9-2007

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This version dated February 23, 2007
before publication in *Production and Operations Management*

Acknowledgements: We thank the associate editor and two anonymous referees for their insightful and constructive feedback. We thank Gilvan Souza for helpful comments on a previous version of this paper, and acknowledge helpful discussion with Abraham Seidmann regarding the applicability of insights from EDI research to the RFID domain. We thank InformationWeek for providing the data for this research. An earlier version of this paper was presented at the 2006 Academy of Management Annual Meeting. Financial support was provided in part by National Science Foundation IGERT grant 0114368, the Stephen M. Ross School of Business at the University of Michigan, the R.H. Smith School of Business at the University of Maryland, and the Michael R. and Mary Kay Hallman fellowship at the University of Michigan Ross School of Business.

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Abstract

Radio Frequency Identification (RFID) technology promises to transform supply chain management. Building on previous research in information systems and supply chain management, this paper proposes a theoretical framework for RFID adoption and benefits, and tests the framework using data on U.S. firms. Our analysis suggests that there is a positive association between information technology (IT) application deployment and RFID adoption. We find that RFID implementation spending and partner mandate are associated with an expectation of early return on RFID investment, and a perceived lack of industry-wide standards is associated with an expectation of delayed return on RFID investment. These results suggest that firms with broad IT application deployment and a critical mass of RFID implementation spending are more likely to report early returns from RFID deployments. This paper extends previous research to understand the relationship between organization characteristics and adoption and expected benefits of the emerging RFID technology.

Key words: *RFID, information technology, adoption, benefits, business value of IT.*

1. INTRODUCTION

Information sharing, coordination and inter-organizational linkages are important elements to achieve integrated, agile and efficient supply chains. Previous research suggests that information technology platforms and capabilities play a major role in transforming supply chain management and order fulfillment processes (Johnson and Whang 2002; Lee and Whang 2001; Pyke, Johnson and Desmond 2001; Rai, Patnayakuni and Seth 2006). Researchers have also shown that information technology improves operational and financial performance by enabling organizational capabilities and coordination with business partners (Bardhan, Mithas and Lin 2006a; Bardhan, Whitaker and Mithas 2006b; Mithas and Jones 2007; Zhu and Kraemer 2002).

Radio Frequency Identification (RFID) promises to transform supply chain management by providing detailed information on the flow of products throughout the value chain. Several large private and public sector organizations have announced their commitment to use RFID in managing their supply chains. Wal-Mart required its top 100 suppliers to place RFID tags at the case- or pallet-level by 2005, and is planning for a total of over 600 suppliers by 2007. The U.S. Department of Defense currently maintains the world's largest RFID cargo tracking system across 2,000 sites and 46 countries. A 2005 AMR Research–RFID Journal survey of 500 companies finds that RFID related spending represents 9.1% of IT budgets, with spending projected to increase 16% by 2006 and another 20% by 2007 (Reilly 2005). A.T. Kearney (2003) projects that retailers using RFID will reduce inventory by 5%, save 7.5% of warehouse labor costs, and increase sales by 0.07%.

Despite the potential of RFID to enable supply chain transformation, there is a limited understanding of the antecedents and business value of RFID. Most of the early RFID research discusses technical issues or descriptive frameworks (Angeles 2005; Asif and Mandviwalla 2005). More recent research considers RFID adoption and benefits using analytical modeling or data analysis based on one focal firm (Delen, Hardgrave and Sharda 2007; Doerr, Gates and Mutty 2006; Gaukler, Seifert and Hausman 2007; Heese 2007; Loebbecke and Palmer 2006). In this paper, we build on previous research in information systems and supply chain management to develop a theoretical model for the antecedents

and business value of RFID for a set of firms. We validate this model by conducting an empirical study across a broad cross-section of U.S. firms using archival data.

We extend previous research to understand the relationship between organization characteristics and adoption and expected benefits of the emerging RFID technology. While previous studies have examined the adoption of interorganizational systems, few studies have addressed both adoption and business value in the same study. While most current RFID research is based on one focal firm, this study addresses RFID adoption and business value for a set of firms. We find that firms with broad IT application deployment and a critical mass of RFID implementation spending are more likely to report early returns from RFID deployment. We also find that partner mandate is associated with an expectation of early returns from RFID, and standards ambiguity is associated with an expectation of delayed returns from RFID deployment. While other research notes that industry standards are a key factor in RFID adoption and benefits (Curtin, Kauffman and Riggins 2007), this paper empirically establishes the connection and shows that the lack of a dominant industry RFID standard has negative implications for RFID benefits.

The rest of the paper is structured as follows. Section 2 reviews the theory and develops hypotheses. Sections 3 and 4 discuss the methodology and present results. Section 5 outlines implications of the study.

2. THEORY AND RESEARCH MODEL

RFID is emerging as a powerful application that promises to transform supply chain management. The RFID technology consists of two primary components – tags and readers. RFID tags carry extensive information on each item, and can be read and tracked instantly. RFID tags have a microchip and antenna. The microchip stores object information (such as a serial number), while the antenna enables the microchip to transmit object information to the reader. The reader creates a magnetic field with the tag antenna, and the tag uses this magnetic field to transmit object information to the reader. This object information can then be integrated into other systems within the supplier and buyer firms, and transferred between firms to improve supply chain effectiveness. Because RFID systems facilitate the integration

and sharing of information within and between firms, we focus on the deployment and benefits of RFID in a supply chain context (Kirby 2003).

Two streams of literature appear relevant for studying RFID in the supply chain context. The first stream is the information systems (IS) literature that studies the use and effect of interorganizational systems (IOS). IOS exist between companies and enable the movement of information across organizational boundaries (Applegate and Gogan 1995; Cash and Konsynski 1985). Beginning with early conceptual research exploring the implications of IOS for changes in firm boundaries (Malone, Yates and Benjamin 1987), the IS literature now draws on both technology adoption (Cooper and Zmud 1990) and business value of IT literature (Barua and Mukhopadhyay 2000; Brynjolfsson and Hitt 1996; Kauffman and Kriebel 1988; Lucas 1993) to study the use and effect of IOS in electronic markets (Choudhury, Hartzel and Konsynski 1998; Mithas and Jones 2007). For example, researchers have shown that the use of electronic data interchange (EDI), a subset of IOS, simultaneously reduces cost and improves quality of transactions between partner firms (Mukhopadhyay, Kekre and Kalathur 1995; Srinivasan, Kekre and Mukhopadhyay 1994).

