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On the Effectiveness of Option Contracts under Supply Disruption

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ABSTRACT

This paper studies the effectiveness of implementing option contracts for the procurement of seasonal products subject to short selling season, demand uncertainty, and supply-side disruption. The research intends to show how profitability and product availability can be enhanced both locally and globally by combining the long-term wholesale price contract and option contracts. Using the newsvendor model, the paper aims to identify business settings with respect to disruption parameters, demand uncertainty, and the option pricing under which the use of option contracts could improve supply chain performance. The main contribution of this research is that the effectiveness of option contracts is investigated under the impact of the supply-side disruption in addition to the demand uncertainty. The option contract-based portfolio procurement displays significant performance enhancement in terms of both the retailer profitability and the reduction in the lost sales quantity when supply-side disruptions prevail. The study of the procurement management subject to seasonal disruption can be readily applied to numerous business situations where the disruption can lead to devastating impacts such as the insufficient or untimely supply of COVID-19 vaccines with limited shelf life.

Keywords: *newsvendor model, option contract, procurement management, supply disruption*

1. INTRODUCTION

Disruptions in the global supply chain are manifested in numerous forms, such as raw material shortages, demand spikes, price volatility, labour shortages or strikes, and natural disasters, to name a few, with their impacts ranging from minor to catastrophic. With the increase in the frequency of disruptive risks in the 21st century, companies are exposed to various levels of vulnerability in their day-to-day business operations. As a result, businesses understand the significance of developing a supply chain resilience plan (Wong *et al*., 2020) so as to mitigate the impact of unforeseen disruptions. Among the different approaches implemented by companies to build resilience in their global supply chain operations is the identification of risk-hedging options available in logistics, transportation, and procurement processes (Sun *et al*., 2020). Businesses proactively look for ways to strengthen the resilience of their supply chains by diversifying supply sources, hedging disruptive risks, and collaborating with key suppliers (Chopra and Sodhi, 2014). In addition to building supply chain resilience, companies have also come to realize the growing significance of operating with shrinking time dimensions in lead time, new product development time, and the product selling season (Olhager, 2013). The general trend of shortened time dimension has created an added challenge as companies are expected to operate with both agility and resilience.

A number of well-coordinated supply chain initiatives have been implemented to mitigate the impact of demand-side uncertainties over the past few decades. Some of these supply contracts have proved to be effective in bringing both the buyers and suppliers to engage in coordination that can achieve optimal or near-optimal performance. Coordination mechanisms that have been studied and implemented with success include buyback contract (S. Wang *et al*., 2021; Pasternack, 1985), revenue sharing contract (Bart *et al*., 2021; Cachon and Lariviere, 2005), quantity discount (Li and Liu, 2006; Tsay, 1999), vendor-managed inventory (van den Bogaert and van Jaarsveld, 2022; Yao and Dresner, 2008), and consignment sales contract (Sarkar *et al*., 2018; Braglia and Zavanella, 2003) among others. Compared with the generalized wholesale price contract, collaborative supply contracts incentivize the stakeholders to hedge risk under demand uncertainty and allow both the vendor and the buyer to operate in a manner that is beneficial for the overall supply chain (Ai *et al*., 2012). A review on the importance of incentive alignment and contract mechanisms for collaborative contracts is summarized in Norrman and Naslund (2019).

Under business settings characterized primarily by supply-side disruptions, however, coordinated supply contracts are not sufficient to mitigate the impact of disruptive risks as they often lead to a significant increase in redundancy-based policies (e.g., maintaining safety stock or strategic reserves) for businesses, which may not be sustainable in the long run. Instead, businesses look for other policies focused on improving supply chain flexibility which are considered effective in mitigating the impact of procurement disruptions without compromising on redundancy or profitability (Chopra and Sodhi, 2004). In particular, for time-sensitive items (e.g., seasonal items, medical supplies, technology products, etc.), broadening procurement options or increasing supplier involvement under price fluctuations, supply shortages, or unforeseeable disruptive events enhances supply chain resilience and business continuity by ensuring timely delivery of products (Wieteska, 2020; Zsidisin and Smith, 2005).

The value of procurement management for short life-cycle products for businesses operating under supply disruptions and demand uncertainties is now more crucial than ever before as many companies use optimal sourcing and procurement planning as a source of competitive advantage (Mohammadivojdan *et al*., 2022; Merzifonluoglu, 2017). As an approach to mitigate the impact of potential price and volume fluctuations, different forms of price contracts are considered for the future delivery of goods from the upstream to the downstream supply chain. For example, business partners can agree on a set price in advance (fixed wholesale price contracts) or agree to the prevailing price in the spot market (spot price contracts), resulting in different risk allocation designs between the parties involved (Polinsky, 1987). However, the spot market price may not always work well for certain products subject to seasonal disruptions or market uncertainties as companies may want to avoid both the volatility of the spot market and the inventory risk of the long-term fixed-price contract. For such cases, one can consider other alternatives, such as an option contract, which guarantees the buying company the future delivery of a fixed quantity at a pre-negotiated strike price (Fu *et al*., 2010). The buyer purchases an option contract at a premium reserve price (a small fraction of the product price) upfront. The buyer can certainly choose not to exercise the option if conditions do not favour doing so, in which case, the buyer simply loses the initial premium payment already made to the supplier. In essence, the primary benefit of the option contract is that it provides the buyer with insurance against a potential raw material shortage as well as a sudden price surge of commodities (Wang *et al*., 2017), a phenomenon commonly observed in global business transactions.

Historical evidence reveals numerous instances of drastic price volatility across industry sectors. For instance, energy prices are known to display high price volatility over time, causing businesses to frequently switch back and forth between the long-term fixed-price contract and the spot market purchase. At the beginning of the COVID-19 pandemic, with sudden contractions in the global demand in most manufacturing sectors, the natural gas price hit its lowest mark of $1.50 per MMBtu (one million British thermal units) in April 2020 (US EIA, 2023). Within two years, however, with the global demand in manufacturing back to its normal level along with the outbreak of the war in Ukraine in early 2022, the natural gas price reached its peak of $9.85 per MMBtu in August 2022, the highest level since the 2008 global recession (US EIA, 2023). It should be noted, however, that this type of price volatility is not limited to the energy sector alone. Businesses are well aware of potential fluctuations with respect to both the supply and the prices of products in key industry sectors, including commodities, electronics, active pharmaceutical ingredients, and semiconductors (Lefebvre, 2022; Knoblich *et al*., 2011).

