RFID Adoption and Productivity Growth in U.S. Retail Supply Chains

Completed Research Paper

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ABSTRACT

Ten years have passed since Wal-Mart's public announcement about its RFID technology adoption plan in 2003. There has been a slowdown of RFID technology adoption since 2008. Many U.S. retailers do not consider adopting the RFID technology because of the uncertainty of return on investment and the lack of business cases. This paper evaluates labor productivity of RFID adopted retailers. This paper uses objective data from financial statements and explains association between RFID technology and adopted retailer's productivity. The regression analyses using the Cobb-Douglas production function suggests that RFID companies have higher labor productivity than non-RFID companies. But the gap between RFID and non-RFID is not significant.

Keywords: RFID, Cobb-Douglas Production Function, Retail Productivity

Introduction

Productivity is defined as a ratio of outputs to inputs, and efficiency is measured by the ratio of observed output to the maximum potential output that can be obtained from inputs (Fried, Lovell & Schmidt., 2007). Productivity measures companies' efficiency in generating outputs with limited input resources, and it can be used to compare companies in the same industry. Maintaining high productivity is a key to maintaining high profitability on a long-term basis. According to the report by National Retail Federation (JD Associate, 2011), there are commonly used key performance indicators (KPIs) in retail industry such as sales, customer returns, transaction counts, labor costs, inventory-to-sales ratio (ISR), inventory turnover ratio (ITR), return on capital employed (ROCE), gross margin return on investment (GMROI). Even if there are many indicators, there is a challenge for measuring retail productivity because of the retail industry's intangible characteristics of outputs and inputs.

RFID technology, a wireless Automatic Identification and Data Capture (AIDC) technology (Fosso Wamba et al., 2008), was introduced into the U.S retail supply chain when Wal-Mart announced its plans to use RFID beginning in 2003. RFID technology is a global phenomenon that began in the U.S. retail industry. It first came into the spotlight when Wal-Mart announced its plan to use the technology during a pilot test in October 2003 (Hunt et al., 2007). Wal-Mart was the first to issue a sweeping RFID technology mandate, which required its top 100 suppliers to put RFID tags on their pallets and cases beginning in January 2005 (RFID Journal, 2003). The mandate was soon expanded to 300 suppliers (Hunt et al, 2007). Wal-Mart announced in 2007 that it would charge Sam's Club suppliers a $2 penalty for each pallet without a RFID tag shipped to distribution centers beginning January 2008 (Weier, 2008). Wal-Mart's RFID initiative is refocused on EPCglobal's 2nd Generation UHF tag standards (Roberti, 2010). While Wal-Mart's initial effort has been focused on IT integration with pallet level RFID tagging, its

recent effort since 2010 has been to investigate item-level RFID tagging for all men's jeans, socks, and underwear (Roberti, 2014).

Like the U.S.'s Wal-Mart, in Europe, Metro AG (Germany) and Tesco (U.K.) began to implement the RFID technology in 2003 and 2004, respectively (OECD, 2008), and Marks and Spencer (U.K.), Carrefour (France), and Ahold (Netherlands), followed suit with RFID mandates of their own (Stigal, 2006; Prabhu 2008). Metro Group announced that some penalty would be imposed on the suppliers without RFID technology (EUJRC, 2007) as Wal-Mart did. In addition, EU Commission adopted the Track and Trace Directive requiring food and beverages to have complete catalogs of anything with the final product for its quality and safety (EUJRC, 2007). RFID tags with temperature sensors can provide this traceability and safety requirement. This requirement is similar to the U.S.'s FDA mandate to use RFID technology for tracking pharmaceutical products.

Use of RFID technology can improve inventory accuracy and supply chain efficiency, which can improve productivity of retail companies. However, there are concerns about RFID's return on investment (ROI) for businesses, and the RFID-adoption rate slowed after 2008 (Edwards, 2008). In addition, many small and medium enterprises (SMEs) are reluctant to adopt RFID technology because they perceive it as unprofitable and risky. While large enterprises are likely to enjoy the economy of scale in RFID implementation, SMEs claim that RFID technology is cost-ineffective because of low demands and high up-front implementation cost (Lee & Lee, 2010).

