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Radio frequency (un)identification: Results from a proof-of-concept trial of the use of RFID technology to measure microenterprise turnover in Sri Lanka ☆

Suresh de Mel [a], Dammika Herath [b], David McKenzie [c,*], Yuvraj Pathak [c]

[a] University of Peradeniya, Sri Lanka
[b] Kandy Consulting Group, Sri Lanka
[c] World Bank, United States

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ABSTRACT

Accurate measurement of stock levels, turnover, and profitability in microenterprises in developing countries is difficult due to the fact that the majority of these firms do not keep detailed records. We test the use of radio frequency identification (RFID) tags as a means of objectively measuring stock levels and stock flow in small retail firms in Sri Lanka. In principle this offers the potential to track stock movements accurately. We compare the stock counts obtained from RFID reads to physical stock counts and to survey responses. We have three main findings. First, current RFID-technology is more difficult to use, and more time-consuming to employ, than we envisaged. Second, the technology works reasonably well for paper products, but very poorly for most products sold by microenterprises: on average we were able to read only about one-quarter of the products tagged, and there was considerable day-to-day variation in read-efficiency. This results from technical issues arising from read efficiency being comprised by liquids, metal, and product stacking. Third, a comparison of survey responses and physical stock-takes shows much higher accuracy for survey measures than RFID. As a result, we conclude that this technology is currently unsuitable for improving stock measurement in microenterprises, except perhaps for a few products.

1. Introduction

In a 2008 nationally representative survey of urban microenterprises in Sri Lanka, 81.3 percent of firms with no employees say they do not keep any accounts for their business.[1] This lack of formal recordkeeping is true of many microenterprises around the developing world, and makes it challenging for researchers to collect accurate data on inventory levels, sales, and profits in such firms (Vijverberg, 1991; Daniels, 2001; De Mel et al., 2009). The large genuine volatility of incomes in such businesses (Collins et al., 2009; Fafchamps et al., 2012) can make recall more difficult, and make it harder to distinguish measurement error from actual fluctuations. A further complication arises in evaluations of interventions, where the receipt of a program (such as access to credit) may affect individual's incentives to report accurately, or, in the case of business training, may even change the accuracy with which respondents can report on their business. As a result many studies of microenterprises suffer from high levels of imprecision and of item-response on profits and sales, or otherwise struggle to measure these concepts at all (see McKenzie and Woodruff (2014) for a review).

Yet accurate measurement of inventory levels, turnover, and profits is crucial for answering many questions of economic interest, such as determining the returns to credit or training, to understanding choices between wage work and self-employment, and measuring levels of poverty and inequality. New technologies have begun to offer the potential to improve measurement in a number of domains (McKenzie and Rosenzweig, 2012), raising the question of whether technology can also provide an objective (not self-reported), accurate, and time- and cost-effective measure of business activity in microenterprises?

This paper reports on a trial of the use of radio frequency identification (RFID) tags to measure inventory levels and turnover

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* Corresponding author.
E-mail address: dmckenzie@worldbank.org (D. McKenzie).

[1] Data from the baseline of the Sri Lanka Longitudinal Survey of Enterprises (SLLSE). See De Mel et al. (2010) for survey details.

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in Sri Lankan microenterprises. RFID tags are increasingly being used in large U.S. retailers like Kohls, Walmart, LLBean, and Best Buy[2] for inventory management. In principle one can apply the tags to new stock as it comes in, and then use a reader to measure stock levels at any point in time without having to physically scan items one by one as would be the case with bar codes. Measuring the flow of stock coupled with price data then can provide data on sales, which could then in turn be coupled with unit cost or mark-up data to provide a measure of profits.

We implement this process in 22 microenterprises in Kandy, Sri Lanka. We accompany the tagging of inventories with physical stock-takes, and with survey elicitation of inventory levels from the firm owners. This enables comparison of the accuracy of RFID reads compared to survey responses. In addition, we tested the accuracy of RFID tagging on a larger range of products in our field office in order to provide evidence on which types of products this technology works for best.

There are three main findings of this proof of concept trial. First, available off-the-shelf technology is more difficult to use and more cumbersome than we had envisaged, and than is suggested by media accounts of the spreading use of this technology. Setting up the system required a period of fine-tuning and overcoming technical obstacles, and then the time taken to scan inventory levels at a firm was approximately 30 min. per firm. Second, in terms of proof of concept, our results show that (i) it is possible to get firms to agree to use this technology; (ii) the technology is able to work reasonably well for paper products and some clothing items; but (iii) the read-efficiency of the technology is very poor for many products offered by microenterprises, and varies from day to day. This poor read efficiency results from technological constraints with reading the tags in the presence of interference from liquids, metals, and stacked products. As a result, RFID technology does not enable accurate measurement of stock levels or turnover in most microenterprises. Third, survey questions on stock levels are much more accurate in terms of matching the results of our physical stock counts, providing some reassurance that relying on survey self-reports can yield reasonably accurate measurement (although this should be caveated by noting that owners may have paid extra attention to these items because of the study and so our surveys may be unusually reliable).