A second and complementary perspective on RFID comes from the supply chain management (SCM) literature that focuses on the use of IT tools to improve supply chain processes. The SCM literature recognizes the importance of managing supply chain relationships to achieve competitive advantage (Lee and Whang 2003), and of leveraging benefits through information sharing across the supply chain (Kulp, Lee and Ofek 2004; Swaminathan and Tayur 2003). Information sharing is the willingness to make strategic and tactical information available to supply chain partners, including forecasts, promotions, inventory levels, sales demand and the movement of goods through the supply chain (Fisher, Hammond, Obermeyer and Raman 1994; Johnson 1998; Lee and Whang 2000). Information sharing can align the incentives of supply chain partners and improve margins, inventory control, customer satisfaction and firm performance (Mithas, Krishnan and Fornell 2005b; Narayanan and Raman 2004). Information technology advances have greatly reduced the cost of sharing information and fostered real-time information sharing, coordination and decision making among companies (Johnson and

Whang 2002; Kopczak and Johnson 2003). Recent research considers adoption and benefits of information technologies such as enterprise resource planning (ERP) and customer relationship management (CRM) systems (Cotteleer 2006; McAfee 2002; Stratman 2007; Tsikriktsis, Lanzolla and Frohlich 2004).

Although the IS and SCM literatures provide insights regarding the use and effect of IOS applications, much of the research in these areas is conceptual or analytical, and most empirical studies have focused on the established EDI, ERP and CRM technologies (Aral, Brynjolfsson and Wu 2006; Hitt, Wu and Zhou 2002; Mithas et al. 2005b; Ray, Muhanna and Barney 2005). While conceptual and analytical studies are important for a theoretical understanding, field research and empirical work are necessary to test the validity and relevance of theoretical arguments. Thus, field based empirical research is a useful complement to theoretical and analytical studies to develop a deeper understanding of the research phenomenon. Our work responds to the calls by Agarwal and Lucas (2005) and Lee and Özer (2007) to study the transformational effect of IT in supply chains, focusing particularly on IT systems such as RFID that facilitate information sharing.

RFID shares some similarities with previous IOS technologies and enterprise systems such as EDI, ERP, CRM and SCM. Similar to these systems, RFID introduces new dependencies, processes and decision rights within and across organizations (McAfee 2006). While these similarities suggest that one may be able to generalize from previous IOS and EDI research to RFID (Angeles 2005), there are also at least two differences that suggest the need to test adoption and business value specifically in the RFID context. First, with the nature of RFID tags and readers, RFID faces unique hardware technical challenges (such as low read rates) compared with the challenges faced by EDI (Ferguson, Hill and Hansen 1990; Ngai et al. 2007; Sullivan 2005). A second difference is that unlike other IOS where variable costs are almost negligible, RFID incurs substantial variable costs due to the use of RFID tags. Together, the unique technical challenges and cost structure associated with RFID make it necessary to test the extent to which the predictions based on IOS research models also apply to RFID.

We next draw on the IOS and SCM literatures to develop the theory underlying our research model, and to identify relevant firm characteristics that explain the antecedents and business value of RFID.

2.1 Organization Resources and RFID Adoption

Organization characteristics have a significant effect on the adoption of technical innovations (Kimberly and Evanisko 1981). Two key organization characteristics that influence the adoption of interorganizational systems are technological resources and financial resources (Iacovou, Benbasat and Dexter 1995). Technological resources include the level of technical sophistication and level of management support for using IT, and financial resources are the capital available for IT investments (Chwelos, Benbasat and Dexter 2001). Technological resources increase the information processing capabilities between partner firms, enabling greater cooperation and collaboration (Bensaou 1997). Information systems and communication networks have reduced the time and cost required for supply chain partners to share, collect and analyze information. A strong IT infrastructure is critical for IOS, because the scope in terms of IT applications and partner firms can grow rapidly (Premkumar 2000). A strong IT infrastructure is required to adopt IOS, integrate with internal IS applications, and establish links with trading partners (Premkumar and Ramamurthy 1995). Prior research shows that sophisticated IT infrastructure is a strong predictor of IOS adoption (Grover 1993). Recent research reinforces that IT assets and infrastructure are a platform that enables firms to pursue important initiatives such as the electronic integration of supply chains and outsourcing to strategic partners (Bardhan et al. 2006a; Bardhan et al. 2006b; Zhu and Kraemer 2002).

Significant financial resources are required to pay for implementation and ongoing expenses of IOS (Iacovou et al. 1995) and RFID. A.T. Kearney (2003) estimates the cost for a large retailer to adopt RFID as $400,000 per distribution center and $100,000 per store, plus $35–$40 million to integrate systems across the entire organization. Industry analysts predict that a large consumer goods manufacturer would spend $9–$25 million to implement RFID (Shutzberg 2004). Based on the above

discussion, we hypothesize that firms with broader IT application deployment and larger IT budgets are more likely to adopt RFID.

H1a: Firms with broader IT application deployment are more likely to adopt RFID.

H1b: Firms with larger IT budgets are more likely to adopt RFID.

