Oper Manag Res (2011) 4:6–13
DOI 10.1007/s12063-011-0049-3

Improving inventory management in the retail store: The effectiveness of RFID tagging across product categories

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Received: 29 September 2010 / Revised: 11 March 2011 / Accepted: 14 March 2011 / Published online: 6 April 2011

Abstract While there is a growing body of evidence that Radio Frequency Identification (RFID) tagging can be effective in improving inventory management in the retail store, retailers have little guidance on best practices for implementation. One important unresolved issue is whether tagging is equally effective across different product categories, and if there is a way to predict which categories are better candidates for deployment. We conduct a field experiment comparing the improvement in inventory record accuracy before and after implementing RFID-enabled adjustments to the inventory management system. We find evidence that the effectiveness of RFID tagging is not homogenous for all products. Reductions in the percentage of stockouts ranged from 21% to 36%, depending on category. Categories that are most likely to see a decrease in stockouts, thanks to RFID, have a greater turnover, greater sales volume, greater product variety, lower item cost, and greater inventory density. We draw inferences for retail supply chains which are considering how best to allocate their resources in the most effective manner.

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Keywords Inventory management · Stockouts · Product category · Radio frequency identification (RFID) · Field experiment

1 Introduction

Retailers have shown a great interest in Radio Frequency Identification (RFID) tags as a means to improve supply chain efficiency and customer relationship management (Hardgrave et al. 2008; Landoc et al. 2006; Lee and Özer 2007). Bhattacharya et al. (2010) find that of the many potential benefits from implementing RFID in the supply chain, the single most prominent is improving inventory management and, in particular, reducing out of stocks. There is evidence that the visibility (Delen et al. 2007) provided by RFID can improve the accuracy of inventory records (Hardgrave et al. 2010). There is, however, skepticism on the part of some retailers of the actual effectiveness of the technology in improving supply chain performance and inventory management in the field, and this has resulted in a reluctance to adopt (Camdereli 2008; Gittlen 2006; Hozak and Collier 2008; McWilliams 2006; Vijayaraman and Osyk 2006). This is unfortunate because RFID has the potential to go beyond the currently realized automational and informational benefits and be truly transformational in the retail industry by inducing process innovation (Visich et al. 2009). Part of the problem is a lack of guidance as to where, how, and when RFID may be most likely to be effectively deployed. The current research addresses one specific aspect of this issue by studying the effectiveness of the technology in improving stockouts across product categories.

Inventory record accuracy is critical to efficient replenishment decision making, as on-hand inventory is a key parameter used in determining replenishment orders. Despite the implementation of collaborative planning, forecasting, and replenishment (CPFR) systems, evidence suggests that retailers' inventory records may be surprisingly unreliable (DeHoratius et al. 2008; Kang and Gershwin 2005). Various studies have found *inaccuracy* rates as high as 55% and 65% (Gruen and Corsten 2007; Raman et al. 2001). Replenishment decisions made using these records as an input are, therefore, unlikely to be optimal, and the efficiency of the inventory management system is compromised.

RFID technology, however, has the potential to provide the retailer heretofore unattainable visibility into the movements of inventory through the supply chain, including within the retail store. Due to the relatively high cost of a tag it is not economically feasible to individually tag many fast moving consumer goods (such as bottles of ketchup or cans of soup). Further, due to degraded read performance for individual products with high metal and liquid content (such as the aforementioned), laboratory testing has shown that tags optimally placed on a case pack generally has a better chance of being read than an individual item (primarily due to airspace provided when items are in a cardboard case, for example) (Patton and Hardgrave 2007). The downside, of course, is that the visibility afforded is less granular than with item level tagging. Even when tagging is at the case pack level, Hardgrave et al. (2009) demonstrate that strategically positioned RFID readers enable visibility of critical inventory movements within the retail store. This, combined with a system of logic built into the inventory management system, can provide visibility at a sufficient degree of granularity to improve inventory record accuracy. The current research investigates the efficacy of case level tagging in improving inventory management in the retail store.

