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Inventory sharing and coordination among *n* independent retailers

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ABSTRACT

Inventory sharing among decentralized retailers has been widely used in practice to improve profitability and reduce risks at the same time. We study the coordination of a decentralized inventory sharing system with n ($n > 2$) retailers who non-cooperatively determine their order quantities but cooperatively share their inventory. There has been very limited research on coordinating such a system due to the many unique challenges involved, e.g., incomplete residual sharing, formation of subcoalitions for inventory sharing etc. In this paper, we develop a coordination mechanism (nRCM) that simultaneously possesses a few important properties—leading to formation of only grand coalition, inducing complete residual sharing, and ensuring each retailer obtains a higher profit as the system size increases. We also consider the impact of asymmetric demand distribution parameter information on the coordination mechanisms when the retailers privately hold such information. We show that although true coordination requires complete information sharing, under any n-retailer inventory sharing coordination mechanism, retailers may not have incentives to share information with all other retailers and will not share true information even if they do so. In this regard, nRCM possesses another important property: it can be implemented under asymmetric information and retailers can obtain profits very close to their first-best profits even if they do not share demand information. Such nice properties of nRCM also hold when retailers have correlated demands. This paper is the first to study coordination mechanism for an n-retailer ($n > 2$) inventory sharing system considering asymmetric information.

1. Introduction

With the help of internet and information systems, collaboration among firms (even independent firms) has become more attractive and popular as firms make every effort to improve profitability by reducing risks and uncertainties. Inventory sharing (or transshipment) among decentralized firms is one of these examples. With the express delivery at relatively low costs, inventory collaboration, in particular, inventory sharing (or transshipment) has drawn increased attention from retailers and manufacturers as they seek to succeed in a highly competitive market. For example, a leading heavy machine manufacturer has taken the initiative to establish service parts inventory sharing among its dealers who are independently owned and operated (Zhao, Deshpande, & Ryan, 2005). By transshipping inventory from a location with excess stock to satisfy the demand of another location with insufficient stock, dealers obtain the benefits of risk pooling with reduced inventory and higher service level at the same time in this capital intensive industry that faces high uncertainty in its demand. Such practices of inventory sharing have also been prevalent in the service parts of automotive and machine tool industries (Kutanoglu & Mahajan, 2009; Narus & Anderson, 1996), and routinely performed in the apparel, music, high-tech products, and electronics industries. There are also examples of inventory sharing among un-related firms through online platforms, e.g., Inventory Locator Service.

To obtain the maximum benefits from sharing inventory, independent retailers modify their order quantities, depending on how the additional profit resulted from transshipment will be allocated among them, in order to take into consideration the inventory transshipment opportunities with other retailers. There has been a stream of literature on the inventory stocking and transshipment decisions in the decentralized inventory sharing system, mostly focusing on two-retailer systems (e.g., Hezarkhani & Kubiak, 2010; Hu, Duenyas, & Kapuscinski, 2007; Rudi, Kapur, & Pyke, 2001; Zhao, Deshpande, & Ryan, 2006, and the references therein). Much less literature has looked at the more realistic n-retailer ($n > 2$) decentralized inventory sharing systems and even lesser on coordination of such systems, due to their complexities.

This paper considers an n-retailer inventory sharing system ($n > 2$), in which the n independent retailers non-cooperatively determine their order quantities but cooperatively share inventory with

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each other. Several unique issues arise in the n-retailer system that make the analysis more complicated. First, depending on the transshipment profit allocation rule, retailers may not completely share their residual demands or residual supplies. As Granot and Sosic (2003) point out, depending on the transshipment profit allocation rule, retailers may hold back their residuals in order to obtain higher profits. Second, depending on the transshipment profit allocation rule, retailers may not want to share inventory with everyone in the system, i.e., they may form subcoalitions when sharing inventory residuals. Third, coordination is much more complicated and profitability of each retailer under coordination may depend on the size of the system, n.

Due to the many challenges involved, previous literature on *coordination* of an n-retailer inventory sharing system is quite scarce. Review of the coordination allocation rules existent in the literature (Section 3) reveals further difficulties involved: Although being a core allocation rule (i.e., formation of only grand coalition) for the inventory sharing game and inducing complete sharing of residuals are important issues to consider when developing coordination allocation rules, these properties cannot be easily achieved simultaneously. In fact, Granot and Sosic (2003) show that based on the conventional game framework, no completely sharing core allocation rule exists for an n-retailer inventory sharing game ($n \geq 4$).

