Q_2) - v\frac{(Q_2)^2}{2}\right) - \left(vQ_2(Q_2-q_o) + vq_o(Q_2-q_o) - v\frac{(Q_2-q_o)^2}{2}\right)\right]\right]\right\}$$

$$+\left\{\frac{1}{2n}\left[vq_o(Q_1+Q_2) - vq_o(Q_2)\right]\right\}$$

$$+\left\{\frac{1}{2n}\left[\left[\left(w_{ec}\frac{(Q_1+Q_2+q_o)^2}{2}-w_{ec}Q_1(Q_1+Q_2+q_o)\right.\right.\right.\right.$$

$$\left.-w_{ec}Q_2(Q_1+Q_2+q_o)\right)$$

$$-\left(w_{ec}\frac{(Q_1+Q_2)^2}{2}-w_{ec}Q_1(Q_1+Q_2)\right.$$

$$\left.\left.-w_{ec}Q_2(Q_1+Q_2)\right)\right]$$

$$+\left[\left(vq_o(Q_1+Q_2+q_o)-v\frac{(Q_1+Q_2+q_o)^2}{2}\right.\right.$$

$$\left.+vQ_1(Q_1+Q_2+q_o)+vQ_2(Q_1+Q_2+q_o)\right)$$

$$-\left(vq_o(Q_1+Q_2)-v\frac{(Q_1+Q_2)^2}{2}+vQ_1(Q_1+Q_2)\right.$$

$$\left.\left.\left.\left.+vQ_2(Q_1+Q_2)\right)\right]\right]\right\}$$

$$+\left\{\frac{1}{2n}[w_{ec}q_o(\gamma+n)-w_{ec}(Q_1+Q_2+q_o)]\right\}$$

After simplifying

$$\pi_{S_2}^N(Q_1,Q_2,q_o)=\ [(Q_2w'+q_ow_o)-(Q_2+q_o)c_2]$$

$$+\left\{\frac{1}{2n}\left[[(\gamma-n)(w_{ep}-2vq_o)]+[(Q_2-q_o)^2(w_{ep})]+\left[\frac{(Q_2)^2}{2}(v-w_{ep})\right]\right.\right.$$

$$+\left[\frac{(Q_1+Q_2)^2}{2}(v-w_{ec})+(Q_1+Q_2)\big(Q_1(w_{ec}-v)-Q_2(w_{ec}+v)\big)\right]$$

$$+\left[\frac{(Q_1+Q_2+q_o)^2}{2}(w_{ec}-v)\right.$$

$$\left.+(Q_1+Q_2+q_o)\big((v-w_{ec})(Q_1+Q_2)+vq_o-w_{ec}\big)\right]$$

$$\left.\left.+[(\gamma+n)(w_{ec}q_o)]\right]\right\}$$

3.3 With Partial Supply Disruption Situation

Since a supply disruption presents, it impacts the normal supplier's production. As a result, the retailer would not obtain the quantity (Q_1) from them. However, when disruption occurs, the supplier still can deliver some product quantity ($Q_1{}'$) to the retailer. The percentage of full order quantity that the supplier can deliver to the retailer is $R_{Q_1'}$, and it can be modeled by a random variable taking value in the range [0,1]. Thus, the amount of quantity which the normal supplier will deliver to the retailer is $Q_1' = Q_1(R)$. It's noted that $Q_1 > Q_1'$. Due to disruption period, the normal supplier must pay the penalty cost p per unit to retailer. Consequently, the normal supplier's profit function in the first stage is $-Q_1'c_1 + Q_1(w) - (Q_1 - Q_1')(p)$. It should be remembered that $p > w$. After the market demand is realized, the retailer determines the amount of exercise option quantity (q_e) which it is appropriate quantity to order from the back-up supplier. However, it is determined by the actual demand and the reserve quantity. Given that the partial supply disruption has presented at the normal supplier, the profit functions can be derived as follows:

1) Profit Function at First Stage (T_1)

In "partial supply disruption" situation, the profit functions of each stakeholder can be derived as following equations:

- The retailer's profit function = - Initial purchasing cost from the normal supplier - Initial purchasing cost from the back-up supplier - Purchasing cost for option quantity + Penalty cost from the normal supplier

$$\pi_r^{T_1}(Q_1, Q_1', Q_2, q_o) = -Q_1 w - Q_2 w' - q_o w_o + (Q_1 - Q_1')p$$

- The normal supplier's profit function = Revenue from the committed order quantity - Production cost - Penalty cost

$$\pi_{S_1}^{T_1}(Q_1, Q_1', Q_2, q_o) = Q_1 w - Q_1' c_1 - (Q_1 - Q_1')p$$

- The back-up supplier's profit function= Revenue from the initial order quantity - Production cost

$$\pi_{S_2}^{T_1}(Q_1, Q_1', Q_2, q_o) = (Q_2 w' + q_o w_o) - (Q_2 + q_o)c_2$$

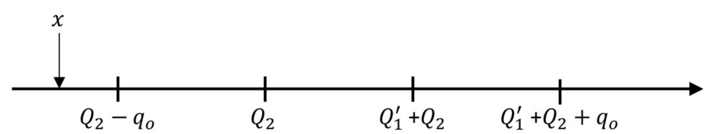
2) Profit Function at Second Stage (T_2)

At the beginning of this period, the retailer knows the delivery amount Q_1' from the normal supplier. After observing the actual demand, the retailer determines the exercised option quantity (q_e). Based on the actual demand, there are five scenarios need to be considered. They can be examined separately in the following cases:

Case I: $x < Q_2 - q_o$

Figure 3.7

Actual demand is less than $Q_2 - q_o$



x is less than $Q_2 - q_o$ in this scenario. Hence, the retailer will transfer the unsold product back to the normal supplier at delivered order quantity $q_b = Q_1'$ In addition, he exercises the maximum put option. Then, the retailer receives full refunds of option quantity $q_e = -q_o$. Both suppliers and retailer face excess inventory. However, it can be sold as salvage.

- The retailer's profit function = Revenue from selling products + Income from delivered order quantity + Income from exercised put option + Salvage value

$$\pi_R^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) = [x(r_p) + Q_1'b + w_{ep}q_o + v(Q_2 - q_o - x)$$

- The normal supplier's profit function = - Cost of buy back quantity + Salvage value

$$\pi_{S_1}^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) = -Q_1'b + Q_1'v$$

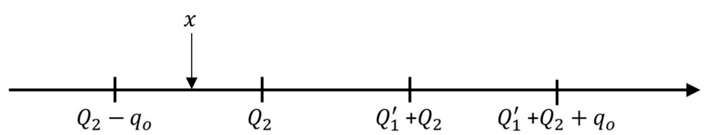
- The back-up supplier's profit function= - Cost of exercised put option + Salvage value

$$\pi_{S_2}^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) = -w_{ep}q_o + v(2q_o)$$

Case II: $\boldsymbol{Q_2 - q_o < x < Q_2}$

Figure 3.8

Actual demand is between $Q_2 - q_o$ and Q_2



In this scenario, the actual demand is greater than or equal to $Q_2 - q_o$ but it is still lower than Q_2. Hence, the retailer will exercise put option at quantity $q_e = -(Q_2 - x)$. The retailer will transfer the unsold product back to the normal supplier at delivered order quantity $q_b = Q_1'$. Both suppliers face excess inventory, and it can be sale as salvage .

