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An Empirical Analysis of the RFID Effect on Suppliers' Financial Performance

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AN EMPIRICAL ANALYSIS OF THE RFID EFFECT ON SUPPLIERS' FINANCIAL PERFORMANCE

Analyse empirique de l'effet de la RFID sur la performance financière des fournisseurs

Completed Research Paper

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Abstract

The objective of this study is to rigorously examine the effects of RFID on suppliers' profitability while adjusting for endogeneity bias arising from the decision process for RFID adoption. To this end, we use a Heckman two-stage estimation method, which allows us to control for endogeneity between a firm's organizational characteristics and its decision for RFID adoption. We find that suppliers faced with both a low level of inventory efficiency and with highly uncertain demand are more likely to adopt RFID. Further, suppliers that have adopted RFID achieve greater financial gains than their counterparts that have not. More importantly, we show that these financial gains result from improved inventory and sales efficiencies after RFID is deployed. In sum, our study sheds new light on what drives supplying firms to adopt RFID and on its role in shaping relatively higher financial performance in a post-adoption period.

Keywords: RFID; SCM; supply chain management; financial performance

Résumé

Cette étude examine les effets de la RFID sur le rendement des fournisseurs. Nous constatons que les fournisseurs confrontés simultanément à un inventaire peu efficace et à une demande fortement incertaine sont plus susceptibles d'adopter la RFID. En outre, les fournisseurs qui ont adopté la RFID réalisent des gains financiers plus importants, comparés à leurs homologues qui ne l'ont pas adopté. Ces gains financiers résultent de l'amélioration de l'inventaire et des ventes suite au déploiement de la RFID.

Introduction

Radio frequency identification (RFID) has gained great attention in academic literature and in practice ever since Wal-Mart mandated that its top suppliers place RFID tags on the cases or pallets (RFID Journal, 2003). Similarly, several private and public organizations, including Target, Tesco, and the U.S. Department of Defense (DoD), have taken significant steps toward the use of RFID in managing supply chains. As a consequence, RFID-related spending is estimated to continuously, grow and reach $3 billion in 2010 (RFID Update, 2005).

In the context of business, RFID is recognized as a technology that improves supply chain efficiency through helping to achieve a better flow of information and materials, and improved inventory efficiency along the value chain (Delen et al., 2007; Whitaker et al., 2007). For instance, RFID may improve inventory accuracy of auto manufacturers by tracking the movement of assembled parts at different stations (Curtin et al., 2007). Firms may benefit from the deployment of RFID technology since RFID allows them to capture and analyze information and material flows in real time (Pisello, 2006). Accordingly, RFID enables firms to realize benefits which include improved inventory controls, warehouse labor cost savings, and increased sales (Abell, 2003; Curtin et al., 2007; Heese, 2007; Whitaker et al., 2007). From a practical point of view, an industry analysis also suggests that U.S. DoD expect to save $1.7b through RFID use (Collins, 2006). Given that RFID has huge potential to save costs and improve performance, business press has paid great attention to RFID projects.

Previous studies have emphasized the potential benefits of RFID. However, most of them primarily take either an analytical or a case-based approach (Barratt and Choi, 2007; Heese, 2007; Gaukler et al., 2007; Lee and Ozer, 2007). Furthermore, most studies focus on the benefits to large retailers or buyers, such as Wal-Mart and the U.S. DoD and address how RFID will bring great benefits to large retailers or buyers (Wailgum, 2004). While these studies contribute to a significant understanding of the value RFID can create, to the best of our knowledge, only a few studies empirically examine the impact of RFID on financial performance from the perspective of suppliers. Given that some suppliers still hold back on RFID adoption due to high adoption costs, technological uncertainty and a lack of business cases (RFID Gazette, 2006; Wailgum, 2004), it is of importance to empirically examine whether RFID will benefit suppliers as it did for large retailers..

The main objective of our study is to examine whether or not RFID improves a supplier's financial performance. For this purpose, we collected two sets of data which consist of suppliers that adopt RFID and their matched firms that do not. Then, we consider the differences in financial performance between two sets of firms by comparing profitability changes over a pre-to-post adoption period. We also account for potential endogeneity between the decision for RFID adoption and financial performance by employing a Heckman's two-stage regression analysis (Heckman, 1979; Maddala, 1983; Greene, 2000). In our context, it is important to reflect the notion of endogeneity since firms do not randomly make decisions as to whether they will adopt RFID or not. That is, a firm's decision for RFID adoption is made based on its own needs, opportunities, and comparative advantages. For instance, firms faced with demand uncertainty may have a greater incentive to adopt RFID. RFID may allow for them to achieve greater benefits by dramatically reducing demand fluctuations. Importantly, this type of dependency raises the issue of endogeneity which should be dealt with explicitly to obtain unbiased estimates (Heckman, 1979; Greene, 2000). Because organizational characteristics are likely to affect adoption choice, we cannot evaluate the true effects of RFID on firm performance if they are not controlled for. By explicitly accounting for potential endogeneity, we can obtain unbiased estimates while estimates from a traditional regression approach such as ordinary least square (OLS) are biased (Heckman, 1979; Greene, 2000). Specifically, our first stage estimation is devoted to uncovering the conditions under which suppliers are likely to adopt RFID. Then, we examine whether these supplying firms that have adopted RFID achieve greater financial gains compared with non-RFID adopters after incorporating the estimates obtained from the first stage.

Our results from the first stage analysis suggest that supplying firms are more likely to adopt RFID when their inventory efficiencies are low and demand fluctuations are not stable. Our estimates from the second stage analysis show that firms that adopt RFID have achieved greater gains in profit margins and return on asset (ROA) relative to their counterparts that did not adopt RFID. Further, we find that these financial gains are attributable to RFID deployment, which improves inventory and sales efficiencies.