The remainder of the paper is as follows. Section 2 provides an introduction to RFID technology, and discusses how it is currently used by large firms, and how it could be used in principle to provide measurement of turnover and profits in microenterprises. Section 3 provides details of our trial, including the technology used, how we selected firms, how the tagging process worked in practice, and our office trial. Section 4 provides the results, and Section 5 concludes. An online appendix provides photograph and video illustrations of the products used and the tagging process.

2. RFID technology and its use to measure inventory levels, turnover, and profits

2.1. RFID technology

Radio-frequency identification (RFID) technology uses radio frequency waves to transmit information.[3] The basic technology consists of an RFID tag and a reader. The RFID tag has an embedded microchip which allows it to store data, and an embedded antenna to transmit this information. Each chip contains an electronic product code (EPC) which allows for unique identification of the tags, along with customized information chosen by the user. The reader is a device that has one or more antennas that emit radio waves and receive signals back from the tag. This information can then be linked to a database on a computer.

There are two types of RFID tags: active and passive. Active tags have their own battery attached to them, and use this power to constantly emit their own signals. As a result they can communicate over ranges of 100 meters or more. An example is the E–Z Pass used to automatically pay tolls on some roads in the U.S. Active tags can be relatively large in size and can cost $15 to $50 per tag, so are typically not used to track inventories apart from a few large, high-value, items. In contrast, passive tags do not have their own power supply, and instead rely on the radio-frequency energy transmitted by the reader to run the circuitry on its chip and reflect a signal back to the reader. This reflection is a weaker signal, and so the reader has to be much closer to the tag in order to be able to read – typically distances of between 5 cm and 3 m depending on the strength of the antenna (Lee, 2003; Holloway, 2006). The range is larger the larger the antenna, which results in a larger tag. The passive tag is much smaller in size than the active tag (typically the size of a sticker or credit card), and considerably cheaper, averaging 20–30 cents per tag. As a result of its size and cost, it is the main type of tag used in inventory and supply chain management.

Passive RFID tags have been trialed for inventory-management in several large retailers in the U.S. and U.K., including Walmart, Marks and Spencer, Sainsburys, Dillards, and Bloomingdales.[4] The main use appears to have been in stockrooms, with these organizations using passive RFID tags to track and inventory large boxes or pallets of inventory. Williams (2008) notes that despite much hype about how RFID would take over retailing, it has been slow to get embraced on the sales floor. However, there have also been several trials of their usage for tracking individual products, with a recent example being fashion store Zara implementing the use of RFID tags in 2014 to track items from factory to point of sale.[5] One of the main barriers to more widespread usage at the individual product level has been cost, with the cost of a tag too high to justify use on high volume, low margin goods (Gillmore, 2011).

RFID technology in principle offers several advantages over barcodes. In particular, they can be programmed to store more information, which can be unique for each item. Common examples given are the possibility of adding expiration dates to perishable products, and manufacturing batch numbers to pharmaceutical products (allowing easy identification of which items to remove from shelves in case of a recall). Moreover, they do not require line of sight reading, and can enable inventory counts without the need to physically scan each item's barcode.

However, since passive tags rely on transmission of radio waves between the reader and tag and back, there are several factors that can prevent accurate reads (Roberti, 2013).[6] The three main issues are liquids, metals, and tag shadowing. Materials containing a large amount of water absorb radio-frequency energy, so that the tag fails to receive enough energy to reflect back a strong signal. Metal can reflect energy away from a tag, or reflect the tag's signal away from the reader. Finally, if items are stacked so that tags are lined up behind one another, the first tag can capture the reader's energy, shadowing the tags on items behind it. The result can be that the first item is read but those behind it are not. Typical

[2] E.g. http://www.rfid24-7.com/article/kohl%e2%80%99s-deploys-rfid-chain-wide-launches-consumer-engagement-apps/ (accessed 28 July, 2012).

[3] The description of RFID technology which follows is drawn from Violino (2005), Gaukler and Seifert (2007), and Holloway (2006).

[4] See for example the set of case studies at http://rfid.auburn.edu/research-papers.cfm.

[5] http://www.reuters.com/article/2014/07/15/inditex-zara-idUSL6N0PQ3MY20140715 (accessed August 1, 2014).

[6] These are typically not issues with active tags, which produce their own signals.

descriptions of RFID technology describe these as potential issues, but we have not found any numerical evidence of their importance in field settings of the sort seen in the typical microenterprise, and discussions of the lack of take-up have focused mostly on cost issues (Gillmore, 2011).

It is therefore an open question as to whether the promise of RFID can be realized in enabling accurate measurement of microenterprise inventories, or whether these technological issues and operational issues limit its effectiveness.