Literature on procurement management is abundant in cases where both the demand and the price are random and exogenous (Lee *et al*., 2013; Martinez-de-Albeniz, 2009), in which either the spot market purchase or the option contract is generally considered along with the long-term wholesale price contract to derive the optimal procurement policy in a multi-stage supply chain. Others focus on the risk management side of portfolio procurement and investigate ways to attain proper risk allocation and risk hedging (Sun *et al*., 2020; Fu *et al*., 2010; Polinsky, 1987). In particular, a series of studies of the proactive portfolio risk management (PRM) initiated at Hewlett-Packard (HP) examine how option contracts can be applied to obtain procurement optimization using a multi-period portfolio approach (Nagali *et al*., 2008; Martinez-de-Albeniz and Simchi Levi, 2005). A research stream that has been gaining momentum is the procurement and sourcing of medicines and vaccines in the global healthcare supply chains. Pazirandeh (2011) presents a decision-making framework for strategic sourcing and distribution of vaccines in developing countries. Shamsi *et al*. (2018) propose an option contract using the Stackelberg game approach to procure required vaccine doses from two suppliers. In a similar context, Martin *et al*. (2020) propose three vaccine procurement contract designs to encourage pharmaceutical companies to bring vaccines to developing countries. More recently, in an empirical study of supply chain disruptions during the COVID-19 pandemic, Khuan *et al*. (2023) emphasize the importance of assisting local suppliers and maintaining a dual sourcing system. It should be noted that governments have been the primary buyers of the COVID-19 vaccines during the pandemic. However, the post-pandemic era is likely to demand proper pricing of future vaccines via different price contracts as more private sector buyers are expected to get involved in securing the available vaccines (Kaplan and Wehrwein, 2021).

This paper fills the research gap in the study of procurement management by investigating the effectiveness of the option contract under *supply-side disruptions*. In particular, this research examines how the option contract included in the portfolio procurement can be applied to provide risk-hedging benefits for companies that face not only uncertain demand and volatile prices but also the unreliable supply of raw materials and parts. Using the newsvendor model, this paper captures the value of the option contract-based portfolio procurement to the stakeholders in a two-stage supply chain subject to supply-side disruption. The rest of the paper is organized as follows: In the next section, research questions are presented, followed by the section on detailed discussions on the modelling of the option contract using the newsvendor model in which both the base case and the option contract-based portfolio procurement are analysed and assessed under supply-side disruptions. The results from the numerical experiments and sensitivity analysis will present managerial insights from different scenarios of business disruptions and the option contract parameters. Conclusions, limitations of the research, and future research direction will be discussed in the last section.

2. OBJECTIVE AND RESEARCH QUESTIONS

The purpose of this paper is two-fold: (i) to assess the effectiveness of the option contract as a risk hedging mechanism for the procurement of products with a short selling season and (ii) to identify business settings under which the use of the option contract can benefit stakeholders as a procurement management tool. Specifically, this research shows how the retailer’s profitability and product availability (e.g., the lost sales quantity or the service level) can improve by incorporating the option contract in the portfolio procurement when the supply is subject to seasonal disruption. Using the newsvendor problem to set up the normative model for the base case (with the long-term wholesale price contract) and the proposed portfolio procurement (with the option contract), this research conducts numerical experiments and sensitivity analysis to discuss operating characteristics of the proposed procurement approach. The paper addresses the following research questions:

1. How effective is the option contract as a risk-hedging mechanism under supply-side disruptions for products with a short selling season?
2. How do business parameters (e.g., demand variability, disruption frequency, and recovery rate) affect supply chain performance with the option contract in place?
3. What are settings under which the portfolio procurement with the option contract could be beneficial to stakeholders in improving the supply chain performance metrics?

3. MODELLING OPTION CONTRACT USING THE NEWSVENDOR PROBLEM

This paper studies a two-stage supply chain in which the vendor supplies the retailer with a product featuring a short shelf-life. Further, the product is subject to supply-side disruptions in addition to demand and price volatility. The supply of products can be disrupted for reasons such as labour disputes, port lockouts, raw material shortages, international warfare, pandemics, etc. Especially, the delay in the delivery of a short shelf-life product can lead to a devastating impact, seriously undermining product availability during the limited selling season. Securing the proper quantity of products at the beginning of the selling season is deemed crucial for products such as seasonal goods, high-fashion items, and time-sensitive vaccines. For these types of goods, the businesses simply cannot afford to have any disruptions occur prior to the season that can jeopardize the delivery of products in time.

In preparation for any potential disruptive events upstream, the retailer should consider measures to hedge the risk to minimize the impact. Amongst different measures to consider for the retailer is the use of a pre-arranged option contract with a different supplier as a contingency plan as depicted in **Figure 1**. As shown, the buyer (retailer) works with two suppliers: The retailer has a long-term fixed-price contract with supplier 1, an overseas supplier deemed unreliable and slow but guarantees low cost. With supplier 2, a local supplier considered reliable and fast but expensive, the retailer has a pre-arranged option contract in place, a practice similar to that of Intel's procurement system (Peng *et al*., 2012). Intel frequently uses a dual-mode procurement system: a regular procurement mode is low-cost but has a longer lead time, and a flexible mode is more expensive but guarantees a shorter procurement lead time. According to the setting depicted in **Figure 1**, the retailer signs the option contract with supplier 2 by paying a reservation fee upfront at a premium (e.g., α% of the unit strike price), which entitles the retailer the right to receive a given quantity at an agreed-upon option strike price. In return, supplier 2 guarantees the maximum delivery quantity by making the commitment to reserve a certain capacity for the retailer (Merzifonluoglu, 2017).

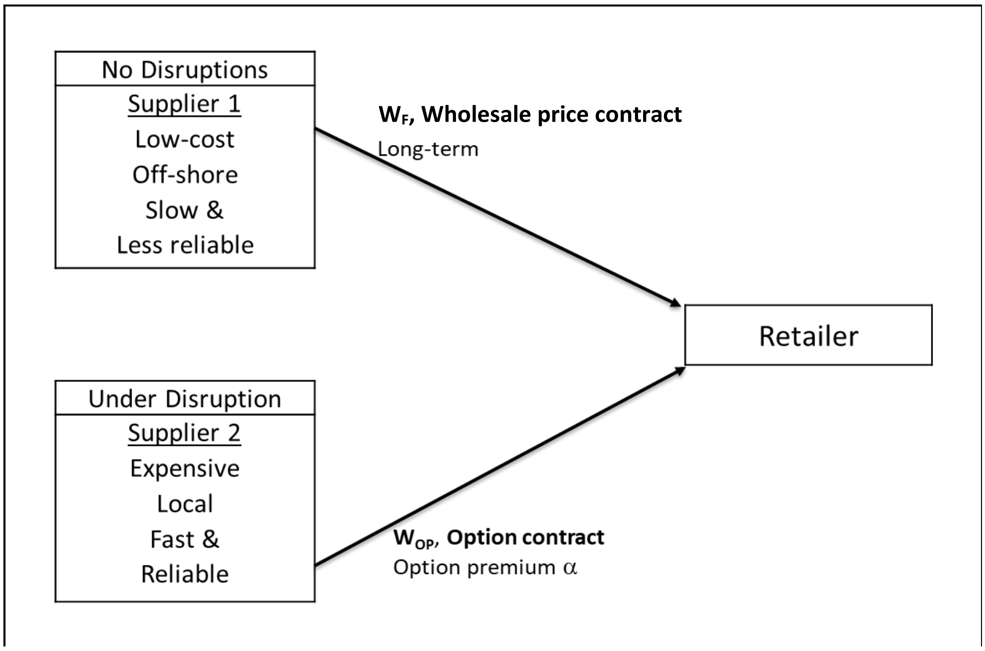

Figure 1 Wholesale price contract vs. option contract

The option contract-based portfolio procurement in this research works as follows: With no disruptions prior to the selling season at supplier 1, the retailer will get the full order quantity delivered from supplier 1 and lose the option premium paid upfront to supplier 2. However, in case of a disruptive event at the offshore supplier (i.e., supplier 1), the shipment cannot proceed to the retailer as scheduled. Instead, the retailer will receive the full order shipment from supplier 2 as per the option contract. In such a case, supplier 1 is deemed exempt from any penalties or any subsequent inventory replenishment responsibility via backorders. The option strike price (plus the premium reservation fee) is typically set higher than the wholesale price set for the fixed long-term contract. With a typical option contract, the exercise of the option is contingent on the volatility of the market price of the product (Nosoohi and Nookabadi, 2019;

Fu *et al*., 2012). In this research, we consider a case where the option contract is contingent specifically on the occurrence of the disruptive event at supplier 1 halting the shipments to the retailer in time for the selling season, a practical case largely missing from the procurement management literature.

