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The effect of Inventory Record Inaccuracy in Information Exchange Supply Chains

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ABSTRACT

The goal of this paper is to quantify the impact of Inventory Record Inaccuracy on the dynamics of collaborative supply chains, both in terms of operational performance (i.e. order and inventory stability), and customer service level. To do so, we model an Information Exchange Supply Chain under shrinkage errors in the inventory item recording activity of their nodes, present the mathematical formulation of such supply chain model, and conduct a numerical simulation assuming different levels of errors. Results clearly show that Inventory Record Inaccuracy strongly compromises supply chain stability, particularly when moving upwards in the supply chain. Important managerial insights can be extracted from this analysis, such as the role of 'benefit-sharing' strategies in order to guarantee the advantage of investments in connectivity technologies.

1. Introduction

The Operations Management community has been identifying Supply Chain (SC) collaboration practices as some of the most effective approaches for limiting SC inefficiencies such as bullwhip effect (Lee, 2010; Lee, Padmanabhan, & Whang, 1997). Information sharing is at the core of collaborative, SC based business models (Cannella, Barbosa-Povoa, Framinan, & Relvas, 2014; Fawcett, Osterhaus, Magnan, Brau, & McCarter, 2007). The concept of information sharing may be used in terms of access to information about the exact physical location of goods en route from supplier to customer at a particular moment (Jonnson & Mattsson, 2013). Depending on the information shared by firms and on how this information is used, different typologies of SC collaboration practices can be realized. For instance, if members share real-time sharing of market demand data for the generation of conjoint forecasting, they can implement a collaborative supply chain structure known in literature as Information Exchange SC (Holweg, Disney, Holmström, & Småros, 2005). This structure has been shown to be able to remove harmful problems resulting from information distortion (Ali & Boylan, 2011; Ali, Boylan, & Syntetos, 2012; Agrawal, Sengupta, & Shanker, 2009; Cannella, 2014; Cannella & Ciancimino, 2010; Dejonckheere, Disney, Lambrecht, & Towill, 2004; Disney et al., 2004; Holweg et al., 2005; Machuca & Barajar, 2004; Trapero, Kourentzes, & Fildes, 2012; Wong, Lai, & Cheng, 2014; Yuan, Shen, & Ashayeri, 2010). However, as the effectiveness of an inventory management system depends on the quality of information used (Ketzenberg, Geismar, Metters, & van der Laan, 2012), inventory accuracy can be reasonable considered one key aspect to ensure the benefits of the Information Exchange SC. Clearly, even if members benefit from up-to-date information on customer demand, various problems may arise if they manage their stock by using policies that assume perfect information on inventory positions, despite system-reported inventory inaccuracies (Bai, Alexopoulos, Ferguson, & Tsui, 2012). More specifically, if the recorded inventory quantity does not match the actual quantity in the shelf, the system will either order unnecessary items, or fail short of orders (DeHoratius & Raman, 2008; Rekik, 2011 ; Rekik, Sahin, Jemai, & Dallery, 2008a; Sahin, Buzacott, & Dallery, 2009; Sarac, Absi, & Dauzre-Prs, 2010). This dysfunction is known in literature as "Inventory Record Inaccuracy" (IRI). The effects of IRI are numerous and can put at risk the financial performance of a firm through diverse factors such as: lost sales, delay penalties, re-scheduling, suboptimal planning and increase in use of small transport vehicles amongst others (Thiel, Hovelaque, & Thi Le Hoa, 2010). In the present day, the difference between physically inventory level and system inventory level is not sufficiently understood to explain or predict its effect on performance (Nachtmann, Waller, & Rieske, 2010; Rekik, 2011; Rekik & Sahin, 2012;

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Rekik, Sahin, & Dallery, 2008b). However, inventory inaccuracy appears to be a significant problem in practice (Kang & Gershwin, 2005, Heese, 2007, Uçkun, Karaesmen, & Savas, 2008, Sahin & Dallery, 2009, Hollinger & Adams, 2010, Xu, Jiang, Feng, & Tian, 2012, Hardgrave, Aloysius, & Goyal, 2013, Mersereau, 2012, Metzger, Thiesse, Gershwin, & Fleisch, 2013, Bruccoleri, Cannella, & La Porta, 2014)

In an empirical investigation, DeHoratious & Raman (2008) observed inaccuracies of 65 percent on 369.567 inventory records collected from 37 leading retailers in USA. In their study, they conclude that these inaccuracies do not only affect retailers' operational performance, but also that of upstream supply chain partners (Kwak & Gavirneri, 2014). Inaccuracies and their eventual correction are likely to increase the bullwhip effect by increasing the variability of orders (Gel, Erkip, & Thulaseedas, 2010, Bruccoleri et al., 2014). The inventory error will propagate through the entire supply chain (Dai & Tseng, 2012). In fact, as shown by Kök and Shang (2014), when an echelon in the SC suffers an IRI problem, it generates orders characterized by a higher variability with respect to orders based on accurate inventory information. These orders are transmitted to the supplier and also impact on its inventory management (Kwak & Gavierneri, 2014). This is mainly because the forecast on the incoming demand from downstream stages of the chain is used by the supplier for setting his/her levels of inventory. Essentially, it is expected that the increased variability of the total demand due to IRI will be transferred from the retailer to the manufacturer (Xu et al., 2012). Thus, inventory loss across locations in a supply chain is a factor that may contribute to the bullwhip effect (Kok & Shang, 2014). This increased variability in the order can generate a negative impact not only in a traditional SCs, but also in collaborative structures in which members share real-time sharing of market demand. For instance, in the Information Exchange SC, even if an upstream member of the supply chain accesses to and benefits from updated information on customer demand, she continues to use the information of orders placed by the downstream stages for the management of her inventory requirements. Thus, she continues to be exposed to a high variability of incoming order, and consequently to a distorted information. This "phantom demand" (Min & Zhou, 2002) caused by the "phantom inventory" (Hardgrave et al., 2013), can undermine the expected benefit of information sharing and the effort in IT investment.