Waller et al. (2006) show that greater inventory record error in the system is associated with decreased fill rate and service level. This suggests that if RFID tagging decreases inventory record accuracy, that it should also result in decreased stockouts (defined for our purposes as a product not available on the store shelf for sale to a customer). Hardgrave et al. (2010) show that RFID tagging is not equally effective across all product categories in reducing inventory record inaccuracy. Specifically, as we will explain in Section 2, tagging was most effective in categories that are characterized by known determinants of inventory record inaccuracy. For product categories for which RFID tagging increases inventory record accuracy, then it should be effective in reducing stockouts.

The typical retailer is estimated to lose about 4% of their annual sales due to stockouts (Gruen and Corsten 2007)—thus, there is much incentive to remedy this situation, if possible. In addition, they estimate that an average food store spends $800/week responding to customer questions about stockouts. Gruen and Corsten (2007) also demonstrate that stockout rates average about 8% worldwide and that they are different across product categories.

The current research examines the efficacy across product categories of RFID tagging in improving inventory management by reducing out of stocks. Our specific research questions are:

1) *Will RFID tagging be equally effective in reducing stockouts across all product categories?*
2) *For what product categories is RFID tagging most effective in reducing stockouts?*

The rest of the paper is organized as follows: Section 2 reviews relevant literature on RFID tagging and inventory record inaccuracy, as well as stockouts. Section 3 describes the research design and the study in the field. Section 4 presents the analysis of the data and the results. Section 5 summarizes the results and draws implications for retailers considering tagging products for inventory management.

2 Literature review and theory development

2.1 RFID and reducing inventory record inaccuracy

There is considerable evidence that retailer inventory records are inaccurate, manifested as a difference between system inventory record and actual inventory (Kang and Gershwin 2005; Raman et al. 2001). To illustrate the magnitude of the problem, Gruen and Corsten (2007) whose study included 166 items from 121 stores, found that 55% of product records were inaccurate and Raman et al. (2001) found 65% inaccuracy in their study. Researchers have proposed RFID as a means of reducing inventory record accuracy and, consequently, as a means to reduce stockouts (Rekik et al. 2008).

DeHoratius and Raman (2008), in an empirical study, find seven known determinants of inventory record inaccuracy: item cost (the retailer's cost of an individual item), quantity sold (or sales velocity; number of units sold of an item per year preceding the audit of that item), sales volume (item cost X quantity sold), audit frequency (frequency of physical inventory audit), inventory density (the total number of units found in a retailer's selling area), product variety (the number of different merchandise categories within a store), and the distribution structure (whether or not it was shipped from a retailer-owned distribution center (DC)). Some of these determinants are product level (cost, velocity, volume, distribution structure) and others are store level (audit frequency, density, variety). Lower cost items, high velocity items, items with greater sales volume, and items shipped from a retailer DC, are associated with higher inaccuracy. Also, stores that have a greater number of distinct products, as well as stores that have a greater number of items per square foot, are associated with higher inaccuracy.

Hardgrave et al. (2010) show that RFID tagging ameliorates the effects of five (item cost, sales velocity, sales volume, inventory density and product variety) of these determinants of inventory record inaccuracy (they experimentally control for the effects of the other two determinants: audit frequency and distribution structure). For example the (positive) influence of sales velocity on inventory record inaccuracy is moderated by inventory visibility due to RFID tagging. Furthermore, pertinent to the current research, they demonstrate that product categories characterized by the determinants of inventory record inaccuracy showed the greatest improvement in reducing inaccuracy as a result of RFID tagging. That is, the product categories that showed the greatest decrease in inventory record inaccuracy were those in which the products had higher sales velocity, lower item cost, higher sales volume, higher inventory density, and higher product variety. Thus, we expect that such product categories characterized by determinants of inventory record inaccuracy would also see the greatest reduction in stockouts as a result of the introduction of RFID tagging for these product categories.