To the best of our knowledge, this is one of the first studies that rigorously examines the impact of RFID on suppliers' financial performances. Our study shows evidence of the tangible value derived from the newly emerging technology RFID. Further, we are able to control for potential endogeneity and identify the sources of financial gains for RFID adopters by incorporating a firm's decision process into the estimation. In sum, we believe that our study sheds new light on why suppliers adopt RFID and whether and how RFID can improve suppliers' financial performance.

The paper proceeds as follows: The next section discuss the relevant theoretical backgrounds and develop hypotheses. We then develop an empirical model. We describe the data we use for analyses. Empirical results are discussed. The final section contains concluding remarks.

Theory and Hypotheses

Why do firms adopt RFID?

RFID is an emerging technology that improves supply chain efficiency by providing greater visibility of inventory and improving information flows along the supply chains. RFID primarily consists of two components, a tag and a reader. An RFID tag is a small device that contains a microchip and an antenna. The tag stores extensive data on individual items. With the RFID tag, a reader transmits a magnetic field that activates the tag, which enables it to transmit and store data (Curtin et al., 2007). This innovation allows firms to integrate and share information within and between firms and enables substantial efficiency gains of supply chains (Heese, 2007; Whitaker et al., 2007). Accordingly, in recent years, an increasing number of firms have initiated RFID projects to improve their supply chain efficiency (Heese, 2007).

We first explore transaction cost economics (TCE) to identify factors affecting a firm's decision for RFID adoption. TCE introduces the notion of bounded rationality and opportunism as characteristics of the behavior of economic agents which incurs transaction costs when these characteristics are combined with uncertainty, asset specificity, and information asymmetry (Williamson, 1985). While asset specificity and information asymmetry also play a critical role in TCE, we focus on uncertainty since one of the primary functions of RFID is to achieve operational efficiencies by reducing uncertainty in supply chains (Lee, 2002; Heese, 2007). Uncertainty can be interpreted as a lack of information that results from ambiguity in future demand (Williamson, 1985, 1991; Aubert et al., 1996). TCE predicts that firms will be more vertically integrated under a highly uncertain environment to minimize potential risk associated with demand uncertainty (Shelansk and Klein, 1995). In our context, suppliers attempt to mitigate the effects of demand uncertainty by deploying RFID which enables them to share information with trading partners. In practice, supplying firms have observed that demand fluctuations increase as they move up a supply chain, with the fluctuation increase being known as the "*bull-whip effect*" (Lee et al., 1997). To mitigate the bull-whip effect, Wal-Mart and Procter & Gamble, for instance, established a vendor-managed inventory (VMI) partnership so that Procter & Gamble can reduce unnecessary demand fluctuations. In a similar vein, RFID acts as a conduit to facilitate information sharing between trading partners (Heese, 2007). Thus, shared information by the aid of RFID allows suppliers to have real-time access to a retailer's sales data and to predict future demand more accurately so that they can reduce demand fluctuations (uncertainties). Thus, we propose the following hypothesis:

Hypothesis 1: *Suppliers faced with large demand fluctuations are more likely to adopt RFID.*

Second, deploying RFID technology may have an impact on inventory controls by tracking material movement and optimizing information flow along the supply chain (Dehning et al., 2007). For instance, RFID can be used to keep track of expensive equipment and can locate items in the right place at the right time. In practice, many organizations decide to adopt RFID to improve inventory efficiency since the technology has the capability of enhancing inventory visibility and tracking the movements of materials (Curtin et al., 2007). Therefore, we expect that suppliers that carry a large volume of inventory may have a greater incentive to adopt RFID. This leads to the following hypothesis:

Hypothesis 2: *Suppliers with a high inventory ratio are more likely to adopt RFID.*

Finally, we identify firm size as a factor that may influence a firm's decision for RFID adoption (Iacovou et al., 1995; Zhu and Kraemer, 2002; Whitaker et al., 2007). In general, firm size may reflect several important aspects of organizational features, such as resources availability and technological experience (Rogers, 1995; Zhu and Kraemer, 2002; Zhu et al., 2006). This is because larger firms may have slack resources so that they can be better positioned in deploying new technologies (Tornatzky and Fleischer, 1990; Iacovou et al., 1995). In our context, RFID deployment viewed as a complex IT project may require a significant commitment of financial resources (Iacovou et al., 1995; Whitaker et al., 2007). For instance, implementation costs of RFID for a typical large consumer goods manufacturer is estimated to be between $9 and $25 million (Shutzberg, 2004). Further, placing RFID tags on their pallets and cases will incur additional costs (Gaukler et al., 2007). Thus, larger firms that can afford costly RFID projects may be better positioned in implementing new technologies such as RFID. This yields the following hypothesis:

Hypothesis 3: *The larger the supplier size, the more likely it is to adopt RFID.*

Next, we move our discussion to whether or not RFID adoption improves a firm's financial performance.

Benefits of RFID

Considering the nature of RFID, it can be viewed as a subset of Interorganizational Systems (IOS) and can be used as a tool to reduce stock-outs and improve inventory turnovers by providing detailed information along the supply chain (Clarke et al., 2006; Curtin et al., 2007). Information Systems (IS) researchers have examined the impact of IOS on business value in the context of EDI, E-business, and RFID. For instance, Mukhopadhyay et al. (1995) find that EDI usage contributes to cost reductions and improves quality of transactions with trading partners. Zhu and Kraemer (2002) show that retail firms achieve greater benefits when they have developed appropriate E-business functionalities. In a similar context, a recent RFID study shows that technical and organizational resources contribute to returns on RFID investments (Whitaker et al., 2007).