- The retailer's profit function = Revenue from selling products + Income from delivered order quantity + Income from exercised put option

$$\pi_r^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) = x(r_p) + Q_1'b + w_{ep}(Q_2 - x)$$

- The normal supplier's profit function = - Cost of buy back quantity + Salvage value

$$\pi_{S_1}^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) = -Q_1'b + Q_1'v$$

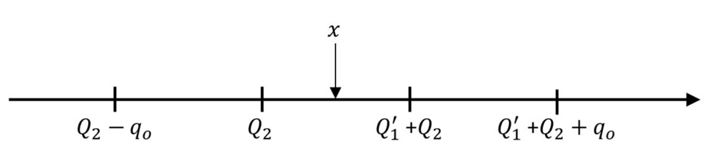
- The back-up supplier's profit function= - Cost of exercised put option + Salvage value

$$\pi_{S_2}^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) = -w_{ep}(Q_2 - x) + v(Q_2 + q_o - x)$$

Case III: $\boldsymbol{Q_2 \leq x \leq Q_1' + Q_2}$

Figure 3.9

Actual demand is between Q_2 and $Q_1' + Q_2$



In this scenario, the actual demand is greater than or equal to Q_2 but it is still less than $Q_1' + Q_2$. Hence, the retailer will transfer the unsold unit back to the normal supplier at quantity $q_b = Q_1' + Q_2 - x$. However, the retailer no need to exercise option quantity, i.e., $q_e = 0$, because only shipped order quantities (Q_1', Q_2) are sufficient to meet the demand. Therefore, the retailer does not have any excess inventory.

- The retailer's profit function = Revenue from selling products + Income from delivered order quantity

$$\pi_r^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) = x(r_p) + (Q_1' + Q_2 - x)b$$

- The normal supplier's profit function = - Cost of buy back quantity + Salvage value

$$\pi_{S_1}^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) = -(Q_1' + Q_2 - x)b + v(Q_1' + Q_2 - x)$$

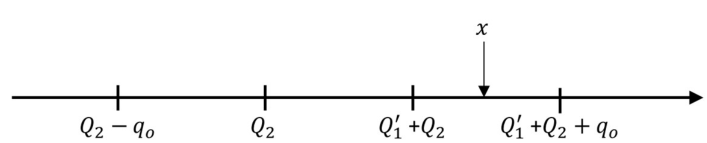
- The back-up supplier's profit function = Salvage value

$$\pi_{S_2}^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) = v(q_o)$$

Case IV: $\boldsymbol{Q_1' + Q_2 \leq x \leq Q_1' + Q_2 + q_o}$

Figure 3.10

Actual demand is between $Q_1' + Q_2$ and $Q_1' + Q_2 + q_o$



In this scenario, the actual demand is greater than or equal to $Q_1' + Q_2$ but it is still less than $Q_1' + Q_2 + q_o$. As a result, the retailer will not transfer the unsold unit back to the normal supplier. Because the demand is higher than the total initial orders, q_b=0. In addition, the retailer will exercise call option to back-up supplier at quantity $q_e = x - (Q_1' + Q_2)$. In this scenario, the retailer does not have any excess inventory.

- The retailer's profit function = Revenue from selling products – Cost of exercised call option

$$\pi_r^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) = x(r_p) - w_{ec}(x - (Q_1' + Q_2))$$

- The normal supplier's profit function = 0

$$\pi_{S_1}^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) = 0$$

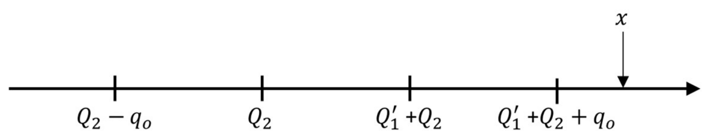
- The back-up supplier's profit function = Income from exercised call option + Salvage value

$$\pi_{S_2}^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) = w_{ec}[x - (Q_1' + Q_2)] + v\big[q_o - [x - (Q_1' + Q_2)]\big]$$

Case V: $x > Q_1' + Q_2 + q_o$

Figure 3.11

Actual demand is greater than $Q_1{}' + Q_2 + q_o$



In this scenario, the actual demand is greater than $Q_1{}' + Q_2 + q_o$. As a result, since the demand is higher than the total initial orders, the retailer will not transfer the unsold unit back to the normal supplier. Thus, the buy-back quantity is $q_b = 0$. In addition, the retailer will exercise call option quantity to back-up supplier at maximum value $q_e = q_o$. In this scenario, there is no excess inventory for the retailer.

- The retailer's profit function = Revenue from selling products – Cost of exercised call option quantity – Shortage Cost

$$\pi_r^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) = (Q_1{}' + Q_2 + q_o)(r_p) - w_{ec}q_o - s\big(x - (Q_1' + Q_2 + q_o)\big)$$

- The normal supplier's profit function = 0

$$\pi_{S_1}^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) = 0$$

- The back-up supplier's profit function = Income from exercised maximum call option

$$\pi_{S_2}^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) = w_{ec}q_o$$

3.3.1 The Full Expressions for Profits of All Members

The addition of profit in the first stage and the expected profit in the second stage generates the full expressions for profits of all stakeholders of the disruption situation. To cope with stochastic demand, the demand is supposed to be uniformly distributed all over the range $[\gamma - n, \gamma + n]$. In details, we have:

• Retailer's profit function

The retailer's expected profit can be derived as follows.

$\pi_R^D(Q_1, Q_1', Q_2, q_o) =$ Profit function at first stage + Expected profit function at second stage

$$\pi_R^D(Q_1, Q_1', Q_2, q_o) = [-Q_1 w - Q_2 w' - q_o w_o + (Q_1 - Q_1')p] + E\left[E[\pi_r^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e)|Q_1']\right]$$

The expression for retailer's profit function in the second stage under disruption situation given the value of Q_1' can be determined as:

$$E\left[E[\pi_r^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e)|Q_1']\right] = \int_{\gamma-n}^{Q_2-q_o} \pi_r^{T_2}\left(Q_1, Q_1', Q_2, q_b, q_o, q_e\right) f(x)dx$$
$$+ \int_{Q_2-q_o}^{Q_2} \pi_r^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) f(x)dx$$
$$+ \int_{Q_2}^{Q_1'+Q_2} \pi_r^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) f(x)dx$$
$$+ \int_{Q_1'+Q_2}^{Q_1'+Q_2+q_o} \pi_r^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) f(x)dx$$
$$+ \int_{Q_1'+Q_2+q_o}^{\gamma+n} \pi_r^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) f(x)dx$$