This paper examines the effectiveness of the option contract compared with the base case, which presumes the use of the long-term wholesale price contract only, with or without the supply-side disruption. For the base case, if a disruptive event occurs at the supplier, disabling its operations and shipments to the retailer prior to the selling season, the effective demand will proportionally be reduced depending on the actual length of the selling season. Lost sales quantity in this scenario will be determined by the total seasonal demand and the duration of the disruption (or based on the recovery process to the normal state). Applying the traditional newsvendor model, the portfolio procurement with the wholesale price contract and the option contract is described using the following notations:

W_F = the price of the item with the long-term wholesale price contract
W_{OP} = the option strike price, where $W_F < W_{OP}$
α = the option premium expressed as a fraction of the strike price
p = unit retail price
s = unit salvage value
$gw(R)$ = unit loss of goodwill cost incurred at the retailer
Q_F = the quantity ordered with the wholesale price contract
Q_{OP}= the quantity ordered with the option strike price
x = market demand, normally distributed with a mean of $\hat{x}$ and a standard deviation of σ
λ = disruption rate over time
μ = recovery rate from the disruptive event over time

The retailer faces the understocking (C_u) and the overstocking costs (C_o) respectively as shown below with no disruptions in (1) and (2), and with a possible disruption in the upstream in equations (3) and (4).

No disruptions:

$$C_U = p - W_F + gw(R) \quad (1)$$
$$C_O = W_F - s \quad (2)$$

With disruption:

$$C_U = p - W_{OP} \cdot (1 + \alpha) + gw(R) \quad (3)$$
$$C_O = W_{OP} \cdot (1 + \alpha) - s \quad (4)$$

The occurrence of the supply-side disruption is random and follows a Poisson process with rate λ over time and the recovery to the normal state occurs with rate μ, with the time to the full recovery following an exponential distribution with an average disruption duration of $1/\mu$. For such a case, the overall supply disruption and the recovery process can be approximated by a capacitated queuing system, *M/M/1/K*. The system capacity *K* can be set as 1 implying that, at any given time, there is at most one disruption occurring at supplier 1 affecting the operations and the shipment to the retailer. As per the results for *M/M/1/K* system from Gross and Harris (1985), state probabilities, p_0 (no disruption) and p_1 (disruption) for the supply disruption and the recovery process can be obtained as follows in (5) and (6):

$$p_0 = \frac{\mu}{\lambda+\mu} \quad (5)$$
$$p_1 = \frac{\lambda}{\lambda+\mu} \quad (6)$$

where $\sum_{n=0}^{1} p_n = p_0 + p_1 = 1$, by definition.

From above, it follows that the expected retailer profit, $\mathrm{E}[P_R(Q_F, Q_{OP})]$, is obtained using the newsvendor model as in (7):

$$\mathrm{E}[P_R(Q_F, Q_{OP})] = \left(\frac{\mu}{\lambda+\mu}\right) \cdot [(p-s)\hat{x} - (W_F - s)Q_F - (p - s + gw(R)) \cdot E(s)_F] + \left(\frac{\lambda}{\lambda+\mu}\right) \cdot [(p-s)\hat{x} - (W_{OP}(1 + \alpha) - s)Q_{OP} - (p - s + gw(R)) \cdot E(s)_{OP}] \quad (7)$$

where $E(S)_F$ and $E(S)_{OP}$ are the expected shortages with no disruptions and with disruptions, respectively.

From equation (7) above, the desired service level for each case is obtained as below in (8) and (9):

No disruptions:

$$SL = {p - W_F + gw(R)} \Big/ {p - s + gw(R)} \quad (8)$$

With disruption:

$$SL = {p - W_{OP}(1 + \alpha) + gw(R)} \Big/ {p - s + gw(R)} \quad (9)$$

4. NUMERICAL EXPERIMENTS AND MANAGERIAL INSIGHTS

4.1 Settings for Numerical Experiments

Numerical experiments are conducted to investigate and understand the dynamics of the procurement process in the supply chain when the option contract is considered by the buyer under supply-side disruptions which halt any shipments to be made from the regular supplier (i.e., supplier 1 in **Figure 1**) to the retailer. The range of parameter values and the assumptions used for the numerical experiments and the sensitivity analysis are summarized in **Table 1**.

Table 1 Parameters and assumptions for simulation experiments

Fixed parameters (per unit)	Parameters (range)
p = $50.00	*cv* = 0.1, 0.3, 0.5
c = $15.00	W_{OP} = $27, $30, $33 (per unit)
s = $10.00	λ = 1, 3, 6, 12 (per year)
W_F = $25	μ = 13, 26, 52, 104 (per year)
gw(R) = $30	
$\hat{x}$ = 1,000 units	**Assumptions**
σ = as per cv	Demand follows a normal distribution
α = 5% of option strike price	Disruption follows a Poisson distribution (with rate λ) and the recovery time follows an exponential distribution (with an avg. of $1/\mu$).
Q_F, Q_{OP} = To be determined for each case as per the service level.	

The retailer faces the market demand with an average of 1,000 units with the demand variability defined by the coefficient of variation (cv) of demand that ranges from 0.1 (low variability) to 0.5 (high variability). As for the range of risk parameters used for simulation runs, the disruption rate (λ) and the recovery rate (μ), which represent the frequency and the duration of disruptions respectively are selected based on existing studies and numerous industry reports to reflect the real disruptive events experienced by businesses across different industry sectors. Tummala and Schoenherr (2011) introduce a structured risk assessment framework called the Supply Chain Risk Management Process (SCRMP) in which they use a risk consequence index and risk exposure values to make a supply chain risk assessment. Using several consequence severity categories and risk probability categories, they present an approach to study the relationship between the frequency and the severity of the consequences of disruptions. Bode and Wagner (2015) implement an empirical investigation of system complexity to identify which supply chain characteristics increase the frequency of disruptions. Revilla and Saenz (2017) develop a taxonomy of how businesses approach supply chain risk management using a cluster analysis of survey data in predicting a firm's supply chain performance based on the frequency of disruptive events. Recently, Mehrotra and Schmidt (2021) develop a model to study characteristics of disruptive events associated with the value of disruption duration information. Other studies find that a larger supply base or different sourcing and procurement arrangements may increase supply chain complexity but mitigate the impact of disruptions (Chaturvedi and Martinez-de-Albeniz, 2011; Choi and Krause, 2006). Crandall *et al*. (2014) show that internal risks tend to display high disruption frequency with a low impact, whereas natural disasters show a low frequency but a high impact. A comprehensive literature review on the research stream of supply chain disruptions and resilience is provided in Katsaliaki *et al*. (2022) in which existing studies are compiled based on the types of disruptions, their impact, resilience methods, and recovery strategies.

