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RESEARCH ARTICLE

HOW DO ENTERPRISE RESOURCE PLANNING SYSTEMS AFFECT FIRM RISK? POST-IMPLEMENTATION IMPACT[1]

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Managing firm risk, or firm performance volatility, is a key task for contemporary firms. Although information technology (IT) has been generally viewed as an effective information processing tool that enables firms to better cope with uncertainty, thus holding the potential to mitigate firm performance volatility, evidence to support this view is lacking in the literature. We theorize that enterprise resource planning (ERP) systems, a major type of enterprise IT applications, can help reduce firm risk and, in particular, we argue that, to uncover the risk reduction effect of ERP systems, a research focus on the post-implementation stage is needed. Based on a sample of 2,127 firm-year observations, we found that ERP systems in the post-implementation stage were associated with reduced firm risk, and that the risk reduction effect was stronger for ERP systems with a greater scope of functional and operational modules, especially functional modules. We further found that, on average, the risk reduction effect of ERP systems became greater when firms' operating environments feature higher uncertainty, while the risk reduction associated with fully deploying ERP system modules seem to level off as environmental uncertainty increases. These findings extend our understanding of the business value of ERP systems by shedding light on the risk reduction benefit of ERP systems.

Keywords: ERP systems, firm risk, performance volatility, post-implementation, environmental uncertainty, ERP system scope, business value

Introduction

Enterprise resource planning (ERP) systems represent a major category of information technology (IT) investment in contemporary firms (Hitt et al. 2002; Sykes et al. 2014). More broadly called enterprise systems, ERP systems "are commercial software systems that automate and integrate many or most of a firm's business processes" (Gattiker and Goodhue 2005, p. 560). ERP systems are designed to support both the functional and operational processes of a firm's value chain,[2] including accounting and finance, human resources, customer and sales, and supply chain management (Barki and Pinsonneault 2005; Ranganathan and Brown 2006). ERP systems aim to provide a unified IT architecture to enhance data consistency and integration of modular applications that support business processes (Morris and Venkatesh 2010).

[1]Viswanath Venkatesh was the accepting senior editor for this paper.

The appendices for this paper are located in the "Online Supplements" section of the *MIS Quarterly*'s website (http://www.misq.org).

[2]Porter and Millar (1985) categorized the processes of a firm's value chain as operational and functional processes. *Operational processes* are involved in the physical creation of products, logistics, and delivery to customers. *Functional processes* provide a common infrastructure (e.g., accounting and human resources management) through which operational processes can take place.

Thus, a purported benefit of ERP systems is to streamline information flows within and across business processes, enabling them to work in concert for information processing (Dorantes et al. 2013).

The theory of organizational information processing (TOIP) suggests that an organization's fundamental task is to process information concerning uncertainty in the environment and to make decisions to deal with it (Galbraith 1974). If the uncertainty cannot be resolved effectively, it can translate into volatility of firm performance, namely firm risk (Kothari et al. 2002). High firm risk influences how investors and business partners perceive a firm; it thus is relevant to firm survivability and prospects (Kaplan et al. 2009). TOIP suggests that, by enabling improved information processing and managerial decision making, IT systems, such as ERP systems, can help a firm better handle uncertainty, thus reducing performance volatility (Tanriverdi and Ruefli 2004). Echoing TOIP, the Committee of Sponsoring Organizations of the Treadway Commission advocates firms using ERP systems for mitigating firm risk (COSO 2013). These theoretical and practical considerations motivated us to examine whether and how ERP systems influence firm risk. Answering this question fills a gap in the literature on the business value of ERP systems. Estimates have suggested that firm investment in enterprise systems accounts for 75 percent of U.S. corporate IT investment and that the global market for ERP systems continues to grow (Gartner 2012). Skepticism has long existed about the business value of ERP systems, however, and, to the best of our knowledge, no research in the ERP systems literature has examined the impact of ERP systems on firm risk based on large-scale data (for a recent literature review, see Dorantes et al. 2013). A related strand of studies has investigated the relationship between IT investment and firm risk (e.g., Dewan et al. 2007). This strand of research has focused on IT investment in general, instead of specific systems, such as ERP systems. Identifying the impact of ERP systems on firm risk, if any, would thus provide important implications for both research and practice.

In this study, we sought to examine the *post-implementation* effect of ERP systems on firm risk. An ERP system initiative spans multiple stages, from adoption to implementation to post-implementation (Morris and Venkatesh 2010). To date, evidence indicates that IT adoptions and implementations increase firm risk (e.g., Dewan et al. 2007). The adoption and implementation risks for ERP systems could be even higher than the risks for other types of information technologies (Kimberling 2013). *Only* after implementations are completed can firms start to use ERP systems for information processing. Prior research drawing on TOIP has focused on the post-implementation stage, which is the stage where an ERP system starts to show impacts on information processing (Gattiker and Goodhue 2005). Grounded in TOIP, our first research question is*: What is the impact of ERP systems on firm risk in the post-implementation stage*? We examined the types of ERP system modules installed, namely *ERP system scope* (Hitt et al. 2002; Ranganathan and Brown 2006). The more types of ERP system modules implemented, the greater is the ERP system scope. Functional modules of an ERP system (accounting and finance modules, human resources modules) support functional processes of a firm's value chain and operational modules of an ERP system (customer and sales modules, supply chain modules) support operational processes of a firm's value chain.[3] Every value chain process requires information processing tasks, which encompass the collection, manipulation, and transmittal of data necessary to conduct that process (Porter and Millar 1985). The respective modules of ERP systems perform the information processing tasks for the processes that they support (Barki and Pinsonneault 2005; Gattiker and Goodhue 2005). ERP systems are appealing because they facilitate streamlined information flows that connect individual modules; thus, economies of scope may accrue as ERP system scope increases. Prior studies, however, have documented mixed evidence for the impact of ERP system scope on firm performance[4] and virtually no evidence for its impact on firm risk. It is important for managers to know whether increasing ERP system scope pays off, because adopting a large-scope ERP system entails high financial costs and managerial complexity (Maruping, Venkatesh, and Agarwal 2009; Venkatesh et al. 2010). Hence we ask the second research question: *How does the post-implementation ERP system impact on firm risk, if any, vary with ERP system scope?* TOIP further emphasizes that when a firm uses an information processing mechanism—for example, ERP systems (Barki and Pinsonneault 2005; Gattiker and Goodhue 2005)—this mechanism works in a specific environment with a certain amount of uncertainty. TOIP thus suggests that there exists a contingent relationship between the impacts of the information processing mechanism and the specific environmental uncer-

[3]According to Davenport (1998), the major types of ERP system modules used in practice are accounting and finance, human resources, customer and sales, and supply chain management. Supply chain modules subsume production and logistics (Davenport 1998; Robey et al. 2002). Following Davenport, Chang (2006) conceived of ERP system modules as including accounting and finance, human resources, marketing and sales, and production. Similarly, Ranganathan and Brown (2006) conceptualized ERP system modules as including accounting and finance, human resources, materials management and operations, and sales and distribution.