The detailed expression of the retailer's expected profit function can then be derived as:

$$\pi_R^D(Q_1, Q_1', Q_2, q_o) = [-Q_1 w - Q_2 w' - Q_o w_o + (Q_1 - Q_1')p]$$
$$+ \left\{\frac{1}{2n}\left[\left[r_p \frac{(Q_2 - q_o)^2}{2} - r_p \frac{(\gamma - n)^2}{2}\right] + [Q_1' b(Q_2 - q_o) - Q_1' b(\gamma - n)]\right.\right.$$
$$+ \left[w_{ep} q_o (Q_2 - q_o) - w_{ep} q_o (\gamma - n)\right]$$
$$+ \left[\left(v Q_2 (Q_2 - q_o) - v q_o (Q_2 - q_o) - v \frac{(Q_2 - q_o)^2}{2}\right)\right.$$
$$\left.\left.\left. - \left(v Q_2 (\gamma - n) - v q_o (\gamma - n) - v \frac{(\gamma - n)^2}{2}\right)\right]\right]\right\}$$
$$+ \left\{\frac{1}{2n}\left[\left[r_p \frac{(Q_2)^2}{2} - r_p \frac{(Q_2 - q_o)^2}{2}\right] + [Q_1' b(Q_2) - Q_1' b(Q_2 - q_o)]\right.\right.$$
$$+ \left[\left(w_{ep} Q_2 (Q_2) - w_{ep} \frac{(Q_2)^2}{2}\right)\right.$$
$$\left.\left.\left. - \left(w_{ep} Q_2 (Q_2 - q_o) - w_{ep} \frac{(Q_2 - q_o)^2}{2}\right)\right]\right]\right\}$$

$$+\left\{\frac{1}{2n}\left[\left[r_p\frac{(Q_1'+Q_2)^2}{2}-r_p\frac{(Q_2)^2}{2}\right]\right.\right.$$

$$+\left[\left(bQ_1'(Q_1'+Q_2)+bQ_2(Q_1'+Q_2)-b\frac{(Q_1'+Q_2)^2}{2}\right)\right.$$

$$\left.\left.\left.-\left(bQ_1'(Q_2)+bQ_2(Q_2)-b\frac{(Q_2)^2}{2}\right)\right]\right]\right\}$$

$$+\left\{\frac{1}{2n}\left[\left[r_p\frac{(Q_1'+Q_2+q_o)^2}{2}-r_p\frac{(Q_1'+Q_2)}{2}\right]\right.\right.$$

$$-\left[\left(w_{ec}\frac{(Q_1'+Q_2+q_o)^2}{2}-w_{ec}Q_1'(Q_1'+Q_2+q_o)\right.\right.$$

$$\left.-w_{ec}Q_2(Q_1'+Q_2+q_o)\right)$$

$$-\left(w_{ec}\frac{(Q_1'+Q_2)^2}{2}-w_{ec}Q_1'(Q_1'+Q_2)\right.$$

$$\left.\left.\left.\left.-w_{ec}Q_2(Q_1'+Q_2)\right)\right]\right]\right\}$$

$$+\left\{\frac{1}{2n}\left[\left[\left(Q_1'r_p(\gamma+n)+Q_2r_p(\gamma+n)+q_or_p(\gamma+n)\right)\right.\right.\right.$$

$$-\left(Q_1'r_p(Q_1'+Q_2+q_o)+Q_2r_p(Q_1'+Q_2+q_o)\right.$$

$$\left.\left.+q_or_p(Q_1'+Q_2+q_o)\right)\right]$$

$$-[w_{ec}q_o(\gamma+n)-w_{ec}q_o(Q_1'+Q_2+q_o)]$$

$$-\left[\left(s\frac{(\gamma+n)^2}{2}-sQ_1'(\gamma+n)-sQ_2(\gamma+n)-sq_o(\gamma+n)\right)\right.$$

$$-\left(s\frac{(Q_1'+Q_2+q_o)^2}{2}-sQ_1'(Q_1'+Q_2+q_o)\right.$$

$$\left.\left.\left.\left.-sQ_2(Q_1'+Q_2+q_o)-sq_o(Q_1'+Q_2+q_o)\right)\right]\right]\right\}$$

After simplifying.

$$\pi_R^D(Q_1, Q_1', Q_2, q_o) = [-Q_1 w - Q_2 w' - Q_o w_o + (Q_1 - Q_1')p]$$

$$+ \left\{ \frac{1}{2n} \left[\left[\frac{(\gamma - n)^2}{2} (v - r_p) - (\gamma - n)\left(bQ_1' + vQ_2 + (w_{ep} + v)q_o\right) \right] \right. \right.$$

$$+ \left[\frac{(Q_2 - q_o)^2}{2} (v - w_{ep}) \right] + \left[\frac{(Q_2)^2}{2} (w_{ep} - b) \right] + \left[\frac{(Q_1' + Q_2)^2}{2} (b - w_{ec}) \right]$$

$$+ \left[\frac{(Q_1' + Q_2 + q_o)^2}{2} (r_p - w_{ec} + s) \right.$$

$$+ (Q_1' + Q_2 + q_o) \Big(Q_1'(w_{ec} - r_p - s) + Q_2 (-w_{ec} - r_p - s)$$

$$\left. + q_o(r_p + w_{ec} - s) \Big) \right]$$

$$+ \left[\frac{(\gamma + n)^2}{2} (s) \right.$$

$$\left. \left. \left. + (\gamma + n) \Big(Q_1'(r_p + s) + Q_2(r_p + s) + q_o(r_p - w_{ec} + s) \Big) \right] \right] \right\}$$

• Normal supplier's profit function

$\pi_{S_1}^D(Q_1, Q_1', Q_2, q_o) =$ Profit function at first stage + Expected profit function at second stage

$$\pi_{S_1}^D(Q_1, Q_1', Q_2, q_o) = [Q_1 w - Q_1' c_1 - (Q_1 - Q_1')p)] + E\left[E\left[\pi_{S_1}^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) | Q_1' \right] \right]$$

The expression for normal supplier's profit function in the second stage under disruption situation given the value of Q_1' can be determined as:

$$E\left[E\left[\pi_{S_1}^{T_2}\left(Q_1, Q_1', Q_2, q_b, q_o, q_e\right) | Q_1' \right] \right] = \int_{\gamma - n}^{Q_2 - q_o} \pi_{S_1}^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) f(x) dx$$

$$+ \int_{Q_2 - q_o}^{Q_2} \pi_{S_1}^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) f(x) dx$$

$$+ \int_{Q_2}^{Q_1' + Q_2} \pi_{S_1}^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) f(x) dx$$

$$+ \int_{Q_1' + Q_2}^{Q_1' + Q_2 + q_o} \pi_{S_1}^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) f(x) dx$$

$$+ \int_{Q_1' + Q_2 + q_o}^{\gamma + n} \pi_{S_1}^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e) f(x) dx$$

The detailed expression of the normal supplier's expected profit function can then be derived as:

$$
\begin{aligned}
\pi_{S_1}^{D}(Q_1, Q_1', Q_2, q_o) = \; & [Q_1 w - Q_1' c_1 - \; (Q_1 - Q_1')p)] \\
& + \left\{\frac{1}{2n}\left[[-Q_1' b(Q_2 - q_o) + Q_1' b(\gamma - n)] \right.\right. \\
& \left.\left. \quad + [Q_1' v(Q_2 - q_o) + Q_1' v(\gamma - n)]\right]\right\} \\
& + \left\{\frac{1}{2n}\left[[-Q_1' b(Q_2) + Q_1' b(Q_2 - q_o)] + [Q_1' v(Q_2) + Q_1' v(Q_2 - q_o)]\right]\right\} \\
& + \left\{\frac{1}{2n}\left[\left[\left(-bQ_1'(\,Q_1' + Q_2) - bQ_2(Q_1' + Q_2) + b\frac{(Q_1' + Q_2)^2}{2}\right)\right.\right.\right. \\
& \quad \left. - \left(-bQ_1'(Q_2) - bQ_2(Q_2) + b\frac{(Q_2)^2}{2}\right)\right] \\
& \quad + \left[\left(vQ_1'(Q_1' + Q_2) + vQ_2(Q_1' + Q_2) - v\frac{(Q_1' + Q_2)^2}{2}\right)\right. \\
& \quad \left.\left.\left. - \left(vQ_1'(Q_2) + vQ_2(Q_2) - v\frac{(Q_2)^2}{2}\right)\right]\right]\right\} \\
& + \left\{\frac{1}{2n}[0]\right\} \\
& + \left\{\frac{1}{2n}[0]\right\}
\end{aligned}
$$