As for the industry-based surveys, the latest Business Continuity Institute's Supply Chain Resilience Report (2023) presents results from 225 respondents from 58 countries and 17 industry sectors. Approximately 11.5% of respondents report at least ten disruptive events in the last 12 months, a decrease compared to 27.8% at the peak of the COVID-19 pandemic in 2021. McKinsey Global Institute's report (2020) on supply chain risk and resilience emphasizes a recent trend in the global supply chain disruption, which clearly exhibits higher frequency and severity than the past. Detailed analysis of 23 industry value chains shows an overall inverse relationship between the frequency and the duration of disruptions, where minor disruptions may last for about a week, but major ones can continue for over two months. The report further reveals that a longer disruption duration (say, a major disruption) is generally associated with a lower frequency of disruptive events. In the simulation experiments and sensitivity analysis of this research, the disruption frequency (λ = 1, 3, 6, 12 per year) and the recovery rate (μ = 13, 26, 52, 104 per year) are selected based on the results from existing literature and the aforementioned industry surveys to capture characteristics and relationships observed in actual supply chain disruptions. A recovery rate value of μ = 13 per year indicates an average disruption duration of approximately 4 (= 52/13) weeks.

In addition to the range of risk parameters selected above, other parameter values used for the procurement process are chosen to cover a broad range of supply chain settings to present results on the effectiveness of the portfolio procurement over the long-term wholesaler price contract. As for the option strike price, W_{OP} of $27, $30, and $33 are used to investigate the impact of the option contract parameters along with the option premium, α = 5%, applied to the option strike price, W_{OP}. Other fixed parameters selected for the numerical experiments include the salvage value, s = $10 per unit, loss of goodwill cost at the retailer, *gw(R)* = $30 per unit, and the long-term wholesale price of W_F = $25. Overall, a total combination of 144 (=3x3x4x4) business scenarios are examined thoroughly for the numerical experiments. For each scenario, simulation runs are conducted using the Crystal Ball® simulation package and summarized over 500 cycles and 10,000 replications.

4.2 Discussions of Results and Managerial Implications

4.2.1 Supply Chain and Retailer Profitability

For all cases considered for the demand variability (in terms of the coefficient of variation, *cv*), the portfolio procurement with the option contract provides a solid protection against lost sales situations resulting in higher retailer profits than the base case, especially when the supply-side disruption prevails with a high disruption frequency and a slow recovery to the normal state as shown in **Figure 2**.

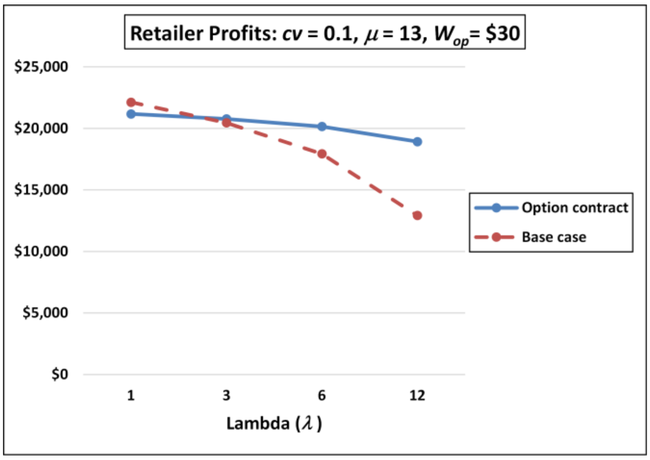

Figure 2 Retailer profits with a slow recovery process: option contract vs. base case

For situations with a relatively low disruption frequency (e.g., λ = 1 or 3 per year), however, the base case with a favourable wholesale price (W_F = $25) for the retailer performs better than or just as well as the portfolio procurement with the option contract in terms of the retailer profits even when the recovery process is relatively slow and ineffective (e.g., μ = 13 per year or an average disruption duration of 4 weeks).

Further, if the retailer already possesses the resilience and the capacity to recover back to the normal state within a short period of time (e.g., μ = 104 per year or an average disruption duration of half a week), then the base case constitutes a better choice than the portfolio procurement for the retailer across all scenarios of the disruption frequency and duration considered in the simulation. That is, for situations in which the retailer is already well prepared to manage the disruptive event with a solid reactive measure to quickly bounce back to the normal state (i.e., when the retailer's setting can be characterized by a high value of μ), designing an option contract in anticipation of supply disruptions does not carry much value for the retailer as the procurement mode switches to the option contract upon the occurrence of a disruptive event without benefitting from the reactive measure. For all cases considered in the numerical experiments, as long as the retailer has a relatively fast recovery measure in place (i.e., a high μ), the retailer will be better off profit-wise by staying with the base case as shown in **Figure 3**.

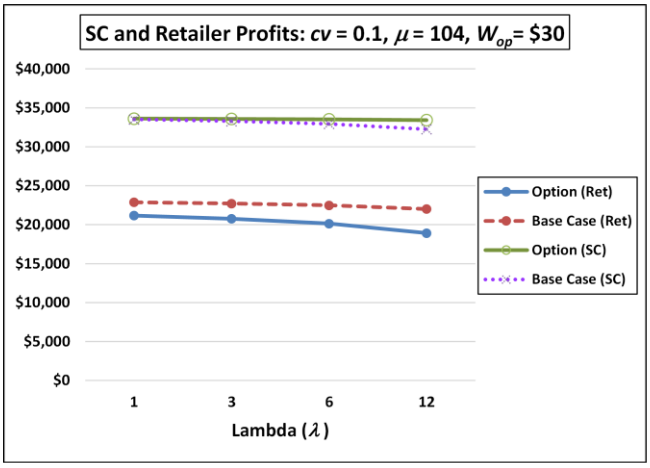

Figure 3 Supply chain profits with a fast recovery process: option contract vs. base case

From the overall systems perspective, however, it should also be noted in **Figure 3** that the use of the option contract-based portfolio procurement results in consistently higher supply chain profitability than the base case. An exception to this phenomenon occurs when a quick recovery to the normal state is possible in the supply chain via reactive measures under high demand variability (i.e., when *cv* = 0.5). In such a setting, the value of portfolio procurement as a risk hedging mechanism is not as pronounced for the overall supply chain profitability as reactive measures can work effectively to restore normal conditions under disruptions. As seen in **Figure 4**, with a strong reactive measure in place, the base case approach performs slightly but consistently better than the portfolio procurement in terms of the supply chain profits and significantly better with respect to the retailer profitability when the demand-side uncertainty prevails (i.e., when *cv* = 0.5). That is, having a solid reactive measure in place can lead to greater effectiveness in achieving good profitability both locally and globally than a mere implementation of portfolio procurement when there is a significant level of demand variability (i.e., high *cv*) as well as supply disruptions (i.e., a high value of λ) prevailing in the supply chain.