Many academic papers (Leung et al., 2007; Visich et al., 2009; Rekik et al., 2009; Sarac et al., 2010; Zhu et al., 2012; Bhattacharya, 2012) argue that there are many advantages for RFID adoption: (1) cost saving effect, (2) revenue increase effect, (3) inventory management efficiency effect, and (4) productivity increase effect. RFID investments enable labor productivity improvements by eliminating manually processes. Decreases in labor cost can be made by reducing the physical counting of inventory and product scanning-error rate. Revenue increases can be made by prevention of theft, shrink, and inventory write-off as well as decreased counterfeiting and decrease in returns (Veeramani, Tang, & Gutierrez, 2008). RFID adoption can also allow improved inventory management accuracy and responsiveness through real time inventory information.

The Cobb-Douglas production function is a well-known economic theory that explains the relationship of outputs with two inputs, labor and capital. Even when this function is developed with only two input factors, it is still widely used for measuring productivity. This paper, using the Cobb-Douglas production function, investigates the effects of RFID technology on the labor productivity of the U.S. retail supply chain. The following is the research hypothesis to test whether RFID adoption gives benefits to adopting retailers in productivity.

> **H** *A significant ~~linear~~ relationship exists between labor input with RFID technology for retail companies and their productivity.*

This study is organized as follows: First, the authors provide a brief literature review. Then, they discuss the research approach, which includes data collection procedure and research methods. After providing outputs, the study ends with a brief discussion section and a conclusion section.

Literature Review

RFID technology diffusion is categorized by three phases (Yang, Kishore, and Liu, 2008): (1) Emergency phase starts with Auto-ID Labs (1999), which is a research group for the RFID and emerging sensing technology, (2) structuralization phase starts with Wal-Mart's first RFID mandate in 2003, and (3) evolution phase starts with EPC Gen 2 RFID tag being announced in 2005. Fosso Wamba and Chatfield (2009) use a contingency model for creating value from RFID technology. They identify three levels of RFID integration: Slap and Ship, Intra-organizational, and Inter/Network-organizational. Table 1 summarizes the benefit and costs of the three levels of RFID integration.

Project Scope	Technological Integration	Organizational Integration / Transformation	Benefit	Costs
Level 1: Slap and Ship Project	Limited with add-on RFID sticker	Little organizational transformation	Internal inventory control for the focal firm	Purchase of RFID tags and printers and extra staffs
Level 2: Intra-Organizational Project	Integration with existing organizational IS (ERP)	Redesign of warehouse	Real-time inventory in the warehouse Operational Cost reduction Improvement of data accuracy and integrity	RFID infrastructure and integration with the existing IS Human resource training cost
Level 3: Inter/Network Organizational Project	External Integration with partner's internal IS	Standardization for business process and interfaces between focal firms and suppliers	Real-time RFID Data in the supply chain network Accurate demand forecasting and procurement planning	Cost of standardization for business process and interfaces Organizational cost for building inter-firm trust

Table 1. Three Levels of FRID Integration and their Cost and Benefit

Hardgrave, Aloysius, & Goyal (2013) study how accurate inventory records are when RFID tags are used. According to their studies, RFID technology decreases inventory record inaccuracy (IRI) by 26% and among the five categories (air-care products, floor-care products, formula, DIY furniture, and quick cleaner), four categories except DIY furniture category improve in IRI.

Visich et al. (2009) and Bhattacharya et al. (2010) analyze existing academic papers about RFID adoption. Visich et al. (2009) find that RFID can reduce stockouts, improve inventory accuracy, increase sales, and speed up goods receipt in retail stores. Bhattacharya et al. (2010) uses content analysis to find RFID retailer benefits: better management of inventory, improved security, increased operational efficiency, increased visibility, and reduced cost. Soon and Gutierrez (2008; 2010) argue that retailers have the power to force the adoption of RFID technology in their supply chain networks because the retailers have more significant benefits than the manufacturers in reduced inventory, lower labor costs, and stockout reduction.

According to Whitaker, Mithas, & Krishnan (2007), appropriate information technology infrastructure, i.e., ERP, is a pre-requisite for successful RFID implementation because most benefits of RFID data comes from reliable and suitable use of data produced by RFID systems and sharing that data among the supply chain partners. They find that RFID implementation spending, even if it is caused by a partner mandate, is positively associated with early return on RFID investment. Collaborative excellence among the supply chain partners is a crucial factor for extending supply chain efficiency, thus system integration among the supply partners is a big hurdle to overcome because usually each supply partner has its own existing system. Therefore, fair sharing of costs and benefits of RFID technology adoption between supply chain partners is important (Panizza, Lindmark, & Rotter, 2010).

