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A two-location inventory model with transshipments in a competitive environment

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ABSTRACT

This paper analyzes the implementation of transshipments among competing firms and the impact of transshipments on their inventory replenishment decisions. Previous studies have shown that transshipments, when implemented between stocking locations operating in the same echelon, improve firm financial performance and customer service through risk sharing and inventory reallocation. However, these studies have not investigated transshipments in a competitive environment; that is an environment where two firms both cooperate through transshipments and compete for customers. In this paper, the rivalry intensity between firms is assessed through a variable, *customer's switching rate*, measuring the percentage of consumers switching sellers in the event of a stockout. The impact of various switching rates on the performance benefits from transshipments is investigated, leading to several important managerial implications. In particular, numerical analyses suggest that transshipment price plays a unique, crucial role in creating benefits for participating firms with asymmetric market demands and various degrees of customer loyalty.

1. Introduction

Saturn has achieved impressive success with after-sales service through the practice of sharing automotive parts among its dealers (Cohen et al., 2000). When one dealer is out of a particular stock keeping unit (SKU), this dealer will first contact a nearby Saturn dealer to see if the SKU is available there. If the part is available, transshipments are implemented from the location with excess stock to the location with insufficient supply. Through transshipments, a dealer can quickly receive the part needed and thus satisfy customer requests for maintenance or repair faster than if the out-of-stock part were backordered from the central distribution center or the original supplier. As a risk-pooling strategy, transshipments provide an efficient and effective approach for firms to reduce inventory carrying costs without negative effects on customer service. Most previous studies follow the line that transshipments, as a mechanism to reallocate resources between two locations at the same level of a supply chain, benefit both the sending outlet and the receiving outlet (e.g., Tagaras, 1989; Krishnan and Rao, 1965; Rudi et al., 2001).

The extant literature has analyzed transshipments between firms that are either centrally controlled (e.g., Krishnan and Rao, 1965) or independently owned (e.g., Rudi et al., 2001; Dong and Rudi, 2004). However, the previous studies did not consider the situation where transshipments are implemented among competing but connected firms. Examples include networks of independent dealers or franchise operators. In these cases, profit maximization is not conducted centrally, but each dealer/operator is engaged in its own profit maximization. Ace Hardware, for instance, is a $13 billion retail cooperative consisting of 4600 independent stores in all 50 US states and 70 other countries (Wikipedia, 2009). For these types of networks, it is not clear whether transshipments lead to increased profits, even for locations with excess inventory. It may be in the best interest of a particular Ace Hardware dealer to not transship inventory to another location with a shortage. The dealer may be able to increase its profits by waiting for consumers, themselves, to switch locations to buy directly from the dealer with surplus inventory.

In this paper, we determine the conditions under which a transshipment policy is likely to increase performance in this type of competitive (but potentially cooperative) environment. Conditions examined include the competitive intensity between firms, the relative size of firms, the level of customer service offered, and the variance in demands facing the firms. In particular, we examine how variations in these conditions affect revenues, profits, and inventory levels of firms. Competitive intensity or rivalry among firms is measured by the variable *customer's switching rate*; the percentage of customers choosing

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an alternative source of supply when his or her primary supplier is out of stock. Specifically, a higher switching rate implies that firms experience a higher degree of rivalry. One of our major findings is that when rivalry is high, it is generally in the best interests of firms not to engage in transshipments but to let consumers, themselves, switch between locations. On average, firms will save transshipment costs and therefore increase their profits.

Following this introduction, Section 2 provides a review of relevant literature on transshipments. Section 3 outlines the modeling framework. The inventory decisions that firms make with and without transshipments are presented in Section 4. A series of numerical examples are developed in Section 5 to illustrate the analytical results. Finally, Section 6 offers conclusions and discusses managerial implications, limitations of the current study, and future research.

2. Literature review

There is a large body of theoretical modeling work on transshipments, dating back to Krishnan and Rao (1965). They analyze transshipments in a setting with a multi-location distribution network that consists of a number of warehouses, characterized by centralized control, independent demand, and identical inventory holding and shortage costs for all locations. Their analysis suggests that under these conditions, transshipments equalize optimal inventory, and service levels throughout stocking locations. Krishnan and Rao (1965) provide a fundamental framework in which the transshipment problem can be explored based on three major assumptions. First, their study identifies a general sequence of events by assuming that transshipments occur after the demand is realized, but before it is satisfied. Second, they are the first to define a *complete pooling policy*. According to this rule, the number of units transshipped from one location to another equals the minimum of the excess stock at one location and the shortage at the other location. Transshipments will not occur if all locations are out-of-stock or all have surplus stock. The third contribution is that the model incorporates transshipment costs, which are incurred when goods are transferred from the overstocked location to the out-of-stock location. Hence, the decision to implement transshipments can be modeled by weighing the tradeoff between total transshipment costs and the sum of inventory holding and shortage costs.