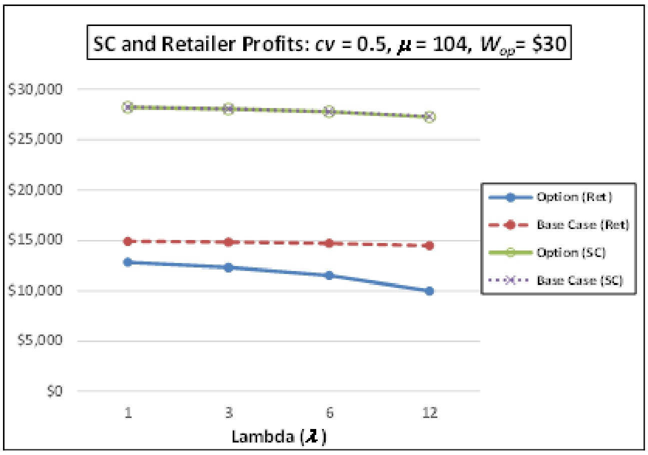

Figure 4 Supply chain profits with high demand variability: option contract vs. base case

4.2.2 % Improvement in Profits

Although the retailer profits monotonically decline in λ (the disruption frequency), the portfolio procurement leads to a significant % improvement in retailer profitability as the disruption frequency increases. Here, the % improvement in profits refers to the percentage increase in the retailer profits by converting from the base case with the wholesale price contract to the option contract-based portfolio procurement. It is evident that incorporating the option contract in the procurement process will be beneficial for the retailer when supply disruptions prevail. That is, the higher the disruption frequency, λ, the greater the % improvement in the retailer profits by implementing the option contract-based portfolio procurement as it provides an effective risk hedging means and protection against lost sales when disruptions occur. **Figure 5** reveals that the impact on the % improvement in the retailer profits appears way more pronounced when the option strike (or the exercise) price is relatively low and close to the wholesale price (about 59% improvement in the retailer profits for λ = 12 and W_{OP} = \$27). However, as observed earlier, the base case with the wholesale price contract may perform better than the portfolio procurement resulting in negative % improvement when the disruptive events are not as frequent (e.g., when λ = 1 per year).

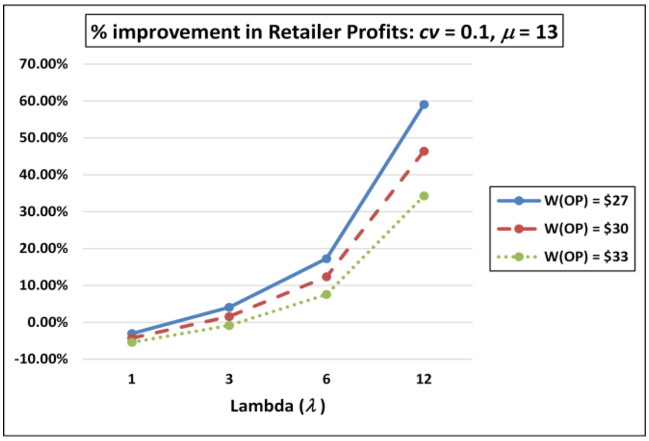

Figure 5 % Improvement in retailer profits: the impact of option strike price

For similar reasons, when the recovery process from the disruption is slow and ineffective (i.e., for low values of μ, say, μ = 13 per year), the portfolio procurement shows significant improvement over the base case when the disruption occurs with high frequency. It is worth noting that the business setting characterized more by the supply-side disruption (high λ, low μ, and low *cv*) than the demand-side uncertainty generally favours the use of the portfolio procurement by the retailer.

Now, the impact of demand variability (*cv*) on % improvement in profits shows an intriguing result under supply disruptions. As shown in **Figure 6**, the lower the demand variability (*cv*), the more effective a role the option contract plays in its protection against the lost sales quantity as illustrated in the % improvement (as high as 46%) in retailer profits. In general, a low demand variability (e.g., *cv* = 0.1) with a relatively low standard deviation of demand requires a modest safety stock level at the retailer, which in turn, provides little protection against uncertainties from either the demand-side or the supply-side, rendering the option contract more valuable as risk-hedging mechanism. However, if the retailer faces high demand variability (high *cv*), the higher safety stock required can be used to mitigate both the demand-side and the supply-side disruptions, diluting the effectiveness of the portfolio procurement to a certain degree.

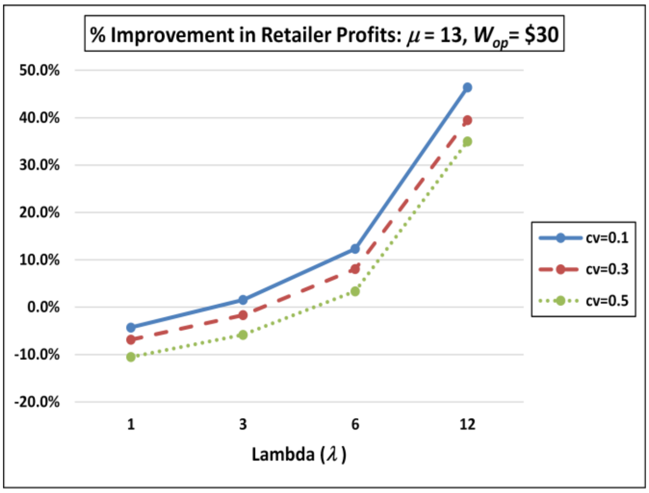

Figure 6 The impact of demand variability and disruption frequency

Especially, when supply-side disruptions occur with high frequency (i.e., a high λ) and go through a relatively slow recovery process (i.e., a low μ), the value of the option contract is more apparent. For such cases, the retailer has a much stronger incentive to consider the option contract-based portfolio procurement as a risk-hedging and profit-improving approach. On the other hand, when supply disruptions exhibit low frequency with fast recovery (i.e., a low λ with a high μ), the base case dominates and outperforms the option contract with respect to retailer profits for all cases of demand variability (*cv*). That is, the value of the option contract for the retailer diminishes when the normal state gets restored after a short disruption duration (i.e., a high μ) for the base case.

4.2.3 % Reduction in the Lost Sales

Results on the lost sales improvement by implementing the portfolio procurement show solid evidence in support of the option contract-based approach, displaying a significant reduction in the lost sales quantity in all of the 144 scenarios considered across all values of *cv*, λ, and μ. As seen in **Figure 7**, when compared with the base case, for a given recovery rate, μ, the portfolio procurement with the option contract shows % reduction in lost sales quantity that ranges from 6% (for low λ and high *cv*) to 85.6% (for high λ and low *cv*), a result largely consistent with that obtained for the retailer profitability.

The option contract appears to be way more effective in reducing the lost sales quantity when applied under the scenarios with low demand variability (i.e., low *cv*), as low *cv* naturally implies a modest safety stock level required, hence insufficient protection against lost sales. The value of using the portfolio procurement becomes significant when demand side variability stays relatively under control and supply-side disruption is dominant.