2.2 Inventory record accuracy and stockouts

Ordering decisions and store forecasting combined are estimated to account for approximately 47% of all stockouts, while retail store shelving practices are estimated to account for a further 25% of stockouts (Gruen and Corsten 2007). They argue that improving perpetual inventory record accuracy is a key avenue toward decreasing stockouts.

There are reasons why these three causes of stockouts may be remedied by improved inventory record accuracy. First and most evident, on-hand inventory is a key parameter in determining optimal order quantities. If on-hand inventory is overstated (i.e., system thinks it has more on-hand than it really does), the store will not place necessary orders to ensure product on the shelf. Store ordering decisions are compromised as a result. Second, the stockouts resulting from overstated inventory result in a distortion of demand, as the store has no way of accurately estimating true demand as there is no visible direct measure of lost sales due to stockouts. The truncated estimate of the demand distribution, therefore, leads to an underestimate of true sales and, eventually, to further stockouts. Consequently, the store forecasting function is biased. Finally, having product in the store does not help if that product is misplaced and not available on the shelf for purchase. If the inventory record accurately shows the location of a product as being in the backroom, a store associate will be able to restock the shelf rather than erroneously record a stockout (and place a further unnecessary order).

Inventory accuracy is an assumed feature of operational plans to ensure product availability on the shelf. Inventory inaccuracy, therefore, is recognized to be a prominent example of poor store execution, or the failure to carry out the operational plan (DeHoratius and Ton 2009). There is a considerable literature (empirical, analytical, and simulation) that suggests that information inaccuracy can lead to stockouts (e.g., Fleisch and Tellkamp 2005; Gruen and Corsten 2007; Kang and Gershwin 2005; Lee and Özer 2007; Waller et al. 2006). RFID tagging has been shown to reduce inventory inaccuracy (Hardgrave et al. 2009, 2010). While it is possible to theorize on the efficacy of tagging in reducing stockouts, the current research designs an experiment to test this assertion in the field.

3 Study design

3.1 Sample

The study included 1,268 products (also referred to as 'stock keeping units' or SKUs) from five categories in 31 stores of a major retailer spread across the United States. The retail stores ranged from 40,000 square feet to 220,000 square feet in area. All of these stores were already RFID enabled as part of a chainwide rollout such that RFID readers were placed at various points in the store and the backroom. The study included products from five separate categories in the stores. These categories were formula (e.g., infant nutritional products, canned soy milk), aircare products (e.g., air fresheners, candles), floorcare (e.g., vacuums, carpet spot remover), ready to assemble furniture (e.g., computer cart, pedestal desk, executive chair), and quick cleaners (e.g., fabric cleaner, microfiber pads). We selected these categories for two reasons: (1) The categories represented a variety of product types, sizes (from baby formula to furniture), case pack sizes (from case pack sizes of 1 to 48), prices (from less than a dollar to several hundred dollars), and sales velocities (from tens of units per day to one per week); and (2) Not all the products in these categories were tagged by the suppliers. The untagged products were used as a control group within the store against which to test the influence of RFID on the tagged items.

3.2 Procedure

After arriving from the DCs, all the product cases pass through a number of RFID readers in the backroom. Figure 1 presents a layout of these readers in a generic backroom, as presented in Hardgrave et al. (2009).

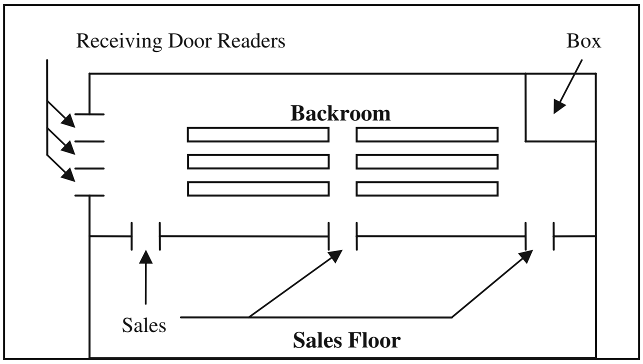

Fig. 1 Retail store read points (reproduced from Hardgrave et al. 2009)

