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Inventory record inaccuracy: Causes and labor effects

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ABSTRACT

Inventory record inaccuracy (IRI) is a pervasive problem in retailing and causes non-trivial profit loss. In response to retailers' interest in identifying antecedents and consequences of IRI, we present a study that comprises multiple modeling initiatives. We first develop a dynamic simulation model to compare and contrast impacts of different operational errors in a continuous (Q, R) inventory system through a full-factorial experimental design. While backroom and shelf shrinkage are found to be predominant drivers of IRI, the other three errors related to recording and shelving have negligible impacts on IRI. Next, we empirically assess the relationships between labor availability and IRI using longitudinal data from five stores in a global retail chain. After deriving a robust measure of IRI through Bayesian computation and estimating panel data models, we find strong evidence that full-time labor reduces IRI whereas part-time labor fails to alleviate it. Further, we articulate the reinforcing relationships between labor and IRI by formally assessing the gain of the feedback loop based on our empirical findings and analyzing immediate, intermediate, and long-term impacts of IRI on labor availability. The feedback modeling effort not only integrates findings from simulation and econometric analysis but also structurally explores the impacts of current practices. We conclude by discussing implications of our findings for practitioners and researchers.

1. Introduction

Inventory record inaccuracy (IRI) refers to the discrepancy between physical and recorded inventory levels, and is a pervasive problem in retailing. Kok and Shang (2014) conclude that IRI can be attributed to shrinkage (e.g., spoilage and theft), transaction errors, and misplacement. Because it is difficult to fully eliminate these execution errors, IRI becomes a norm rather than an anomaly in the retail sector. Kang and Gershwin (2005) report that inventory accuracy in a global retailer is on average only 51%. DeHoratius and Raman (2008) find 65% of the inventory records at a retail chain to be inaccurate, and Oliva et al. (2015) observe that more than 60% of SKUs in a European retail store have IRI. Most surprisingly, in a retail store that had not even started operating, Raman et al. (2001) found that the system had incorrect records for 29% of the items and estimated that IRI reduces a company's total profits by 10%. At the firm level, IRI can significantly distort aggregate book value of inventory and business decisions. At the item level, IRI can delay ordering decisions because most extant inventory models do not differentiate between physical and system inventories. IRI also interrupts shelf replenishment even when there is plenty of inventory in the backroom. Consequently, retailers suffer severe out-of-stock (OOS) and significant economic loss.

To tackle IRI and associated OOS in retailing environments, radio-frequency identification (RFID) has been deemed as a promising solution (Heese, 2007; Lee and Ozer, 2007). However, issues such as cost, ownership, and privacy/security hinder the full implementation of RFID at the item-level (Kapoor et al., 2009). Even when RFID becomes cheap enough to be fully adopted like barcoding, the fact that retail operations is a complicated issue involving people, processes, and technology makes error-free operations extremely difficult to achieve. In order for retailers to enhance execution quality and data integrity, it is important for managers to understand the causes of IRI and identify the policy levers that they can use to reduce it.

While some empirical work has focused on product and store attributes that affect IRI (e.g., DeHoratius and Raman, 2008), in this work we explore the impact of store staffing levels and operational performance on IRI. Our study comprises multiple modeling initiatives. First, grounded on empirical observations and field work,

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we formulate a dynamic model of continuous review (*Q*, *R*) inventory system and explicitly incorporate multiple execution errors into the model. The (*Q*, *R*) policy is often used for fast moving products and widely adopted by retailers, including numerous mass merchants that carry a large number of items (Kang, 2004; Kang and Gershwin, 2005) and stores that we work with. To compare and contrast the impact of different errors and their interactions, we conducted a full-factorial experimental design. We find that backroom shrinkage and shelf shrinkage errors are the dominant drivers of IRI and that, under-shelving, along with erroneous checkout and data capture, have negligible impact on IRI when compared to shrinkage. We also find that the interaction effects between error sources are non-substantial and mostly seem additive and linear. These primary findings hold under different distributional assumptions and parameter settings.

Next, we investigated the relationships between labor availability and IRI using longitudinal data from five stores in a global retail chain. After deriving a robust measure of IRI through Bayesian computation and estimating panel data models that control for store-section and time fixed effects, we find strong evidence that more full-time labor reduces IRI whereas part-time labor fails to alleviate it. Finally, we articulate the reinforcing relationships between labor and IRI by formally assessing the gain of the feedback loop based on our empirical results. We find that the work pressure introduced by IRI does further increase IRI, but the gain of feedback loop is not enough to compound its growth. We also analyze the intermediate and long-term effects of IRI on labor availability and use the developed structure to assess the impact of current staffing practices on performance.