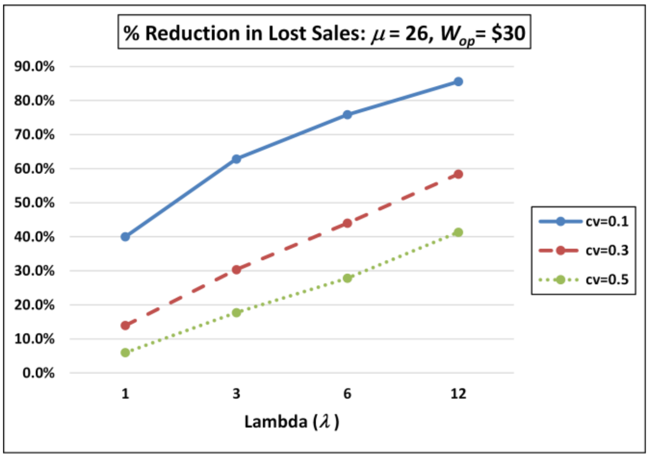

Figure 7 % reduction in lost sales with the portfolio procurement approach

Table 2 shows a side-by-side comparison of the results on supply chain profits, retailer profits, service levels, and the lost sales quantity for the base case and the portfolio procurement, in which the reduction in the lost sales quantity is evident, especially for cases with a high disruption frequency (e.g., λ = 12 per year) as displayed in **Table 2**.

Further, the effectiveness of the use of the option contract-based procurement in keeping the lost sales quantity under control is clear and significant when the retailer lacks reactive measures. For a given recovery process (i.e., for a given value of μ), the option contract provides solid stability in terms of the lost sales incurred when the disruptive events increase as indicated by just a small increase in the lost sales quantity.

Table 2 Numerical results for profits, service levels, and lost sales: option contract vs. base case

cv = 0.3, W_{op} = $30									
Base case					**Portfolio procurement**				
λ = 1	μ = 13	μ = 26	μ = 52	μ = 104	λ = 1	μ = 13	μ = 26	μ = 52	μ = 104
SC Profits	$29,776	$30,369	$30,674	$30,797	**SC Profits**	$30,838	$30,841	$30,840	$30,837
Ret Profits	$18,162	$18,536	$18,741	$18,821	**Ret Profits**	$16,916	$16,917	$16,917	$16,915
Service level	76.8%	77.4%	77.9%	78.3%	**Service level**	78.3%	78.3%	78.3%	78.3%
Lost sales	53	43	39	37	**Lost sales**	37	37	37	37
λ = 3	μ = 13	μ = 26	μ = 52	μ = 104	λ = 3	μ = 13	μ = 26	μ = 52	μ = 104
SC Profits	$27,546	$29,326	$30,236	$30,612	**SC Profits**	$30,738	$30,732	$30,741	$30,732
Ret Profits	$16,734	$17,855	$18,471	$18,713	**Ret Profits**	$16,455	$16,450	$16,457	$16,450
Service level	73.2%	75.0%	76.6%	77.6%	**Service level**	77.6%	77.6%	77.6%	77.6%
Lost sales	86	56	44	40	**Lost sales**	39	39	39	40
λ = 6	μ = 13	μ = 26	μ = 52	μ = 104	λ = 6	μ = 13	μ = 26	μ = 52	μ = 104
SC Profits	$24,182	$27,753	$29,583	$30,343	**SC Profits**	$30,575	$30,381	$30,584	$30,581
Ret Profits	$14,577	$16,836	$18,065	$18,561	**Ret Profits**	$15,753	$15,762	$15,762	$15,760
Service level	67.7%	71.3%	74.5%	76.5%	**Service level**	76.5%	76.5%	76.5%	76.5%
Lost sales	135	75	50	42	**Lost sales**	42	42	42	43
λ = 12	μ = 13	μ = 26	μ = 52	μ = 104	λ = 12	μ = 13	μ = 26	μ = 52	μ = 104
SC Profits	$17,191	$24,641	$28,269	$29,794	**SC Profits**	$30,270	$30,277	$30,263	$30,271
Ret Profits	$10,301	$14,813	$17,427	$18,242	**Ret Profits**	$14,369	$14,376	$14358	$14,272
Service level	56.6%	63.9%	70.5%	74.4%	**Service level**	74.4%	74.4%	74.4%	74.4%
Lost sales	233	113	64	47	**Lost sales**	47	47	47	48

For instance, as revealed in **Table 2**, when the option contract-based portfolio procurement is used, the average lost sales quantity increases from 37 units when λ = 1 per year to 47 units when λ = 12 per year (about 27% increase) under a slow recovery process (i.e., when μ = 13 per year or an average disruption duration of 4 weeks). However, as shown in **Table 2** and **Figure 8**, without the portfolio procurement in place, the base case procurement results in the average lost sales quantity growing dramatically from 53 units when λ = 1 to 233 units when λ = 12 per year (approximately 340% increase) for the same recovery rate of μ = 13 per year. As the frequency of the disruptive events increases, so will the incentive to use the option contract, which is evident from the strong protection against the lost sales quantity provided by the option contract-based portfolio procurement even when the retailer lacks in reactive measures.

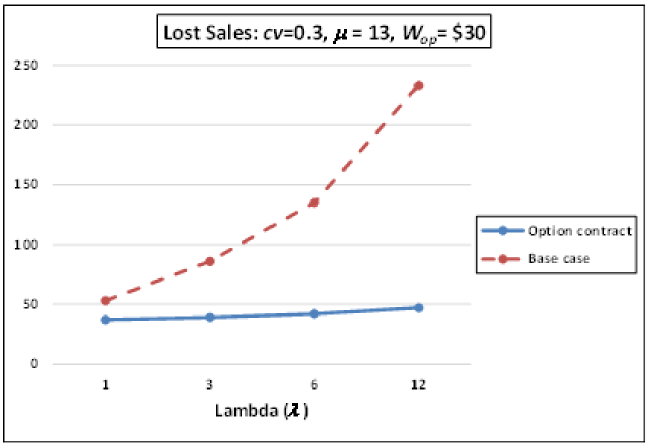

Figure 8 Lost sales quantity: option contract vs. base case

It should be noted that for a given frequency rate of disruption, λ, both the lost sales quantity and the service level remain the same when the option contract is implemented regardless of the effectiveness of the reactive measures to recover to the normal state. This is because the occurrence of a disruptive event immediately halts any shipments to be made from the regular supplier (or supplier 1) to the retailer and triggers the usage of the option contract with the local supplier (or supplier 2) in such a way that makes the procurement process independent of the recovery process post-disruption. That is, a fast and effective recovery process does not necessarily benefit the retailer when the option contract is used. For any base case scenarios without the option contract-based procurement, however, a proper implementation of reactive measures is crucial as it would be the only approach to keep the proliferation of lost sales situations in check when disruptions occur. In summary, the use of the portfolio procurement with the option contract not only provides a safety net for the retailer who may be lacking in reactive measures but also keeps the stock-out situations under control when supply-side disruptions prevail.

5. CONCLUSION

This paper provides insights into the value of the procurement management approach using the option contract as a risk-hedging mechanism against supply-side disruptions. It is noted that the base case dominates and outperforms the option contract-based procurement system when the supply chain is characterized mainly by demand-side uncertainties. However, the option contract-based portfolio procurement proves beneficial in terms of both the retailer profitability and the reduction in lost sales quantity when the supply-side disruptions prevail. In essence, business settings characterized by low option strike price and relatively high supply-side risk factors (i.e., with a high disruption frequency and a slow recovery process) enhance the value of using the portfolio procurement.