Our study is in line with previous studies on the value of RFID but is distinct from them because we examine the impact of RFID on financial performance from the suppliers' perspective. RFID can help achieve operational efficiencies by coordinating the flow of materials and improving inventory transparency. With the use of RFID tags and readers, suppliers that adopt RFID minimize inventory costs in a post-adoption period by lowering order costs, reducing batch size, and improving order fulfillment (Cachon and Fisher, 2000). These positive changes will, in turn, improve the financial performance of RFID adopters (Kinney and Wempe, 2002; Dehning et al., 2007). That is, firms that have adopted RFID achieve inventory efficiency along the supply chain, resulting in higher financial performance than their counterparts.

Hypothesis 4a: *Suppliers that adopt RFID will improve inventory efficiency, resulting in greater financial performance in a post-adoption period relative their counterparts that do not.*

In addition to the direct effect of RFID on inventory efficiency, the use of RFID may also improve sales efficiency measured as sales per unit of labor by reducing labor required to monitor goods and inventory flow and improving accuracy in operations scheduling, data collection, and quality management (Pisello, 2006; Curtin et al., 2007). That is, RFID enables workers to monitor incoming and outgoing materials faster and more accurately. For instance, the implementation of RFID allows Dell computers to check the configurations of assembled PC in real time, to automate the printing of outgoing address labels, and so on. Because of the automated business processes, Dell Computers could realize substantial labor cost savings (Hoffman, 2005). In this context, we conjecture that RFID adoption is positively associated with sales efficiency in a post-adoption period, leading to higher financial performance. This yields the following hypotheses.

Hypothesis 4b: *Suppliers that adopt RFID will improve sales efficiency, resulting in greater financial performance in a post-adoption period relative to their counterparts that do not.*

Empirical strategy

The profit function

In this section, we describe an empirical model that examines the financial impact of RFID. Following the IT business value literature, we construct two indices for firm profitability (Barua et al., 1995; Hitt and Brynjolfsson, 1996; Bharadwaj, 2000; Stratopoulos and Dehning, 2000). These two are i) profit margins which measure how effectively a firm generates its operating profits and ii) return on asset (ROA) which illustrates how effectively a firm deploys its assets to generate net income. As discussed, we expect that firms that have adopted RFID achieve greater financial gains relative to those that have not. These gains for RFID adopters result from two channels: i) improved inventory efficiency and ii) improved sales efficiency. This yields:

$$(1a)\ \Delta Profit_{i,t+1} = \beta_0 + \beta_1 \Delta IR_{i,t+1} + \beta_2 \Delta SE_{i,t+1} + \varepsilon_i$$

where Δ denotes the first difference from adoption year to one year after RFID is adopted. Subscript *i* and *t* denote firm (*i*) and time (*t*). *IR* is the ratio of inventory to sales. *SE* is the sales efficiency measured as the sales per unit of labor.

Based on our earlier discussion (see H4a and H4b), we include inventory ratio and sales efficiency in the profit function. In particular, the dependent variable of equation (1a) is specified as a profit change in a post-adoption period by taking the first difference. Then, we use corresponding changes of inventory ratio and sales efficiency as independent variables. We do so since firms may not realize benefits immediately after deploying new technologies like RFID (Brynjolfsson and Hitt, 2000).

In addition to two factors contributing to profitability, we include several control variables to capture additional variations in profitability. First, we note that a supplier's financial performance depends on its bargaining power. For instance, sales ratio attributable to four major retailers in the U.S. has increased to 40.1% in 2004 from 16.8% in 1992, indicating that an increase in buyer (retailer) concentration has occurred over recent years (Gosman and Kohlbeck, 2006). If a large buyer uses its bargaining power with suppliers, they may be forced to lower prices to maintain business. As a result, suppliers' financial performances can be squeezed by the power of larger buyers (Bloom and Perry, 2001; Bianco and Zellner, 2003). When large buyers are likely to wield their bargaining power, a supplier's market share may be able to work as a safeguard in mitigating the potential influence of large buyers

(Scherer and Ross, 1990). Since a substantial portion of our sample firms have relationships with larger buyers (retailers) such as Wal-Mart, we include a supplier's market share to capture its potential effects on profits.

Second, we note that time-invariant industry-specific factors may have a substantial influence on firm profitability. For instance, a firm that operates in a more concentrated industry may have an opportunity to capture higher economic rents than do others in a less concentrated industry (Bain, 1956; Melville et al., 2007). Some industries may be characterized by a high entry barrier since firms may be required to achieve a certain level of scale economies and incur high up-front costs to do business. However, these industry-specific factors are likely to change relatively slowly. Therefore, we can capture industry-specific effects by including industry dummies (Hitt and Brynjolfsson, 1996).[1] We also include year dummies to capture any unobserved time-varying effect.

Finally, we include a zero-one dummy for RFID, which allows us to evaluate the impact of RFID on firm profitability. If we find a positive and statistically significant coefficient of *RFID*, therefore, we can argue that a firm's profits are positively associated with RFID adoption. Thus, we have a following specification extended from equation (1a):

$$(1b)\ \Delta Profit_{i,t+1} = \beta_0 + \beta_1 \Delta IR_{i,t+1} + \beta_2 \Delta SE_{i,t+1} + \beta_3 MS_{i,t+1} + \beta_4 RFID_{i,t} + controls + \varepsilon_i$$

where *IR*, *SE,* and *MS* in equation (1b) denote inventory ratio, sales efficiency and market share of firm *i* at time *t+1*, respectively. $RFID^*_{i,t}$ is a zero-one dummy for firm *i* at time *t*. It takes on 1 if RFID is adopted or 0 otherwise at time *t*. Controls include industry dummies at the 2-digit SIC level and year dummies.