2.2 Organization Resources and RFID Benefits

Technological and financial resources are also important to achieve business value from IOS implementation. We extend previous research on the role of technological and financial resources in IOS adoption to investigate their role in IOS implementation and benefits. We posit that greater investments of technological and financial resources in RFID implementation will be associated with early benefits from RFID. IOS implementation frequently involves a need to change and upgrade internal systems (Saunders and Clark 1992). Firms with highly integrated and digitized processes are better prepared to integrate their IOS systems and achieve greater benefits (Iacovou et al. 1995). For example, researchers have suggested that while implementing EDI in purchase order processing may provide some benefits, integrating EDI information into requirements planning and production is likely to provide greater benefits (Riggins, Kriebel and Mukhopadhyay 1994). The compatibility of IOS with internal IT systems leads to greater integration internally and with supply chain partners, and greater implementation success (Premkumar, Ramamurthy and Nilkanta 1994). Similarly, a strong IT platform is required to achieve greater benefits from RFID implementation. Firms may need to upgrade existing applications and invest in new hardware and software, to aggregate and filter data generated by RFID, and to integrate this data with enterprise systems (Dutta, Lee and Whang 2007).

Financial resources are important for successful IOS investments, as the cost of integrating IOS to achieve greater benefits can be substantial (Iacovou et al. 1995). The costs can include investment in hardware and software, ongoing support and maintenance, and modifications to current IT systems (O'Callaghan, Kauffmann and Konsynski 1992). IOS investment by a firm has a significant positive effect on the extent to which IOS is used to process data and link to trading partners, leading to greater benefits (Williams, Magee and Suzuki 1998). Based on the similarities between RFID and IOS, we posit

that firms with extensive IT integration and higher RFID implementation spending are more likely to expect an early return on RFID investment.

H2a: Firms that engage in more extensive IT integration in connection with RFID implementation will expect an early return on RFID investment.

H2b: Firms that spend more on RFID implementation will expect an early return on RFID investment.

2.3 Partner Mandates and RFID Benefits

The relationship between partner firms is also a key factor in the adoption of inter-organizational systems. Dependency (or power) is an important aspect of a dyadic relationship (Hart and Saunders 1998; Pfeffer and Leong 1977), and arises when one firm depends on another firm for a large portion of its sales revenue or incoming materials (Hart and Saunders 1997). Coercive pressures surface when a dominant firm exerts formal or informal pressures on dependent partner firms (DiMaggio and Powell 1983). A dominant firm that controls scarce and important resources may demand that dependent partner firms adopt programs that serve the dominant firm's interests. When dependency is high, dependent firms may have to comply to secure their survival. In previous IOS research, dependency relates to the potential of the dominant firm to encourage IOS adoption, and enacted power measures the strength of rewards and threats used to exercise power (Chwelos et al. 2001; Hart and Saunders 1997).

Researchers have studied the implications of power in IOS adoption using analytical models. When a manufacturer (buyer) initiates an IOS network, the buyer can reward or penalize suppliers to influence adoption patterns, and adoption by a supplier can generate positive externalities for the buyer and negative externalities for other suppliers (Barua and Lee 1997; Riggins et al. 1994; Wang and Seidmann 1995).

Previous research has also shown empirically that dominant firms exercise their power to influence their dependent partner firms to adopt IOS. From the dependent firm perspective, there is a strong relationship between dependency and IOS adoption (Iacovou et al. 1995), and requirements by dominant firms are key drivers of the adoption decision (Bouchard 1993). Enacted trading partner power

and greater coercive pressures are a significant predictor of IOS adoption (Chwelos et al. 2001; Teo, Wei and Benbasat 2003). These findings are relevant in the RFID context because dominant entities such as Wal-Mart and the Department of Defense are mandating use of RFID by their top suppliers (Barratt and Choi 2007; Curtin et al. 2007).

Despite the negative connotations of terms such as "power" and "mandate," partner mandate can also be viewed in a positive way. Previous research suggests that while the dominant firm registers early gains (Mukhopadhyay et al. 1995), ultimately all firms benefit from IOS (Premkumar 2000). Dependent agents who adopt IOS gain in the amount and share of business from dominant firms (O'Callaghan et al. 1992). Further, dependent firms can strategically combine supply chain management systems with their relationship-specific and non-contractible investments to improve their relative advantage, enhance their benefits and create negative externalities for their competitors (Bakos and Brynjolfsson 1993; Subramani 2004). Based on the above discussion, we hypothesize that firms deploying RFID because of a partner mandate will expect an early return on RFID investment.

H3: Firms that deploy RFID because of a partner mandate will expect an early return on RFID investment.

2.4 Data Standards and RFID Benefits

A common language for communicating about business is a pre-requisite for coordinating diverse organizations. Information systems facilitate use of a common language by standardizing data elements and document structures (Goodhue, Wybo and Kirsch 1992). Data standards make it easy for firms to communicate, interpret and manipulate information, and are an essential feature of inter-organizational systems (Markus, Steinfield, Wigand and Minton 2006; Zhu, Kraemer, Gurbaxani and Xu 2006). Lack of document standards is considered a barrier to IOS adoption (Williams et al. 1998). Common standards enable firms to share information with their supply chain partners through the Internet, which then enables the partners to coordinate and collaborate (Rai et al. 2006; Swaminathan and Tayur 2003). The benefits of standards increase as the interdependence between partners increases (Goodhue et al. 1992).

RFID enables supply chain partners to communicate product information down to the individual item level, which makes standards among supply chain partners critical (Shutzberg 2004). Standards are an important element of managing data quality, which is important as firms increasingly rely on data-driven technologies (Parssian, Sarkar and Jacob 2004). Supply chains in which a dominant firm imposes standards for information sharing experience better business performance relative to competitors, including measures such as stock availability and cycle time (Min and Mentzer 2004). Despite the fact that standards are a critical success factor and potential barrier for IOS (Allen, Colligan, Finnie and Kern 2000; Curtin et al. 2007; Ferguson et al. 1990; Murphy, Daley and Hall 1998), few research papers have empirically examined the effect of standards on business value in an electronic commerce context (Kauffman and Walden 2001). Based on the above discussion, we hypothesize that the lack of RFID standards will be associated with an expectation of delayed return on RFID investment.

H4: Firms experiencing a lack of RFID standards as a challenge in RFID implementation will expect a delayed return on RFID investment.