The supply chain structure used in this research with a single retailer and two suppliers can be considered a limitation in gaining a relevant perspective on the dynamics of implementing the portfolio procurement for products with a short shelf-life under a realistic and complex business setting. A future research extension that entails deeper investigation into the procurement management for multiple businesses in a multi-stage supply chain will be a challenging yet crucial task for the sake of gaining insights into risk mitigation. Any sub-optimal procurement and inventory decisions by the stakeholders under supply-side risk can easily lead to further disruptions and delays in fulfilment (Marcucci *et al.*, 2022). In particular, with a growing emphasis on the importance of developing a decentralized system to avoid the risk of a single point of failure (Tang *et al.*, 2014; Clark, 2012), the value of proper procurement management that encompasses procurement and inventory decisions across multiple locations is immense in mitigating disruptive risks in the supply chain (Ohmori *et al.*, 2023). In a similar context, the use of blockchain-based smart contracts is currently being applied in procurement processes in various fields, such as public procurement (Sanchez, 2019), healthcare supply chains (Omar *et al.*, 2021), and food supply chains (Sharma *et al.*, 2022). A further examination of blockchain technology and its applications in procurement management can be a meaningful one as blockchain technology is based on the premise of decentralized decision making involving multiple users (M. Wang *et al.*, 2021). Another possible extension for future research includes adding the spot market purchase as one of the components of the portfolio procurement as that broadens the supply-side options in the procurement process.

REFERENCES

Ai, X., Chen, J., and Ma, J. (2012). Contracting with Demand Uncertainty Under Supply Chain Competition. *Annals of Operations Research* 201 (1), pp. 17 - 38.

Bart, N., Chernonog, T., and Avinadav, T. (2021). Revenue-Sharing Contracts in Supply Chains: A Comprehensive Literature Review. *International Journal of Production Research* 59 (21), pp. 6633 - 6658.

Bode, C., and Wagner, S. M. (2015). Structural Drivers of Upstream Supply Chain Complexity and the Frequency of Supply Chain Disruptions. *Journal of Operations Management* 36 (1), pp. 215 - 228.

Braglia, M., and Zavanella, L. (2003). Modelling an Industrial Strategy for Inventory Management in Supply Chains: the "Consignment Stock" Case. *International Journal of Production Research* 41 (16), pp. 3793 - 3808.

Business Continuity Institute (2023). *BCI Supply Chain Resilience Report 2023*. Available at https://www.thebci.org/resource/bci-supply-chain-resilience-report-2023.html (Accessed: 28 April 2023).

Cachon, G. P., and Lariviere, M. A. (2005). Supply Chain Coordination with Revenue-Sharing Contracts: Strengths and Limitations. *Management Science* 51 (1), pp. 30 - 44.

Chaturvedi, A., and Martinez-de-Albeniz, V. (2011). Optimal Procurement Design in the Presence of Supply Risk. *Manufacturing and Service Operations Management* 13 (2), pp. 227 - 243.

Choi, T. Y., and Krause, D. R. (2006). The Supply Base and its Complexity: Implications for Transaction Costs, Risks, Responsiveness, and Innovation. *Journal of Operations Management* 24 (5), pp. 637 - 652.

Chopra, S., and Sodhi, M.S. (2004). Managing Risk to Avoid Supply-Chain Breakdown. *Sloan Management Review* 46 (1), pp. 53 - 61.

Chopra, S., and Sodhi, M.S. (2014). Reducing the Risk of Supply Chain Disruptions. *Sloan Management Review* 55 (3), pp. 73 - 80.

Clark, G. (2012). Understanding and Reducing the Risk of Supply Chain Disruptions. *Journal of Business Continuity & Emergency Planning* 6 (1), pp. 6 - 12.

Crandall, R. E., Crandall, W. R., and Chen, C. C. (2014). *Principles of Supply Chain Management 2nd Ed*., CRC Press, Boca Raton, FL.

Fu, Q., Lee, C., and Teo, C. (2010). Procurement Management Using Option Contracts: Random Spot Price and the Portfolio Effect. *IIE Transactions* 42 (11), pp. 793 - 811.

Fu, Q., Zhou, S. X., Chao, X., and Lee, C. (2012). Combined Pricing and Portfolio Option Procurement. *Production and Operations Management* 21 (2), pp. 361 - 377.

Gross, D., and Harris, C. M. (1985). *Fundamentals of Queuing Theory 2nd Ed*., John Wiley & Sons, New York, NY.

Kaplan, D. A., and Wehrwein, P. (2021). Price Tags on the COVID-19 Vaccines. *Managed Healthcare Executive* 31 (3), pp. 26 - 27.

Katsaliaki, K., Galetsi, P., and Kumar, S. (2022). Supply Chain Disruptions and Resilience: a Major Review and Future Research Agenda. *Annals of Operations Research* 319, pp. 965 - 1002.

Khuan, L. S., Shee, H. K., and See, T. S. (2023). Strategies to Mitigate Supply Chain Disruptions During COVID-19: the Lived Experience of SC Professionals. *Operations and Supply Chain Management: An International Journal* 16 (1), pp. 62 - 76.

Knoblich, K., Ehm, H., Heavey, C., and Williams, P. (2011). Modeling Supply Contracts in Semiconductor Supply Chains. *Proceedings of the 2011 Winter Simulation Conference (WSC)*, Phoenix, AZ, USA, pp. 2108 - 2118.

Lee, C., Li, X., and Xie, Y. (2013). Procurement Risk Management Using Capacitated Option Contracts with Fixed Ordering Costs. *IIE Transactions* 45 (8), pp. 845 - 864.

Lefebvre, B. (2022). Biden's Battling One Energy Price Nightmare. Here Comes Another. *Politico*. Available at https://www.politico.com/news/2022/05/13/rising-gasoline-prices-biden-natural-gas-00031424 (Accessed: 29 May 2022).

Li, J., and Liu, L. (2006). Supply Chain Coordination with Quantity Discount Policy. *International Journal of Production Economics* 101 (1), pp. 89 - 98.

Marcucci, C., Antomarioni, S., Ciarapica, F. E., and Bevilacqua, M. (2022). The Impact of Operations and It-Related Industry 4.0 Key Technologies on Organizational Resilience. *Production Planning & Control* 33 (15), pp. 1417 - 1431.

Martin, P., Gupta, D., and Natarajan, K.V. (2020). Vaccine Procurement Contracts for Developing Countries. *Production and Operations Management* 29 (11), pp. 2601 - 2620.

Martinez-de-Albeniz, V. (2009). Using Supplier Portfolios to Manage Demand Risk. *Handbook of Integrated Risk Management in Global Supply Chains*. Edited by Kouvelis, P., Boyabatli, O., Dong, L., and Li, R. *John Wiley & Sons*, Hoboken, NJ.

Martinez-de-Albeniz, V., and Simchi-Levi, D. (2005). A Portfolio Approach to Procurement Contracts. *Production and Operations Management* 14 (1), pp. 90 - 114.

McKinsey Global Institute (2020). *Risk, Resilience, and Rebalancing in Global Value Chains*. Available at https://www.mckinsey.com/capabilities/operations/our-insights/risk-resilience-and-rebalancing-in-global-value-chains (Accessed: 28 April 2023).