2.2. How can this technology be used in theory to measure sales and profits?

The goal is to enable the research team to measure stock levels and stock flows in the microenterprise without having to require the business owner to do anything at the time of each sale.[7] This can be accomplished in principle through the following steps.

Step 1: Itemize the different products carried by the store, print tags, and apply them to the products.

This could involve a physical stock-take to determine how many of each item the store has to begin with, or just a listing of all the different products the store carries. Then tags would be printed which would identify the date of tagging, product, and price of the product. For example, a tag could identify a particular product as a large bar of yellow "Sunlight" brand soap, priced at 45 SLR, and tagged on December 1, 2013.

Step 2: Immediately after applying all these tags, scan them to obtain a read of the total stock level of the firm on this day t.

This provides both information on physical stock numbers of each item (e.g. 8 large bars of yellow "Sunlight" brand soap), and, through using the prices of each item, the value of inventory at date t, denoted $Stock_t$.

Step 3: When new stock is purchased by the owner, apply tags to this before it is offered for sale.

There are several ways this could be done. Tags could be left with the owner to apply him or herself to the items, so long as they clearly indicate which product they should go on; or research assistants could arrange to meet the owner when new stock is being delivered or purchased and tag this new stock. In the firms in our study, the two most common restocking frequencies were weekly (36.1 percent of items) and monthly (32.2 percent of items), with only 2 percent of items being restocked daily. So depending on the type of business, it may be feasible to have research assistants do this new tagging. Denote the value of retagged inventories between t and $t+s$ by $Retag_{t,t+s}$.

Step 4: Return to the business and scan the tags on day $t+s$

This should ideally be done at the same time of day as the initial read, and will provide a read of the number of items and value of stock levels on day $t+s$, $Stock_{t+s}$.

Step 5: Calculate sales over the period of s days

Sales can then be calculated as:

$$Sales_{t,t+s} = Stock_t + Retag_{t,t+s} - Stock_{t+s} \quad (1)$$

Step 6: Calculate an estimate of profits based on mark-ups or unit costs

Using the price and unit cost for each item, or the mark-up, one can determine the profit made from selling each item. Since sales will be available at the product level, profit on each product over the period of s days can then be calculated and added up.

2.3. Practical issues to consider

The great advantage of this procedure is that it does not require the owner to have to do anything at the point of sale. That is, we are not reliant on the owner to record or remember every single transaction made, nor to adopt a new sales process such as scanning bar codes at the time of sale. However, there are several practical issues to consider. The first is that it may not be cost-effective or feasible to tag all of the different products sold by the firm. In this case one can then take a sample of the products sold and at least track movements in inventory levels and sales for this subsample, potentially then scaling this up by some elicited sales share to get an approximation of total sales. Second, for some products there may not be a fixed price, with the owner negotiating with each customer. Using an average price charged should still provide a reasonable approximation in most cases, with the opportunity to update this average price at the time of each retagging. Third, the procedure above would treat as sales items which are thrown away or given away or used for home use. The former is more of a concern for highly perishable products, and in principle regular RFID scans of the trash pile could help alleviate this. Items given away would have to be recorded through survey questions, while in principle having the owner keep the tags of items taken for home use could allow recording of this component. How important these issues are will depend on the types of products sold. In most cases the procedure should in theory provide a reasonable approximation, and moreover, not be subject to differential reporting bias between treatment and control groups in experimental interventions.

3. Details of our proof-of-concept trial

3.1. Technology used

We invited quotes from leading manufacturers of RFID printers and chose to buy the Zebra RZ400 printer ($2950), from their reseller *Barcoding* based on a combination of responsiveness to our queries and price. This printer is described as an "easy to use, robust, industrial-strength printer" with favorable ratings on industry websites.[8] This was coupled with the NiceLabel software[9] ($450) which is designed for use with leading RFID printers, and which encodes the RFID tags. To read, store, and extract the RFID data from tagged products we used the Motorola MC 3190 Z handheld RFID-enabled reader ($3900) supplemented with the recommended rAgent mobile software ($1300) for processing of the RFID read data. The total fixed costs of hardware and software were thus $ 8600. We purchased 24,000 Alien 9629 2″ by 1″ RFID passive tags for $5280 (an average of 22 cents per tag).

3.2. Selection of firms and products

We selected 24 microenterprises operating in markets around Kandy, Sri Lanka to participate in the study. We carried out an initial screening exercise based on revenue, profit, varieties of goods, number of items and percentage of varieties that were non-taggable in eight geographic regions. To be included in the sample, firms needed to have monthly revenue less than 500,000 LKR ($3846), monthly profit less than 100,000 LKR ($769), number of varieties of goods less than 100, number of items less than 2000 and non-taggable varieties to be less than 50%. The justification for

[7] An alternative approach would be to introduce bar code scanners and/or cash registers in an attempt to get business owners to record every transaction. This requires much greater behavior change on the part of firm owners, and we are unaware of studies that test such an approach.