Panizza et al. (2010) argued that the lack of a global standard prevents companies from interoperability. The standardization of RFID tags and Electronic Product Codes (EPC), a global product identifier, is a main issue associated with adopting RFID. Use of standard RFID technology across overall supply chain is a critical factor for streamlined flow of information sharing among the partners in the same supply chains (Matta, Koonce, & Jeyaraj, 2012). International Organization for Standardization (ISO) and the industry consortium EPCglobal are two main organizations supporting RFID standardization. "GS1 Gen2" is the current RFID standard, which was adopted in 2006. There are four frequency ranges used for RFID communications: LF, HF, UHF, and Microwave. UHF frequency ranges used in the U.S. are incompatible with those used in Europe. While Europe assigns 860-960 MHz, the U.S. uses 902-928 MHz. In addition,

because RFID is operated in unlicensed bands, there is a possibility for radio frequencies to make conflicting signals (EUJRC, 2007).

Productivity measurement is a challenge in the retail industry, because no consensus on the proper measures of retail inputs and outputs has been established (Manser, 2005). Reynolds, Howard, Dragun, Rosewell, & Ormerod (2004) discuss the concept of output in the retail sector. Since retail output includes a large service element, labor productivity is measured by the gross value added for each worker. Dawson (2005) shows that retail output is different from that of manufacturing because retail is spatially disaggregated and networked. The efficiency of the network's operation with large numbers of suppliers is a critical factor impacting retail productivity. Foster, Haltiwanger, & Krizan (2005) discuss the massive restructuring in the U.S. retail trade industry during the 1990s with the intensive adoption of information technology, including inventory control, scanning, and credit card processing, which contributes to productivity growth in the U.S. retail sector.

Reardon and Vida (1998) compare monetary and physical measures of productivity inputs using Cobb-Douglas production functions. They suggest capital input measures be (1) square footage of space, or (2) dollar value of assets, rent, or the insured value of the establishment. The study suggests as labor input measures should be (1) the number of employees/time worked by employees, or (2) the amount of money paid to employees. They find that monetary measures are empirically equal to physical measures of retail inputs. Reardon and Vida (1998) also suggest an output measure for retail industry: (1) gross sales, (2) number of transactions, or (3) value added. Griffith and Harmgart (2004) define value added in the retail industry as output minus the cost of goods sold and other intermediate inputs. Baldwin and Gu (2011) use the trade margin, which is a value-added output in the retail industry. In general, sales or gross income, which is sales less the cost of goods sold, are commonly used output measurements in the retail industry (Manser, 2005).

Because RFID investment is a kind of IT investment, previous studies about relationship between IT investment and supply chain productivity give a theoretical background for RFID's productivity study. There have been some studies about IT productivity of retail industry: Cachon and Fisher (2000) find that information sharing through IT investment leads to higher performance of retail supply chain costs; Carr (2003) argues that firms' IT spending does not guarantee the superior in their financial result; Shah and Shin (2007) investigate the relationship among IT investment, inventory, and financial performance with retail industry data of 1960 to 1999. They find that there is no direct link between IT investment and financial performance in retail industry but IT investment improves inventory performance which leads to a positive financial performance. Their conclusion is that there exists indirect effect on financial performance through inventory management from IT investment.

There are numerous articles (EUJRC, 2007; Rekik, Sahin, & Dallery, 2008, 2009; Sarac et al., 2010; Leung, Cheng, Lee, & Hennessy, 2010; Vos, Cullen, & Cranefield, 2012) that correlate labor-cost saving with an adoption of RFID technology, which can lead to improve labor-productivity. Their conclusion comes from subjective data which is produced by their survey.

Data Collection

This study uses the *Compustat* database to obtain annual financial statements for U.S. retail companies, including balance sheets and income statements. In addition, the data for the number of full-time employees is added. NAICS, the North America Industry Classification System, is the U.S. industry classification standard used in the federal statistics. The companies in the U.S. retail industry have a NAICS code beginning with 44 and 45. Between 2008 and 2011, there are 267 U.S. companies in the *Compustat* database that have an industry sector in retail. Among them, 141 companies are selected based on two criteria:

- Each has four years of financial data, from 2008 through 2011, listed in the *Compustat* database.