[4]Prior studies have found benefits associated with greater ERP system scope, such as increased firm productivity (Hitt et al. 2002) and stock market returns (Ranganathan and Brown 2006). Other studies, however, have found no relationship between ERP system scope and firm performance (Gattiker and Goodhue 2005). Hitt et al. (2002) found that ERP system benefits decrease when firms fully implement ERP system modules.

tainty that the firm is facing (Premkumar et al. 2005). Extending TOIP to the context of information processing and firm risk, it is arguable that firms dealing with high environmental uncertainty often need to process a large amount of complex information (Xue et al. 2011), and in such situations, ERP systems would be expected to be particularly valuable as an IT-enabled information processing mechanism. Such an expectation would encourage managers to act proactively to engage ERP systems for reducing firm risk in highly uncertain environments. It is especially relevant in today's business environments, which are becoming increasingly volatile (Kaplan et al. 2009). This remains a theoretical conjecture, however, as relevant evidence is lacking in the literature. Thus, our last research question is: *How does environmental uncertainty affect the post-implementation ERP system impact on firm risk?*

Literature Review

ERP System Business Value

Prior studies have documented mixed evidence on ERP system initiatives and firm performance (see Appendix A for a review of illustrative studies). Using a short-window event study method, prior research (Ranganathan and Brown 2006) has found positive market reactions to ERP system adoption announcements. Using a long-window event study method and using firm announcements to identify when ERP systems were implemented, Dehning et al. (2007) compared firm performance two years prior to and two years after implementation and found a post-implementation increase in return on sales (ROS), but not in return on assets (ROA). Hendricks et al. (2007) examined changes in firms' financial performance over a two-year implementation period and a three-year post-implementation period and found modest evidence for a post-implementation increase in profitability, but no evidence for an improvement in stock returns. Using vendor-provided archival data for ERP system adoption, Hitt et al. (2002) showed that ERP system adoption had a positive relationship with Tobin's q and ROA, but no relationship with return on equity (ROE). Using more recent data, Aral et al. (2006) found no increase in firm profitability after ERP systems go live. Qualitative research has provided complementary insights by identifying various reasons for problematic or failed ERP system initiatives.[5] More recent studies have found ERP system impacts at more micro levels, such as order-fulfillment performance (Cotteleer and Bendoly 2006), process efficiency and effectiveness (Karimi et al. 2007), and users' job performance and job satisfaction (Bala and Venkatesh 2013; Morris and Venkatesh 2010; Sykes et al. 2014).

IT and Firm Risk

There are two views regarding how IT affects firm risk: On the one hand, IT implementation is inherently risky. On the other hand, *post-implementation* IT can be a useful tool for information processing.

Regarding IT implementation risk, the literature has offered two underlying rationales: complex and challenging implementation and digital options. First, IT implementation is inherently risky because of technological complexity and implementation challenges (Keil et al. 2000; Maruping, Venkatesh, and Agarwal 2009). Second, from a digital options perspective, firms attempt to implement IT as a general infrastructure, based on which they initiate, and seek to benefit from, follow-on projects in the future (Fichman et al. 2005). It is uncertain, however, whether future environments will generate profitable projects. Dewan et al. (2007) found a positive relationship between IT hardware capital and firm risk, implying that high risk is embedded in IT implementations. Using a different approach to examine IT implementation risk, Dewan and Ren (2007) collected data about e-commerce adoption announcements (i.e., starting to or planning to implement e-commerce) and found that e-commerce adoption was associated with an increase in firm risk as assessed by the stock market, and after accounting for the risk premium, stock market returns to e-commerce adoptions became nonsignificant. Otim et al. (2012) collected firms' announcements of IT investments (including hardware and software in general and various systems, such as decision support systems, Internet/Intranet, and client-server systems) and found that, on average, the investments were followed by a greater likelihood of underperforming competitors. They attributed the finding to the inherent uncertainty of IT investments. In brief, prior studies have provided strong support for the riskiness of IT implementation.

Other research has indicated, however, that post-implementation IT can help reduce firm risk because of its role in enhancing information processing. Prior studies have attributed (part of) firm risk to uncertainty embedded in managers' information processing and decision making in day-to-day operations. Tanriverdi and Ruefli (2004) argued that "in terms of managerial decision making, higher risk is generally associated with less accurate information" (p. 433). Managerial errors in decision making or inappropriate decisions may cause variability of business performance

[5]These include a mismatch between ERP system functions and ERP system use context (Wang et al. 2006), insufficient user skills and user learning (Robey et al. 2002), user resistance (Wagner et al. 2010), lack of managerial involvement (Staehr 2010), and dissonance between user behavior and managerial policies (Berente et al. 2010), among others.

(Ashbaugh-Skaife et al. 2009). If IT improves the quality of information that managers have, then it is reasonable to expect reduced uncertainty in managerial decision making and a reduction in firm risk (Tanriverdi and Ruefli 2004). Further, IT systems can provide a technological basis for integrating processes that are characterized by information sharing and effective coordination across processes (e.g., Barua et al. 2004; Rai et al. 2006).[6] While past work has developed the rationale that IT enables process integration and has shown that IT-enabled process integration creates performance benefits (e.g., Rai et al. 2012), integrated processes should also reduce firm risk, given improvements in information quality and visibility for decision makers and in the coordination of decision making within and across business processes. A classic example is the bullwhip effect in which demand changes cause stock-out or excess inventory, increasing the *variability* of sales and inventory costs (Lee et al. 1997). An IT-enabled solution is to enhance information sharing from customer-facing to supply chain management processes, enabling these processes to sense and respond to demand changes (Yao and Zhu 2012). Given these two different effects of IT on firm risk (implementation risk versus post-implementation information processing), how an ERP system initiative affects firm risk differs across the various stages of the ERP system life cycle.

ERP System Life Cycle

The life cycle of an ERP system initiative spans from adoption to implementation to post-implementation (Markus and Tanis 2000). An ERP adoption decision triggers chartering activities (e.g., selecting vendors and consultants, and implementation planning and preparation) and is followed by the implementation stage, where the adopting firms engage in installation, configuration, and roll-out (Gosain, Lee, and Kim 2005). If implementation is successful, a system go-live indicates the beginning of the post-implementation stage (Morris and Venkatesh 2010). The implementation risk of ERP systems is embedded mainly in the adoption and implementation stages. For instance, selecting inappropriate systems and vendors may cause an ERP system implementation failure (Wagner et al. 2010; Wang et al. 2006). When an ERP system initiative moves to the post-implementation stage, it naturally means that the adopting firm has (largely) resolved the implementation risk. Although some risk may still exist when the firm installs new hardware and software for maintenance and upgrading, adoption and implementation are the riskiest stages (Olson 2004). Importantly, it is in the post-implementation stage that firms can start using the implemented systems for information processing (Gattiker and Goodhue 2005). To sum up, the implementation risk of ERP systems is salient before system go-live, while the information processing effect is salient in the post-implementation stage.