[8] See for example http://www.itpro.co.uk/609036/zebra-rz400—rfid-printer (accessed July 29, 2014).

[9] http://www.nicelabel.com/Solutions/Applications/Label-Design/RFID-label-design (accessed July 29, 2014).

Table 1
Baseline characteristics of pilot firms.

	Mean	StdDev	Percentiles			Maximum
			25th	50th	75th	
Business Characteristics						
Value of stock on hand	84,143	70,512	50,000	60,000	100,000	300,000
Number of items for sale among top 30 products	579	395	316	484	730	1820
Proportion of top 30 products that are taggable	0.69	0.15	0.57	0.63	0.80	0.95
Number of items for sale that are taggable	290	187	168	243	365	765
Number of items for sale actually tagged	282	118	184	262	367	543
Weekly revenue from top 30 products	22,073	18,444	5550	15,934	32,300	66,200
Percent of sales from top 30 products	75.9	21.2	58	85	91	100
Monthly profit	16,786	11,589	7000	15,000	20,000	48,000
Owner Characteristics						
Owner is Female	0.24	0.44	0	0	0	1
Age of owner	52.62	11.65	47	53	61	75
Years of Education	10.24	2.59	9	11	13	13
Age of business (years)	14.85	15.33	4	8.5	23	53
Keeps no business records	0.95	0.22	1	1	1	1
Number of paid employees	0.05	0.22	0	0	0	1

Notes: Data is for 22 small firms used in pilot. All amounts expressed in Sri Lankan Rupees (1 USD = 130 SLR).

using this screening criteria was to ensure a focus on small scale enterprises where RFID technology would be feasible. In order to select one firm that met all the listed criteria, research assistants had to visit about 4–5 enterprises. Microenterprise owners were told that the purpose of the study was to test the feasibility of a new technology for helping monitor stock, and were offered 5000 LKR ($38) to compensate them for their time and cooperation in the study. Two of the firms decided to drop out after an initial pilot tagging exercise leaving us with a sample of 22 firms. Of these 2 firms were closed on repeated occasions due to health related reasons and so were dropped during the course of the study, leaving us with complete data on 20 firms.

These microenterprises are retail stores with no paid employees. The majority of them sell food and beauty items, with a couple of stores selling plastic goods or cloth. Table 1 provides some basic descriptive statistics of these firms. Although the median firm has been in business for 9 years, 95 percent keep no business records. The median value of stock on hand is estimated at 60,000 LKR ($461), with median monthly profits of 15,000 LKR ($115).

In the baseline survey the owners were asked to list their thirty highest selling products, the aim being for us to cover the products that contributed most to their profits. The median firm said that 85 percent of total sales came from these top 30 products. Our field team then did a physical stock-take of these products. The mean number of items sold by a firm in the survey among their top 30 products was 579, with a median of 484 items. Given that existing literature had noted the possibility that liquids and metals can interfere with radio frequency signals to make it difficult to detect the signals from RFID tags, we then excluded items such as canned beverages, products in tin boxes, and juice bottles. In addition we excluded loose products sold by weight (such as spices), to arrive at a list of "taggable" products from among the top 30 most sold items. On average 69 of the top 30 most sold products were taggable.

Then based on the stock take and this listing of which were taggable, we printed tags for the firm in our field office, and returned the next day to apply the tags to this selection of products from the firm. On average we tagged 282 products per firm. At this time we also scanned the RFID tags to provide information on the baseline stock level of the selected products in these firms.

A detailed multi-media appendix provides a visualization of this process. This includes a flowchart of the set-up process (Appendix 1), photographs showing products tagged in the store (Appendix 2), and a video of the scanning process taking place (Appendix 3).

3.3. Scanning, re-tagging, surveying, and physical stock count

Each product was given a unique 12 digit ASCII string identification number. This is then converted into a 24 digit hexadecimal string that is encoded on the tags. The resulting xml database is uploaded to the memory of the rAgent software on the RFID reader, and bifurcated into 22 "picklists" by the unique store identifiers. Then the field team would go to the store and hold the reader in the vicinity of the tagged goods to scan these items. For each tag detected, the reader runs through the picklist to attempt to find a match, and then records the number of unique RFID tags detected, time-stamping the counter. This was then stored in the reader database, and extracted each day in our field office.

Our field team would go to the microenterprise each day during selected weeks to carry out these scans.. Information on new incoming stock was provided to the field team during these daily visits, allowing retagging to take place as required.

In our initial design, we had expected the RFID reads to provide an accurate measure which we could then compare survey responses to. We therefore had firms rotating between different types of survey questions: a one week recall which asked item by item for inventory levels and sales of all products tagged, and then one day recall which asked about the three highest selling products (Appendix 4 provides the questionnaires). However, it became apparent that the RFID reads were significantly lower than reported in the surveys, and so in order to have a reliable gold standard to assess which was correct, we also implemented physical stock takes. We then use the data for the 14 days for which we have both RFID reads and stock-take data for the firm.