We control for other relevant variables to account for alternative and complementary explanations in our models for RFID adoption and business value. We control for firm size, because large organizations have greater resources to implement RFID and acquire the latest technology. Prior studies found a relationship between firm size and the adoption of technical innovations (Damanpour 1992; DeLone 1981; Grover 1993; Lehman 1985; Moch and Morse 1977), and subsequent studies confirm empirically that firm size is significant in predicting IOS adoption (Mithas, Jones, Krishnan and Fornell 2005a; Premkumar, Ramamurthy and Crum 1997). We also control for the two industry sectors that are widely known to be the primary initial adopters of RFID, the manufacturing industry and trade and logistics industry (Angeles 2005). These two industries account for almost 80% of the RFID market (Perez 2003).

3. RESEARCH DESIGN AND METHODOLOGY

This study is based on data from two separate surveys conducted by *InformationWeek*, a leading and widely circulated IT publication. *InformationWeek* is considered to be a reliable source of

information, and previous academic studies have also used data from *InformationWeek* surveys (Bharadwaj, Bharadwaj and Konsynski 1999; Mithas et al. 2005b; Rai, Patnayakuni and Patnayakuni 1997; Whitaker, Mithas and Krishnan 2005).

The first of the two surveys for this study, the *InformationWeek* 500 survey (IW 500), was conducted during mid 2004 (Cuneo 2004). This annual benchmarking survey targets top IT managers in large firms, and collects data on the IT department and operations, along with an overview of major IT initiatives. Three hundred and fifty-four firms responded to this survey with complete responses for the variables of interest. RFID-related data from this survey is used for the model on RFID adoption. For this survey, we complemented the *InformationWeek* data with revenue and industry data from Compustat for publicly traded firms, and from Dun & Bradstreet for privately held firms.

The second survey for this study, the *InformationWeek* RFID survey (IW RFID survey), was conducted during early 2005 (Bacheldor 2005). This one-time survey targeted IT managers in large firms, and collected more detailed data on the RFID deployment and expectations regarding benefits. Forty-four firms that are currently using or pilot testing RFID responded to this survey with complete responses for the variables of interest. Data from this survey is used for the model on RFID benefits.

3.1 Variable Definition

Table 1 describes the variables used in this study. Tables 2 and 3 provide descriptive statistics and correlation for our model variables. The relevant questionnaire items from the IW 500 and IW RFID surveys are available from the authors on request.

Table 1. Description of Variables

Variable	Description	Source
RFID Adoption	Four point scale indicating the extent to which a firm has deployed RFID (0=not deployed, 1=development or testing, 2=limited deployment, 3=wide deployment).	IW 500 survey
IT Application Deployment	Eight item formative index indicating the deployment of IT systems in a firm. IT systems covered by this scale are enterprise resource planning, supply chain management, customer relationship management, data warehouse, business intelligence, web services, content management, and product lifecycle management.	IW 500 survey
IT Budget	IT budget as a percentage of firm revenue.	IW 500 survey
RFID Benefits	Six point scale indicating time horizon when the firm expects to see a return on its RFID investment (1=not sure, 2=three years or more, 3=two to three years, 4=one to two years, 5=less than a year, 6=already seeing a return). Note that this variable represents the respondent's expectation, not actual benefits.	IW RFID survey
IT Integration	Six item formative index indicating the number of systems the firm had to upgrade before it could begin its RFID implementation. IT systems covered by this scale are enterprise resource planning, warehouse management system, database management system, product lifecycle management, data warehouse, and storage.	IW RFID survey
RFID Spending	Bracketed variable indicating the amount the firm plans to spend on RFID implementation, integration and consulting fees in 2005 (amounts in millions) (1=less than $0.5, 2=$0.5-$0.9, 3=$1-$4.9, 4=$5-$49).	IW RFID survey
Partner Mandate	Indicates that mandate from a retail or supplier partner is a factor driving the firm to adopt RFID (1=yes, 0=no).	IW RFID survey
Standards Ambiguity	Indicates that lack of universal standards has posed a challenge for firm in RFID adoption (1=yes, 0=no).	IW RFID survey
Firm Size	Natural log of annual firm revenue in the RFID adoption model, and seven point bracketed variable indicating annual firm revenue in the RFID benefits model (amounts in millions) (1=less than $6, 2=$6-$49, 3=$50-$99, 4=$100-$499, 5=$500-$999, 6=$1,000- $4,999, 7=$5,000 or more).	Compustat, Dun & Bradstreet, IW RFID survey
Industry	Control for two industry sectors considered as early adopters of RFID – manufacturing (two-digit NAICS codes 31, 32, 33), and trade and logistics (two-digit NAICS codes 42, 44, 45, 48, 49). Base category is firms in other sectors.	Compustat, Dun & Bradstreet, IW RFID survey

Table 2. Descriptive Statistics and Correlations for Variables in RFID Adoption Model

(n=354)

	Mean	Std. Dev.	Min	Max	1	2	3	4	5	6
1 RFID Adoption	0.57	0.78	0.00	3.00	1.00					
2 IT Application	5.62	1.68	0.00	8.00	0.21*	1.00				
3 IT Budget	0.04	0.06	0.00	0.82	-0.01	-0.01	1.00			
4 Firm Size	8.23	1.20	4.71	12.13	0.20*	0.20*	-0.07	1.00		
5 Manufacturing	0.33	0.47	0.00	1.00	0.24*	0.22*	-0.14*	0.07	1.00	
6 Trade and Logistics	0.17	0.38	0.00	1.00	0.12*	0.03	-0.13*	0.04	-0.32*	1.00

* Correlation significant at $p<0.05$

Table 3. Descriptive Statistics and Correlations for Variables in RFID Benefits Model

(n=44)