Prior studies have attempted to disentangle the two risk effects (implementation risk versus information processing). One useful approach is to introduce contingency factors to examine whether one effect may outweigh the other under certain conditions. Kobelsky, Hunter, and Richardson (2008) showed that firm risk was positively related to IT investment, with the relationship being less positive for larger firms. One interpretation is that larger firms can better tolerate IT implementation risk. Dewan and Ren (2011) found that firm risk was positively related to IT investment, on average, while the relationship was negatively moderated by the firm boundary strategies of increasing product diversification and vertical integration. This finding is in line with TOIP, implying that the information processing capability of an IT helps firms better coordinate and resolve uncertainty involved in business activities across more diversified businesses and more industry sectors.

The second approach is to focus on technologies with completed implementations. Along this line, Dorantes et al. (2013) found that after ERP system go-live events, firms issued earnings forecasts more frequently and their forecasts had fewer errors. They interpreted this finding to mean that, in the post-implementation stage, ERP systems help create a transparent information environment, such that top management can make informed forecasts based on timely data describing a firm's operations and economic reality. Gattiker and Goodhue (2005) drew upon TOIP to theorize ERP system benefits for improving plant performance. They contended that it is appropriate to focus on the post-implementation stage to examine the performance impacts of ERP systems. The rationale was that, in order for an ERP system to take effect in organizational information processing, the organization must use it, and the organization can use it only after the system implementation is complete. In the same vein, Cotteleer and Bendoly (2006) examined the post-implementation impact of ERP systems on order fulfillment. In a variety of other contexts, such as inter-firm technologies (Mukhopadhyay and Kekre 2002; Rai et al. 2012), researchers have investigated the post-implementation stage, when the implementation risk is mitigated and the benefits from deploying the technologies start to surface. We took the second approach (i.e., a post-implementation focus), because it would allow us to largely rule out the confounding effect of implementation risk.

[6]We thank an anonymous reviewer for suggesting this mechanism through which post-implementation IT can work to reduce firm risk.

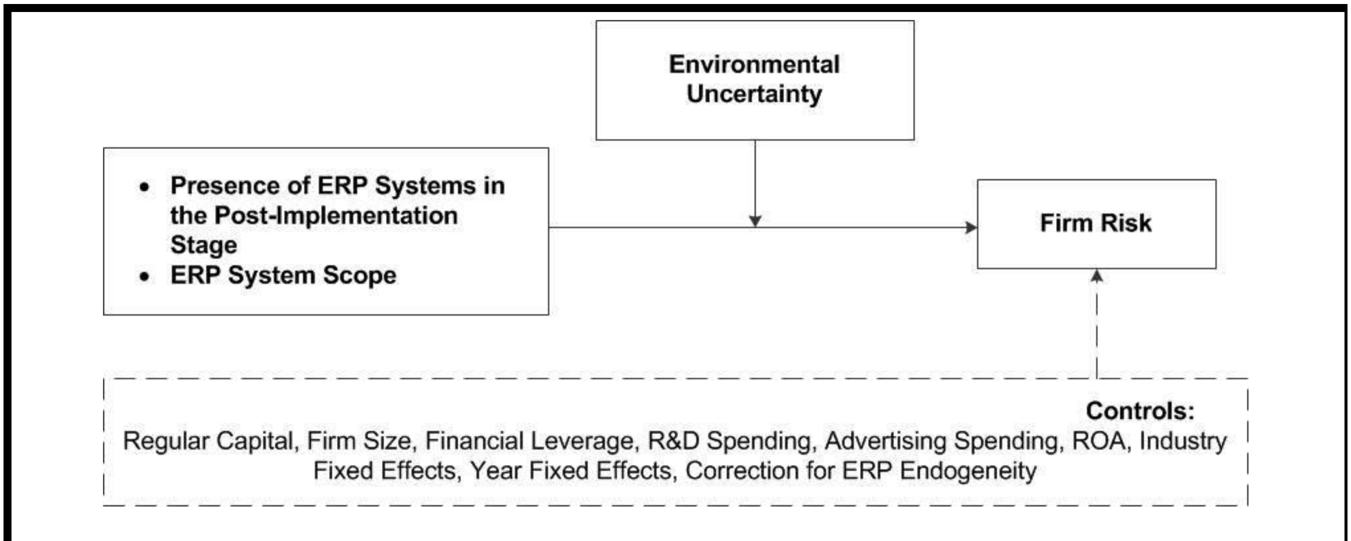

Figure 1. Research Model

Model and Hypotheses

We propose a model, as shown in Figure 1. To answer the first research question, the model relates firm risk to a dichotomous variable indicating the presence of ERP systems in the post-implementation stage (called *ERP system presence* for short). To answer the second research question, the model relates firm risk to the scope of the ERP system modules installed (called *ERP system scope* for short). To answer the third research question, the model examines the moderation effect of environmental uncertainty.

ERP Systems and Firm Risk

ERP systems can have three effects—automation, standardization, and integration—that help lower firm risk. The *automation* effect means that when there are changes in a firm's operating environment, ERP systems automatically trigger information processing in the respective value chain processes (Hitt et al. 2002; Gattiker and Goodhue 2005). When customers change their orders, for example, ERP systems automatically trigger information processing in financial accounting management (e.g., automated generation of account and payment forms, invoices, and credit evaluation), customer relationship management (e.g., updates of customer purchases, opportunities for cross-sales and up-sales, and scheduling of fulfillment and support), and supply chain management (e.g., immediate changes in production plans, inventory stock levels, employee work schedules, purchase orders to suppliers, and co-scheduling with business partners) (McAfee 2002). When there are problems in a firm's internal production processes (e.g., bottleneck and stock-out), an ERP system can automatically update downstream and upstream processes, so that the firm can make corresponding changes efficiently (Park and Kusiak 2005). When a firm's suppliers change product specifications, the firm's ERP system can automatically process such changes by mapping with internal data for product configuration and then determining whether adjustments are needed in its own product engineering. Automated information processing enables a firm to respond efficiently to changes in its operating environment. Compared to a manual process or aging legacy systems, modern ERP systems eliminate manual work and reduce the amount of time and effort needed to resolve data incompatibilities (which often exist in legacy systems). As such, when a firm needs to address changes in its operating environment, it can make efficient adjustments in a timely fashion in respective business processes. Conversely, if the enterprise value chain is slow in responding to changes in the firm's operating environment, some unnecessary work-in-progress inventory may start to accumulate, adding to the firm's operation costs, and the lead time for order fulfillment may become longer, retarding collection of cash flows (Lee et al. 1997). In these cases, environmental changes translate into performance variability. ERP systems can attenuate performance variability by making operations more efficient.

ERP systems have a *standardization* effect on business processes, in that ERP firms follow system-embedded approaches to carrying out business processes (Cotteleer and

Bendoly 2006). No matter whether such system-embedded approaches are based on vendor knowledge of so-called industry "best practices" (Wagner et al. 2010) or firm-specific knowledge of how to address environmental uncertainties (Maruping, Zhang, and Venkatesh 2009), ERP systems have been viewed as an effective approach to impose "protocols" for conducting business processes, so that these processes can be controlled and standardized (Cotteleer and Bendoly 2006). The standardization effect can play an instrumental role in reducing operational variability, because standardization reduces managerial discretion in information processing and decision making (Brazel and Agoglia 2007; Venkatesh and Bala 2012; Venkatesh et al. 2007). From the perspective of TOIP, managers' day-to-day activities include processing information about internal operations and external changes and deciding how to respond to them. Managerial discretion may lead to variations in process operations and performance, which ultimately affect firm-level output (Ashbaugh-Skaife et al. 2009). In the ERP system literature, "the deployment of ERP is often described as motivated by the firm's desire to reduce such variation through the standardization of business processes" (Cotteleer and Bendoly 2006, p. 645). Following this line of research, we expected that ERP systems would reduce firm performance variability in the post-implementation stage.