After simplifying.

$$
\begin{aligned}
\pi_{S_1}^{D}(Q_1, Q_1', Q_2, q_o) = \; & \left[Q_1 w - Q_1' c_1 - \; (Q_1 - Q_1')p)\right] \\
& + \left\{\frac{1}{2n}\left[\left[(\gamma - n)\big(Q_1'(b + v\,)\big)\right] + [(Q_2 - q_o)(2vQ_1')]\right.\right. \\
& \quad \left.\left. + [(Q_2)^2(b - v)] + \left[\frac{(Q_1' + Q_2)^2}{2}(v - b)\right]\right]\right\}
\end{aligned}
$$

• Back-up supplier's profit function

$\pi_{S_2}^{D}(Q_1, Q_1', Q_2, q_o) =$ Profit function at first stage +

Expected profit function at second stage

$$
\pi_{S_2}^{D}(Q_1, Q_1', Q_2, q_o) = \; [(Q_2 w' + q_o w_o) - (Q_2 + q_o)c_2] + E\left[E\left[\pi_{S_2}^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e)|Q_1'\right]\right]
$$

The expression for back-up supplier's profit function in the second stage under disruption situation given the value of Q_1' can be determined as:

$$E\left[E\left[\pi_{S_2}^{T_2}\left(Q_1, Q_1^{'}, Q_2, q_b, q_o, q_e\right)|Q_1^{'}\right]\right] = \int_{\gamma-n}^{Q_2-q_o} \pi_{S_2}^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e)f(x)dx$$

$$+\int_{Q_2-q_o}^{Q_2} \pi_{S_2}^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e)f(x)dx$$

$$+\int_{Q_2}^{Q_1'+Q_2} \pi_{S_2}^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e)f(x)dx$$

$$+\int_{Q_1'+Q_2}^{Q_1'+Q_2+q_o} \pi_{S_2}^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e)f(x)dx$$

$$+\int_{Q_1'+Q_2+q_o}^{\gamma+n} \pi_{S_2}^{T_2}(Q_1, Q_1', Q_2, q_b, q_o, q_e)f(x)dx$$

The detailed expression of the back-up supplier's expected profit function can then be derived as:

$$\pi_{S_2}^{D}(Q_1, Q_1', Q_2, q_o) = \left[(Q_2 w' + q_o w_o) - (Q_2 + q_o)c_2\right]$$

$$+\left\{\frac{1}{2n}\left[\left[-w_{ep}q_o(Q_2 - q_o) + w_{ep}q_o(\gamma - n)\right] + \left[2vq_o(Q_2 - q_o) + 2vq_o\big((\gamma - n)\big)\right]\right]\right\}$$

$$+\left\{\frac{1}{2n}\left[\left[\left(-w_{ep}Q_2(Q_2) + w_{ep}\frac{(Q_2)^2}{2}\right) - \left(-w_{ep}Q_2(Q_2 - q_o) + w_{ep}\frac{(Q_2 - q_o)^2}{2}\right)\right] + \left[\left(vQ_2(Q_2) + vq_o(Q_2) - v\frac{(Q_2)^2}{2}\right) - \left(vQ_2(Q_2 - q_o) + vq_o(Q_2 - q_o) - v\frac{(Q_2 - q_o)^2}{2}\right)\right]\right]\right\}$$

$$+\left\{\frac{1}{2n}\left[vq_o(Q_1' + Q_2) - vq_o(Q_2)\right]\right\}$$

$$+\left\{\frac{1}{2n}\left[\left[\left(w_{ec}\frac{(Q_1'+Q_2+q_o)^2}{2}-w_{ec}Q_1'(Q_1'+Q_2+q_o)\right.\right.\right.\right.$$

$$\left.-w_{ec}Q_2(Q_1'+Q_2+q_o)\right)$$

$$-\left(w_{ec}\frac{(Q_1'+Q_2)^2}{2}-w_{ec}Q_1'(Q_1'+Q_2)\right.$$

$$\left.\left.-w_{ec}Q_2(Q_1'+Q_2)\right)\right]$$

$$+\left[\left(vq_o(Q_1'+Q_2+q_o)-v\frac{(Q_1'+Q_2+q_o)^2}{2}\right.\right.$$

$$\left.+vQ_1'(Q_1'+Q_2+q_o)+vQ_2(Q_1'+Q_2+q_o)\right)$$

$$-\left(vq_o(Q_1'+Q_2)-v\frac{(Q_1'+Q_2)^2}{2}+vQ_1'(Q_1'+Q_2)\right.$$

$$\left.\left.\left.\left.+vQ_2(Q_1'+Q_2)\right)\right]\right]\right\}$$

$$+\left\{\frac{1}{2n}[w_{ec}q_o(\gamma-n)-w_{ec}q_o(Q_1'+Q_2+q_o)]\right\}$$

After simplifying

$$\pi_{S_2}^D(Q_1,Q_1',Q_2,q_o)=\ [(Q_2w'+q_ow_o)-(Q_2+q_o)c_2]$$

$$+\left\{\frac{1}{2n}\left[\left[\frac{(\gamma-n)^2}{2}\left(w_{ep}q_o+2vq_o\right)\right]\right.\right.$$

$$+\left[\frac{(Q_2-q_o)^2}{2}\left(w_{ep}+v\right)\right.$$

$$\left.+(Q_2-q_o)\left(Q_2\left(w_{ep}-v\right)+q_o\left(v-w_{ep}\right)\right)\right]$$

$$+\left[\frac{(Q_2)^2}{2}\left(v-w_{ep}\right)\right]+\left[\frac{(Q_1'+Q_2)^2}{2}(w_{ec}-v)\right]$$

$$\left.\left.+\left[\frac{(Q_1'+Q_2+q_o)}{2}\left(v-w_{ep}\right)\right]+[(\gamma+n)(w_{ec}q_o)]\right]\right\}$$

3.4 The General Expressions for Profits of All Members

The general expression for profit function of all supply chain's members can be computed as:

- Retailer’s profit function

  $\pi_R = (\pi_R^D \cdot P_d) + (\pi_R^N \cdot (1 - P_d))$

- Normal supplier’s profit function

  $\pi_{S_1} = \left(\pi_{S_1}^D \cdot P_d\right) + \left(\pi_{S_1}^N \cdot (1 - P_d)\right)$

- Back-up supplier’s profit function

  $\pi_{S_2} = \left(\pi_{S_2}^D \cdot P_d\right) + \left(\pi_{S_2}^N \cdot (1 - P_d)\right)$

Finally, the total supply chain’s profit function can be determined as:

- Supply Chain’s profit function

  = Retailer’s profit function + Normal supplier’s profit function + Back-up supplier’s profit function

  $= \pi_R + \pi_{S_1} + \pi_{S_2}$

CHAPTER 4
NUMERICAL EXPERIMENTS

4.1 Numerical Experiments

In this section, MATLAB will be used to perform the numerical experiments. The studies are carried out to examine the coordination of the buy-back and option contracts in the case of a partial supply disruption at the normal supplier. Furthermore, this research also compares the outcomes with and without back-up supplier when partial supply disruption occurs at the normal supplier to ensure that the proposed model is worth to be adopted. The following conditions must be followed by the input parameters.