- Each is listed in a traditional U.S. stock market, including NYSE, NASDAQ, or AMEX.

No official document shows when and which companies adopted the RFID technology for their supply chain operation. The publicly traded companies in U.S. stock markets must follow disclosure of material events affecting a company for investors' decision-making, which is a part of the U.S. Security and

Exchange Commission (SEC) regulation. Because RFID adoption needs significant capital expenditure, the decision to invest or not invest in the RFID technology is a significant event to be published (Jeong and Lu, 2008). Some retailers announce their RFID implementation in their annual reports to the public or issue a press release about their use of RFID technology. Some developers of RFID technology produce RFID case studies based on their customer company's experiences.

The authors try to find the RFID news using keywords such as RFID, stock ticker symbol and/or names of 141 companies in the following methods: (1) Google key word searching (http://www.google.com), (2) key word searching in RFID article database from RFID Journal (http://www.rfidjournal.com), which is a leading RFID bimonthly journal magazine as a source of RFID news and information, (3) article searching in online magazines of supply chain/logistics/retail, and (4) key word searching in press release database from BusinessWire (http://www.businesswire.com).

If there is more than one article about the same RFID investment announcement in many sources, the earliest article and RFID Journal article is chosen as a source of RFID technology adoption. There are 141 U.S. retail companies and 24 RFID adopted U.S. retail companies (See table 2). The year 2006 is a boom for RFID adoption and since 2008, the cumulative number of companies with RFID adoption has been stable.

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Number of RFID Adopted Retailers	1	1	2	5	10	3	0	1	1	0
Cumulative Number	1	2	4	9	19	22	22	23	24	24

Table 2. Number of RFID adopted U.S. Retail Companies

Panel Data Regression Model and Results

Cobb-Douglas Production Function with RFID Technology

As explained earlier, the Cobb-Douglas production function is widely used to represent the relationship between an output and two inputs, capital (K) and labor (L) (Bao Hong, 2008). The function has a form:

$$P(L,K) = AL^\alpha K^\beta \text{---(1)}$$

Where P = total production, L = labor input, K = capital input, A = total factor productivity, α = output elasticity of labor, and β = output elasticity of capital.

Total production refers to the monetary value of all goods produced in a year. Hours worked by full-time employees and fixed assets are usually used to generate labor and capital inputs. Total factor productivity (TFP) is "the portion of output not explained by the amount of inputs used in production" (Comin, 2006). Instead, it is determined by long-term technological change (Lipsey and Carlaw, 2001). TPF is assumed to be a constant that is independent of both labor and capital. Output elasticity measures the change of output to a change of labor or capital (Bao Hong, 2008), where α denotes output elasticity of labor, and β denotes output elasticity of capital.

RFID companies assume that when the RFID technology is introduced, operation costs will lessen and the workers' efficiency will increase. With this assumption, γ, the output elasticity of labor with RFID technology was added to equation (1) to find the labor productivity with RFID technology:

$$P(L,K) = AL^{\alpha+\gamma*RFID} K^\beta \text{---(2)}$$

In equation (2), the output elasticity of labor for RFID companies (RFID = 1), is α+γ, and for non-RFID companies (RFID = 0), it is α. Applying the log transformation to the equation (2), the following equation is produced:

$$ln\ P(L,K) = ln(A) + \alpha\ ln(L) + \gamma\ RFID\ ln(L) + \beta\ ln(K)\text{--------------------------------(3)}$$

In equation (3), output elasticity of each input (α, β, γ) becomes a coefficient of log-transformed variables.

According to the Organization for Economic Co-operation and Development (OECD) labor statistics (2012), U.S. employees work around 1,800 hours per year. Table 3 shows the annual average number of working hours for U.S. workers from 2008 through 2011.

Year	2008	2009	2010	2011
Average Annual Working Hours	1,792	1,767	1,778	1,787

Table 3. Average Annual Working Hours per U.S. Worker
Source: OECD Labor Statistics (OECD, 2012)

The product of the number of full-time workers per company (*EMP*) and average annual working hours (*WH*) is the total number of hours worked at a company per year. This product (*EMP-WH*) and fixed assets (*FA*) are used for labor input and capital input, respectively.