The *integration* effect suggests that value chain processes become tightly coupled and responsive to each other throughout an enterprise-wide system (Barua et al. 2004; Rai et al. 2006). From the view of TOIP, business processes and organizational units work in concert over a unified information processing platform (e.g., ERP systems) to cope with uncertainties. ERP systems enable business integration throughout an enterprise, both horizontally and vertically. Horizontally, ERP systems enable multiple sites that handle the same processes to work as a unified whole. For instance, ERP systems enable sales offices in different regions to coordinate exchanges of information about orders and pooling of resources to fulfill the orders, thus averaging out the impact of demand fluctuations across regions (Lee 2004). Vertically, ERP systems enable downstream and upstream processes to respond to each other's needs, so as to react to market changes in a collaborative fashion (Barki and Pinsonneault 2005). Evidence has suggested that when business processes for managing customers and sales and for managing production and supply chain become connected, the enterprise is better able to meet customers' changing demands (Gosain, Malhotra, and El Sawy 2005). Empirical evidence also has suggested that when a firm's business processes for financial accounting and for sales operate over an integrated platform, the firm can make needed changes effectively in order fulfillment to adapt to changes of customers' product specifications, thus smoothing financial flows (Mukhopadhyay and Kekre 2002) and material flows (Park and Kusiak 2005). ERP systems collect information about market changes and apply the information to respective value chain processes so that they can respond to the changes; as a result, ERP systems connect value chain processes and transform them into an *information value chain* that enhances enterprise agility to sense and respond to market volatility (Sambamurthy et al. 2003). The literature has documented evidence that ERP systems enable firms to become more agile and adaptive to changing business environments (Karimi et al. 2007). Given the same levels of market-wide shocks (e.g., demand changes, supply interruption, technology advancement, etc.), agile firms are better able to address environmental changes, and thus their performance is less likely to be influenced by such changes. Thus, we hypothesize:

> *Hypothesis 1: A reduction in firm risk is associated with the presence of ERP systems in the post-implementation stage.*

ERP System Scope

A greater ERP system scope accrues as larger numbers of ERP system modules are installed. We predict that the greater the ERP systems scope, the stronger is the risk reduction effect of ERP systems, because of economies of scope.

First, an ERP system with a greater scope enhances information flows across more processes along the enterprise value chain. Information flows over an ERP platform connect value chain processes and enable them to automatically trigger and respond to each other, thus creating *a greater degree of automation*. A case study showed that when supply disruptions happened in the late 1990s, most PC manufacturers were unable to deliver products to customers on time and experienced high fluctuations in performance, with Dell being a notable exception (Lee 2004). Dell changed prices across its product lines overnight. That action allowed the company to steer consumer demand away from the products built with parts that were affected by the supply disruptions, and toward other products that did not use those parts. Dell's capability of avoiding performance volatility was enabled by its high degree of process automation in different processes, which operated over an enterprise-wide ERP system connecting all product lines.

Second, when an ERP system standardizes and integrates data from more value chain processes, economies of scope can be achieved with *a more comprehensive data analysis* in managers' information processing and decision making

(Pinsonneault and Rivard 1998; Tanriverdi and Ruefli 2004). An ERP system with such a greater scope synthesizes information from a wider range of processes to depict a firm's operations and economic reality. This allows managers to access a greater amount of timely and accurate information about value chain processes, conduct a more comprehensive data analysis to understand firm operations, and disseminate information and knowledge to the whole organization. Empirical evidence suggests that access to richer data enables managers to make more informed decisions (Padmanabhan et al. 2006). As one example, having a richer set of data about processes throughout the enterprise, managers are better able to "observe" bottlenecks that cause variability in operations and respond to these issues accordingly (Cotteleer and Bendoly 2006).

Third, as ERP system scope increases, more value chain processes can adapt in concert, on an ERP system platform, to address changes in the firm's operating environment (Hitt et al. 2002; Ranganathan and Brown 2006). *A broader range of business integration* may therefore enable the enterprise to accommodate changes in the firm's operating environment more effectively (Bala and Venkatesh 2007; Gosain, Malhotra, and El Sawy 2005), thereby mitigating performance variability. This reasoning is in line with evidence that when a firm's operations cover a greater variety of business activities, its investment in IT is more likely to reduce firm risk (Dewan and Ren 2011). A plausible interpretation is that when the firm uses IT to integrate a greater variety of business activities, the capability of the IT to reduce firm risk is likely to become more apparent (Dewan and Ren 2011). We built our analysis on the prior evidence and explicitly examined whether a greater ERP system scope, suggesting more value chain processes working over an integrated, enterprise-wide platform, can lead to a greater risk reduction outcome. Thus, we hypothesize:

> *Hypothesis 2a: The risk reduction effect of ERP systems is increasing in ERP system scope.*

Further, according to the value chain framework (Porter and Millar 1985), which classifies ERP system modules as either functional or operational (recall the definitions in the "Introduction"), we expected that the two types of ERP system modules might play different roles in risk reduction at a given level of ERP system scope. This was motivated by Barki and Pinsonneault's (2005, p. 175) proposition that "Implementing the functional modules of an ERP system will result in greater organizational effectiveness than implementing its operational modules." Barki and Pinsonneault illustrated such organizational effectiveness by discussing how functional modules of an ERP system can improve firm responsiveness to changes in the market, which, in turn, can help reduce firm risk.[7] As defined earlier, the functional and operational modules of ERP systems support functional and operational processes of a firm's value chain, respectively (Barki and Pinsonneault 2005; Ranganathan and Brown 2006). Functional processes comprise a corporate infrastructure that supports the *entire* value chain, because every operational process must involve such functions as accounting and human resources management (Porter and Millar 1985). To establish such a corporate infrastructure, functional processes have a "linkage"—using Porter and Millar's terminology—with each of the operational processes. This linkage makes it possible to channel, save, aggregate, and analyze data from each operational process so that corporate accounting and human resources management can function. Supporting functional processes, the accounting modules of ERP systems capture data that depict a firm's economic reality based on its products and services and daily operations across the entire value chain; and the human resources modules of ERP systems capture data about human resources management (e.g., recruitment, training, compensation scheme, work-force scheduling) across the entire value chain. Using data collected across the entire value chain, these functional modules help managers make "global" decisions. Unlike the functional processes of ERP systems, the operational processes communicate mainly with adjacent downstream and upstream processes (Porter and Millar 1985). As such, the operational modules of ERP systems mainly capture data from proportions of operational processes along an enterprise value chain. Hence, relative to the operational modules of ERP systems, we expected the functional modules to contribute more to organizational effectiveness in information processing to resolve uncertainties (Barki and Pinsonneault 2005). Thus, we hypothesize:

