Reserve or Not? Ordering Emergency Supplies from an Opportunistic Supplier Facing Yield and Demand Uncertainties

1. Introduction

Recent years, the global supply chain has been increasingly challenged by unexpected and undesired events. Familiar terms such as COVID-19, the Russia-Ukraine conflict, the Israel-Palestine conflict, and Red Sea tensions triggers surges in demand for emergency supplies while simultaneously causing shortages in raw materials. The pain point of reserving emergency supplies lies in the difficulty of demonstrating their economic and social effects during the long period with low-probability but potentially influential events. On a micro level, the profit-driven nature of companies, coupled with the various financial capacity, might dissuade them from maintaining additional emergency reserves for critical production materials. This dichotomy presents a complex challenge for emergency reserve management: ensuring sufficient inventory levels to handle unpredictable, high-impact events without incurring prohibitive costs. This is also one of the main reasons why we frequently witness a substantial mismatch between inadequate supply and skyrocketing demand during sudden disaster events.

To address the challenge, we investigate a novel two-sided-subsidy-embedded agreement reserve scheme. This scheme is designed for the bilateral supply chain and aims to enhance preparedness against demand and yield uncertainties in an efficient and cost-effective manner. Unlike traditional reserve methods that require heavy investment in inventory, or Vendor-Managed Inventory (VMI) systems that place the inventory management burden on solely the supplier, the agreement scheme offers a balanced approach that aligns the incentives of both buyers and supplier through a form of subsidy that incorporates both incentives and default penalties.

Within this framework, buyers place advance orders for emergency supplies that do not require immediate delivery. In the event of an emergency, the supplier is obligated to fulfill these orders. In return, the buyer commits to paying the supplier a periodic subsidy (e.g., monthly), regardless of whether an emergency occurs. However, rational opportunistic supplier may engage in speculative behavior using the random production yield and the stochastic nature of emergencies. To regulate such behavior, the agreement reserve scheme mandates that the supplier compensates the buyer for any shortfall in delivery, regardless of the quantity of shortage.

2. Research Questions and Summary of Findings

The primary objective of our paper aims to delineate the optimal inventory strategies under the agreement reserve scheme and two benchmarks, and examine how the characteristics of emergencies (e.g., frequency) and commodity attributes (e.g., wholesale price) influence the decision of supplier and buyer. By comparing with the traditional reserve and VMI schemes, this study explores the conditions under which the agreement reserve is financially preferred.

We answer the research question by formulating the interaction of buyer and supplier under the Stackelberg game setting, facing two sources of uncertainty: the random yield from the supplier's production and the random demand surge from the end market. By integrating a subsidy with default penalty, the agreement reserve scheme successfully incentivizes the supplier to maintain higher inventory levels, reducing the impact of the double-marginalization, thereby enhancing the preparedness towards the supply disruptions. Our analysis incorporates a modified newsvendor model, revealing the two-sided subsidy can provide a viable alternative to the supplier, the buyer, and the supply chain to manage the risks raised from emergencies, leading to a win-win-win solution.

We find that the rational opportunistic supplier's decision on the level of speculation bases on the capacity of the random yield, and this speculative behavior is irrelevant of the buyer's ordering quantity, meaning the buyer's order size, if diverging from the optimal decision, does not influence the supplier's degree of speculation. Moreover, we discover that the presence of subsidy results in the supplier under the agreement reserve scheme performing better in terms of profit than under the VMI scheme; similarly, buyer under the agreement reserve scheme outperforms that under the traditional reserve in profitability. From the perspective of the entire supply chain's performance, the agreement reserve is particularly suitable for scenarios with a lower probability of emergency, addressing a pain point that existing reserve schemes struggle to manage effectively.

We also find that, at least when the wholesale price is relatively low, supplier under the agreement reserve scheme experiences overstocking compared to the centralized supply chain decision. This outcome demonstrates that when a lower wholesale price fails to motivate supplier to stock inventory, the subsidy and default penalty effectively fulfill this role. Due to the narrow profit margin, supplier cannot afford the consequences of default, hence tending to overstock to minimize the risk of being penalized, even if this inventory level exceeds that of the centralized supply chain inventory.

3. Innovative Element in Our Paper

Our work builds on the growing literature of supply chain disruption (Ang et al. 2017, Dong et al. 2018, Lücker et al. 2021), with subsidy design (Arifoğlu and Tang 2022). We also incorporate

both the yield uncertainty and the market volatility (Dong et al. 2023). This paper contributes to the field of emergency management in operations by showcasing how strategic subsidy can overcome the conventional trade-offs between the inventory availability and financial expenditure, providing policymakers and practitioners an an effective tool for improving emergency preparation and responsiveness.

Three features set our paper apart from the existing literature. First, we study the coupling effect of subsidy and penalty on an opportunistic supplier, who tends to speculate inventory rationally, whereas most of the above literature considers the incentive tools without defining obligations. Moreover, to the best of our knowledge, our work is among the first to bring incentive program design into the emergency supplies management literature as a proactive scheme. Finally, we ensure the inventory quantity, by providing a subsidy, against the same objective supplier, whereas most two-sided subsidy mechanism considers putting their incentive and punishment on different objectives. Hence, our work provides new insights into the impact of using subsidies in preparation for supply chain disruption, along with supplier's random production yield and demand.

References

Ang, Erjie, Dan A Iancu, Robert Swinney. 2017. Disruption risk and optimal sourcing in multitier supply networks. *Management Science* **63**(8) 2397–2419.

Arifoğlu, Kenan, Christopher S Tang. 2022. A two-sided incentive program for coordinating the influenza vaccine supply chain. *Manufacturing & Service Operations Management* **24**(1) 235–255.

Dong, Lingxiu, Sammi Yu Tang, Brian Tomlin. 2018. Production chain disruptions: Inventory, preparedness, and insurance. *Production and Operations Management* **27**(7) 1251–1270.

Dong, Lingxiu, Guang Xiao, Nan Yang. 2023. Supply diversification under random yield: The impact of price postponement. *Production and Operations Management* .

Lücker, Florian, Sunil Chopra, Ralf W Seifert. 2021. Mitigating product shortage due to disruptions in multi-stage supply chains. *Production and Operations Management* **30**(4) 941–964.