1. $w_{ep} < b < w_{ec}$: To ensure that unsold products are always preferred to transfer back to the normal supplier.
2. $w_{ep} < w < w_{ec}$: To ensure that the retailer and back-up supplier will get the benefit from option contract.
3. $v < w_{ep}$: To convince the retailer to transfer unsold items back to the normal suppliers.
4. $p < r_p$: To ensure that the penalty cost per unit of the normal supplier is lower than the retailer's price.
5. $s < p - w$: To ensure that the penalty cost per unit of the normal supplier can cover the shortage cost of the retailer.

It is supposed that the demand pattern follows the uniform distribution within the range $[r - n,\ r + n]$. The values for the parameters are shown below.

w	=	10	Normal supplier's wholesale price
w'	=	12	Back-up supplier's wholesale price
r_p	=	18	Retailer's selling price
b	=	5	Normal supplier's buy-back price
w_o	=	2	Unit option premium price of back-up supplier
w_{ep}	=	4	Unit put option price of back-up supplier
w_{ec}	=	15	Unit call option price of back-up supplier
s	=	3	Shortage penalty cost

v	=	2	Salvage value of unsold product
c_1	=	5	Production cost per unit of normal supplier
c_2	=	7	Production cost per unit of back-up supplier
p	=	14	Penalty cost per unit of normal supplier
P_d	=	0.05	Probability of supply disruption
$1 - P_d$	=	0.95	Probability of no supply disruption
r	=	1000	
n	=	300	

When disruption occurs, the supplier still can deliver some product to the retailer. The ratio (R) of full order quantity that the supplier can deliver to the retailer can be modeled by a random variable taking value in the range [0,1]. Assume that this variable is a discrete random variable which have four possible outcomes: R_1, R_2, R_3 and R_4, and the distribution of the ratio R can be defined as follows:

1. The probability (p_1) that the main supplier cannot provide any product (R_1 = 0): 0.3
2. The probability (p_2) that the main supplier can provide only 25% of full order amount (R_2 = 0.25): 0.2
3. The probability (p_3) that the main supplier can provide only 50% of full order amount (R_3 = 0.50): 0.2
4. The probability (p_4) that the main supplier can provide only 75% of full order amount (R_4 = 0.75): 0.3

Firstly, this research will illustrate if it is appropriate to provide a backup supplier in the event of a supply disruption. When the system has/has no a backup supplier, all of the values mentioned above are used to compare the numerical experiment outcomes. The results are presented in Table 4.1.

Table 4.1

Comparison Results with/without Back-up Supplier

Optimal Results	Without Back-up Supplier	With Back-up Supplier
Q_1: Initial order quantity to the normal supplier	2,864	720
Q_2: Initial order quantity to the back-up supplier	0	503
q_o: Option quantity	0	254
Retailer's Profit	1,603.87	5,287.17
Normal Supplier's Profit	3,507.22	2,855.50
Back-up Supplier's Profit	0	1,875.98
Supply Chain's Profit	5,111.09	10,018.65

Based on the results, it is confirmed that retailer's profit increases from 1,603.87 to 5,287.17 when back-up supplier is used in the supply system. In addition, the whole supply chain's profit also increases from 5,111.09 to 10,018.65 when the back-up supplier is presented. As a result, it is sufficient to conclude that having the backup supplier in the event that the normal supplier suffers the partial supply disruption will help increase the retailer's benefit as well as the profit of the entire supply chain.

4.2 Sensitivity Analysis

In this section, some of the main input parameters will be studied by changing their values to observe the trends of how these parameters impact order quantities as well as the retailer's, main supplier's, backup supplier's, and overall supply chain's profits. The results are reported in the following sub-sections.

4.2.1 Sensitivity Analysis with Respect to b

Buy-back price (b) is varied from 4 to 7 with increments of 0.5 in this section to examine the impact on optimal order quantities and expected profits. The result in table 4.2 presents the profits of the retailer, the suppliers and the whole supply chain, and also the optimal order quantities when b increases. Figure 4.1 shows the trends of profits and optimal order quantities against b.

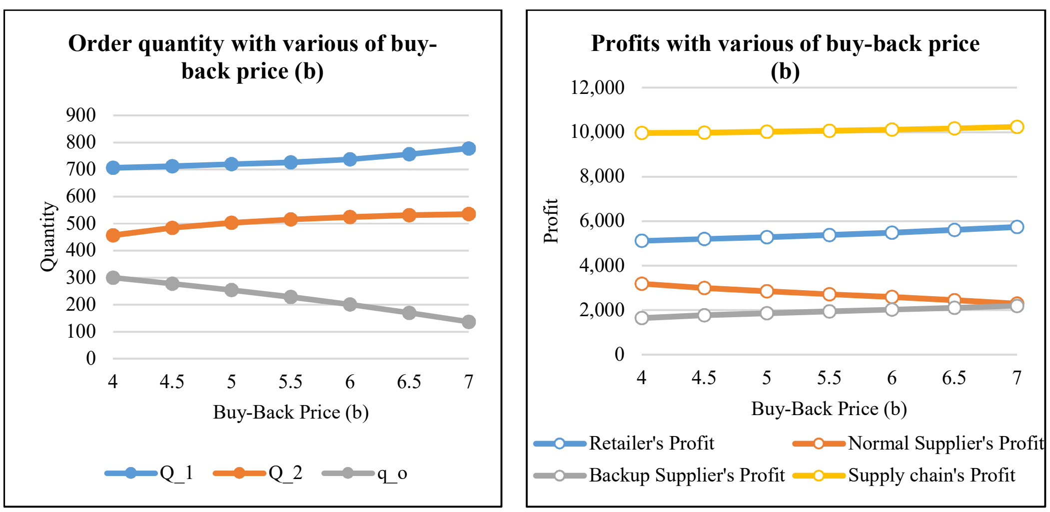
Table 4.2

Optimal Ordering Quantities and Profits with Respect to Value of b

b	Q_1	Q_2	q_o	Profit of Retailer	Profit of Normal Supplier	Profit of Back-up Supplier	Total Supply Chain Profit
4	706	457	300	5,120.80	3,196.21	1,648.00	9,965.01
4.5	712	484	278	5,198.96	3,007.85	1,779.82	9,986.62
5	720	503	254	5,287.17	2,855.50	1,875.98	10,018.65
5.5	726	515	229	5,385.23	2,724.77	1,953.81	10,063.81
6	738	524	201	5,493.55	2,594.14	2,030.50	10,118.20
6.5	756	531	170	5,613.02	2,452.85	2,110.75	10,176.63
7	778	535	137	5,744.88	2,299.09	2,200.88	10,244.84

Figure 4.1

Order Quantities and Profits at Various Values of Buy-back Price (b)



From the results, when the buy-back price (b) increases, the initial order quantities from normal (Q_1) and back-up suppliers (Q_2) tend to increase. These patterns are reasonable because the retailer will have a motivation to order more. However, the increase in the initial order quantity (Q_2) from the back-up supplier will lead to the decrease in option quantity (q_o). Related to profit, the profit of the retailer will increase due to the increase in buy-back price (b), and the profit of the back-up supplier will also increase due to the increase in order quantity (Q_2). However, the profit of the main supplier will be reduced due to the increase in buy-back price (b). Anyway, the total profit of the whole supply chain will increase.

4.2.2 Sensitivity Analysis with Respect to w_o

In this section, option premium price (w_o) is varied from 0 to 4 with increments of 0.5 to analyze the impact on optimal order quantities and expected profits. Table 4.3 presents the profits of the retailer, the suppliers, and the whole supply chain when w_o increases, and also the optimal order quantities and optimal option quantity. Figure 4.2 shows the trends of profits and optimal order/option quantities against w_o.