> *Hypothesis 2b: At any given level of ERP system scope, the risk reduction effect of ERP systems is increasing in the number of functional modules.*

Environmental Uncertainty

When firms' operating environments feature different degrees of uncertainty, firms have varying information processing needs (Premkumar et al. 2005). Environmental uncertainty originates from two aspects of a firm's operating environment: dynamism and complexity (Duncan 1972). When a

[7]Kobelsky, Hunter, and Richardson (2008) submitted that IT "enables the firm to better and more quickly respond to unexpected challenges arising from the business and competitive environment…decreasing earnings volatility from what it would have been otherwise" (p. 155).

firm's operating environment features high complexity (e.g., a large number of competitors), the firm needs to process a great deal of information concerning uncertainties (e.g., a large amount of competitive actions) (Kamien and Schwartz 1982). When a firm's operating environment features high dynamism (e.g., high product clock-speed), the firm needs to cope with uncertainties and process environmental information frequently (Mendelson and Pillai 1998). The prior literature drew upon the positive association between environmental uncertainty and firms' information processing needs to analyze IT value. The logic is that when IT is needed more, it is more valuable and creates greater business value (Melville et al. 2004). Dewan and Mendelson (1998) conceptualized IT value as the frequency and amount of information cues that IT handles. Broadbent et al. (1996) argued that enterprise systems are especially valuable to firms operating in a volatile environment. Using firms' IT budget data, Kobelsky, Richardson, et al. (2008) found that firms operating in more uncertain environments spent more on IT, implying that IT was highly valuable to those firms. Premkumar et al. (2005) found that IT applications in supply chain contexts led to greater procurement performance when environment uncertainty was high.

Along the same line of reasoning, we apply the notion that higher environmental uncertainty is associated with greater information processing needs. This notion allowed us to analyze the business value of ERP systems in terms of reducing firm risk. First, when environmental uncertainty is higher, changes appear to be more intensive in firms' operating environments. As a result, firms need to collect, process, and disseminate information about the changes more frequently and to make corresponding adjustments in value chain processes. In such high uncertainty environments, *automated* information processing by ERP systems is expected to have a greater impact. Kobelsky, Hunter, and Richardson (2008) used the bullwhip effect to illustrate how IT, by enabling information sharing along the enterprise value chain, can reduce performance volatility in uncertain environments with high levels of demand variation. They theorized that the risk reduction effects of IT are conditional:

> They are only expected to be salient when both a high level of uncertainty exists and IT facilitates information sharing. Absent changes in the firm and its environment, there is no change-related information to communicate, precluding IT from reducing volatility (p. 157).

Second, when firms need to process a large amount of information cues in the market (e.g., competitors' launching new products, promotions, and campaigns; supply disruptions and price adjustments by suppliers; demand changes), ERP systems can help process various types of information over an *integrated* platform and disseminate information to decision makers for prompt reactions. Managers need the integrated data for decision making when facing a complex set of information cues in the market. If a large number of information cues comes to managers in a piecemeal fashion, managers experience a greater mental burden in digesting the information and making corresponding decisions (Pinsonneault and Rivard 1998). Once equipped with integrated data, managers are better placed to make decisions to address uncertainty. Third, when information processing becomes more frequent and complex, managerial errors and inappropriate decisions are more likely to happen (Dechow and Dichev 2002). In such cases, the *standardization* effect of ERP systems can be particularly salient for reducing operational uncertainty resulting from managerial discretion (Brazel and Agoglia 2007; Venkatesh et al. 2007). Based on the above discussion, we expected the risk reduction effect of ERP systems to be stronger in more uncertain environments. As discussed above, we attributed the risk reduction effect to the presence of ERP systems (H1), to ERP system scope (H2a), and particularly to functional modules at a given level of ERP system scope (H2b). Combining these considerations, we hypothesize:

> *Hypothesis 3: The higher the environmental uncertainty, the greater is the risk reduction effect associated with (H3a) the presence of ERP systems, (H3b) ERP system scope, and (H3c) the number of functional modules at a given level of ERP system scope.*

Method

Data and Sample

We used the Compustat database to construct measures for firm risk and for the control variables. We used the Computer Intelligence (CI) database to construct measures for the ERP variables. The sampling frame of the CI database was Fortune 1000 firms. After combining the CI data with the Compustat database and computing the needed variables, our final dataset included 2,127 firm-year observations during a 3-year period (2001–2003), consisting of 981 unique firms. As shown in Table 1, the firms in the sample were in a wide range of manufacturing and service industries.

Table 1. Sample

Industry Groups (based on SIC codes)	Description	*N* (firm years)
01–19	Agriculture, Mining/Construction	93
20–23,27	Other Non-durable Manufacturing	162
26, 28, 29	Process Manufacturing	195
36–38, 357	High-tech Manufacturing	404
24, 25, 30–35 (Except 357),39	Other Durables	341
40–48	Transportation/Communications	84
49	Utilities	149
50–59	Retail/Wholesales	291
60–69	Financial Institutions	136
70–99	Services and Others	272
Total		2,127

Regression Specification and Variables

To test our hypotheses, our regression equation specification was as follows:

$$\textit{Firm Risk}_{it} = \textit{Intercept} + (\textit{ERP Variables})_{it} + (\textit{Environmental Uncertainty})_{it} + (\textit{ERP Variables})_{it} \times (\textit{Environmental Uncertainty})_{it} + \textit{Controls}_{it}$$

This regression specification relates firm risk of firm *i* in year *t* to ERP variables (to test H1 and H2) and proposes that environmental uncertainty moderates the relationship (to test H3). Next we describe our variables, with a summary of the variables presented in Tables 2 and 3.

Firm Risk: We used earnings volatility as a proxy for firm risk (Kothari et al. 2002), which was measured as the standard deviation of annual earnings over five years from t to $t + 4$.

ERP Variables: The presence of post-implementation ERP systems (*ERP_PRESENCE*) indicated whether or not a firm had an ERP system installed in place in year *t*. Using an indicator variable to examine ERP system impacts follows prior literature. Aral et al. (2006) employed an indicator variable (equal to one after an ERP system is installed) to estimate the performance impact of ERP systems. Other studies have used an indicator variable to differentiate between periods prior to ERP go-live and post-ERP go-live (i.e., post-implementation) and regressed firm performance on the indicator variable (Dorantes et al. 2013; Hitt et al. 2002). Morris and Venkatesh (2010) used the same approach to examine the post-implementation effect of an ERP system on users' job characteristics. Similarly, Dehning et al. (2007) and Hendricks et al. (2007) compared firm performance before and after ERP system implementation.