		Mean	Std. Dev.	Min	Max	1	2	3	4	5	6	7	8
1	RFID Benefits	2.95	1.51	1.00	6.00	1.00							
2	IT Integration	2.00	1.52	0.00	6.00	0.21	1.00						
3	RFID Spending	1.70	1.02	1.00	4.00	0.22	0.45*	1.00					
4	Partner Mandate	0.34	0.48	0.00	1.00	0.25	0.22	-0.07	1.00				
5	Standards Ambiguity	0.57	0.50	0.00	1.00	-0.18	0.12	0.02	0.34*	1.00			
6	Firm Size	5.02	1.97	2.00	7.00	-0.05	-0.02	0.01	-0.16	-0.15	1.00		
7	Manufacturing	0.57	0.50	0.00	1.00	-0.03	0.18	0.11	0.34*	-0.11	-0.04	1.00	
8	Trade and Logistics	0.11	0.32	0.00	1.00	-0.13	0.10	-0.11	-0.26	-0.12	0.07	-0.41*	1.00

* Correlation significant at $p<0.05$

Of the 354 firms from the IW 500 survey, 103 firms indicated that RFID is in testing or development, 35 firms have a limited deployment of RFID, and 10 firms have a wide deployment of RFID. On average, firms in the IW 500 have a relatively broad deployment of IT applications (average 5.62, scale of 0-8). There is a positive correlation between IT application deployment and RFID deployment (0.21). Of the 44 firms from the IW RFID survey, on average firms reported that they expect to receive benefits from RFID in two to three years. RFID benefits have a positive correlation with partner mandate (0.25), RFID spending (0.22) and IT application upgrade (0.21), and a negative correlation with standards ambiguity (-0.18).

3.2 Estimation Models and Econometric Issues

Because of the differences in the nature of the dependent variables RFID adoption and RFID benefits, we use ordered probit and OLS respectively to estimate these models, as we describe below.

3.2.1 RFID Adoption

The scale for the RFID adoption variable (0=not deployed, 1=development or testing, 2=limited deployment, 3=wide deployment) is not an interval level scale, and this variable appears as an ordered choice in our dataset. Therefore, we conducted analysis for RFID adoption using the ordered probit approach that does not assume equal intervals between deployment levels in the dependent variable.

Let the RFID deployment propensities be expressed by:

$Y_i^* = \beta' X_i + e_i$, where X_i is a set of explanatory variables, β is a vector of parameters and e_i are disturbances.

We do not observe Y_i^*, instead we observe the ordinal dependent variable Y_j, j=1,2,…m depending on the values of thresholds or cutoff points α_{j-1} and α_j as follows:

$Y_i = j$ if $\alpha_{j-1} < Y_i^* < \alpha_j$ where α_j are constants with $\alpha_0 = -\infty$, $\alpha_m = +\infty$, and $\alpha_0 < \alpha_1 < \ldots < \alpha_m$.

The probability distribution of Y_i is given by:

$$\text{Probability}(Y_i = j \mid X_i) = \Phi[\alpha_j - \beta' X_i] - \Phi[\alpha_{j-1} - \beta' X_i] \quad (1)$$

where Φ denotes the cumulative normal distribution function.

We conducted additional analysis using ordered logit, by specifying Φ as a logistic cumulative distribution function, and found similar results to those using ordered probit. We also tested the "parallel regression" or proportional odds assumption implicit in ordered probit and ordered logit. Because the coefficients of the explanatory variables were similar when we ran a series of binary probit models, we did not find evidence for violation of the parallel regression assumption, providing confidence for the use of ordered probit.

3.2.2 RFID Benefits

Our estimation model for RFID benefits is as follows:

$$RFID\ Return = Constant + \beta_{21}\ Mandate + \beta_{22}\ Standards + \beta_{23}\ IT\ Integration + \beta_{24}\ RFID\ Spending + \beta_{25}\ Firm\ Size + \beta_{26}\ Manufacturing + \beta_{27} Trade\ and\ Logistics + \varepsilon \quad (2)$$

We use ordinary least squares (OLS) to estimate equation (2). We tested for multi-collinearity by computing condition indices. The highest variance inflation factor (VIF) was 1.51, indicating that multi-collinearity is not a serious concern in our analysis. We accounted for heteroskedastic error distribution and calculated heteroskedasticity consistent errors for this model. We also conducted a sensitivity analysis using ordered probit and found results qualitatively similar to the OLS results. We interpret and discuss the OLS results in this paper, because OLS is more robust and estimates fewer parameters compared to the ordered probit approach that requires a larger sample size to reliably estimate cut-off

points between intervals. We checked the normality of residuals in the OLS model using a residual plot and the Shapiro-Wilk and Shapiro-Francia tests. The residual plot and formal tests provided support for the normality of residuals.

Because both the dependent and independent variables came from the same survey instrument, we conducted Harman's one-factor test to assess the sensitivity of our results to common method bias. For both survey instruments, the principal component analysis of all measurement items yielded multiple factors with eigen values exceeding one. Because no single factor emerged as a dominant factor accounting for most of the variance in either survey, common method variance is unlikely to be a serious problem in the data.

4. RESULTS

We provide results of the ordered probit estimation for equation (1) in Table 4, and results of the OLS estimation for equation (2) in Table 5.

Table 4. Parameter Estimates for RFID Adoption

		RFID Adoption Ordered Probit Coefficient	p value
IT Integration	β_{11}	0.101***	(0.007)
IT Budget	β_{12}	1.217	(0.131)
Firm Size	β_{13}	0.142***	(0.004)
Manufacturing	β_{14}	0.804***	(0.000)
Trade and Logistics	β_{15}	0.769***	(0.000)
Observations		354	
Chi-square		59.86	
Prob > Chi-square		0.000	
Pseudo R^2		0.084	

* significant at 10%; ** significant at 5%; *** significant at 1% (all one tailed)

Table 5. Parameter Estimates for RFID Benefits

		RFID Benefits OLS[1] Coefficient	Robust p value
Partner Mandate	β_{21}	1.333***	(0.007)
Standards Ambiguity	β_{22}	-1.265***	(0.003)
IT Integration	β_{23}	0.163	(0.180)
RFID Spending	β_{24}	0.292**	(0.049)
Firm Size	β_{25}	-0.040	(0.379)
Manufacturing	β_{26}	-1.074**	(0.037)
Trade and Logistics	β_{27}	-0.998*	(0.097)
Constant	β_{20}	3.319***	(0.001)
Observations		44	
F		4.65	
Prob > F		0.001	
R^2		0.299	