Mehrotra, M., and Schmidt, W. (2021). The Value of Supply Chain Disruption Duration Information. *Production and Operations Management* 30 (9), pp. 3015 - 3035.

Merzifonluoglu, Y. (2017). Integrated Demand and Procurement Portfolio Management with Spot Market Volatility and Option Contracts. *European Journal of Operational Research* 258 (1), pp. 181 - 192.

Mohammadivojdan, R., Merzifonluoglu, Y., and Geunes, J. (2022). Procurement Portfolio Planning for a Newsvendor with Supplier Delivery Uncertainty. *European Journal of Operational Research* 297 (3), pp. 917 - 929.

Nagali, V., Hwang, J., Sanghera, D., Gaskins, M., Pridgen, M., Thurston, T., Mackenroth, P., Branvold, D., Scholler, P., and Shoemaker, G. (2008). Procurement Risk Management (PRM) at Hewlett-Packard Company. *Interfaces* 38 (1), pp. 51 - 60.

Norrman, A., and Naslund, D. (2019). Supply Chain Incentive Alignment: The Gap Between Perceived Importance and Actual Practice. *Operations and Supply Chain Management: An International Journal* 12 (3), pp. 129 - 142.

Nosoohi, I., and Nookabadi, A. S. (2019). Outsource Planning with Asymmetric Supply Cost Information Through a Menu of Option Contracts. *International Transactions in Operational Research* 26, pp. 1422 - 1450.

Ohmori, S., Torres, A. J. R., and Mahmoodi, F. (2023). Multi-Echelon Inventory Optimization Under Disruption Risk. *Operations and Supply Chain Management: An International Journal* 16 (2), pp. 177 - 189.

Olhager, J. (2013). Evolution of Operations Planning and Control: from Production to Supply Chains. *International Journal of Production Research* 51 (23-24), pp. 6836 - 6843.

Omar, I.A., Jayaraman, R., Debe, M. S., Salah, K., Yaqoob, I., and Omar, M. (2021). Automating Procurement Contracts in the Healthcare Supply Chain Using Blockchain Smart Contracts. *IEEE Access* 9, pp. 37397 - 37409.

Pasternack, B. (1985). Optimal Pricing and Returns Policies for Perishable Commodities. *Marketing Science* 4 (2), 166 - 176.

Pazirandeh, A. (2011). Sourcing in Global Health Supply Chains for Developing Countries. *International Journal of Physical Distribution & Logistics Management* 41 (4), pp. 364 - 384.

Peng, C., Erhun, F., Hertzler, E. F., and Kempf, K. G. (2012). Capacity Planning in the Semi-Conductor Industry: Dual Mode Procurement with Options. *Manufacturing and Service Operations Management* 14 (2), pp. 170 - 185.

Polinsky, A.M. (1987). Fixed Price Versus Spot Price Contracts: A Study in Risk Allocation. *Journal of Law, Economics, and Organization* 3 (1), pp. 27 - 46.

Revilla, E., and Saenz, M. J. (2017). The Impact of Risk Management on the Frequency of Supply Chain Disruptions: A Configurational Approach. *International Journal of Operations and Production Management* 37 (5), pp. 557 - 576.

Sanchez, S. N. (2019). The Implementation of Decentralised Ledger Technologies for Public Procurement. *European Procurement and Public Private Partnership Law Review* 14 (3), pp. 180 - 196.

Sarkar, B., Zhang, C., Majumder, A., Sarkar, M., and Seo, Y. W. (2018). A Distribution Free Newsvendor Model with Consignment Policy and Retailer's Royalty Reduction. *International Journal of Production Research* 56 (15), pp. 5025 - 5044.

Shamsi, N., Torabi, S. A., and Shakouri, H. (2018). An Option Contract for Vaccine Procurement Using the SIR Epidemic Model. *European Journal of Operational Research* 267 (3), pp. 1122 - 1140.

Sharma, M., Joshi, S., Luthra, S., and Kumar, A. (2022). Managing Disruptions and Risks Amidst COVID-19 Outbreaks: Role of Blockchain Technology in Developing Resilient Food Supply Chains. *Operations Management Research* 15, pp. 268 - 281.

Sun, X., Chung, S., Choi, T., Sheu, J., and Ma, H. L. (2020). Combating Lead-Time Uncertainty in Global Supply Chain's Shipment-Assignment: Is It Wise to be Risk-Averse? *Transportation Research Part B: Methodological* 138 (C), pp. 406 - 434.

Tang, S. Y., Gurnani, H., and Gupta, D. (2014). Managing Disruptions in Decentralized Supply Chains with Endogenous Supply Process Reliability. *Production and Operations Management* 23 (7), pp. 1198 - 1211.

Tsay, A. (1999). The Quantity Flexibility Contract and Supplier-Customer Incentives. *Management Science* 45 (10), pp. 1339 - 1358.

Tummala, V. M. R., and Schoenherr, T. (2011). Assessing and Managing Risk Using the Supply Chain Risk Management Process (SCRMP). *Supply Chain Management: An International Journal* 16 (6), pp. 474 - 483.

US Energy Information Administration (EIA) (2023). Henry Hub Natural Gas Spot Price. Available at https://www.eia.gov/dnav/ng/hist/rngwhhdD.htm (Accessed: 7 May 2023).

van den Bogaert, J., and van Jaarsveld, W. (2022). Vendor-Managed Inventory in Practice: Understanding and Mitigating the Impact of Supplier Heterogeneity. *International Journal of Production Research* 60 (20), pp. 6087 - 6103.

Wang, C., Chen, J., and Chen, X. (2017). Pricing and Order Decisions with Option Contracts in the Presence of Customer Returns. *International Journal of Production Economics* 193, pp. 422 - 436.

Wang, M., Wu, Y., Chen, B., and Evans, M. (2021). Blockchain and Supply Chain Management: a New Paradigm for Supply Chain Integration and Collaboration. *Operations and Supply Chain Management: An International Journal* 14 (1), pp. 111 - 122.

Wang, S., Gurnani, H., and Subramanian, U. (2021). The Informational Role of Buyback Contracts. *Management Science* 67 (1), pp. 279 – 296.

Wieteska, G. (2020). The Impact of Supplier Involvement in Product Development on Supply Chain Risks and Supply Chain Resilience. *Operations and Supply Chain Management: An International Journal* 13 (4), pp. 359 - 374.

Wong, C. W. Y., Lirn, T., Yang, C., and Shang, K. (2020). Supply Chain and External Conditions Under Which Supply Chain Resilience Pays: An Organizational Information Processing Theorization. *International Journal of Production Economics* 226, pp. 1 - 11.

Yao, Y., and Dresner, M. (2008). The Inventory Value of Information Sharing, Continuous Replenishment, and Vendor-Managed Inventory. *Transportation Research Part E: Logistics and Transportation Review* 44 (3), pp. 361 - 378.

Zsidisin, G. A., and Smith, M. E. (2005). Managing Supply Risk with Early Supplier Involvement: A Case Study and Research Propositions. *Journal of Supply Chain Management* 41 (4) pp. 44 - 57.

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