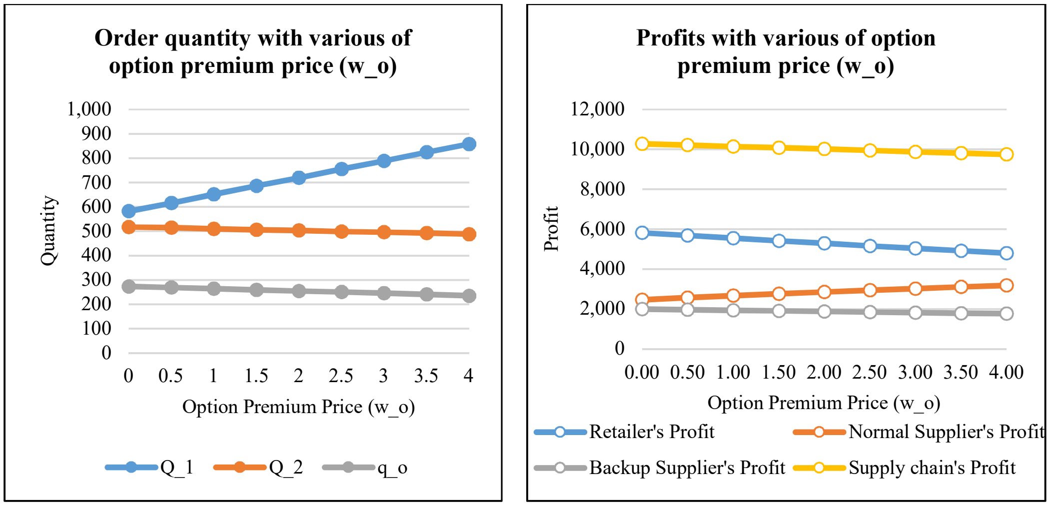
Table 4.3

Optimal Ordering Quantities and Profits with Respect to Value of w_o

w_o	Q_1	Q_2	q_o	Profit of Retailer	Profit of Normal Supplier	Profit of Back-up Supplier	Total Supply Chain Profit
0	582	517	273	5,814.99	2,462.84	1,999.84	10,277.67
0.5	616	514	269	5,679.48	2,565.09	1,965.98	10,210.55
1	651	510	264	5,546.34	2,668.36	1,933.77	10,148.47
1.5	686	506	259	5,415.57	2,767.08	1,902.44	10,085.08
2	720	503	254	5,287.17	2,855.50	1,875.98	10,018.65
2.5	755	499	250	5,161.15	2,945.13	1,841.55	9,947.83
3	789	496	245	5,037.49	3,024.36	1,816.88	9,878.74
3.5	824	492	240	4,916.21	3,104.78	1,789.10	9,810.09
4	858	488	235	4,797.31	3,178.98	1,767.14	9,743.43

Figure 4.2

Order Quantities and Profits at Various Values of Option Premium Price (w_o)



From the results, when the premium option price (w_o) rises, the initial order quantity from the back-up supplier (Q_2) will decrease. This trend is reasonable. Due to the decrease in Q_2, the order quantity from the normal supplier (Q_1) will increase. Then, due to the increase in Q_1, there is no need to have a high flexibility in the option contract. Therefore, the option quantity (q_o) is also reduced.

Related to the profit, it can be observed that the profits of the retailer and the back-up supplier decreases when the option price increases due to the reduction in both Q_2 and q_o. However, the profit of the main supplier will increase due to the increase in Q_1. As a consequence, the total supply chain profit will decrease.

4.2.3 Sensitivity Analysis with Respect to w_{ep}

In this section, the put option price (w_{ep}) is varied from 2 to 6 with increments of 0.5 to analyze the impact on optimal order/option quantities and expected profits. Table 4.4 shows the outcomes of the retailer, the manufacturer, and the total supply chain when w_{ep} rises, and also the optimal order quantities and optimal option quantity. Figure 4.3 shows the trends of profits and optimal order/option quantities against w_{ep}.

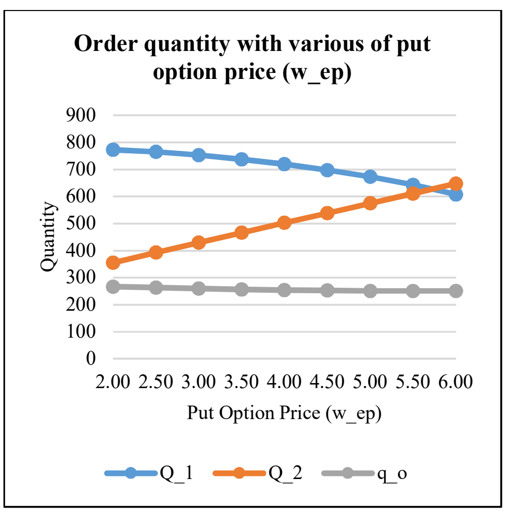
Table 4.4

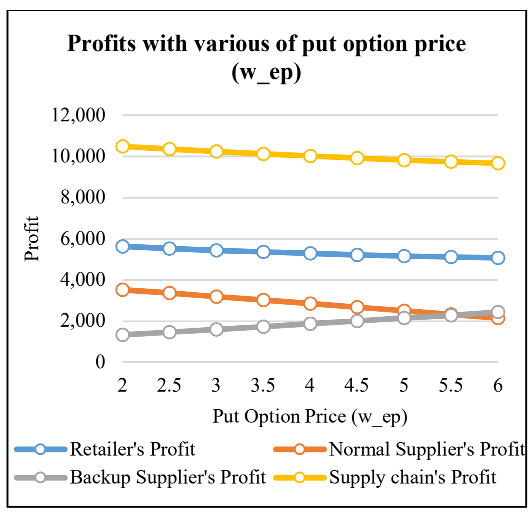
Optimal Ordering Quantities and Profits with Respect to Value of w_{ep}

w_{ep}	Q_1	Q_2	q_o	Profit of Retailer	Profit of Normal Supplier	Profit of Back-up Supplier	Total Supply Chain Profit
2	773	355	267	5,634.78	3,522.29	1,336.47	10,493.55
2.5	765	393	263	5,533.41	3,359.46	1,468.16	10,361.04
3	753	430	260	5,442.12	3,193.32	1,602.66	10,238.10
3.5	738	467	257	5,360.23	3,023.85	1,738.14	10,122.22
4	720	503	254	5,287.17	2,855.50	1,875.98	10,018.65
4.5	698	539	253	5,222.52	2,683.38	2,010.56	9,916.45
5	673	575	251	5,165.93	2,510.24	2,151.03	9,827.20
5.5	643	611	251	5,117.21	2,332.59	2,292.99	9,742.79
6	608	648	251	5,076.24	2,147.81	2,444.12	9,668.17

Figure 4.3

Order Quantities and Profits at Various Values of Put Option Premium Price (w_{ep}*)*





From the results, when put option price (w_{ep}) raises, option quantity (q_o) from the back-up supplier has a trend to decline. However, we can see that the initial order quantity (Q_2) from the back-up supplier increases while the initial order from normal supplier (Q_1) is reduced.

These patterns are appropriate because when the put option price (w_{ep}) raises, the retailer has an incentive to increase the initial order quantity from the back-up supplier. This will lead to the deceases in both option quantity and order quantity from the main supplier. The above trends in order/option quantities lead to the increase in profit of back-up supplier and the decrease in profit of normal supplier. It is also noted that the retailer's profit and the whole supply chain decrease due to the increase in w_{ep}.