3.4. Field office trial of additional products

We supplement the proof of concept trial in actual firms with testing in the Kandy Consulting Group (KCG) field office. This was done for several purposes. First, it enabled us to test whether the read efficiencies obtained in firms would be higher in a more controlled environment. Second, it enabled us to test a much broader range of products. This included paper and other stationary products, fruits and vegetables, footwear, and higher value items such as a laptop computer, fans, compact discs, and cellphones. Appendix 2 provides photographs of these products.

4. Results

4.1. More difficult to use than expected

Since this is a proof of concept trial, the first set of results concerns the feasibility of implementing this process. Our (naïve) prior based on online descriptions of printers as easy to use, and of standard desktop printers, was that this should be simple plug-and-play technology that could be easily set up within a day or two. In addition, we were under the impression that since the RFID reader did not have to physically scan a barcode item by item, it would be able to quickly scan the entire tagged inventory. In practice the process turned out to be much more difficult to set up and more time consuming to employ than expected.

We purchased the printer, reader, and tags in Washington D.C. and shipped them to Colombo, Sri Lanka. The printer is large (10.9″ width × 13.3″ height × 18.7″ depth) and heavy (32.4 pounds, shipping weight of 49 pounds). The equipment was held up in customs for over two weeks due to the size of the package. The size of the printer also makes it impractical to take from microenterprise to microenterprise and print tags on location.

The set-up process required trial and error to correctly calibrate the printer to correctly print the tags, to figure out which memory bank on the RFID tag to store the product information on, and to configure the software correctly for both printing and reading purposes. Appendix 5 describes this process in more detail. Ultimately we were able to print and read the tags. We did two trials on successive days. In the first we printed 70 tags and were able to successfully read 69 of them, and on the second day we printed 200 tags and were able to read 198 of them. These tags were not attached to any product, so merely were a test of whether the tags were being printed and then read correctly.

In addition to being more time-consuming to set-up than anticipated, the time taken to read the scanned product information was much longer than expected. When the reader scans the tags, it searches through a picklist to find each one, looping through each time. It took one to two hours to generate a new picklist each evening to use the next day, and then averaged 10–15 min to scan the selected 280 or so items in a firm, and another 15 min to process the tags by finding matches against the database on the reader (this was usually done while traveling from one store to another). We were able to scan 20 firms in a day, but this took the entire day. This has obvious implications for the cost of employing such technology. At 22 cents per tag, tagging lots of products per firm can add up, and it clearly would not be cost effective for these business owners to employ this technology. Nevertheless, we could see this being used in some impact evaluations to obtain an objective measure of stock turnover at a tagging cost of perhaps $80–100 per firm that may not greatly exceed the cost of a survey round in some contexts. However, given the high cost ($5200) of the reader and reader software, if a reader can only manage 20–22 firms in a day, then the cost of using this technology on a large number of firms becomes more prohibitive.

4.2. Accuracy of the RFID measurement

We present results for the days for which we have RFID reads, physical stock-takes, and survey reports. Table 2 provides the results of the field trial at the product level, while Table 3 aggregates by product category. We see the main items tagged were packets of biscuits, plastic items, clothing, soap and washing powder, and clay and china pots. In total out of 4773 tagged items physically counted in the stores by our field teams, the RFID reader was only able to read 1210 items, or 25.4 percent. The highest read efficiency (defined as percent of tags counted which were actually read) is for plastic basins, where we were able to read 76.1 percent of the tagged items, while there are five items for which we were unable to read any product tags at all.

Moreover, there is considerable variation in the read efficiency for the same product over different days, as indicated by the standard deviation, and for the same type of product over different brand/product size/store combinations. For example, we see one type of soap bars (sunlight soap small) had 52.5 percent average read efficiency, although with a standard deviation of 18 percent across days. Moreover, five other types of soap bars had read efficiencies below 10 percent. As a result, soap as a category has the second lowest read efficiency in Table 3.

If the RFID read efficiency was always the same fraction, then one could re-scale the number of products read to get a more accurate estimate of the true stock on hand. However, as Table 2 shows, the read accuracy varies across products, and for the same product over different days. As a result, when we aggregate up, the overall read efficiency varies from day-to-day. This is shown in Fig. 1, where the aggregate read efficiency varies between 7.0 percent and 43.8 percent across days.

We then turn to results from our KCG office trial. Our first trial tested similar products as those tested in firms in the field trial. To simulate a firm-like environment some of these products were moved around to a different location within the room, or taken out or added from one day to the next. Appendix 6 reports the results. In total we read 485 of 2004 tags (24.2 percent), which is very similar to our read efficiency in the field of 25.4 percent. This suggests it is not the field setting that was leading to the low read efficiency.