As the products are unloaded from the trucks into the backroom, readers on the receiving doors take the first read of the products arriving at the store and this inventory is recorded in the system as being in the backroom. Another set of readers is placed next to the doors going to the sales floor. These readers record all the products that are taken from the backroom to the sales floor. As it is common practice for products to be taken out to the shop floor and then returned to the backroom, the system does not record the product as being on the shelf yet. When the shop floor readers get a second read on the same case, the products are recorded as being returned to the backroom. It should be noted that store policy does not allow partial cases to be placed on the shelf, and therefore either the entire contents of the case are on the shelf or returned to the backroom. A final set of readers is placed in the box crushers. If the empty carton is read in the box crusher, then the system knows the product has been stocked on the shelf; otherwise, a read at the sales floor door with no corresponding read at the box crusher indicates the product is in the backroom.

All SKUs in the five categories included in the study were physically counted at two separate points in time (a baseline period and a treatment period) by an independent firm specializing in counting inventory. The first count was conducted 1 week prior to the implementation of the RFID auto-adjust system that updated the existing inventory management system using RFID reads. The second count was conducted 2 months after the first count, or approximately 7 weeks after the implementation of the RFID auto-adjust system. Because of the number of items involved in these categories (there were 39,484 units in the baseline period physical count and 26,353 units in the treatment period physical count in the 1,268 SKUs in the study), each of the physical inventory counts of items in these five categories took 5 days to complete.

For this study, we considered an item out of stock anytime the independent inventory counting firm found the number of products on the retail shelf to be zero (empty shelf space). All the test group items were RFID tagged at the case level. All the control group items did not have any RFID tags on them and, thus, were managed by the system using POS information, manual barcode scans, and other data capture such as loading dock arrivals using non-RFID technology only. This within store comparison of the products, before and after the implementation of the RFID auto-adjust system, allowed us to determine the difference in the levels of product stockouts as a result of RFID tagging using the auto-adjust system.

3.3 Results

The goal of this study was to determine the influence of RFID tagging on stockouts for different product categories. In order to examine this influence, we conducted within store comparisons between tagged and untagged products. More specifically, we compared the difference between the percentage of stockouts for tagged versus untagged products in the baseline as compared to the treatment period. The expectation was that RFID tagging would reduce inventory inaccuracy in the retail store (Camdereli and

Table 1 OOS comparison between treatment and baseline periods for tagged and untagged SKUs

	Tagged SKUs			Untagged SKUs			Improvement (Tag–unt)
	% OOS Baseline (sample size)	% OOS Treatment (sample size)	Difference (treat–base)	% OOS Baseline (sample size)	% OOS Treatment (sample size)	Difference (treat–base)	
FloorCare	28.35% (3265)	20.69% (3266)	−7.66%***	19.19% (269)	48.46% (864)	27.27%***	−36.94%
Aircare	14.12% (4548)	12.45% (3931)	−1.67%*	40.01% (1721)	74.85% (765)	32.79%***	−36.46%
Furniture	12.17% (127)	11.58% (81)	−0.59% *n.s.*	15.68% (413)	10.13% (371)	−7.55%*	4.95%
Formula	16.00% (1600)	2.43% (1378)	−13.57%***	15.04% (839)	28.06% (692)	11.01%***	−26.59%
Cleaners	9.01% (1017)	7.53% (881)	−1.48% *n.s.*	14.96% (171)	35.30% (126)	18.34%***	−21.82%

***$p<.001$, *$p<.05$

The Baseline % OOS and Treatment % OOS have been masked by adding a constant to the true values in order to protect the confidentiality of the retailer. The Differences (Treat–Base) and Improvement (Tag–Unt) reported are actual values. The reported *p*-values for the statistical tests are based on the undisguised % OOS values