4.2.4 Sensitivity analysis with respect to $\boldsymbol{w_{ec}}$

In this section, the call option price (w_{ec}) is varied from 11 to 19 with increments of 1 to analyze the impact on optimal order/option quantities and expected profits. Table 4.5 shows the retailer's profit, the manufacturer's profit, and the whole supply chain's profit when w_{ec} raises, and also the optimal order quantities and optimal option quantity. Figure 4.4 shows the trends of profits and optimal order/option quantities against w_{ec}.

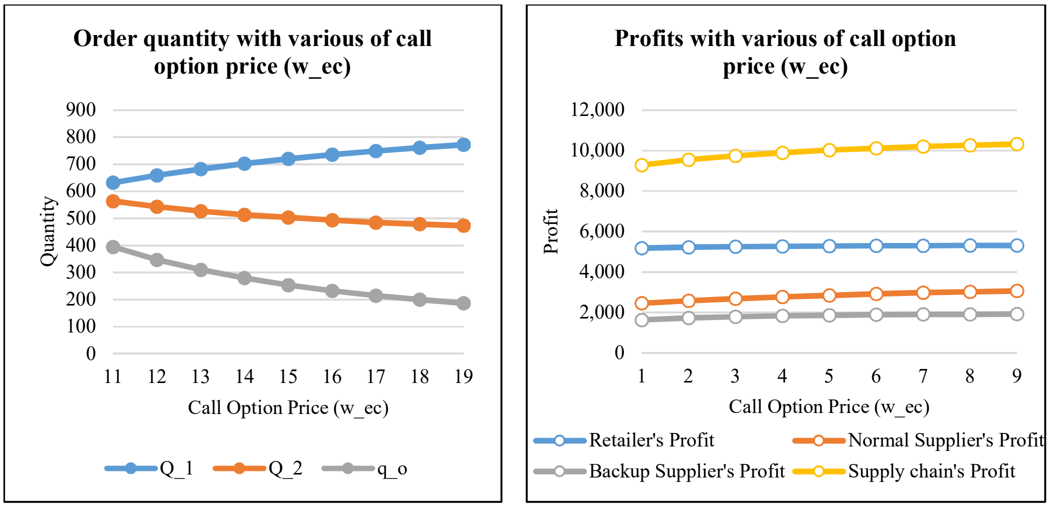
Table 4.5

Order Quantities and Profits at Various Values of Call Option Premium Price (w_{ec})

w_{ec}	Q_1	Q_2	q_o	Profit of Retailer	Profit of Normal Supplier	Profit of Back-up Supplier	Total Supply Chain Profit
11	632	564	395	5,188.45	2,461.81	1,637.14	9,287.40
12	659	544	347	5,227.96	2,585.08	1,736.80	9,549.84
13	682	527	310	5,254.70	2,691.39	1,801.33	9,747.41
14	702	514	280	5,273.51	2,778.79	1,843.52	9,895.82
15	720	503	254	5,287.17	2,855.50	1,875.98	10,018.65
16	736	493	233	5,297.36	2,924.85	1,894.93	10,117.13
17	749	485	215	5,305.14	2,980.86	1,913.87	10,199.87
18	761	479	200	5,311.16	3,027.71	1,922.50	10,261.37
19	772	473	187	5,315.93	3,072.56	1,927.61	10,316.10

Figure 4.4

Order Quantities and Profits at Various Values of Call Option Premium Price (w_{ec})



From the results, when the call option price (w_{ec}) increases, option quantity (q_o) and initial order quantity from the back-up supplier (Q_2) decrease. These trends are understandable because the retailer becomes less motivated to order from the back-up supplier. This will lead to the increase in order quantity (Q_1) from the normal supplier. It is interesting to notice that when w_{ec} increases, even though the retailer will reduce both the option quantity (q_o) and the initial order quantity (Q_2) from back-up suppliers, the back-up supplier's profit still increases due to the increase in call option price (w_{ec}). Also, due to the fact that the retailer increases order quantity from normal supplier (Q_1), both the retailer's profit and the normal supplier's profit go up. Consequently, total supply chain profit will increase.

4.2.5 Sensitivity Analysis with Respect to P_d in Decentralized System

In this section, the supply disruption probability (P_d) is varied from 0.01 to 0.10 with increments of 0.01 to analyze the effect on optimal order/option quantities and expected profits in decentralized system. Table 4.6 shows the profits of the retailer, the manufacturer, and the whole supply chain when P_d raises, and also the optimal order quantities and optimal option quantity. Figure 4.5 shows the trends of profits and optimal order/option quantities against P_d.

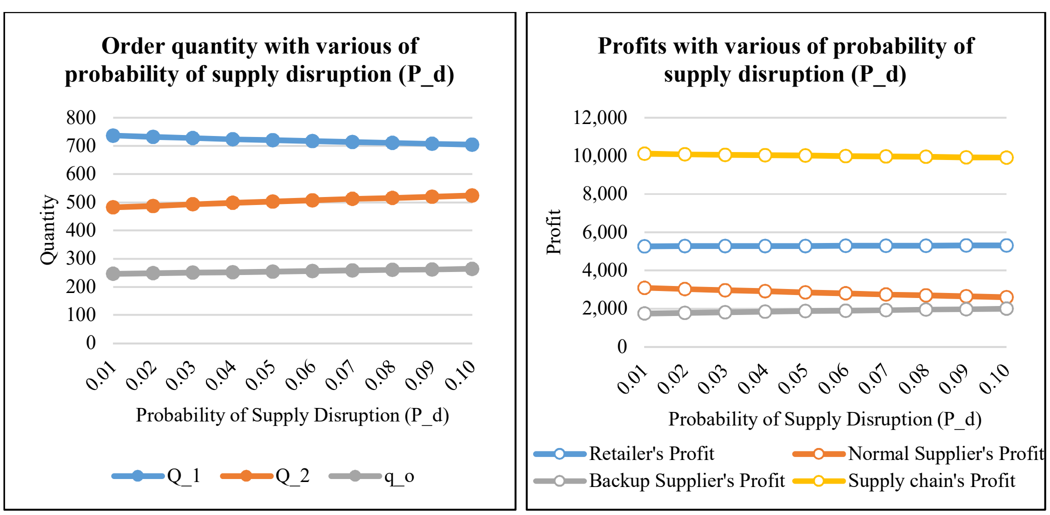
Table 4.6

Optimal Ordering Quantities and Profits with Respect to Value of P_d

P_d	Q_1	Q_2	q_o	Profit of Retailer	Profit of Normal Supplier	Profit of Back-up Supplier	Total Supply Chain Profit
0.01	737	482	246	5,272.05	3,097.77	1,752.31	10,122.13
0.02	732	487	249	5,275.16	3,035.36	1,782.81	10,093.32
0.03	728	493	251	5,278.54	2,972.38	1,811.54	10,062.46
0.04	724	498	252	5,282.69	2,913.60	1,846.27	10,042.55
0.05	720	503	254	5,287.17	2,855.50	1,875.98	10,018.65
0.06	717	507	256	5,292.07	2,803.68	1,901.63	9,997.38
0.07	714	512	258	5,297.50	2,748.93	1,925.79	9,972.22
0.08	711	516	260	5,303.22	2,698.11	1,951.30	9,952.63
0.09	708	520	262	5,309.28	2,647.78	1,976.76	9,933.82
0.10	705	524	264	5,315.67	2,597.92	2,002.16	9,915.74

Figure 4.5

Order Quantities and Profits at Various Values of P_d in Decentralized system



From the results, when supply disruption probability P_d raises, the retailer increases the initial order and option quantities (Q_2 and q_o) from the back-up supplier to cope with higher probability of supply disruption. On the other hand, the retailer will reduce the initial order quantity (Q_1) from the normal supplier.