Our paper contributes to practice and theory in four significant ways. First, the simulation model has a simple but realistic structure that addresses the issue that most retail inventory models ignore – the dynamics between the retail shelf and the backroom used for extra storage (Eroglu et al., 2013) – and allows for a joint assessment of the relative impact of operational errors in IRI. Second, despite the abundance of optimization models developed to tackle IRI, empirical investigations are scant. By econometrically estimating the effects of labor allocation on IRI, we broaden empirical knowledge of IRI and develop new research opportunities. Retail managers should be aware of labor effects on data quality, which is deemed to be an important source for competitive advantage (Redman, 1995). Third, we articulate the reinforcing relationships between labor and IRI by formally assessing the gain of the feedback loop based on our empirical findings and analyzing immediate, intermediate, and long-term impacts of IRI on labor availability. The feedback modeling effort not only integrates findings from simulation and econometric analysis but also structurally explores the implications of current practices. Last, we illustrate the utility of a joint use of system dynamics and econometrics. Such a combination widens our ability to answer questions of what-if and what-is given unobservable factors (i.e., execution errors) and limited observations of IRI over time. Using dynamic simulation, Bayesian shrinkage estimation, panel data modeling, and causal loop modeling enhances our understanding of IRI while responding to the call for adopting multiple methods (Boyer and Swink, 2008).

The rest of our article is organized as follows. Section 2 briefly reviews relevant literature to frame our contribution. Section 3 presents a continuous-time simulation analysis that enables us to identify the main drivers of IRI. We then postulate and articulate how those drivers of IRI are associated to store labor. Section 4 shows econometrical estimation results of labor availability on IRI. Section 5 presents feedback loops and behavioral dynamics associated with the impact of IRI on labor availability. We conclude by discussing managerial and theoretical implications of our findings.

2. Literature review

A significant number of studies have attempted to analyze causes and effects of IRI in recent years (e.g., Fleisch and Tellkamp, 2005; DeHoratius and Raman, 2008). Due to the randomness of errors that cause IRI and uncertainties in the distribution of IRI, simulation has been widely adopted to assess the effect of IRI on a retail supply chain (Fleisch and Tellkamp, 2005) or a retail outlet (Nachtmann et al., 2010). Among simulation studies on IRI, the continuous review (*Q*, *R*) system has been the focus of investigation. Kang and Gershwin (2005) analyzed how stock loss (shrinkage) causes IRI and severe OOS. They found that OOS increases monotonically in stock loss. Thiel et al. (2010) simulated the impact of IRI on service level and in contrast with Kang and Gershwin (2005), they observed that OOS is not a monotonic function of IRI when error rate is symmetric with a zero mean. Following Kang and Gershwin (2005), Agrawal and Sharda (2012) concentrated on IRI attributed to stock loss, and examined how the frequency of inventory audit affects OOS and average inventory. Similarly, in the first part of our paper we develop a dynamic simulation model of the (*Q*, *R*) inventory system. Our model differs from the aforementioned studies in two ways. First, while most models address a single source of error (Sahin and Dallery, 2009), Lee and Ozer (2007) point out that modeling efforts are needed to articulate the joint effect of multiple errors. Our model takes into account multiple errors (both operational and information-related) simultaneously. Although Fleisch and Tellkamp (2005) also assessed the impact of several errors using stochastic simulation, we analyze operations inside a retail store instead of flows in a three-echelon supply chain. Second, while existing simulation studies on IRI stress the *consequences* (e.g., inventory level, fill rate) of poor data quality (Nachtmann et al., 2010), our analysis focuses on the impacts of different *antecedents* of IRI.

While simulation analysis enhances our understanding about antecedents and consequences of IRI, there is still limited empirical knowledge about IRI due to the low availability of data. Few studies empirically investigate IRI through analyzing actual data on inventory discrepancies. Sheppard and Brown (1993) presented the first analysis to empirically assess how product-related factors affect IRI within a manufacturing plant. In retail stores, Raman (2000) and Oliva et al. (2015) both found that more than 60% of items had inaccurate records. Using data from a single store, Oliva et al. (2015) derived empirical estimates of an aggregate model that characterizes inventory information decay. The estimated functional form is further incorporated into inspection policy design. To our knowledge, the only cross-store econometric analysis of IRI is by DeHoratius and Raman (2008). They collected cross-sectional data on IRI from a retail chain to empirically examine IRI. The econometric analysis performed in the second part of our paper differs from DeHoratius and Raman (2008) in three important ways. First, expanding their efforts on examining how product, and store, related attributes affect IRI, we assess the association between labor decisions and IRI in each product sector. Second, we obtain longitudinal observations of IRI and labor decisions, which allow us to test labor effects while tackling unobserved factors. Third, our econometric estimation focuses on developing an operational functional form for the impact of labor on IRI (Richmond, 1993), as opposed to a correlational study to test hypotheses.

Finally, our work is also informed by system dynamics (Forrester, 1958; Sterman, 2000) efforts to assess the impact of labor and staffing levels on operational performance (e.g., Anderson, 2001; Oliva and Sterman, 2001; Lyneis and Ford, 2007). While we adopt from these articles the feedback perspective on staffing