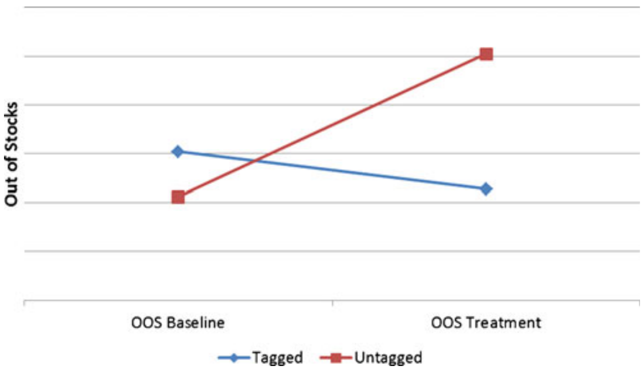

Fig. 2 Floorcare category out of stocks in baseline and treatment periods

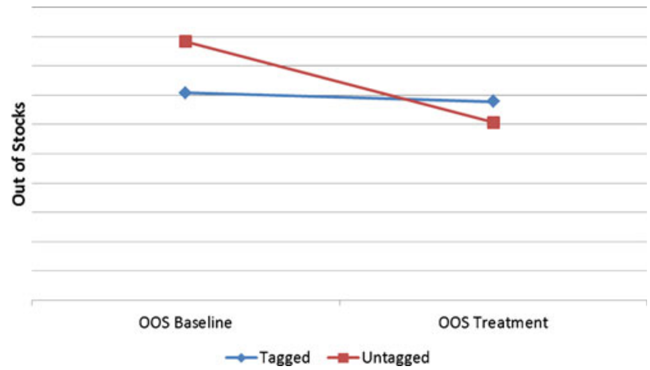

Fig. 4 Ready-to-assemble furniture category out of stocks in baseline and treatment periods

Swaminathan 2010; Hardgrave et al. 2010) which, in turn, would reduce stockouts in the store (Waller et al. 2006). Therefore, as RFID auto-adjust improved inventory records for the tagged products, without influencing untagged products, the overall difference in stockouts for the tagged products versus the untagged products is expected to decrease.

As shown in Table 1, our expectations were largely confirmed. Specifically, for tagged items, we found that the stock outs for all the categories, except ready to assemble furniture, decreased in the treatment period as compared to the baseline period. For untagged items, we found that the percentage of stockouts for the categories, except ready to assemble furniture, increased from the baseline to treatment period. Finally, we calculated overall improvement in the percentage of stockouts for tagged items over untagged items. As expected, we found that all categories except for ready to assemble furniture improved by the implementation of RFID tagging.

Figures 2, 3, 4, 5, and 6 show plots of the percentage of stock outs for all five categories. Except for ready to assemble furniture, we see a consistent pattern where stock outs decreased for tagged items and increased for untagged items in a comparison between the baseline and treatment periods. For ready to assemble furniture, we did not see any apparent influence of RFID tagging.

Moreover, Table 1 reports a test for a difference in proportions between two independent groups—we found these differences to be significant, consistent with RFID tagging reducing stockouts for four out of the five categories. For tagged items, we found a significant decrease in OOS for categories other than ready to assemble furniture and quick cleaners. For untagged items, we found a significant increase in out of stocks (OOS) for categories other than ready to assemble furniture.

Table 1 also shows that in the categories for which RFID tagging did decrease stockouts, the estimates for the percentage decrease in stockouts, when controlling for the untagged SKUs (i.e., the control group), ranged from 21% to 36%.

We investigate the one product category that showed no influence of RFID tagging on inventory management—ready to assemble furniture. As seen in Table 2, in comparison to the other categories in this study, furniture features low sales velocity (number of units sold of an item per year), high item cost, and low density (the total number of units found in a retailer's selling area). This observation is consistent with Hardgrave et al. (2010) who show that RFID tagging ameliorates the effects of known determinants (DeHoratius and Raman 2008) of inventory record accuracy. Since furniture is not characterized by these