Our second field office test worked with stationary items and office products that we expected to work better with the RFID technology. Again reading took place over several weeks. Table 4 reports the results. In total we were able to read 2111 tags out of 2586 (81.6 percent). Fig. 2 shows that this greater read accuracy over the standard microenterprise inventory products occurs on every day, and ranged between 70 percent and 90 percent. Importantly it also shows that there is no tendency for performance to worsen over time.

Finally, we test a broader range of goods, including 118 products over 6 or more days. Photographs of all these products are provided in Appendix 2, and item-by-item read efficiencies in Appendix 7. We aggregate the results by category in Table 5. Overall we read 1343 out of 3609 tags, for a 37.2 percent read efficiency. Footwear was the category with highest overall read efficiency, with us able to read 82.1 percent of tags on average, including 100 percent of the gents' slippers we tagged. We also had 100 percent read efficiency on our risograph (a high-speed digital printing machine used for printing our survey questionnaires for other projects), and 89 percent efficiency (reading the item on 8 out of 9 days) for our photocopy machine. In sharp contrast, the read efficiency was only 6.4 percent for fresh fruits and vegetables, including zero tags being read for mango, watermelon, coconut, pears, apples, and papaya. It is also worth noting that stationary performs much worse in this last trial than in Table 4. The main stationary items in our last trial were notebooks, which were stacked in a pile with the tags affixed to the covers. The RFID reader appears unable to read the tags of items stacked under several other books, likely reflecting the shadow tagging phenomenon.

4.3. Survey accuracy

In contrast, simply asking firm owners to report how many of each item they had in stock appears vastly more accurate than using the RFID technology. Table 2 compares the number of items reported by the owner to the number subsequently counted by our field team in the physical stock count. On average the survey measure is 99.4

Table 2
Comparison of accuracy of RFID reads and survey measures in pilot firms by product.

Product name	Product category	Aggregate RFID count	Aggregate survey count	Aggregate stock count	RFID Accuracy		Survey Accuracy	
					Percentage of tags read	Std Dev of % tags read	Survey to stocktake % ratio	Std Dev of survey to stocktake % ratio
Plastic Basin	Plastic Items	51	56	67	76.1	40.7	83.6	36.1
Munchee Marie Biscuits	Biscuits	176	259	234	75.2	34.1	110.7	16.0
Tikiri Marie (Small)	Biscuits	66	104	101	65.3	38.6	103.0	14.5
Rice Sieve Clay (Large)	Clay or China	28	33	43	65.1	91.9	76.7	17.5
Dustbin (Small)	Plastic Items	266	466	467	57.0	222.6	99.8	7.6
Sunlight Soap Small	Soap	42	79	80	52.5	18.0	98.8	2.6
Maliban Chocolate Cream Biscuits	Biscuits	84	185	173	48.6	38.1	106.9	11.6
Gold Marie Biscuits	Biscuits	73	169	158	46.2	37.9	107.0	44.1
Uniform Whitening die	Liquid	17	39	39	43.6	71.9	100.0	0.0
Clay Pot Cover (Small)	Clay or China	28	36	69	40.6	36.0	52.2	25.1
Bread Pack	Plastic packed food	2	5	5	40.0	50.0	100.0	0.0
Lifebuoy Soap (Large)	Soap	9	24	23	39.1	28.7	104.3	11.2
Baby Bathtub Plastic	Plastic Items	14	43	42	33.3	18.8	102.4	7.6
Plastic Basin (Small)	Plastic Items	87	247	272	32.0	23.3	90.8	19.9
Bucket (Small)	Plastic Items	21	69	68	30.9	20.5	101.5	20.6
Cream Cracker Biscuits 150g	Biscuits	6	22	22	27.3	31.9	100.0	0.0
Batik Sarong	Clothing or Other	54	235	221	24.4	13.1	106.3	12.5
Indian Sarong	Clothing or Other	25	96	115	21.7	14.5	83.5	18.4
Surf Excel Washing Powder (Small)	Washing powder	20	82	111	18.0	8.2	73.9	39.6
Tea Leaves 100g pack	Tea	10	54	60	16.7	17.7	90.0	18.5
Sanitary Towel	Clothing or Other	30	170	183	16.4	25.0	92.9	15.1
Diana Biscuits	Biscuits	31	203	196	15.8	18.1	103.6	6.3
Lifebuoy Red	Soap	9	70	60	15.0	14.6	116.7	20.8
Clay Pot (Small)	Clay or China	16	112	145	11.0	10.6	77.2	21.2
Printed Sarong	Clothing or Other	14	220	181	7.7	9.9	121.5	68.6
Munchee Bourbon 100g	Biscuits	1	14	14	7.1	0.0	100.0	0.0
Bun	Plastic packed food	9	138	142	6.3	17.9	97.2	19.7
Baby Soap	Soap	5	100	109	4.6	9.0	91.7	25.6
Sunlight Yellow	Soap	14	853	807	1.7	2.4	105.7	40.1
Lifebuoy Soap (Small)	Soap	1	65	64	1.6	5.8	101.6	8.6
Lux Soap	Soap	1	54	66	1.5	3.4	81.8	12.2
Tipitip Pack (Small)	Plastic packed food	0	80	80	0.0	0.0	100.0	0.0
Sunlight Washing Powder Small	Washing powder	0	100	106	0.0	0.0	94.3	25.6
Green Sunlight Soap (Large)	Soap	0	3	3	0.0	n.a.	100.0	n.a.
Cream Cracker	Biscuits	0	112	112	0.0	0.0	100.0	11.8
Rock Salt Packet	Plastic packed food	0	145	135	0.0	0.0	107.4	13.6
AGGREGATE		1210	4742	4773	25.4		99.4	