We used a set of indicator variables to describe ERP system scope, a total of four levels, from *Level 1* to *Level 4*. Prior research has used a similar approach (e.g., Hitt et al. 2002).[8] As shown in Table 3, the indicator variable *Level 1* equals one (i.e., $L1 = 1$) for firms having installed one of the four types of ERP system modules, and equals zero for all other firms in the sample. *Level 2* equals one (i.e., $L2 = 1$) for firms having installed two types of ERP system modules; *Level* 3 equals one (i.e., $L3 = 1$) for firms having installed three types of ERP system modules; and *Level 4* equals one (i.e., $L4 = 1$) for firms having installed all four types of ERP system modules. Further, we examined all possible combinations of functional modules (accounting and finance; human resources) and operational modules (customer and sales; supply chain). Take *Level 2* as an example: When firms select two (out of the four) types of ERP system modules, there is a total of six combinations. As shown in Table 3, we used six indicator variables (*L2A–L2F*) for the six combinations, respectively. For instance, an indicator variable *Level 2A* equals one (i.e., $L2A = 1$) for firms with accounting and finance modules and human resources modules implemented, and equals zero for all other firms in the sample.

[8] Hitt et al. examined firms implementing SAP systems. They found that more than 90 percent of their sample firms implemented one of the four common combinations of SAP's ERP system modules. They used four "Level x" indicator variables for those four combinations, respectively.

Table 2. Continuous Variables (Firm Risk, Environmental Uncertainty, Control Variables)

	Variable	Definition	Mean	S.D.	1Q/Median/3Q
Dependent variable					
Firm Risk	Volatility of firm performance	Source: Kothari et al. (2002), Dewan et al. (2007) Standard deviation of realized annual earnings (scaled by total assets) over the next 5 years	0.045	0.052	0.015/0.028/0.052
Environmental uncertainty					
EU_PMV	Environmental uncertainty (*EU*) based on previous margin volatility (*PMV*)	Source: Nevo (2001), Kobelsky, Richardson et al. (2008) Standard deviation of the past five years' income before extraordinary items (scaled by sales)	0.075	0.644	0.012/0.023/0.048
EU_ICR	Environmental uncertainty (*EU*) based on industry concentration ratio (*ICR*)	Source: Kamien and Schwartz (1982), Kobelsky, Richardson et al. (2008) The total market share of the 4 largest firms in a SIC 2-digit industry, multiplied by minus one	-0.411	0.155	-0.500/-0.380/-0.298
Control variables					
PPE	Regular capital	Source of the following control variables: Kothari et al. (2002), Dewan et al. (2007) Property, plant, and equipment (*PPE*) scaled by total assets	0.291	0.211	0.128/0.240/0.418
SIZE	Firm size	Firm size, the natural logarithm of market value of equity at fiscal year-end (in $ Mil)	6.700	1.867	5.569/6.738/7.960
LEV	Financial leverage	Total liability divided by total assets	0.569	0.235	0.406/0.568/0.716
R&D	R&D spending	R&D spending scaled by total assets	0.020	0.040	0.000/0.000/0.020
ADV	Advertising spending	Advertising spending scaled by total assets	0.011	0.028	0.000/0.000/0.007
ROA	Return on assets	Income before extraordinary items divided by total assets	0.023	0.093	0.004/0.033/0.070

Table 3. Indicator Variables (ERP System Presence, ERP System Scope)

Presence of ERP systems in the post-implementation stage	ERP System Scope	Functional modules		Operational modules		Obs.	Percent
		Accounting & finance	Human resources	Supply chain	Customer & sales		
ERP_PRESENCE = 0: A sample firm had no ERP system installed						356	16.74
ERP_PRESENCE = 1: A sample firm had an ERP system installed							
	Level 1 (*L1* = 1)	One type of ERP system modules installed				382	17.96
	Level 2 (*L2* = 1)	Two types of ERP system modules installed					
	Level 2A (*L2A* = 1)	x	x			273	12.83
	Level 2B (*L2B* = 1)	x		x		104	4.89
	Level 2C (*L2C* = 1)	x			x	37	1.74
	Level 2D (*L2D* = 1)			x	x	18	0.85
	Level 2E (*L2E* = 1)		x	x		24	1.13
	Level 2F (*L2F* = 1)		x		x	8	0.38
	Level 3 (*L3* = 1)	Three types of ERP system modules installed					
	Level 3A (*L3A* = 1)	x	x	x		342	16.08
	Level 3B (*L3B* = 1)	x	x		x	78	3.67
	Level 3C (*L3C* = 1)	x		x	x	56	2.63
	Level 3D (*L3D* = 1)		x	x	x	14	0.66
	Level 4 (*L4* = 1)	Four types of ERP system modules installed				435	20.45
Total						2,127	100.00

Note: "x" indicates the types of ERP system modules installed.

Environmental Uncertainty: We used two proxy variables to measure environmental uncertainty (*EU*), one based on a firm's previous margin volatility (*EU_PMV*) and the other based on a firm's industry concentration ratio (*EU_ICR*). We followed the literature (Kobelsky, Richardson et al. 2008) and used the standard deviation of a firm's margin in the past five years (year *t*-5 through year *t*-1) as a proxy for the firm's environmental uncertainty in year *t*. The economics literature has argued that margin volatility is closely related to shocks in the firm's business environment (Karuna 2007). "Variations in demand elasticity and competitive behavior can take place and, of course, do occur. They raise or lower the price/cost margin" (Greenhut and Greenhut 1991, p.365). Empirical research has associated a firm's margin volatility with variations in firm-specific business environments concerning demand (Nevo 2001) and supply (Malliaris and Malliaris 2008). We defined the concentration ratio of a firm's industry as the total market share of the four largest firms in a SIC two-digit industry. We multiplied the concentration ratio by minus one, so that *higher* values on the resultant variable *EU_ICR* represent *less* concentrated industries. The economics literature has long argued that less concentrated industries tend to be more dynamic (i.e., more innovations or new competitive actions) (Kamien and Schwartz 1982). Less concentrated industries also represent a more complex environment, where a firm needs to cope with competitive actions by a large number of rivals (Hou and Robinson 2006). Earlier, we explained that environmental uncertainty can be conceived as originating from two aspects of an environment: complexity and dynamism. Conceptually, the two variables we used (*EU_PMV* and *EU_ICR*) together tapped into complexity and dynamism; prior empirical research used these variables to represent characteristics of a firm's operating environment, with higher values representing more uncertain environments (Kobelsky, Richardson et al. 2008).

Control Variables: We followed prior studies (Dewan et al. 2007; Kothari et al. 2002) and controlled for factors that may influence firm risk. These include regular capital, firm size, financial leverage ratio, R&D spending, advertising spending, industry fixed effects, and year fixed effects. In addition, we controlled for firms' return on assets (*ROA*), because ERP systems may affect return on assets (e.g., Hitt et al. 2002) and firm risk and return can be intermingled (Dewan et al. 2007). Finaly, we controlled for the possible endogeneity of ERP system investments. We employed a two-step Heckman (1979) approach. At the first step, we used a probit model to predict the presence of an ERP system. One explanatory variable was the industry level of ERP system presence (as documented in our Fortune 1000 sample), capturing firms' tendency to follow each other. We included the two proxies for environmental uncertainty as explanatory variables, to partial out the effect that uncertainty may influence firm risk through ERP systems (Kobelsky, Richardson et al. 2008). Another explanatory variable we used was firm size, because larger firm sizes may accompany ERP system investments (Anderson et al. 2006). We also controlled for industry fixed effects and year fixed effects. At the second step, we computed the inverse Mills ratio (IMR) based on the estimated probit model and included it in our regressions for hypothesis testing. This helped correct for the possible endogeneity of ERP system investment (Heckman 1979).

