Production Disruption

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Two kinds of incentive strategies, cost-sharing and penalty, are examined in dealing with production disruption, with consideration of production process reliability as an endogenous factor for a two-echelon supply chain.

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1. Introduction

Production disruption, emerging as one of the most important problems in real-world supply chain management, is increasingly arousing the interests of both researchers and practitioners [1][2]. A production disruption not only directly affects the operational performance of manufacturers, but also breaks the balance of the supply chain system and then affects the long-term sustainability of the supply chain. In 2020, for example, the supply disruption due to the COVID-19 pandemic in Europe drove Volkswagen to stop production, which caused significant loss to his partners. Similarly, in Japan, three giant automakers–Toyota, Honda, and Nissan–all suffered from significant operational performance impacts owed to production disruption [3]. Hendricks, Singhal, and Powell summarized the serious damage caused by production disruptions on the operational performance of manufacturers, which may lead to losses in the wealth and the reputation of shareholders [4][5][6]. Obviously, production disruption has a direct impact on the sustainability of the supply chain. Production disruption may also cause an increase in cost and in resource waste, which runs counter to the goal of global sustainable development. As a result, more and more firms have begun to place serious concerns on production disruption management. While they are beginning to appreciate the importance of supply chain disruptions, managing these disruptions remains a major challenge.

Generally, there are two broad categories of risks influencing production disruptions. The first category of risks originates from natural disasters (e.g., earthquake and epidemic) or social/economic events (e.g., strikes, financial crises, terroristic attacks), which are exogenous and uncontrollable. Previous studies on these risks mainly focused on five important strategies, including multiple sourcing, backup supply, inventory, emergency purchases, and demand management. These strategies have been extensively studied, aiming to mitigate the negative consequences of production disruptions [7][8][9]. The second category of risks arises from unqualified raw materials, design deficiency, and a lower technology level, which are more probable to happen but endogenous and controllable. As stated by Tunca and Zhu [10], it is common in the retail industry that a percentage of products offered by a manufacturer have some problems due to process or design issues. This will make the products unsellable, leading to a supply disruption. To deal with this kind of risk, one effective way is to offer incentives to manufacturers to improve their production process reliability. For example, Tang et al. proposed an approach by which retailers invest in improving suppliers' processes to reduce the likelihood of production disruptions [11].

Among the existing incentives, cost-sharing is an effective approach in improving production process reliability [11]. However, there is an underlying assumption for this strategy, that is, retailers have to be abundant in capital because cost-sharing will bring about additional cost. For those retailers who have insufficient capital at hand, this incentive may not be a good choice, possibly not even a feasible option. This motivates researchers to consider another type of incentive: to impose a penalty on the manufacturer for his default due to disruption, which is quite common and practical as an ex-ante strategy in supply chain disruption management [12]. Obviously, one of the main advantages of a penalty strategy is that the retailer need not prepare additional funds for the incentive. In fact, it is not unusual that a penalty is imposed for unfulfilling products in the reality. However, they also showed that a higher penalty from the retailer might bankrupt the supplier, which will in turn hurt her own benefit and even the whole supply chain from the viewpoint of long-term sustainability [12]. To this end, the retailer must determine a proper penalty level. Researchers will try to answer the question of what strategy should be adopted, cost-sharing or penalty, when incentives are required to stimulate the manufacturer improving his production process reliability to avoid a possible disruption. In addition, what is the most appropriate level of the penalty if a penalty strategy is preferred?