As mentioned earlier, estimating total production in the retail industry is challenging due to intangible output measures. Because the output of retail industry is a product that is a combination of physical items and various services such as assembly, display, delivery, and/or installation. Since service is intangible, retail outputs should be measured in dollar units (Ingene & Lusch, 1999). There are two common output measures in the retail industry: sales and gross income (Ingene & Lusch, 1999; King & Park, 2004; Manser, 2005). According to King & Park (2004), while the U.S. Bureaus of Labor Statistics uses sales, the U.S. Census Bureau uses gross income as a measure of retail output. In this study, gross income (*GI*) is used for the output in the production function. To estimate the production functions of U.S. retail industries, these three variables (*GI*, *EMP-WH*, and *FA*) are plugged into equation (3):

$$ln(GI_{it}) = ln(A) + \alpha \, ln(EMP\text{-}WH_{it}) + \beta \, ln(FA_{it}) + \gamma \, RFID_{it} * ln(EMP\text{-}WH_{it}) + \varepsilon_{it} \dots\dots(4)$$

Where *EMP-WH* equals the number of full-time employees multiplied by the annual average working hours, *FA* = fixed assets, *GI* = gross income, for $i = 1 \sim 141$ and $t = 2008 \sim 2011$.

Base Model

Table 4 presents output from the base regression model, equation (4). The R^2 is very high (0.9267) and the model (*F-stat*) and coefficient (*p-value*) are significant at the 1% level. When the Cobb-Douglas production function was studied in 1928, constant return to scale (CRS) was assumed, i.e., $\alpha+\beta = 1$, which means that the output change is proportional to the input change. Therefore, the range of α and β, if they are meaningful, should be between 0 and 1. The coefficients of this model, $\alpha = 0.4180$ and $\beta = 0.3883$ are in the acceptable range. The base regression model needs to be tested for the assumption of homoskedasticity and no serial correlation. The *p-value* in the BP test is 0.01981, which means that homoskedasticity assumption is not rejected at 1%. The Durbin-Watson *d* statistic is 0.5653, which means there is autocorrelation. The VIF values of three variables are 5.106, 5.119, and 1.581, respectively, i.e. no strong multicollinearity. To overcome the autocorrelation problem, two approaches were offered: fixed effect and random effect. According to Greene (2012), while the fixed effect assumes that individual heterogeneity is correlated with independent variables, the random effect assumes that the individual heterogeneity is uncorrelated with the independent variables. Jerry A. Hausman developed a test for determining which model is appropriate. With the Hausman test, the null hypothesis is rejected with *p-value*=4.598e-15. Therefore, the preferred model is the fixed effect model. Table 5 summarizes test result of the base model.

R^2	F-stat (*p-value*)	Degree of Freedom	Intercept (*p-value*)	α (*p-value*)	β (*p-value*)	γ (*p-value*)
0.9267	2361.0 (0.000)	3, 560	5.5675 (0.000)	0.4180 (0.000)	0.3883 (0.000)	0.0178 (0.000)

Table 4. Results from the Base Regression Model

Test Name	Test Value	Critical Value	Result
Breusch-Pagan Test	BP = 9.8582 p-value=0.01981	α=0.01	Homoskedasticity
Durbin-Watson Test	$DW\ d$ =0.5653 p-value < 2.2e-16	$d_L(n$=550, α=.01, k=4) =1.79126 $d_H(n$=550, α=.01,k=4) =1.81312	Autocorrelation
Hausman Test	Chi-square = 69.8491 p-value = 4.59e-15	α=0.01	Fixed Effect
VIF	5.119208 ($lnFA_{it}$) 5.106354 ($lnEMP$-WH_{it}) 1.581382 ($RFID_{it}\ lnEMP$-WH_{it})	10	No strong Multicollinearity

Table 5. Test Statistics and Results

Fixed Effect Model

Baltagi (2005) explains a procedure to estimate the fixed effect regression model. The model adds some dummy variables in each step. There are two kinds of dummy variables: intercept dummy and slope dummy. The intercept dummy variable has an additive form and the slope dummy has a productive form with independent variables. Since the panel data in this study has two dimensions, individual company and time, the dummy variables used in this model are dummy variables for both individual and time dimensions. The following are six models used for the development of fixed model with the dummy variables:

- Model 1: Base regression model with no dummy variable.
- Model 2: Adding individual intercept dummies (D_i) to model 1.
- Model 3: Adding time intercept dummies (T_i) to model 2.
- Model 4: Adding individual slope dummies for the first independent variable (ln(EMP-$WH)*D_i$) to model 2.
- Model 5: Adding individual slope dummies for the next independent variable (ln($FA)*D_i$) to model 4.
- Model 6: Adding time slope dummies (ln(EMP-$WH)*T_i$ & ln($FA)*T_i$) for each independent variable as well as time intercept dummies (T_i) to model 5.