In this paper, we develop a novel approach to the coordination of the n-retailer inventory sharing system, which possesses the above important properties simultaneously, i.e., all retailers will completely share residual supply/demand and will form only grand coalition. The key of this mechanism is the involvement of a third party, e.g., the manufacturer, as a facilitator of retailers' transshipment, through payments between the facilitator and the retailers. Such involvement requires us to extend from the conventional framework. Specifically, in the conventional cooperative game framework, the core allocation rule is defined (in the transshipment context) given that the sum of all retailers' allocated transshipment profits equals the total transshipment profit. We propose a different mechanism (nRCM) in which a third-party (e.g., manufacturer) is involved to coordinate the n retailers, who subsidizes the transshipment profit allocation such that the sum of the retailers' allocated transshipment profits is twice as much as the original total transshipment profit. The subsidy is provided/offset by a premium fee collected by the manufacturer before each retailer makes ordering decisions. nRCM not only leads to coordination, complete sharing, but also ensures formation of only grand coalition (i.e., no retailers will form subcoalition of inventory sharing, which is similar to the stability property of conventional core allocation rules). Although manufacturer is the natural candidate as the facilitator, third-party logistics partners or even a finance arrangement of transshipment fund could fulfill such role as well, as will be discussed.

In addition, most of the previous work related to coordination in an inventory sharing system has assumed that retailers' demand parameters are known to all participating retailers in the inventory sharing network and hence has used such information in making each retailer's inventory stocking and inventory sharing decisions. Such an assumption can be unrealistic for decentralized supply chains. In designing the coordination mechanism, we also take into consideration of the issues of asymmetric information on demand parameters.

Yan and Zhao (2011) are the first to consider decentralized inventory sharing with asymmetric information. They focus on a system with *two* retailers and analyze the coordination of such a system when the two retailers hold private demand distribution parameter information. Studying the coordination of an n-retailer inventory sharing with asymmetric demand parameter information is not a simple extension of the two-retailer system due to the many unique issues arising for n-retailer systems as we discussed earlier, and also their intermingling with information asymmetry, another layer of complexity. In addition, since true coordination can only be achieved with complete demand parameter information, under information asymmetry, we consider the cases when retailers share their information and also when retailers do not share information. Specifically, when retailers share information, under the n-retailer system, they not only need to decide whether they will share true information (the issue of incentive compatibility) as they do under the two-retailer system, but also need to decide whether they have incentives to share demand information with all other retailers, which is unique in the n-retailer system.

Further, when designing a coordination mechanism, how much information is required to implement such a mechanism is a key. For example, while the probability assignment coordination in Anupindi and Bassok (1999) requires all retailers to share demand distribution parameters to calculate the coordinating probability, the total profit allocation in Anupindi, Bassok, and Zemel (2001) requires all retailers to share *all* demand distribution parameters, realized demands, as well as retailers' order quantities. A mechanism can only be implemented for a system where the required information is readily available.

We show a few important results in our analysis of information asymmetry. First, which piece of a retailer's demand distribution parameter information is useful to other retailers depends on how the transshipment profit is allocated among retailers in the n-retailer system. As long as the transshipment profit allocated to each retailer is only related to retailers' residual supply/demand, a retailer will only need the other retailers' demand standard deviation information (not mean demand) for his decisions. Second, although true coordination requires retailers share complete demand distribution parameter information with each other, under any coordination mechanism/allocation rule, retailers may not have incentives to share information with all other retailers and will *not* share true information even if they do so. This poses a dilemma to coordinating the system with asymmetric information. Finally, nRCM is designed to provide an indirect but effective solution to this dilemma. It minimizes the impact of information asymmetry, i.e., nRCM can be implemented without information sharing and retailers obtain profits close to their first-best solutions even if they do not share information.

Our work enriches the current literature in a few important aspects. First, we design a coordination mechanism (nRCM) that possesses four important properties simultaneously—leading to formation of only grand coalition for inventory sharing, inducing complete residual sharing, ensuring each retailer obtains a higher allocated profit as the size of the system (n) increases, and deliver close to first-best results even under asymmetric information. Second, to the best of our knowledge, we are the first to study the impact of asymmetric demand information on coordination mechanisms of the n-retailer inventory sharing system. We analyze important issues both with information sharing (e.g., incentives to share information with each other and truth-telling) and without information sharing (Bayesian equilibrium solutions). We also develop nRCM which deals with the asymmetric information effectively and provide a viable option for the difficult problem of coordinating a decentralized system with asymmetric information. Finally, we also extend our results to the case when retailers have correlated demands.

The rest of this paper is organized as follows. In Section 2, we formally introduce the model framework of the n-retailer inventory sharing game. In Section 3, we discuss allocation rules, properties of allocation rules, and briefly review coordinating allocation rules developed in the previous literature (all under complete information) in terms of these properties. We also introduce the necessary game-theoretic terminologies there. In Section 4, we describe the coordination mechanism we design (nRCM) and analyze its properties under complete information. In Section 5, we study the impact of asymmetric information on any coordination mechanism/allocation rule and analyze the performance of nRCM under asymmetric information. In Section 6, we consider the extension with correlated demands. We