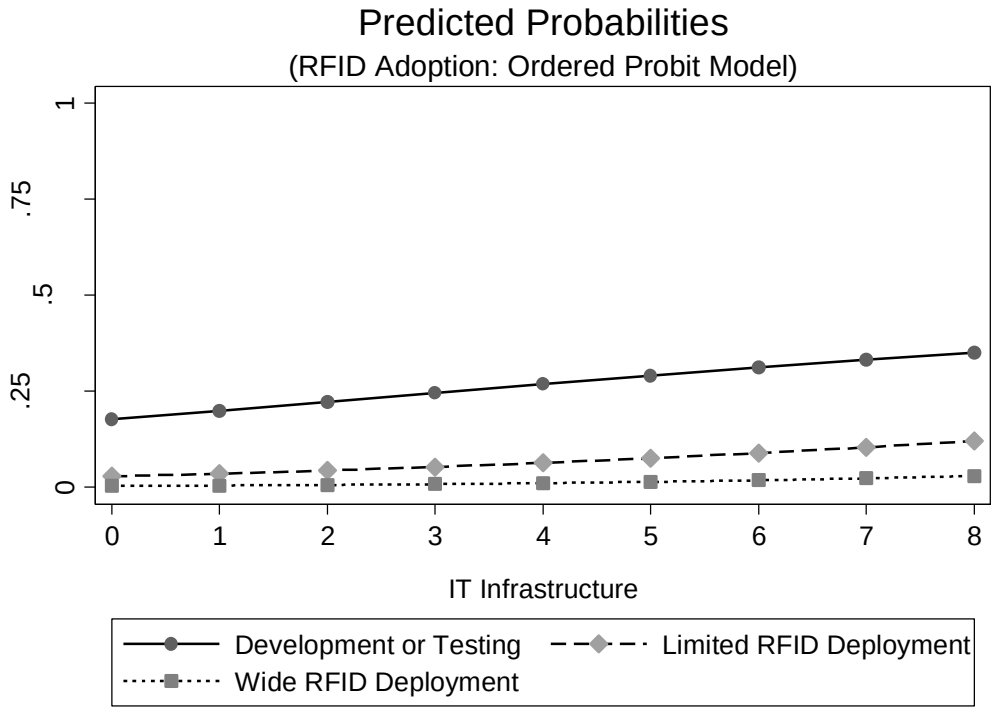
* significant at 10%; ** significant at 5%; *** significant at 1% (all one tailed)
[1] Ordered probit yields qualitatively similar results

4.1 Results: RFID Adoption

Consistent with Hypothesis 1a, our results show that firms with broader IT application deployment are more likely to adopt RFID (β_{11}=0.101, p<0.007). Because the effect of IT application deployment on RFID deployment depends on the value of other explanatory variables, we hold other variables at their mean values in computing the predicted probabilities of RFID deployment at different levels of IT application deployment. As shown in Figure 1, firms report an increase in RFID deployment as the level of IT application deployment increases. Figure 1 also shows that most firms that have adopted RFID are in early stages of deployment (i.e., testing or limited deployment).

Figure 1. Effect of IT Application Deployment on RFID Adoption

This figure shows that firms with broader IT application deployment (scale from 0=narrow IT deployment to 8=broad IT deployment) are more likely to deploy RFID.



Hypothesis 1b, positing that firms with larger IT budgets as a percentage of revenue are more likely to adopt RFID, is not supported (β_{12}=1.217, p<0.131). This result suggests that financial resources alone may not predict RFID adoption by firms. This may be because firms are less likely to implement RFID unless they have adequate IT infrastructure in place to process the data generated by RFID.

The results showing the effect of control variables on RFID adoption provide useful insights. Firm revenue has a positive and statistically significant association with RFID adoption (β_{13}=0.142, p<0.004), suggesting that larger firms are more likely to adopt RFID, perhaps because of greater availability of slack resources or greater expectations of RFID benefits. We also find that firms in the manufacturing (β_{14}=0.804, p<0.000) and trade and logistics industries (β_{15}=0.769, p<0.000) are more likely to adopt RFID than firms in other industries. This finding is consistent with the practitioner literature that indicates greater use of RFID in these industries.

4.2 Results: RFID Benefits

Hypothesis 2a, suggesting that firms engaging in more extensive IT integration in connection with an RFID implementation expect an early return on RFID investment, is not supported (β_{23}=0.163, p<0.180). One explanation may be that firms are still in a learning phase, and it may take some time to realize benefits. For example, bar codes were initially implemented with automation benefits in mind, and it was not until much later that firms realized benefits through better information sharing and continuous review of inventories.

Consistent with Hypothesis 2b, our results show that firms that spend more on RFID implementation expect an early return on RFID investment (β_{24}=0.292, p<0.049). Because of the 0.45 correlation between the RFID spending and IT integration variables, we conducted a test to assess the joint significance of IT integration and RFID spending on RFID return (β_{23} and β_{24}=0), and find moderate support for this conjecture (p<0.10). This suggests that technical and financial resources together are a good predictor of early return on RFID investment, even though we do not find support for the individual significance of IT integration in our data.

Our results support Hypothesis 3 (β_{21}=1.333, p<0.007), and indicate that firms that deploy RFID because of a partner mandate expect an early return on RFID investment. Consistent with Hypothesis 4, our results show that firms that are concerned with the lack of RFID standards expect a delayed return on RFID investment (β_{22}= -1.265, p<0.003).

Considering the control variables, firm size does not have a statistically significant association with RFID benefits. The manufacturing industry (β_{26}= -1.074, p<0.037) and trade and logistics industry (β_{27}= -0.998, p<0.097) are both associated with expectation of a delayed RFID return, though the relationship for trade and logistics industry is only moderately statistically significant. Because these two industries currently account for most of the RFID market, this may suggest that return expectations change as firms and industries get further into the implementation cycle.