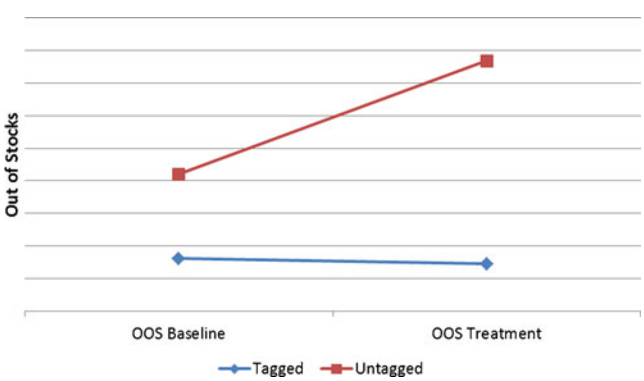

Fig. 3 Aircare category out of stocks in baseline and treatment periods

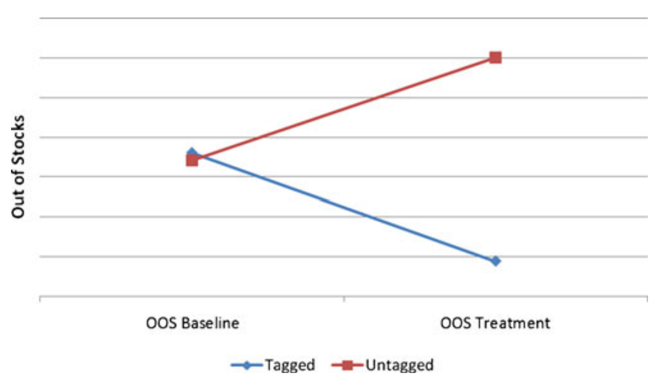

Fig. 5 Formula category out of stocks in baseline and treatment periods

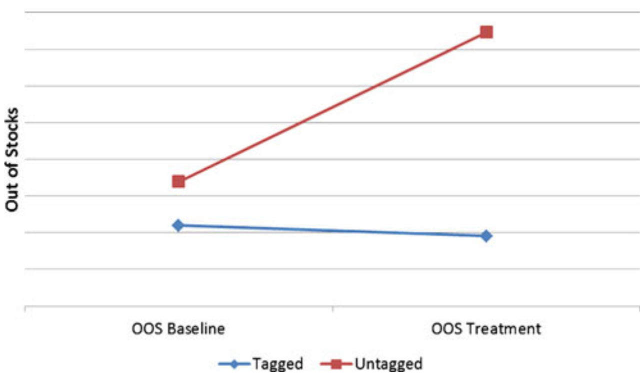

Fig. 6 Quick cleaners category out of stocks in baseline and treatment periods

known determinants, RFID tagging did improve inventory accuracy for this product category. Consequently, we expected in the current research to find that RFID tagging would be most effective in reducing stockouts for product categories characterized by these known determinants, and less effective for categories that are not characterized by these known determinants.

4 Conclusions

The research questions motivating this research may be answered as follows: First, the effectiveness of RFID tagging in improving inventory management is not the same across all product categories. We found that tagging was effective for some categories, with estimates for the reduction in the percentage of stockouts ranging from 21% to 36%. We also found that tagging was not effective for one category out of the five in our study. Second, we found that this variability in the effectiveness of tagging has a theoretical basis for explanation, and is not a mystery that may be attributed to mere statistical chance. The evidence indicates that tagging is most effective for product categories that have predictable record inaccuracy which causes stockouts. This is based on the profile of a category with respect to known causal factors associated with inventory inaccuracy (DeHoratius and Raman 2008) and, thus, should be possible to predict at least qualitatively the extent to which the inventory record may be inaccurate. Hardgrave et al. 2010 show that case-level RFID tags can ameliorate the effects of each of these factors that are associated with inventory inaccuracy.