These trends look reasonable and the increase in P_d will lead to profit loss from the normal supplier. However, the profits of the back-up supplier and the retailer increase. Anyway, the total supply chain profit will decrease when P_d increases.

4.2.6 Sensitivity Analysis with Respect to P_d in Centralized System

In this section, the supply disruption probability (P_d) is varied from 0.01 to 0.10 with increments of 0.01 to analyze the effect on optimal order/option quantities and expected profits in centralized system. Table 4.7 shows the profits of the retailer, the manufacturer, and the whole supply chain when P_d raises, and also the optimal order quantities and optimal option quantity. Figure 4.6 shows the trends of profits and optimal order/option quantities against P_d.

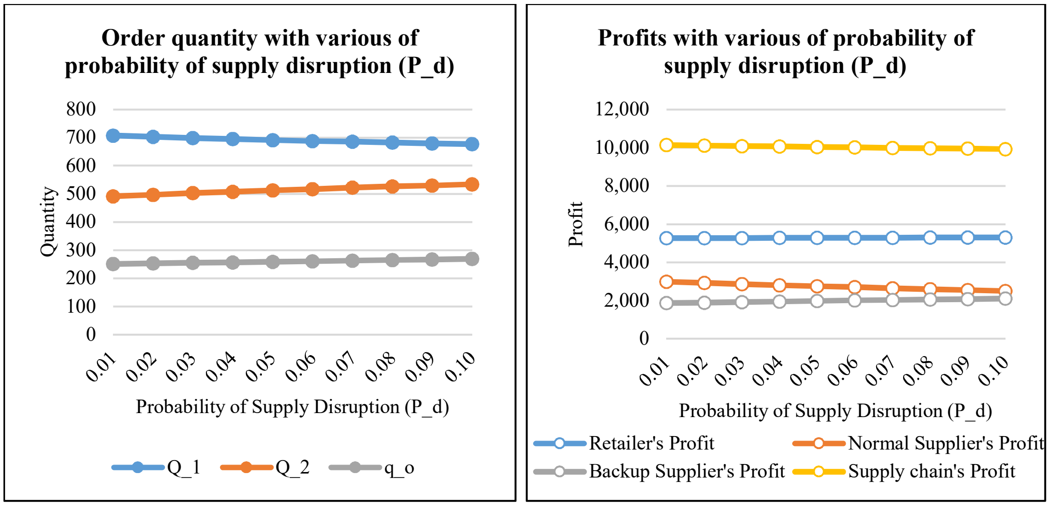
Table 4.7

Optimal Ordering Quantities and Profits with Respect to Value of P_d

P_d	Q_1	Q_2	q_o	Profit of Retailer	Profit of Normal Supplier	Profit of Back-up Supplier	Total Supply Chain Profit
0.01	708	492	251	5,275.04	2,991.70	1,871.42	10,138.15
0.02	703	497	254	5,276.84	2,930.71	1,902.17	10,109.72
0.03	699	503	256	5,279.22	2,869.38	1,930.63	10,079.23
0.04	695	508	257	5,282.62	2,812.11	1,964.91	10,059.64
0.05	691	513	259	5,286.10	2,755.51	1,994.43	10,036.04
0.06	688	517	261	5,290.02	2,705.14	2,019.89	10,015.05
0.07	685	522	263	5,294.50	2,651.97	2,043.71	9,990.18
0.08	683	526	265	5,299.50	2,604.80	2,063.54	9,967.84
0.09	680	530	267	5,304.67	2,555.86	2,088.74	9,949.27
0.10	677	534	269	5,310.17	2,507.39	2,113.87	9,931.43

Figure 4.6

Order Quantities and Profits at Various Values of P_d in Centralized System



From the results, when the supply disruption probability P_d raises, the retailer will increase the initial order quantity (Q_2) and option quantity (q_o) from the back-up supplier. On the other hand, the retailer will reduce the order quantity (Q_1) from the normal supplier because of the higher supply disruption probability.

These trends seem reasonable and the increase in P_d results in an increase in retailer's profit. The fact that the retailer increases both Q_2 and q_o and reduces initial order quantity (Q_1) from normal supplier will lead to the rise in profit of the back-up supplier but the decrease in profit of the normal supplier. As a result, the total profit of the whole supply chain will drop.

According to the results for both decentralized and centralized systems showed in table 4.6 and table 4.7, we can see that the supply disruption probability affects both systems in the same way. When the supply disruption probability increases, the retailer's profit increases in both decentralized and centralized systems. In terms of the normal supplier, his profit is reduced in both systems due to the higher probability of supply disruption. This is a reasonable trend as retailer will move further away from risky supplier, and rely more on back-up supplier. It is also worth noting that total supply chain profits in both systems decrease with the increased supply disruption probability.

4.3 Coordination Analysis

At this step, supply chain coordination will be examined by comparing the centralized system and decentralized system. The table 4.8 shows the results.

Table 4.8

Supply Chain Coordination

P_d	Supply chain's profit (Centralized system)	Supply chain's profit (Decentralized system)	% Efficiency
0.01	10,138.15	10,122.13	99.84%
0.02	10,109.72	10,093.32	99.84%
0.03	10,079.23	10,062.46	99.83%
0.04	10,059.64	10,042.55	99.83%
0.05	10,036.04	10,018.65	99.83%
0.06	10,015.05	9,997.38	99.82%
0.07	9,990.18	9,972.22	99.82%
0.08	9,967.84	9,952.63	99.85%
0.09	9,949.27	9,933.82	99.84%
0.10	9,931.43	9,915.74	99.84%
	Average		**99.83%**

From table 4.8, it can be seen that the total supply chain's profit in the centralized system is always higher that the profit in the centralized system. However, the total supply chain profits in both systems are very close to each other with 99.83% of the average coordination efficiency. As a result, we can confidently say that using the proposed contract can help coordinate the supply chain.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

This research derived a supply contract between single-retailer and dual-sourcing (i.e., the normal supplier and the back-up supplier). The normal supplier may suffer a partial supply disruption, and so, the supplier can deliver some amount of full-order quantity to the retailer during disruption period. In order to minimize the effect of supply disruption on demand fulfillment, the retailer will sign a purchase agreement with a back-up supplier. From the results of this research, we can confirm that the use of back-up supplier can improve the supply chain profit. When a partial supply disruption occurs, the supply chain becomes more profitable. In addition, the ability of the contracts to coordinate of the supply chain was also examined by analyzing the total profits under centralized and decentralized systems.

From sensitivity analyses, we can observe the effect of input parameters on all members in the supply chain (both the retailer and the suppliers). In specific, the results have shown that buy-back price (b), option premium price (w_o), put option price (w_{ep}), call option price (w_{ec}) and supply disruption probability (P_d) influence retailer's decision on both initial orders (Q_1, Q_2) and option quantity (q_o). Moreover, supply chain coordination under supply interruption can be achieved with quite high coordination efficiency (99.83% on average).

The study discussed here should be extended for more research in order to address the scenarios when the retailer signs other kinds of agreements with the normal supplier and/or the back-up supplier under existence of supply disruption.

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