5. DISCUSSION

Our goal in this paper is to study the antecedents and business value of RFID. We next discuss our main findings, research and managerial implications, and limitations and suggestions for future research.

5.1 Findings

Consistent with our expectations, we find that firms with a broad IT application deployment are more likely to adopt RFID. This finding is consistent with prior research that sophisticated IT infrastructure is a strong predictor of IOS adoption (Grover 1993; Mithas et al. 2005a). As a firm strengthens its IT infrastructure by implementing systems such as enterprise resource planning and supply chain management, the firm is better able to process, integrate and store the additional data generated by RFID as goods move through the supply chain. The broader IT application deployment also enables the firm to better monitor its business operations and leverage RFID capabilities to improve those operations. We do not find a statistically significant relationship between IT budget and RFID adoption. This suggests that RFID adoption may not strictly be determined by the sheer amount of financial resources a firm possesses, but instead by how the firm prioritizes and allocates those resources to new technology projects such as RFID.

Turning to the business value of RFID, we find that RFID implementation spending is positively associated with expectation of an early return on RFID investment. Higher RFID spending implies that the firm is allocating greater resources to secure the necessary technology and expertise, enabling the RFID implementation to be completed properly and on time to begin generating benefits for the firm.

We also find that implementing RFID because of a partner mandate is positively associated with expectation of an early return on RFID investment. This empirical result is consistent with the theoretical and analytical work indicating that dominant firms gain benefits from IOS implementations, and are in position to use some of these benefits to reward dependent firms check (Barua and Lee 1997; Riggins et al. 1994; Wang and Seidmann 1995). Dependent firms may use the potential of benefits from the dominant firm to justify their business case for adoption.

Firms concerned with the lack of industry-wide RFID standards expect a delayed return on RFID investment. This finding extends prior systems adoption research in which standards, interoperability and interconnectivity impact the likelihood of adoption (Chau and Tam 1997). Our results suggest that industry-wide RFID standards would impact the ability of a firm to execute RFID broadly with all of its supply chain partners. As RFID standards are developed and agreed, this would change the expectation of firms to receive an earlier return on RFID investment, and should spur further RFID adoption. Recent RFID developments suggest that this process may be underway, as the Generation 2 standard (which incorporates and expands four previous standards) has been approved and published by the International Organization for Standardization (ISO) as an international standard (ISO Update 2006; York 2005).

5.2 Research Implications

This paper extends the literature on inter-organizational systems and supply chain management. While most previous IOS literature focuses on the impact of technological and financial resources on IOS adoption and use (Chwelos et al. 2001; Iacovou et al. 1995), this paper extends that work to investigate the impact of technological and financial resources on RFID benefits. Our finding that RFID implementation spending is positively associated with expectation of early RFID benefits suggests that firms should invest appropriately in RFID implementation to receive benefits. Similarly, this paper builds on prior theoretical work on the role of partner mandates in IOS benefits (Barua and Lee 1997; Wang and Seidmann 1995), by empirically addressing the role of partner mandates in RFID benefits. Our results show that a dependent firm who implements RFID at the mandate of a dominant firm expects early benefits from the RFID implementation (O'Callaghan et al. 1992), adding empirical evidence to the theoretical work. Finally, our paper includes the role of standards in RFID benefits (Williams et al. 1998), which is absent from most prior IOS literature.

We also contribute to the supply chain management literature by extending previous research in the context of ERP and CRM technologies (Cotteleer 2006; McAfee 2002; Stratman 2007; Tsikriktsis et al. 2004) to the RFID context. While previous SCM research recognizes that information technologies foster information sharing and reduce costs (Johnson and Whang 2002; Kopczak and Johnson 2003), this

paper helps to explain how other factors within the firm (e.g., RFID implementation spending) and external to the firm (e.g., partner mandate) facilitate business value through RFID technology. Finally, complementing the SCM literature that notes the importance of industry standards (Swaminathan and Tayur 2003), this paper empirically shows that ambiguous standards may negatively impact returns from RFID investment.

RFID offers three implications for subsequent theory building. First, the current early stage of RFID deployment is being driven largely by the coercive pressures of dominant partners. However, as RFID deployment progresses, it will be important to study when mimetic and normative forces (DiMaggio and Powell 1983) become more significant factors in RFID adoption, and whether RFID benefits differ across firms depending on the type of force that shaped RFID adoption for each firm. For example, it is possible that firms that adopt RFID due to mimetic influences may expect and experience lower benefits than firms that adopt RFID due to coercive influences, because firms that adopt RFID due to coercive influences presumably have the active support of a major business partner.

Second, firms with global operations that adopted RFID in the earliest stages did so before RFID had an approved international standard. As discussed above, an international standard for RFID has only recently been approved, which should encourage the next round of adopters. These early adopters may have evaluated the standards uncertainty in a different manner than firms that chose to wait until an international standard was approved. It would also be important to study how early adopters resolved the uncertainty on RFID standards and the drivers that factored into their approach, and to understand how RFID costs and benefits compare for early adopters (pre-international standard) and later adopters (post-international standard). For example, there may be the need for a model to analyze the tradeoff between the benefits from proceeding down a learning curve for RFID implementation, and the costs of needing to re-implement RFID technology and related processes due to any changes in standards.

Third, RFID provides opportunities for theory building in the area of services science (Horn 2005). Most prior IOS research focuses primarily on benefits from supply chain processes that relate to the tracking of physical objects, and directs less attention to potential benefits of efficiency and

effectiveness for customer service processes associated with production, delivery and consumption of the physical objects. Unlike other IOS that are primarily business-to-business oriented (e.g., EDI, ERP), RFID also has a significant business-to-consumer component. Therefore, RFID has the potential to facilitate a much better understanding of consumer behavior and customer service processes, if firms can alleviate privacy concerns related to the collection and analysis of RFID data gathered from customer transactions. An interesting area for research will be to explore whether RFID can enable firms to generate benefits in terms of productivity and service effectiveness at the same time.