By adding control variables and an RFID dummy in the profit function, we believe that our empirical model captures a substantial portion of variations in firm profitability. However, it is worthwhile to recall that a supplier's decision to adopt RFID may not be exogenous and influenced by its unique characteristics. For instance, it may be easier for a larger firm to invest in a new technology such as RFID due to financial and organizational slack available (Whitaker et al., 2007), or a firm that operates in a more dynamic industry may have a greater incentive to adopt RFID to reduce demand uncertainty (Melville et al., 2007). When endogeneity is likely to matter, we cannot obtain unbiased estimates using a traditional regression technique such as by estimating equation (1b) with an RFID dummy variable (Greene, 2000). Accordingly, we need to look for an alternative way that allows us to control for potential endogeneity (Maddala, 1983; Chang and Gurbaxani, 2008). In the next section, we discuss how we can obtain unbiased estimates by accounting for potential endogeneity.

The profit function after accounting for endogeneity

The RFID decision is made based on potential costs and benefits. This implies that a supplier's choice for RFID adoption is a function of ex-ante expectation of its future profitability depending on its organizational characteristics. Particularly, this type of dependency raises the issue of endogeneity (Heckman, 1979; Greene, 2000). Therefore, we take the endogeneity into consideration by explicitly incorporating a firm's organizational characteristics into the estimation procedure. Based on our discussion earlier (see theory section and hypotheses section), we use demand fluctuations and an inventory ratio as factors that lead RFID adoption to be favorable. We construct a variable for demand fluctuations by measuring the difficulty in prediction of future demand (Mills and Schumann, 1985; Melville et al., 2007). We also use a ratio of inventory to sales one year prior to RFID adoption since suppliers with a high inventory ratio may expect to gain greater benefits from using RFID (Kinney and Wempe, 2002). Then, we incorporate these factors by modeling the selection function with a latent variable ($RFID^*_{i,t}$) which represents the preference of a supplier either to adopt RFID ($RFID_{i,t}$ =1) or not ($RFID_{i,t}$ =0) (Heckman, 1979; Lee, 1983; Maddala, 1983). This yields the following systems equations:

$$(2)\ \Delta Profit_{i,t+1} = \beta_0 + \beta_1 \Delta IR_{i,t+1} + \beta_2 \Delta SE_{i,t+1} + \beta_3 MS_{i,t+1} + controls + \varepsilon_i$$

$$(3)\ RFID_{i,t} = \begin{cases} 1 & \text{if } RFID^*_{i,t} = \gamma_0 + \gamma_1 DF_{i,t-1} + \gamma_2 IR_{i,t-1} + \gamma_3 FS_{i,t-1} + controls + \eta_i > 0 \\ 0 & \text{otherwise} \end{cases}$$

where *DF*, *IR* and *FS* in equation (3) denote demand fluctuations, inventory ratio and firm size of firm *i* at time *t-1*, respectively. ε_i and η_i are error terms. The definition of all other variables is discussed in equation (1).

As in equation (1b), the profit function includes inventory ratio, sales efficiency, a supplier's market share and

[1] Our model also automatically controls for a portion of industry-specific effects since a substantial part of industry heterogeneity can be removed by first-difference specification.

control variables. However, equation (2) does not include a dummy variable for RFID adoption, which is denoted as $RFID_{i,t}$ in equation (1b). Rather than directly estimating the RFID variable by plugging it into the profit function, we separate it and form systems equations. That is, the systems equations allow us to examine the effect of RFID on firm profitability through the selection function (eq.3) while accounting for potential endogeneity (see Maddala, 1983 for details).

To resolve the dependency, we also allow the correlation between the profit function (eq. 2) and the selection function (eq. 3). In other words, the decision process of RFID adoption is reflected on the profit function through correlation between two functions.[2] More specifically, a two-stage regression approach is employed to estimate the systems of equations while controlling for endogeneity (Lee 1983; Maddala 1983). In the first stage, we run the probit regression to estimate the probability of a supplier to adopt RFID based on its organizational characteristics (eq.3). Then, the profit function (eq.2) is estimated by incorporating the inverse mill's ratio (IMR),[3] which is estimated at the first stage analysis.

As a result of a two-stage estimation procedure, we can compute the expected profit for a supplier that adopts RFID as follows (see appendix 1 for proof).

$$(4)\ \mathrm{E}(\Delta Profit_{i,t+1} \mid RFID^{*}_{i,t} > 0) = \beta_0 + \beta_1 \Delta IR_{i,t+1} + \beta_2 \Delta SE_{i,t+1} + \beta_3 MS_{i,t+1} + controls + \rho\sigma IMR$$

where $IMR = \dfrac{\phi(\gamma_0 + \gamma_1 DF_{i,t-1} + \gamma_2 IR_{i,t-1} + \gamma_3 FS_{i,t-1} + controls)}{\Phi(\gamma_0 + \gamma_1 DF_{i,t-1} + \gamma_2 IR_{i,t-1} + \gamma_3 FS_{i,t-1} + controls)}$, IMR is the inverse mills ratio. ϕ and Φ are the normal density and normal distribution function, respectively. ρ is the correlation between the performance equation and the selection equation. σ_ε is the standard deviation of performance.

We note that the inverse mills ratio (IMR) measures the covariance between the decision for RFID adoption and profits. Accordingly, the statistical significance of the IMR coefficient provides useful information about the extent to which the profit and selection functions are interrelated. As shown in equation (4), expected profitability is dependent on the inverse mills ratio (IMR) while being associated with unconditional expectation of profits. In addition to the statistical significance of the selection term, the sign of the coefficient of IMR is worthwhile to note. The positive coefficient of IMR implies that RFID adopters are more likely to achieve greater benefits due to their characteristics that make the adoption of RFID more attractive. Accordingly, traditional regression techniques such as OLS provide estimates biased upward.[4]

Data

The sample for this study consists of firms that have adopted RFID, which are identified by searching primary press media including Business Wire, PR Newswire, and many others. We use a variety of combinations of keywords, such as *RFID*, *implement*, *adopt*, *select*, *announce*, and *SCM,* in the Lexus/Nexus search engine to capture as many RFID-associated events as possible. We do not consider RFID adoption before 2003 since the use of RFID in the supply chain drew media attention primarily after Wal-Mart mandated the use of RFID tags for its suppliers in 2003; prior to that, the media did not report a firm's plan for RFID adoption as frequently as they do now (RFID Journal, 2003). We also consult Compustat to obtain financial information for an analysis we conduct. We drop any firms from our analysis if they are privately-held or if Compustat does not provide financial information such as sales, inventory, and profit-based measures. As a result, we collect 62 suppliers that adopted RFID.