4.1 Limitations

Like any other empirical research, our study had some limitations and, thus, provides avenues for future research. Our study used data from a single retailer and there is always a possibility that the findings of this study, especially the empirical estimates, may not generalize to other retailers. In trying to assess whether other retailers may observe similar improvements, we note that the retailer involved in the study has a reputation for being very good at inventory management. Since this retailer may be expected to have an already efficient inventory management system, the potential for improvement may be low and, thus, the estimates of improvement in the percentage of stockouts (21–36%) could be conservative compared to other retailers with similar stores. On the other hand, the retailer in our study has SKU variety, sales velocities, sales volumes, and inventory density greater than the average retailer. Thus, the complexity of the environment they operate in may be expected to result in a baseline stockout rate greater than the average retailer and, therefore, the potential for improvement could be smaller for retailers with smaller stores. Finally, the categories used in the study may not be representative of all categories (e.g., the categories may have higher or lower than average stockouts); thus, the findings may over or under-estimate the potential of RFID).

The study included just five product categories and each product category is characterized by the profile of factors (velocity, cost, volume, variety, density). It is not possible to understand the effect of the product attributes on stockouts with bivariate correlations, not controlling for the other attribute values. Future studies that include more

Table 2 Characterization of product categories

Category	Velocity	Item cost	Sales volume	Variety	Density	% Improve
Floorcare	13	60	30	61	9	−36.94%
Aircare	100	0	9	100	100	−36.46%
Furniture	0	100	0	26	0	4.95%
Formula	61	34	100	16	57	−26.59%
Cleaners	19	15	8	0	31	−21.82%

To protect the confidentiality of the retailer, values for Velocity, Item Cost, Sales Volume, Variety, and Density have been scaled to a zero to 100 scale for comparison, with zero representing the lowest value and 100 representing the highest value than five categories could possibly compute an equation that can predict the improvement in stockouts given the profile of attribute values for a category.

We used a quasi-experimental design (Shadish et al. 2002) in this field study. We were not able to randomly assign SKUs within a category to the treatment and control groups as we were subject to the willingness and ability of suppliers to tag their products. However, the fact that we were able to use an experimental design of any kind at all gives us some confidence in the primary findings as it is also based on credible theory on the determinants of inventory record accuracy (DeHoratius and Raman 2008).

Future research should replicate the findings of this study with a different retailer and categories and should examine how and why these findings would be similar or dissimilar in different environments.

4.2 Implications

RFID tagging goes a long way in helping retailers address the problem of how best to allocate their resources in the most efficient manner. Adopting the technology requires time and resources. Equipping a store with readers, developing and implementing software that will integrate RFID read information with inventory management systems, eventually integrating these into customer relationship management systems—these have significant infrastructure cost implications. The cost of tagging products is an operational expense that will impact the bottom line. As retailers weigh the costs and benefits of adoption (McFarlane and Sheffi 2003), among other things, they need to be able to estimate the effectiveness of tagging across their many product categories in reducing stockouts, and to estimate the resultant reduction in lost sales and the increase in customer satisfaction. While pilot testing could give them some guidance, individual tests for all types of products are likely to be prohibitively expensive, or at least, a significant hindrance to quick implementation. The broadly generalizable theory-based insights such as from the current research may help them to make estimates more quickly than would be otherwise possible.

Researchers can also incorporate the insight that it is not equal opportunity for all when considering RFID as a means of reducing stockouts for product categories in a retail store. Either by parametrization or by building contingency models, they may be able to develop new findings that will inform practitioners—and may be tested empirically. Thus, theoretical and empirical insights may stimulate each other and result in greater insight (Fisher 2007).

Prior research has argued that RFID technology helps in effective store execution by influencing forecasting, ordering, and replenishment decisions. Despite the insights from this research, there has been continued skepticism among the retailers regarding the actual effectiveness of RFID technology in improving supply chain performance. One reason is that the rich theoretical insights from the many analytical papers that have explored the issue still leave some doubts as to the actual efficacy of practice in the complex environment of the real world retail store with human factors, unmeasurable uncertainty, and undocumented operational practices. This study helps provide empirical evidence with the kind of ecological validity that may help as it was conducted in stores in the field conducting business as usual. In conjunction with other research methodologies such as analytical models, laboratory experiments and simulations, we may begin to have the comprehensive understanding of issues necessary to convert theory to practice.

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