Results

Table 4 presents results for firm risk and the presence of ERP systems (*ERP_PRESENCE*). It reports a model with controls only in Column (1), a model with *ERP_PRESENCE* added in Column (2), and the full model in Column (3). We mean centered the moderating variables (*EU_PMV* and *EU_ICR*) to reduce the impact of collinearity (Aiken and West 1991). The negative and significant coefficient on *ERP_PRESENCE* suggests that, in the post-implementation stage, the presence of ERP systems is associated with a reduction in firm risk. This supported H1. The significant and negative interaction between environmental uncertainty and *ERP_PRESENCE* suggests that the risk reduction effect of ERP systems is stronger in more uncertain environments. The results are robust regardless of whether environmental uncertainty (*EU*) was measured based on previous margin volatility (*EU_PMV*) or the industry concentration ratio (*EU_ICR*). Therefore, we found support for H3a.

Table 5 presents results for firm risk and ERP system scope. The regression in Column (1) does not address the moderation of environmental uncertainty; such a regression specification assumes that each of the four ERP system scope variables (*L1–L4*) has a constant (i.e., average) effect across all degrees of environmental uncertainty (Aiken and West 1991). We found that the regression coefficients on the scope variables became more negative as ERP system scope increased from *Level 1* to *Level 4*. An F-test rejected a null hypothesis that the coefficients are equal. Further, t-test results suggest that the coefficient on *Level 4* is lower (i.e., more negative) than the coefficient on *Level 1* or *Level 2* and that the coefficient on *Level 3* is lower than the coefficient on *Level 1*. Based on these results, we found support for H2a, wherein we expected economies of scope in firm risk and ERP system scope (i.e., the greater the ERP system scope, the stronger the risk reduction effect). In Column (2), the moderating variables are mean centered, so the coefficients on ERP system scope from *Level 1* to *Level 4* represent their effects at the mean value of environmental uncertainty (Aiken and West 1991). Interest-

Table 4. Firm Risk and ERP System Presence

	Dependent Variable = Firm Risk					
	(1)		(2)		(3)	
ERP_PRESENCE			-0.0768***	(0.0221)	-0.0881***	(0.0223)
Environmental uncertainty						
EU_PMV					0.0661***	(0.0176)
EU_PMV × ERP_PRESENCE					-0.0662***	(0.0176)
EU_ICR					0.0184	(0.0158)
EU_ICR × ERP_PRESENCE					-0.0393*	(0.0169)
Control variables						
PPE	-0.0069	(0.0053)	-0.0067	(0.0053)	-0.0057	(0.0053)
SIZE	-0.0040***	(0.0006)	-0.0018*	(0.0008)	-0.0016	(0.0008)
LEV	-0.0164***	(0.0044)	-0.0152***	(0.0045)	-0.0155***	(0.0044)
R&D	0.2910***	(0.0288)	0.2790***	(0.0289)	0.2663***	(0.0296)
ADV	0.1215***	(0.0347)	0.1119**	(0.0346)	0.1103**	(0.0344)
ROA	-0.2339***	(0.0117)	-0.2356***	(0.0117)	-0.2296***	(0.0118)
IMR			0.0374**	(0.0123)	0.0437***	(0.0125)
Year & industry fixed effects	Included		Included		Included	
N	2,127		2,127		2,127	
Adj. R^2	0.325		0.332		0.339	

Note: Standard errors in parentheses; ***p < 0.001, **p < 0.01, *p < 0.05.
All variables are defined in Tables 2 and 3.

Table 5. Firm Risk and ERP System Scope

	Dependent Variable = Firm Risk			
	(1)		(2)	
ERP System scope				
Level 1 (L1)	-0.0783***	(0.0223)	-0.0909***	(0.0224)
Level 2 (L2)	-0.0796***	(0.0222)	-0.0929***	(0.0223)
Level 3 (L3)	-0.0838***	(0.0223)	-0.0975***	(0.0223)
Level 4 (L4)	-0.0850***	(0.0226)	-0.0932***	(0.0227)
Environmental uncertainty				
EU_PMV			0.0706***	(0.0175)
EU_PMV × L1			-0.0377*	(0.0187)
EU_PMV × L2			-0.0707***	(0.0177)
EU_PMV × L3			-0.0724***	(0.0175)
EU_PMV × L4			0.0762	(0.0446)
EU_ICR			0.0203	(0.0156)
EU_ICR × L1			-0.0464*	(0.0213)
EU_ICR × L2			-0.0497*	(0.0205)
EU_ICR × L3			-0.0520**	(0.0198)
EU_ICR × L4			-0.0294	(0.0197)
Control variables				
PPE	-0.0074	(0.0053)	-0.0062	(0.0053)
SIZE	-0.0013	(0.0009)	-0.0010	(0.0009)
LEV	-0.0131**	(0.0045)	-0.0128**	(0.0045)
R&D	0.2700***	(0.0291)	0.2520***	(0.0297)
ADV	0.1070**	(0.0347)	0.0925**	(0.0344)
ROA	-0.2369***	(0.0117)	-0.2203***	(0.0119)
IMR	0.0398**	(0.0124)	0.0471***	(0.0125)
Year & industry fixed effects	Included		Included	
N	2,127		2,127	
Adj. R^2	0.333		0.350	

Note: Standard errors in parentheses; ***p < 0.001, **p < 0.01, *p < 0.05.
All variables are defined in Tables 2 and 3.

ingly, we found the strongest risk reduction effect when ERP system scope was *Level 3* instead of *Level 4*. An interpretation is that, at mean environmental uncertainty, diseconomies of scope set in as ERP system scope reaches the highest level. The presence of both diseconomies and economies of scope also helps explain the nonsignificant interaction of *Level 4* with environmental uncertainty. Other than *Level 4*, we found significant interactions between environmental uncertainty and ERP system scope from *Level 1* to *Level 3*, and the magnitude of the interactions increased from *Level 1* to *Level 3*. These results partially support H3b, wherein we expected that increasing ERP system scope would pay off in terms of reducing firm risk, especially in more uncertain environments.

We used the effect size (f^2) to examine how meaningful the risk reduction benefit of an ERP system is. Following Cohen (1988), we calculated

$$f^2 = (R^2_{full} - R^2_{excluded}) / (1 - R^2_{full})$$

where R^2_{full} and $R^2_{excluded}$ represent R^2 of the full regression model and R^2 of a partial regression model with a set of explanatory variables excluded, and f^2 is the effect-size measure for the set of variables excluded. By convention, effect sizes of 0.02, 0.15, and 0.35 are termed small, medium, and large, respectively (Cohen 1988). We chose R&D spending, which has been generally considered to be a major risk factor, as a benchmark (e.g., Kothari et al. 2002). Based on the regression results reported in Column (3) of Table 4, the effect size of R&D spending and the effect size of ERP systems (including its primary effect and interactions with uncertainty) were estimated to be 0.0385 and 0.0161, respectively. Based on the regression results reported in Column (2) of Table 5, R&D spending and ERP system scope variables had effect sizes of 0.0344 and 0.0376, respectively. Hence, regarding their effect on firm risk, ERP systems and R&D spending had comparable effect sizes, *between a small and medium effect size* (Cohen 1988). It is worth noting that, although the magnitudes of their respective effect sizes were comparable, ERP systems reduced firm risk (i.e., negatively related to firm risk) and R&D spending increased firm risk (i.e., positively related to firm risk).