Next, we create a matched sample of 62 firms that have not adopted RFID as a benchmark for performance improvements of RFID adopters. Following the Finance and IS literature, we begin with a set of firms that are in the same 2-digit SIC code but that did not adopt RFID (Barber and Lyon, 1997: Bharadwaj, 2000). From the screened

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[2] The estimation methods that ignore the correlation between the profit function and the selection function lead to biased estimates (Maddala, 1983; Greene, 2000).

[3] It is a monotonic decreasing function of the probability that an observation is selected into the sample (Heckman, 1979).

[4] We will compare the results estimated from 2-stage regression with those from OLS to check the direction of biasness later.

dataset initially based on the 2-digit SIC code, we select the matched firm for the RFID firm as the one closest in size measured as market capitalization (Li and McNally, 2007).[5]

Descriptive statistics for the key variables are presented in table 1. We match the data of each RFID adopter with its corresponding non-adopter in an adoption year (year 0). Further, note again that our study examines the financial performance of firms after RFID adoption and identifies the drivers for RFID adoption by examining organizational factors prior to the decision for RFID adoption. Accordingly, our sample spans from 1 year before RFID adoption to 1 year after RFID adoption.[6] The average firm size measured in sales is $1.27 and $0.69 billion for RFID and matched firms, respectively. This indicates that larger firms have been more aggressive in adopting RFID. Profit margins measured as the ratio of operating profits to sales vary from -0.009 to 0.535 and from -0.115 to 0.506 for RFID and matched firms, respectively. Likewise, another profitability index, ROA measured as the ratio of net income to total assets, shows a similar pattern. We also consult Compustat to compute sales efficiency, inventory ratio, a supplier's bargaining power and demand fluctuations. Sales efficiency is measured as sales per unit of labor. We use an inventory ratio as an inverse measure for inventory efficiency by dividing total inventory into sales. The market share of a supplier is constructed as a proxy for its bargaining power (Gottinger, 2003). To compute a firm's market share, we aggregate the sales of all firms that operate in the same 2-digit SIC industry with our sample firm. Accordingly, market share is expressed as a firm's sales divided by the total sales made in the same 2-digit SIC industry. We also obtain demand fluctuations by regressing sales on a constant term and a time trend over 10 years and divide the resulting standard errors by the average sales of a firm (Mills and Schumann, 1985; Melville et al., 2007). Accordingly, the index captures the degree of difficulty for a firm to predict its sales demand. Our sample also indicates that all variables encompass a wide range, which leads to higher explanatory power in regression analyses.

Table 1 : Summary statistics for the key variables

	RFID firms				Matched firms			
	Average	min	max	Std	Average	Min	max	std
Sales (M$)	12,656.7	87.9	86,696.0	18,036.9	6,940.1	39.1	41,374.8	9,184.4
profit margins	0.179	-0.009	0.535	0.096	0.173	-0.115	0.506	0.105
ROA	0.076	-0.361	0.898	0.124	0.061	-0.415	0.302	0.083
Sales efficiency	421.9	85.5	3,854.3	479.0	347.6	47.3	2,159.4	320.9
Inventory ratio	0.123	0.010	0.377	0.068	0.124	0.015	0.393	0.067
Market share	0.0380	0.0000	0.1910	0.0500	0.0330	0.0000	0.8290	0.1070
Demand fluctuation	0.020	0.000	0.072	0.016	0.015	0.002	0.095	0.014

Next, it is useful to see if there is any systematic difference between two sets of firms in a way consistent with RFID adoption before proceeding with our formal analysis. It appears that the decline of inventory ratio for RFID firms is small from the pre-adoption period to the post-adoption period (-0.11%). However, non-RFID firms experienced a

[5] While we follow the standard approach to choose appropriate matched firms, our sample selection criteria might affect our test results. To check the robustness, we also select the firm that is closest in size measured as total asset (Stratopoulos et al, 2000) and as net sales (Kinney and Wempe, 2002). Results are qualitatively similar to those obtained from original estimates.

[6] While we capture the effect of RFID by examining the profitability for a post-adoption period (1 year after RFID is adopted), it is worthwhile to expand the post-adoption period to longer years for a longitudinal analysis. Since most of RFID decisions were made recent years after 2003, however, we are not able to expand our dataset in longer periods. As the technology becomes mature over time, we will be able to do further analyses.

2.03% increase in inventory ratio. This implies that a barely significant improvement of inventory efficiency for RFID firms may be due to external environments which influence both RFID and non-RFID firms. To isolate external effects, we use control-firm adjusted inventory ratio for a year prior to RFID adoption and for a year after RFID adoption. We test control-firm adjusted paired changes from a year prior to RFID adoption to a year after adoption for inventory ratio (column 3 in table 2). This type of paired-test allows us to examine the net changes in inventory ratio and sales efficiency, which are not driven by industry heterogeneity and economic conditions over sample periods (Bharadwaj, 2000). Our test shows that there is a significant difference in an inventory ratio between two sets of firms (p=0.0423). As in the case of inventory efficiency, however, there is no significant difference in sales efficiency between two periods, 1 year prior to RFID adoption and 1 year after RFID adoption. However, our test shows that the paired-difference in sales efficiency between two sets of firms is marginally significant (p=0.094). In general, table 2 shows that RFID firms have achieved higher inventory and sales efficiency relative to their counterparts which implies the heterogeneity between two sets of firms. These preliminary results motivate us to more formally examine the effect of RFID on the financial performance of RFID firms. Further, recall that this motivates us to employ a two-stage Heckman procedure which accounts for potential endogeneity by incorporating firm heterogeneity in the first stage analysis.