There are 140 intercept dummy variables for individual companies and 3 time intercept dummy variables. In addition, there are 140 individual slope dummy variables for ln(EMP-$WH)$ and ln($FA)$ and 3 slope time dummy variables for ln(EMP-$WH)$ and ln($FA)$. The total number of dummy variables that are used in Model 6 is 429.

Table 5 presents the results of the six fixed-effect models. The *p-values* of model (2) and (3) from the BP tests are near zero, so the two models qualify as heteroskedastic. The *p-values* of coefficients in model (2) and (3) are based on HC standard errors.

Model (2) through (6) do not have autocorrelation problems because their d values are greater than d_L (1.87766, n=550, K=21, α=0.01). Considering *p-values* of coefficients in model (2) through (6), only model (2) is acceptable. All coefficients of independent variables in model (2) are significant at 1% level and overall fit of the regression model is significant at 1% level. RFID companies (α + γ = 0.3994) are more elastic for labor change than the non-RFID companies (α =0.3934) by 0.006, which means the RFID companies with an 1% increase of labor input produced 0.006% more increase in gross income than the non-RFID companies. Thus, even if there is a difference in labor productivity between RFID companies and non-RFID companies, the gap between two is very small. Adding all three coefficients, i.e., α+β+γ, is 0.5373, which is less than 1.0. This is called the decreasing return to scale (DRS), i.e., if inputs increase 1%, the production total increases less than 1%.

Model No.	Number of Variables	BP Test *p-value*	Durbin Watson *d*	R²	F-Stat (*p-value*)	Degree of freedom	*ln(A)* (*p-value*)	α (*p-value*)	β (*p-value*)	γ (*p-value*)
(1)	4	0.020	0.565	0.9267	2361 (0.000)	3, 560	5.5675 (0.0000)	0.4180 (0.0000)	0.3883 (0.0000)	0.0178 (0.000)
(2)*	144	0.000	2.000	0.9956	668 (0.000)	143, 420	10.1714 (0.0000)	0.3934 (0.0070)	0.1379 (0.0001)	0.0060 (0.0069)
(3)*	147	0.000	1.964	0.9958	674.7 (0.000)	146, 417	10.4905 (0.0000)	0.3599 (0.0134)	0.1509 (0.0000)	0.0039 (0.0730)
(4)	284	0.475	2.649	0.9980	493.7 (0.000)	283, 280	16.6620 (0.0548)	0.0727 (0.8943)	0.0594 (0.1241)	0.0025 (0.7795)
(5)	424	0.451	2.888	0.9996	739.2 (0.000)	423, 140	16.8600 (0.2970)	0.0751 (0.8494)	0.0444 (0.9628)	0.0027 (0.6497)
(6)	433	0.506	2.862	0.9997	909.1 (0.000)	432, 131	27.6700 (0.0637)	-0.2407 (0.5096)	-0.2697 (0.7554)	0.0007 (0.8979)

Table 6: Comparison of results of six fixed effect models
Note: * p-values from HC standard errors

Discussion

The RFID companies are big companies in the U.S. retail industry. Based on the average amount of annual sales of 141 retail companies in 2011, the average annual sales of RFID companies is $52.3 billion and that of non-RFID companies is $4.5 billion. Among 141 U.S. retail companies, the 24 RFID retail companies' market share is 70.5% and that of the 117 non-RFID companies' is only 29.5%. Even if there are only 17% (24 out of 141) of RFID companies in the retail industry, the effect on the industry is much larger due to the influence of their market power. According to Carlton and Perloff (1999), the most common measure of concentration in an industry is the share of sales by the four largest firms, called a C4 ratio. Generally speaking, if the C4 ratio is over 40% and less than 60%, the market is considered a loose oligopoly. The number one retail company's market share (C1 ratio) is around 25% and the top four companies' market share (C4 ratio) is around 41%. It means that a small number of big retailers lead the U.S. retail industry and their decision to choose a technology will become a market standard sooner or later. In the list of 141 U.S. retailers of 2011, ordered by sales amount, there are eight RFID companies out of top ten retailers and 15 RFID companies out of top 20 retailers. There is only one RFID company in the bottom 50% of 141 retailers. Therefore, RFID companies are high rankers in the retail industry hierarchy. As other papers mention, despite the fact that the RFID companies are setting the market trends, the smaller companies are fiscally unable to adopt RFID or are unwilling due to the smaller companies' inability to take chances given the state of the economy and the weak fiscal foundations these small companies have.