5.3 Managerial Implications

This study has three managerial implications. First, a firm considering RFID must ensure that it has the appropriate IT infrastructure in place. A strong IT infrastructure can give the firm the ability to process, store and integrate the additional data produced by RFID, and to leverage RFID to improve the firm's business operations. A weak IT infrastructure may indicate that the firm needs to make some internal investments prior to pursuing RFID. Similarly, a firm must consider the required investment to properly implement RFID. Insufficient RFID spending may lead to not having the necessary technical or human resources to complete the implementation in a timely and proper manner, and could delay RFID benefits.

Second, as firms begin to evaluate and implement RFID, vendors will be competing for the firms that would establish successful RFID implementations. Particularly in the early stages of an advanced technology, vendors want to have "success stories" that they can market to prospective clients. Vendors will want to identify firms that are prepared to field successful RFID implementations, and will need to know the characteristics of these firms. Our study suggests that vendors should focus their marketing efforts on firms with broad IT application deployment and a sufficient budget for RFID implementation, and that these firms are more likely to report early returns from RFID implementations.

Third, in contrast with trade press stories about the "unfortunate" lot of suppliers who are "forced" to implement and bear the costs of RFID because of a partner mandate, our study shows that these firms expect an early return from their RFID investments. Firms that are considering compliance to

an RFID mandate from a dominant business partner can take this into consideration as they make their decision. Although our results indicate that firms implementing RFID under mandate from a dominant partner expect early returns, dominant firms may nevertheless want to consider subsidizing their suppliers to implement RFID, particularly in the early stages of the technology. This may benefit the overall supply chain, and early success stories may motivate other suppliers to adopt RFID. GE's move to subsidize its suppliers by absorbing the cost of RFID tags appears to be consistent with this concept (Lucas 2005).

5.4 Limitations and Suggestions for Future Research

The primary limitation of this paper involves operationalization of the RFID benefits variable. This study uses the respondent's expectation of when the firm would see a return on RFID investment and did not capture the actual return. Our approach is consistent with previous research showing that these perceptions are a reasonable approximation of actual results (Dess and Robinson 1984; Venkatraman and Ramanujam 1987) and follows previous research that uses the perceptions of a senior informant in place of actual results (Ramamurthy, Premkumar and Crum 1999; Tallon, Kraemer and Gurbaxani 2000). The use of expected benefits is particularly relevant early in the adoption cycle for an emerging technology, when firms have not yet achieved or not documented actual results (Emmelhainz 1988; Murphy-Hoye, Lee and Rice 2005; Ramamurthy and Premkumar 1995; Saunders and Clark 1992). However, as RFID deployments mature and firms are able to quantify and document actual benefits, future studies should examine and document actual benefits attributable to RFID similar to business value of IT research on other technologies.

A second limitation of this study is that our findings are associational in nature. Because of the cross-sectional nature of our data, our findings do not imply causality. As Curtin, Kauffman and Riggins (2007) note, future research should use more advanced techniques such as the quasi-experimental propensity score approach (Dehejia and Wahba 2002; Heckman 2005; Mithas, Almirall and Krishnan 2006; Rosenbaum and Rubin 1983) to assess the extent to which the use of RFID causes improvements in firm performance. These techniques require larger sample sizes, something we did not have in our RFID

benefits dataset due to the early stage of RFID deployment. However, as more firms deploy RFID, the greater availability of data will allow for exploration of causal effects.

We suggest three opportunities to extend this work. First, most firms are currently at an early stage of RFID deployment. For example, as of early 2007 Wal-Mart has installed RFID at five of its 120 distribution centers and 1,000 of its 6,000 stores (McWilliams 2007). Accordingly, follow-up surveys or case studies should be conducted at a later point once firms are further into the RFID deployment cycle. Similar to previous studies (Fearon and Philip 1999; Mukhopadhyay et al. 1995), these follow-up surveys or case studies should capture actual operational and financial benefits. Detailed data will enable an assessment of the extent to which RFID provides benefits through revenue growth and/or cost reduction (Rust, Moorman and Dickson 2002). Although recent research suggests that aggregate IT investments have greater impact on profitability through revenue growth than through cost reduction (Mithas, Bardhan and Goh 2006), there is need for future studies to assess whether this impact holds at the level of individual technologies. Even if RFID has higher variable costs than other technologies such as bar codes, if RFID facilitates greater product availability and customer satisfaction then firms are likely to be better off in terms of financial results and shareholder value (Anderson, Fornell and Mazvancheryl 2004; Fornell, Mithas, Morgeson and Krishnan 2006).

Second, the benefits from RFID will not come strictly from the technology itself. The benefits will come from the changes in business processes to take advantage of the information provided by RFID (Dutta et al. 2007), which will result in reduced inventory levels and shorter replenishment lead times (Kirby 2003). This is similar to the IOS context, where business processes are reengineered and collaborative practices are implemented to take advantage of IOS (Cash and Konsynski 1985; Kulp et al. 2004; Mithas et al. 2005a), and this reengineering and collaboration provides the opportunity for companies to gain competitive advantage (Galliers, Swatman and Swatman 1995). This may be particularly important in fast clockspeed industries or business areas that can benefit from real-time information (Blackburn, Guide, Souza and Wassenhove 2004; Hagel 2003). Future research should consider the business process implications of RFID implementation, and how changes to business process

will directly tie to business benefits. Dutta and Roy (2004) provide a useful framework to link IT projects to business benefits via the physical and information flows in underlying business processes.

To conclude, this paper empirically tests the effect of IT application deployment and IT budget on RFID adoption, and the effect of IT integration, RFID spending, partner mandate and standards ambiguity on expectation of RFID benefits. We find a positive association between IT application deployment and RFID adoption. We also find a positive association of RFID spending and partner mandate with expectation of early RFID benefits. These results suggest that firms with strong IT infrastructure and sufficient implementation spending are more likely to field successful and beneficial RFID implementations. These findings are important as firms more broadly deploy RFID in their supply chain networks.

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