Table 2: Inventory ratio and sales efficiency changes for RFID and matched firms

	RFID firms	Matched firms	Paired differences	p-value
Inventory ratio				
Pre RFID adoption	0.1232	0.1110	0.01216	N.S.
Post RFID adoption	0.12204	0.1313	-0.00929	N.S.
$\Delta(\text{inventory ratio})_R - \Delta(\text{inventory ratio})_M$	-0.0011	0.0203	-0.0214	0.042
Sales efficiency				
Pre RFID adoption	342.90	324.98	17.97	N.S.
Post RFID adoption	472.23	363.02	109.22	N.S.
$\Delta(\text{Sales efficiency})_R - \Delta(\text{Sales efficiency})_M$	129.34	38.09	91.25	0.094

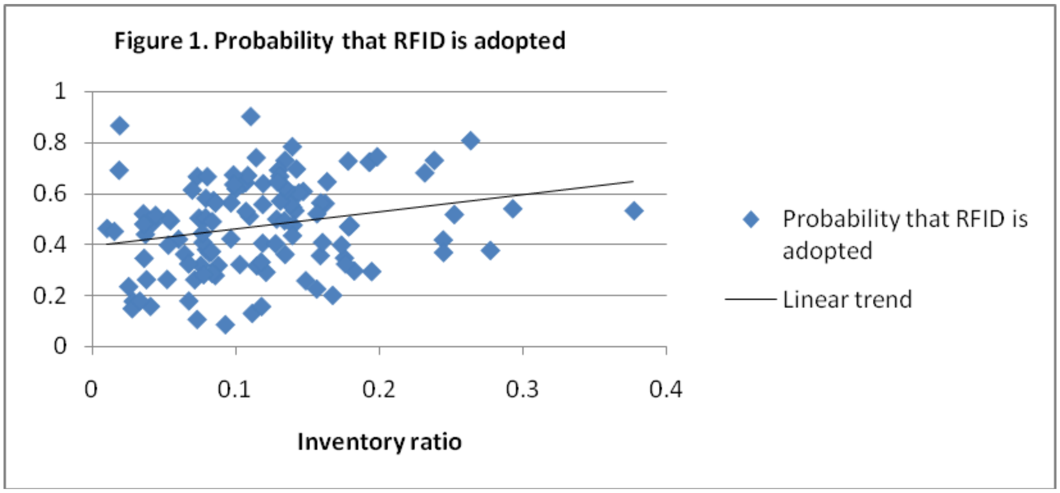
* Δ denotes the first difference; N.S. denotes non-significant; subscript *R* and *M* are RFID firms and their matched sample firms, respectively.

Results

As discussed earlier, suppliers that adopt RFID will achieve higher profit margins than non-RFID adopters. However, a single equation framework addresses limited information on what organizational factors force suppliers to adopt RFID and what allows them to achieve higher profit margins over the years. Our two-stage estimation procedure provides a deeper insight into conditions under which suppliers adopt RFID and into whether their decision leads to higher performance.

We first begin by presenting the results of the selection function that captures organizational drivers for RFID adoption (see table 3). The variable of demand fluctuations expressed as a deviation from previous sales is positively associated with RFID adoption. As expected, supplying firms faced with larger demand fluctuations are more likely to adopt RFID (*H1 supported*). This is consistent with the notion that RFID provides the potential for firms to facilitate the sharing of demand information along the supply chain which can remove a significant portion of demand uncertainty (Cachon and Fisher, 2000; Lee et al., 2000).

RFID is recognized as a technology that improves inventory efficiencies by enhancing the visibility of materials and coordinating the flow of materials (Mclntyle, 2006; Pisello, 2006). Accordingly, firms with a high level of inventory are more likely to adopt RFID, which results in higher inventory efficiencies. Consistent with our expectation, we find that a prior inventory ratio is positively associated with the probability of RFID adoption at the 10% significance level. To visualize our idea, we compute the expected probability that a firm adopts RFID based on the estimates obtained from the 2-stage estimation procedure. Then, we plot the probability against inventory ratios. Figure 1 presents that the probability that a firm adopts RFID increases as its inventory ratio increases. Taken together, our estimates and figure 1 confirm that firms are more likely to adopt RFID when their inventory efficiency is low (*H2 supported*).



Firm size measured as a firm's sales volume is positive and statistically significant at the 1% level (*H3 supported*). This may result from more slack resources available for larger firms to initiate costly RFID projects, which is consistent with previous studies (Zhu and Kraemer 2002; Zhu et al. 2006; Whitaker et al. 2007).
Taken together, all the variables in the selection function are statistically significant implying that a firm's decision for RFID adoption is influenced by several organizational characteristics.

Table 3: Estimates from the selection function[7]

	Profit margins	ROA
Previous inventory	3.76 (1.67)*	3.76 (1.67)*
Demand fluctuations	20.94 (2.19)**	20.94 (2.19)**
Firm size	0.23 (2.75)***	0.23 (2.75)***
Constant	-2.98 (-2.71)***	-2.98 (-2.71)***

*p<0.1 **p<0.05; *t* statistics are included in parentheses. Year and industry dummies are not reported for expositional brevity.