Notes: Data is aggregated over all days and products for which we have survey, stock count, and RFID measures. Standard deviation is the standard deviation across days. n.a. denotes no standard deviation available as product only present for one day.

Table 3
Accuracy of RFID Reads and Survey Measures in Pilot Firms by Product Category.

Product category	Aggregate RFID count	Aggregate survey count	Aggregate stock count	RFID Accuracy		Survey Accuracy	
				Percentage of tags read	Std Dev of % tags read	Survey to stocktake % ratio	Std Dev of survey to stocktake % ratio
Plastic Items	439	881	916	47.9	34.0	96.2	10.5
Liquid	17	39	39	43.6	71.9	100.0	0.0
Biscuits	437	1068	1010	43.3	27.0	105.7	8.7
Clay or China	72	181	257	28.0	17.7	70.4	19.1
Clothing or Other	123	721	700	17.6	9.9	103.0	17.1
Tea	10	54	60	16.7	17.7	90.0	18.5
Washing Powder	20	182	217	9.2	9.8	83.9	21.8
Soap	81	1248	1212	6.7	5.1	103.0	26.0
Plastic Packed Food	11	368	362	3.0	11.0	101.7	13.4

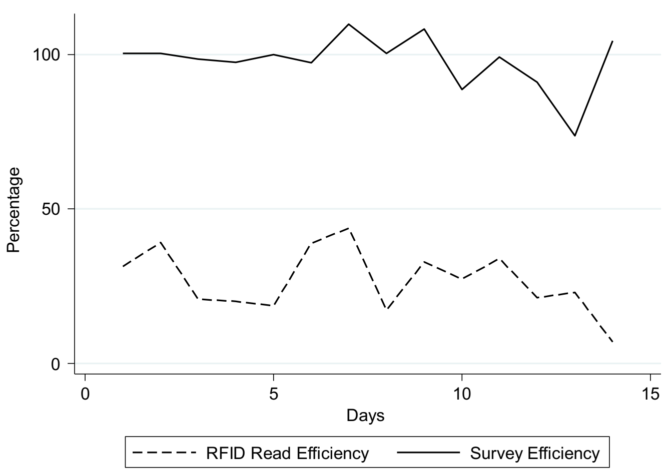

Fig. 1. Comparison of the accuracy of the RFID reads and of survey measures. *Notes:* RFID read efficiency defined as total number of tags read by RFID reader as a percentage of number of tagged products counted in physical stock-take; Survey Efficiency is total number of items of tagged products reported by owner in survey as percentage of number counted in physical stock-take. Results are aggregated across all firms in the field trial.

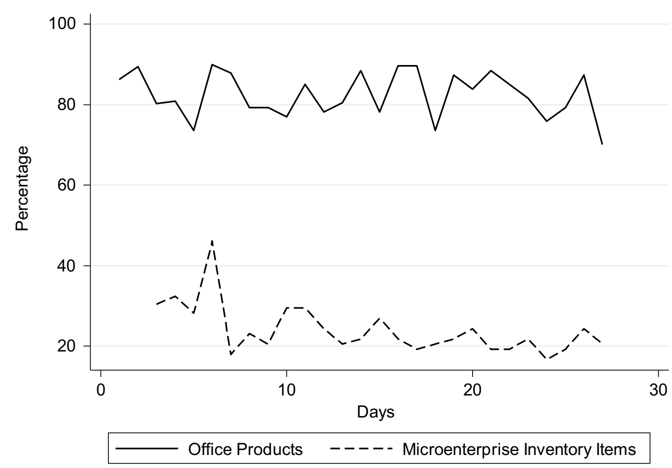

Fig. 2. Comparison of the RFID read accuracy of office products and micro-enterprise inventories. *Note:* results from KCG Field Office Trial.

percent of the actual enumerated amount. Moreover, when we consider this item by item, the median item has survey response exactly equal to the count, and 50 percent of the items have a survey to stock-take ratio between 91.3 and 104.0 percent. Fig. 1 shows the survey responses dominate the RFID reads in terms of accuracy on every day for which we have both measures.

We acknowledge here the possibility that firm owners may have been paying more attention than usual to these items in their inventory because we had applied tags to them, and because we returned to ask about these items on multiple days. Nevertheless, the results demonstrate that surveys can obtain accurate information on inventory levels, and it would be of interest in future studies to test this further.