Moreover, IRI problems can occur for each echelon of a multi-echelon inventory system instead of a single echelon (Gumrukcu, Rossetti, & Buyurgan, 2008). Transaction errors (i.e. shipment errors, delivery errors, scanning), shrinkage errors (i.e. consumer or employee theft, shoplifting, administration and paperwork errors, vendor fraud), and inaccessible inventory (i.e. misplaced item) (Sarac et al., 2010) may affect both retailers and manufacturers of the same information sharing SC. In this case, it is expected that inventory errors across several members could even more exasperate the information distortion and propagate the bullwhip effect along the SC (Dai & Tseng, 2012, Xu et al., 2012). Despite the importance of this phenomenon, only a few papers have explored the impact of inaccurate information on the benefits of information sharing (Kwak & Gavierneri, 2014). Indeed, most related literature makes the aprioristic assumption that data used is highly accurate (Kapoor, 2009).

In this context, this paper wishes to contribute to this stream of literature by analysing the impact of the IRI on the dynamics of collaborative supply chains, both in terms of operational performance (i.e. order and inventory stability) and customer service level.

The rest of the paper is organized as follows. Section 2 explains the main motivations of our study and presents the problem statement and details the objective of our work. The modelling assumptions and the mathematical formalisms are presented in Section 3. Section 4 reports simulation experiments and discusses the performance metrics adopted in this work, i.e., bullwhip ratio, inventory variance ratio and backlog. Sections 5 and 6 provide discussions and managerial implications, respectively. Conclusions and suggestions for future research developments are presented in the last section.

2. Research motivation and problem statement

In the scientific literature, there are two main streams of research dealing with SC modelling and analysis under the assumption of IRI. The former has focused on the optimization of inventory policies in presence of errors (Sahin et al., 2009), while the latter on the impact of inventory data inaccuracies on the behaviour of SCs. The studies belonging to the first stream usually adopt OR techniques, mainly due to the fact that these techniques are very suitable at a local (i.e. single-node) tactical level in the design of SCs and in day-by-day decision making (Cannella & Ciancimino, 2010; Riddalls, Bennett, & Tipi, 2000). Thus, this approach is the most appropriate tool for solving problem such as the determination of the optimal order policy in presence of error (Sahin et al., 2009), or the required buffer size to minimize shortage costs for specific order rules (Thiel et al., 2010), among others.

On the contrary, studies in the second stream are commonly undertaken using methodologies based on the dynamics of system (i.e. system dynamics simulation, discrete event simulation, or agent-based simulation). These approaches are considered to be more suitable for studying the implications of the strategic design on SC performance and on the global behaviour of the network (Riddalls, Bennett, & Tipi, 2000, Cannella, Barbosa-Povoa, Framinan, & Relvas, 2013a, Dominguez & Framinan, 2013). Furthermore, the majority of these studies in this stream mainly focus on the impact of IRI on traditional SC structure. To the best of our knowledge, only few studies have analysed the effect of the IRI in collaborative SCs (see e.g. Fleisch & Tellkamp, 2005, Sari, 2008, Dai & Tseng, 2012). Although these works have certainly contributed to show how the whole performance of a specific SC structure can be affected by the discrepancy between the physical inventory and the information inventory, they have not addressed on the dynamic effect at the different stages of the SC. The only work that explicitly studies the effect of IRI in a collaborative SC (i.e. Sari, 2008) measures the total cost for the entire SC and the customer service level of the retailer. In addition, there are not quantitative studies showing how IRI impacts on customer service level in the upstream partners of a SC[1]. Nonetheless, in the presence of structured contracts between partners, if the retailer receives her orders after the due date, the supplier might be subject to a penalty (Eliman & Dodin, 2013). In fact, the cost of late-delivered and cancelled orders due to stock-outs is commonly observed in practice, and needs to be considered (Miranda & Garrido, 2009, Lu, Tsai, & Chen, 2012). Therefore, it can be concluded that the effect of IRI is not confined to the operational performance of the retailer but also impacts the performance of upstream SC partners (Xu et al., 2012, Dai & Tseng, 2012).

Motivated by these observations, the proposed research aims at contributing to the quantification of the impact of IRI on the operational performance and customer service level in collaborative SCs. More specifically, the objective is to analyse and contrast the effect of IRI on the different stages of a collaborative SC structure. To fulfil this research objective, we study and compare the response of the different echelons of the Information Exchange Supply Chain (IESC) (Holweg et al., 2005) in terms of demand amplification, inventory stability and customer service level of under two scenarios (1) accurate inventory record and (2) error in inventory record. In order to study the performance of the different echelons we adopt a classical four-serial multi-echelon structure (i.e. 1 Retailer, 1 Wholesaler, 1 Distributor and 1 Manufacturer) as in other several studies dealing with the dynamics of supply chains (see e.g. Sterman et al., 1989,

[1] The related literature rarely emphasizes the effect of inventory inaccuracy upon service-level quality (Thiel et al. 2010)