There is a debate about investment in information technology (IT) and benefits from it. Challenges for huge IT projects always go with uncertainty about productivity benefit. The productivity benefit does not show up immediately. The benefit from large IT investments goes with a time lag and quantifying the financial returns from the IT investment is hard to achieve (Dehning & Richardson, 2002). Electronic Medical Records (EMR) is a hot issue in the healthcare industry for the last decade. It is expected to reduce medical expense and to increase productivity in the U.S. healthcare industry. However, some empirical studies show that EMR leads to greater health spending and lower productivity. Other studies present that there is no EMR saving to offset adoption cost (Dranove, Forman, Goldfarb, & Greenstein, 2012). The adoption of EMR is progressing slowly, at least, in the smaller practices (Gans, Kralewski, Hammons & Dowd, 2005). According to Jha, DesRoches, Kralovec & Joshi (2010), the share of hospitals that adopted electronic medical records is only 11.9% in 2009, and small, rural, and public hospitals are less likely to adopt the EMR system than larger, urban, and private hospitals. Even if in many cases, costs rise after EMR adoption, hospitals in strong IT locations reduce costs sharply after the first year of EMR adoption compared to that of pre-adoption (Dranove et al., 2012). The same story can be applied to the RFID technology investment. As Whitaker et al. (2007) states, successful RFID projects depend on whether the RFID company has a well-functioned ERP system or not. Because the RFID project is not just

building an independent IT system, it might have little chance to become successful without a skilled IT staff and a robust existing IT system. In addition, the supply chain partners' ability to integrating RFID systems can also be a successful factor of RFID technology investment. Therefore, benefit of RFID technology adoption starts with big retailers and it will spread over to the retail industry as times go by.

There are some limitations in this paper. First, the output measure in retail industry is value-added income. However, it is not easy to calculate the value-added income, i.e., a free one year warranty is a value-added feature. Retail industry's service improvement by RFID adoption is hard to capture with financial statement data. In this paper, gross income is used for retail output proxy, which estimates a little higher labor productivity for retail industry. The second limitation is economy of scale effect for RFID adoption companies. Lee and Lee (2010) mention there is a cost advantage for RFID technology adoption due to the size of company. Because of relatively short period of RFID history, the data used in this paper is not good enough to categorize RFID companies based on their size. The third limitation is that because RFID investment belongs to IT investment, introduction of the number of IT employee and the amount of IT investment spending could enhance the production function regression in this paper. As we mentioned earlier, Whitaker et al. (2007) argue that existing information systems like ERP is a pre-requisite for the success of RFID project. RFID companies productivity gains should be explained RFID investment as well as integration effort between the existing information systems and RFID.

Conclusion

Ten years have passed since Wal-Mart's public announcement about its RFID technology adoption plan in 2003. Some large competitors of Wal-Mart in the U.S. retail industry jumped on the trend of RFID technology adoption. However, many U.S. retailers have been hesitant to adopt the RFID technology because of the uncertainty of return on investment and the lack of business cases demonstrating efficiency and productivity of RFID technology adoption.

The Cobb-Douglas production function suggests, using U.S. retail industry data, that RFID companies have a higher elasticity of labor to gross income than the non-RFID companies, which indicates why RFID companies have higher labor productivity. But the gap between RFID and non-RFID is not significant.

Fosso Wamba (2011) argues that RFID technology will appear as an interactive innovation like telephone, Internet, and E-commerce. Collins et al. (2010) assert that RFID technology is a disruptive technology to transform supply chain into a more efficient system. In the EUJRC report (2007), RFID technology will enable total factor productivity gain through business process efficiency. The effect of disruptive technology or interactive innovation does not show up immediately. The total factor productivity is a long-term based concept. If this study expands over the 2011 data, it is expected to demonstrate more clearly the effects of RFID technology adoption in the retail supply chain network.

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