Next, we estimate the two profit functions specified as either a form of i) profit margins or ii) ROA. Table 4 reports an overview of the results for the two profit functions with the inverse mills ratio which is used to control for

[7] The estimates from the probit regression are the same for both profit margins and ROA since the selection function in the first stage is specified with the same variables. That is, we first run the probit regression which use RFID adoption as a dependent variable and organizational characteristics discussed earlier as independent variables. Therefore, the estimates from the first stage probit analysis are identical without regard that we use profit margins or ROA as a dependent variable in the second stage. Recall that we use both profit margins and ROA to check the robustness of our results.

endogeneity in the 2nd stage estimation procedure.

Table 4: Estimates of the profit function

	Profit margins	ROA
Post Inventory	-0.442 (-3.13)***	-0.563 (-1.94)*
Post Sales efficiency	0.00006 (1.98)**	0.00017 (1.71)*
Supplier's Market share	-0.188 (-1.58)	-0.104 (-0.50)
Constant	0.009 (0.22)	-0.047 (-0.59)
Inverse Mill's ratio	0.134 (2.06)**	0.151 (1.81)*

*p<0.1, **p<0.05, ***p<0.01; *t* statistics are included in parentheses. Year and industry dummies are not reported for expositional brevity.

We expect that RFID improves inventory efficiency, which is viewed as a lowered inventory ratio in a post-adoption period. Our estimates suggest that the coefficient of inventory ratio in the profit function is negative and significant, as expected at the 1% and 10% significance level for both profit margins and ROA, respectively. Of course, this is not surprising since firms with a high level of inventory efficiencies may automatically be associated with in higher profits (Kinney and Wempe, 2002). We conjecture that RFID allows firms to identify hidden costs associated with large buffer stocks by tracing the flows of materials and information. Thus, firms may be able to reduce inventory investments by the aid of RFID. From the preliminary analysis (see figure 1), we also find that RFID adopters achieve greater gains in inventory efficiency one year after RFID adoption than their counterparts. When combined with our preliminary analysis, our results suggest that firms that adopted RFID have improved inventory efficiency over years, leading to higher profit margins (*H4a supported*). In a similar vein, firms may improve sales efficiency, measured as sales per unit of labor over years, after deploying RFID since it enables them to streamline and optimize traditional packing and shipping activities (Curtin et al., 2007). As in the case of improved inventory efficiency in a post-adoption period, RFID is expected to enhance profit margins through improved sales efficiency (*H4b supported*).

We also include a supplier's market share to capture potential variations in profitability driven by the bargaining power of a supplier in its supplier-buyer relationship. Unlike our expectation, however, the coefficient of a supplier's market share is not positively associated with two profitability measures. Further, the signs of coefficients are negative, although both of them are not significant. Given that RFID projects are primarily motivated by large retailers in a supplier-buyer relationship, we conjecture that profitability of suppliers may have been squeezed by retailers' market power. (Galibraith and Stiles, 1983; Kelly and Gosman, 2000). For instance, large retailers like Wal-Mart increased market power over years and mandate that their top suppliers adopt RFID (Bloom and Perry, 2001; Gosman and Kohlbeck, 2006).[8] In a situation like this, retailers' bargaining power may have a stronger effect on a supplier's profitability than that of a supplier (Cool and Henderson, 1998; Schamlensee, 1985). In another word, a supplier's bargaining power proxied as market share might not play a critical role in shaping profitability in our context. Further, suppliers that are forced to adopt RFID are usually large and are more likely to be represented in our sample. This may also mitigate the effect of suppliers' market share, leading to insignificant contribution of market share to profitability.

Next, it is worthwhile to note the sign and significance of the selection term, the inverse mills ratio (IMR). We find a positively significant coefficient of the selection term (IMR), implying that suppliers that adopt RFID achieve relatively greater gains in profit margins and ROA than do randomly selected suppliers. This indicates that firms with unobservable advantages from RFID technology are more likely to adopt RFID and achieve greater benefits in

[8] Due to a lack of data, we are not able to identify a set of suppliers that are forced to adopt RFID and another set of suppliers that are not. However, we have no prior reasons for profit-maximizing suppliers to comply with large retailers' requests without consideration of their own costs-benefits analysis. Accordingly, we do believe that it is important to reflect suppliers' decision process for RFID adoption as we do here.

a post-adoption period. On the other hand, a traditional regression analysis such as OLS does not account for unobservable benefits. Accordingly, OLS produces estimates that are biased upward. Table 5 reports the difference of OLS estimates from 2-stage estimates we use for analyses. Our test results suggest that OLS estimates are biased upward at the 5% or 10% significance level. This allows us to make stronger statements regarding the roles of endogeneity in estimating the effects of RFID.

Table 5: The differences of OLS and 2-stage estimation

	Profit margins			ROA		
	2 stage	OLS	Differences	2 stage	OLS	Difference
Post Inventory	-0.442***	-0.426***	0.016*	-0.563*	-0.543*	0.020**
	(-3.13)	(-2.64)	(-1.87)	(-1.94)	(-1.65)	(-1.97)
Post Sales efficiency	0.00006**	0.00009*	0.00003*	0.00017*	0.00021*	0.00004*
	(1.98)	(1.71)	(-1.65)	(1.71)	(1.82)	(-1.76)
Supplier's Market share	-0.188	-0.137	0.052	-0.104	-0.036	0.068
	(-1.58)	(-1.18)	(-1.23)	(-0.59)	(-0.15)	(-1.59)

*p<0.1, **p<0.05, ***p<0.01,+: the coefficients are computed as the difference between coefficient obtained from OLS and those obtained from 2-stage estimation

Conclusion

In this paper, we examine the impact of RFID on firm profitability using a sample of supplying firms that adopt RFID and their matched firms. For this purpose, we first analyze the organizational drivers for suppliers to adopt RFID and examine whether a supplier's decision for RFID adoption improves profits. Consistent with our expectation, the RFID decision is made based on future benefits and costs that are dependent on a supplier's organizational characteristics. We find that suppliers encountered with a low level of inventory efficiency are more likely to deploy RFID. Further, firms faced with large fluctuations in sales demand are more aggressive in RFID adoption. This is consistent with our notion that suppliers consider RFID as a way to improve inventory efficiencies and to stabilize future demand fluctuations through improved information sharing and the flows of materials along the supply chains. Our results also show a positive association between RFID adoption and firm size, possibly due to available resources slack that a firm needs for investments in new technologies such as RFID.