To address these issues, researchers consider a two-stage supply chain, where the manufacturer and the retailer are directly connected, and discuss their optimal strategies based on a Stackelberg game. First, researchers start with a basic model consisting of a retailer and a manufacturer, where the retailer faces a deterministic demand and the manufacturer's production process is subject to uncertain disruptions. Disruption probability is expressed as a function of a manufacturer's investment in process improvement. The retailer can influence the manufacturer's investment strategy by providing different incentives. However, demand is not always determined in practice, and actual demand will change with the quality of products, logistics, environment, and other factors, especially for seasonal products, such as electrical appliances. Hence, researchers extend the basic model to a more general and practical model, where the demand is stochastic. In order to obtain a more robust strategy for the uncertain setting, researchers also develop a loss-averse model, which shows the retailer's tradeoff between gain and loss. For all the models, researchers investigate the interactions between the retailer and the manufacturer with a Stackelberg game framework. The retailer, as a leader, determines the quantity ordered from her upstream firm, the proportion of cost-sharing or the penalty level for non-delivery. The manufacturer, as the follower, decides the investment level, in terms of the level of production process reliability. Based on this framework, researchers compare the performance of a penalty strategy with that of cost-sharing, and researchers analyze the efficacy of each strategy in improving production process reliability.

2. Production Disruption

With supply chain disruptions being more and more frequently occurring in business operations, the relative issues arouse the increasing interests of scholars [13]. Among the existing literature, disruptions are typically modeled from two perspectives: decentralized or centralized settings. In decentralized models, the emphasis is usually placed on interactions between the supply chain partners via, e.g., the framework of a Stackelberg game [14][15]. These papers focused on how a retailer used proper incentive mechanisms to motivate a manufacturer's investment in reliability and/or recoverability. On the other hand, centralized models have been used to explore disruption management for the supply chain as a whole. Such models tried to optimize the total benefits or costs of the supply chain system by employing effective disruption management strategies (e.g., [16]).

A large body of operational approaches for hedging against production disruptions have been proposed: multi-sourcing [17], carrying inventory [18][19], backup production options [20][21], demand management [9], and production process improvement [22][23]. Multi-sourcing is a commonly adopted approach used to mitigate the influence of the potential supply chain disruption. In the multi-sourcing model, retailers often split their orders to avoid goodwill costs because a single manufacturer is unable to supply [24][25]. For example, Tang et al. discussed the retailer's preference between single and dual sourcing strategies, showing that despite the benefit of a larger order in sole sourcing mode, dual sourcing might lead to a higher expected profit for the retailer under the same wholesale price [11]. A recent study by Gupta and Ivanov [26] extended this approach by considering risk-averse suppliers, and it analyzed the impact of the risk-averse feature on dual sourcing decisions under delivery disruption. Inventory management also plays an important role in production disruption. Much of current work focuses on either stochastic demand or production yield. Schmitt et al. modeled both of them, investigating the inventory systems subject to supply chain disruptions [27]. Besides the above two approaches, production process improvement is another prevailing strategy in production disruption management. Through empirical analysis, Krause et al. found that direct involvement is an effective strategy in improving reliability [28].

While multi-sourcing, carrying inventory, and production process improvement are ex-ante strategies in disruption management, backup production is an effective ex-post approach in reducing losses due to production disruption. Yang et al. investigated a downstream firm that faced a supplier privileged with private information about delivery disruptions. They found that the value of supplier backup production for the downstream firm was not larger under symmetric information [29].

Even though the relevant strategies have been widely considered and studied by scholars, with a few exceptions, most of the existing research assumes that the retailer is risk neutral. However, it is well known that the retailer may exhibit a different attitude to the risk, such as risk-neutral, risk-seeking, and risk-averse, when production disruption occurs. Especially, a small/medium-scale downstream retailer usually tends to avoid the risk when facing probable production disruptions. That is, the decision maker is generally risk-averse. The existing literature involves a variety of objective functions capturing risk-averse behavior, e.g., the loss-averse model [30][31], mean-variance model [32], mean-standard deviation model [33], max-min model [34], min-max regret model [35], and conditional value-at-risk (CVaR) model [36], among which the mean-variance model, the mean-standard deviation model, and the CVaR model have been widely considered under supply chain disruptions. The max-min model and the min-max regret model are especially advantageous to situations with an unknown demand distribution. However, they are often criticized by producing over conservative decisions [37].

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