4.4. Discussion: why did RFID underperform and when does it work best?

These results demonstrate very disappointing overall performance of RFID tags. One concern might be that since we tested this technology using only one printer and reader, we may have had faulty equipment or that we used them incorrectly. Certainly we experienced a lot of difficulties getting this technology up and

Table 4
Read efficiency for office products in KCG field office trial.

Product name	Aggregate RFID count	Aggregate stock count	Percentage tags read	Std Dev of % tags read
Computer Chairs (Old)	13	14	92.9	8.2
Magazine Files 3 in.	109	122	89.3	24.1
Lever Arch Files 3 in.	60	68	88.2	22.2
Computer Chairs (New)	59	68	86.8	26.2
Duplicating Paper Packet with Printed cover	624	724	86.2	19.0
Paper Bundle (Cat A)	425	494	86.0	20.5
Standing Fans	5	6	83.3	17.7
Stationery pack	78	95	82.1	39.4
Paper Bundle (Cat B)	126	161	78.3	20.4
Magazine Files 4 in.	231	305	75.7	18.8
Duplicating Paper Packet without Printed cover	127	170	74.7	24.9
Paper Bundle (Cat C)	254	359	70.8	24.4
AGGREGATE	2111	2586	81.6	

Table 5
RFID read percentages for final KCG office trial, by products category.

Category name	# of tags read	Total # of tags	% Tags read	Std dev (in %)
Footwear	133	162	82.10	8.69
Other	62	81	76.54	17.95
Spice packets	61	81	75.31	4.90
Toothbrush and paste	80	108	74.07	10.58
Clothing	53	81	65.43	10.31
Washing powder	49	81	60.49	18.52
High-end items	197	387	50.90	7.02
Soap	79	162	48.77	8.23
Eggs	42	90	46.67	22.36
Clay and China	37	81	45.68	8.69
Plastic items	56	135	41.48	8.68
Office Supply Items	121	324	37.35	4.63
Liquid	56	162	34.57	5.40
Tea	35	108	32.41	2.78
Plastic packed food	143	477	29.98	3.94
Stationary	95	324	29.32	13.11
Fresh Fruits and Vegetables	40	585	6.84	5.86
Biscuits	4	162	2.47	4.04
Dry fruits	0	18	0.00	0.00
Broom	0	18	0.00	0.00
AGGREGATE	1343	3609	37.21	

Results represent aggregate numbers for 6 days. For individual products refer to Appendix 7.

running, but we were able to print tags and read almost all of them before they were applied to any product, and to get very high read efficiencies on particular products. So we do not believe this can be the main explanation for the poor performance.

The more likely explanation appears to be that the technology does not work very well with certain types of products. The literature had pointed to the possibility of interference from liquids and metals. This may have been the problem with some of our products – for example, the packaging on some of the packets of biscuits contains a thin metallic layer, while some of the fruits have high water content. But it also appears that the technology does not work very well when items are stacked in a pile on top of each other, removing line of sight between the tag and the reader. But having goods stacked like this is very common in a microenterprise setting (see videos of the store settings in Appendix 3), and if one needs to physically pull out each item and scan it one by one, then RFID offers little advantage over just reading a bar code or physically counting items. These issues may be less severe if more powerful antennae are used. However, we did not want to use larger RFID tags because we did not want the tags to take up too much of the packaging and lead to the microenterprise owners or their customers complaining, and the tags we had were still relatively large in size compared to the products they were being placed upon. As technology improves, presumably it will be possible to use small tags with more powerful antenna.

Based on our results, the current technology works best with a few large items like photocopiers for which there is clear line of sight and no other tags, and for stationary items so long as they are not stacked up. This accords with the current most common use of RFID tags in large stores, which is to track large boxes of goods in warehouses – here the tags would be on large paper items, with clear line of sight in reading.

5. Conclusions

The fact that most microenterprise owners in the developing world keep no records makes it difficult for researchers to measure inventory levels, profits, and sales. RFID in theory offers a potential way for researchers to overcome this problem and obtain objective measures of stock flow. However, our proof of concept trial finds that currently this technology performs very poorly in practice with the types of goods sold by many microenterprise retailers. Moreover, the technology is relatively complicated and expensive to set up and use. As such, we do not see RFID as a solution to this measurement problem in the near future, despite news accounts of its increasing use in large retailers in developed markets. As a silver lining, our analysis finds that simple survey questions asking microenterprise owners how much they have of each item can do very well on average at matching the amount measured by physical stock counts (although this may in part reflect the added attention the owner directed to the tagged items). This will not alleviate all concerns about deliberate or systematic misreporting in response to an intervention or because of tax concerns, but does suggest that fact that owners do not keep records need not itself be a large barrier to obtaining reasonably accurate measures of stock. The challenge then remains for future work to develop and test other objective measures of inventory and sales turnover.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.deveng.2015.06.001.

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