Building on Krishnan and Rao (1965) and Tagaras (1989) investigates the effect of transshipments on customer service levels, measured by non-stockout probability and fill rate. Tagaras (1989) finds that the complete pooling policy improves the service level in a two-location distribution system, and that the service levels at both locations will be equalized through transshipments under the condition that the locations have identical market demands and inventory cost structures. Under such a condition, complete pooling is an optimal rule through which the two locations minimize their joint expected costs.

The approach of minimizing total expected cost has been widely applied to solving the classic *newsvendor problem* (e.g., see Rudi et al. (2001) for a description of this problem). The newsvendor problem has been extended by Robinson (1990) and Axsater (2003) into a multi-period, multi-location context. Robinson (1990) verifies that as a recourse action, the practice of transshipments among retail outlets provides an alternative for retailers to making all orders at the beginning of each replenishment cycle, thus affecting order-up-to levels. Assuming that retail outlets adopt a complete pooling policy when transshipments are implemented, Robinson (1990) finds a heuristic solution for the optimal order-up-to point, and further validates this heuristic using a Monte Carlo technique. Robinson (1990) suggests that the non-negative base stock order-up-to level in the final period will also be the optimal order-up-to level for all other periods under a transshipment policy. In comparison, Axsater (2003) develops an alternative heuristic rule for transshipments in a general order-quantity, reorder-point (Q, R) continuous review inventory management system. The decision rule differs from Robinson (1990) in that it minimizes the expected costs under the assumption that no further transshipments after the present period will take place. This decision rule can be applied repeatedly in multiple periods as an approximate optimization solution.

Other research that has explored transshipments in a continuous, periodic inventory review setting includes Needham and Evers (1998), Herer and Rashit (1999), and Xu et al. (2003). In these studies, the authors relax the assumption of complete pooling and instead consider the magnitude of transfers under a transshipment policy to be endogenous. The transshipment levels can be categorized into three inventory reallocation rules including: no-transshipments, partial pooling, and complete pooling.

Recently, there has been a growing body of research studying transshipments in a game theoretical framework. Granot and Sosic (2003), for example, develop a three-stage game-theoretical model in a decentralized distribution environment consisting of a number of retailers selling identical products. In the first stage, the model assumes that each retailer independently makes an initial order quantity decision before demand is realized. In the second stage, after demand is realized, each retailer decides how much of the residual stock it wants to share with other retailers. Extra stock is then transshipped to meet the excess demand at other locations and additional profit is allocated among retailers in the final stage. The modeling work in Granot and Sosic (2003) suggests that the profit allocation rule adopted by retailers has a direct impact on the value of residual stock that each retailer is willing to share with other retailers, which, in turn, affects the degree of transshipments implemented among retailers. Therefore, it is argued that the inventory replenishment decisions of firms are strategically interrelated in such a decentralized environment.

Intuitively, as explained by Rudi et al. (2001), when Firm *A* carries a large inventory, then Firm *B* is inclined to keep a small inventory because transshipments enable it to draw upon the excess inventory stored at firm *A*'s location in the event of a stockout. On the other hand, when Firm *A* carries a small inventory, Firm *B* tends to keep a large inventory because transshipments make it possible for Firm *B* to reduce excess inventory in the case of short-demand. Indeed, Rudi et al. (2001) show that in an order quantity game, the best-response functions are monotonically decreasing, and that the slope is less than one in absolute value. These findings support the existence of a unique Nash equilibrium in a simultaneous two-location inventory decision- making game. Moreover, Rudi et al. (2001) find that there exist transshipment prices that would induce the decentralized, local optimal inventory decisions to result in the equivalent profit outcomes as in the global, joint profit maximization setting. The study by Hu et al. (2007) generalizes and refines the findings from Rudi et al. (2001) in that it provides the conditions that are sufficient and necessary to guarantee the existence of transshipment prices that can help coordinate inventory decisions made by firms individually but lead to the global optimal profits. They challenge the universal existence of the coordinating transshipment prices as suggested by Rudi et al. (2001) and conclude that such prices will exist if and only if the cost parameters at the two locations are symmetric. Building upon similar framework, Dong and Rudi (2004) show how transshipments between two retailers affect the profitability of the upper-level supplier.