Our first stage estimates are incorporated into the second stage estimation, which allows us to control for potential endogeneity between a firm's RFID decision and profitability. We show that RFID adopters have achieved greater benefits in a post-adoption period, which are attributable to improved inventory and sales efficiencies. This is in line with our notion, in an analysis of the selection function, that firms adopt RFID to improve inventory efficiency. We also find a positively significant coefficient for the inverse mills ratio (IMR). This suggests that the organizational characteristics analyzed in the first stage have a significant impact on a supplier's decision for RFID adoption. Thus, the use of a two-stage estimation procedure is critical in estimating the effects of RFID on financial performances. In sum, our results provide evidence that RFID adopters outperform non-adopters in the improvement of profit margins and ROA over a post adoption period.

To the best of our knowledge, this is one of the first studies that examines the financial effects of RFID. We extend the literature by rigorously examining the business value of RFID in the context of financial performance. Further, we are able to provide an in-depth understanding of how RFID improves the financial performance of RFID adopters by explicitly incorporating the drivers for RFID adoption into the estimation procedure.

Our study also provides valuable insights for managers. First, we show that RFID can be used to leverage inventory as a competitive weapon by better managing supply chain. Managers should also note that RFID may deliver greater benefits when firms are operated in a more dynamic business environment. Second, our study suggests that the benefits of RFID may not be limited to efficiency gains in inventory management. We show that RFID adopters financially outperform their counterparts by improving sales efficiency. Accordingly, managers should evaluate RFID projects periodically to see if they can benefit from RFID. Finally, our study guides managers who are mandated to adopt RFID but delay their decision by documenting tangible benefits from RFID.

Finally, it is worthwhile to address the limitations of our study. First, our search for data collection from the media may favor large firms. Accordingly, our data sample might be drawn from a set of large firms. Since large firms are more likely to be better positioned in adopting new technologies, we should be careful in applying our results to smaller firms. Second, the implementation of RFID is still in an immature stage, and firms have started deploying RFID only in recent years. Therefore, we consider a short time period, which does not allow us to gauge the long-term effects of RFID. Finally, due to a lack of available data, we are not able to include IT capabilities as a complementary asset to RFID; doing so might provide more insights to researchers and managers (Bharadwaj, 2000; Brynjolfsson and Hitt, 2000). We are also not able to control for potential influence of business partner's mandates on suppliers' RFID adoption. Further research will benefit from a richer dataset. Despite these limitations, we believe that our research provides valuable insights into the value of RFID and an understanding of the nature of benefits derived from RFID adoption.

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Appendix 1

In this appendix, we prove how a supplier's profit is associated with its organizational factors by deriving the expected profit. Following the literature (Heckman, 1979; Maddala, 1983; Greene, 2000), we assume that error terms for the profit function (ε_i) and the selection function (η_i) follow normal distribution. Then, the expected profit is specified as follows:

$$\text{(A1)}\; \mathrm{E}(\Delta Profit_{i,t+1} | RFID^*_{i,t} > 0) = E(P\Delta rofit_{i,t+1} | \gamma w_{i,t-1} + u_{i,t-1} > 0)$$

where γ and w are a set of parameters and variables that denote supplier *i*'s organizational characteristics.

When the profit and the selection functions have a bivariate normal distribution, we can decompose the expected profit into two components, unconditional expectation and conditional expectation of error term as follows:

$$\text{(A2)}\; E(\Delta Profit_{i,t+1} | RFID^*_{i,t} > 0) = E(\Delta Profit_{i,t+1}) + E(\varepsilon_i | \gamma w_{i,t-1} + u_{i,t-1} > 0)$$

Under the assumption of bivariate normal distribution for ε_i and η_i the second term of the right hand side can be represented via normal density and cumulative functions and correlation between the profit and the selection functions (Greene 2000). This yields:

$$\text{(A3)}\; \begin{aligned} &E(\Delta Profit_{i,t+1} | RFID^*_{i,t} > 0) \\ &= \beta_0 + \beta_1 \Delta IR_{i,t+1} + \beta_2 \Delta SE_{i,t+1} + \beta_3 MS_{i,t+1} + controls + \sigma_{\varepsilon_1} \rho \; f(\phi w_i) / F(\phi w) \end{aligned}$$

where f is a normal probability density function and *F* is a cumulative normal distribution function. ρ is the correlation between the profit function and the selection function. σ_{ε_1} is the standard error in the profit function. $f(\phi w_i) / F(\phi w)$ is the inverse mills ratio.

Before we describe the meaning of equation (A3), recall that prior inventory ratio and demand fluctuations induce suppliers to adopt RFID (see table 3). Further, the expected profit of suppliers that adopt RFID is determined by the last term, $\sigma_{\varepsilon_1} \rho_1 f(\phi w_i) / F(\phi w)$. That is, the effects of a supplier's organizational characteristics have two parts. One is due to their influence on increasing the tendency to adopt RFID, and the other is due to its influence on profit through the selection function as shown in equation (A3).

Our results show the positive correlation (ρ) between the profit and the selection functions. This indicates that a higher tendency to adopt RFID, which is driven by prior inventory ratio and demand fluctuations in the selection function, is positively associated to higher productivity.

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