Figure 2 further presents the moderation effect of environmental uncertainty. Based on Column (3) of Table 4, an inference for how environmental uncertainty moderates the risk reduction effect of ERP systems can be drawn as follows:

Risk reduction effect of ERP systems = Δ (firm risk)
= (risk of firms with *ERP_PRESENCE* being one)
– (risk of firms with *ERP_PRESENCE* being zero)
= –0.0881 – 0.0662 × *EU_PMV* – 0.0393 × *EU_ICR*

Using the above inference, Figure 2A shows how the risk reduction effect is conditional on environmental uncertainty. As environmental uncertainty increased, there was a greater risk reduction benefit associated with ERP systems. In Figure 2A, environmental uncertainty was measured by *EU_PMV*. Using the other measure, *EU_ICR*, yielded a similar pattern. Figure 2B presents the risk reduction effect associated with each of the four levels of ERP system scope (*L1–L4*), conditional on environmental uncertainty. When environmental uncertainty was set at the 20th, 40th, or 60th sample percentile, the risk reduction effect increased in ERP system scope. When environmental uncertainty was set at the 80th percentile, however, the association between ERP system scope and the risk reduction effect became U-shaped. The U-shaped relationship suggests diseconomies of scope when deploying ERP modules fully (i.e., *L4*) in highly uncertain environments.

Table 6 presents results for ERP system modules. We found strong support for H2b. At each of the three levels, from *Level 1* through *Level 3*, the results show the same pattern, that the larger the number of functional modules, the stronger is the risk reduction effect. Take *Level 2* shown in Column (1) as an example: Within *Level 2*, Table 6 shows that the largest regression coefficient magnitude occurred when there were two types of functional modules (-0.0808) and the smallest regression coefficient magnitude resulted when there were two types of operational modules (-0.0666); their difference was statistically significant based on a t-test. Finally, we found strong support for H3c. Take *Level 2* in column (2) as an example. The combination of two types of functional modules had the highest primary effect (within *Level 2*). This combination was also the *only* one (within *Level 2*) that had a consistently negative and significant interaction with the two measures for uncertainty. To conclude, at a certain level of ERP system scope, having more functional modules was found to pay off in terms of reducing firm risk, especially in more uncertain environments. This is consistent with our expectation in H3c.

Regarding control variables (in Tables 4 through 6), R&D spending and advertising spending were positively associated with firm risk, consistent with prior literature (Dewan et al. 2007; Kothari et al. 2002). The negative relationship between financial leverage and firm risk follows the prediction of finance theory (White et al. 1998). ROA was negatively associated with future firm risk. This is supported by the argument that a negative or lower performance indicates a shock to firms that will experience volatile performance in the future (Dechow and Dichev 2002). The positive coefficient on IMR indicates that the regression error terms of the two stages in the Heckman approach were positively correlated, suggesting that high firm risk may drive firms to pursue ERP systems.

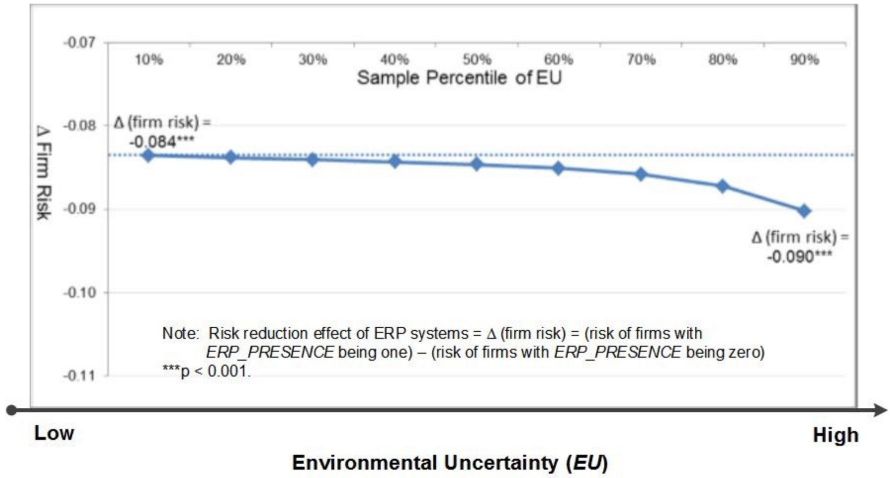

Figure 2A. Risk Reduction Associated with the Presence of ERP Systems, Conditional on Environmental Uncertainty

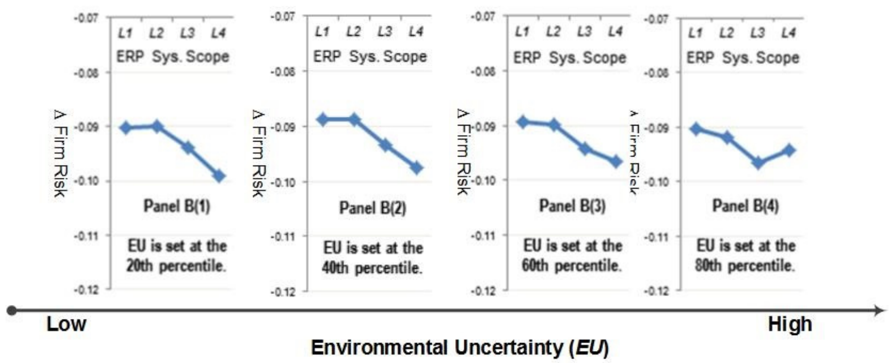

Figure 2B. Risk Reduction Associated with ERP System Scope, Conditional on Environmental Uncertainty

Figure 2. Moderation Effect of Environmental Uncertainty

Robustness Checks

Together, a collection of various robustness tests (Appendix B through Appendix F) yielded the same conclusion about how ERP systems affected firm risk as we have seen in the main analysis shown in Table 4 through Table 6. Below, we describe these tests in turn.

Environmental Uncertainty: Our main analysis included the two proxies for uncertainty in each regression. In Appendix B, we used the two uncertainty proxies one at a time.

Sample-Split Analysis: Appendix C reports robustness checks based on subsamples. Each subsample included firms with no ERP systems and firms with *one* of the four levels of ERP system scope. This analysis served two purposes. First, this test could show the risk reduction effect at one level of ERP system scope, using firms with no ERP systems as a benchmark. It was an alternative approach to examine how the risk reduction effect may vary with ERP system scope. Second, readers might be concerned that the significant results of our main analysis were driven by a large sample size. This concern was alleviated, as we used smaller samples in Appendix C.

ERP System Scope Breakdown: As illustrated in Table 3, we further broke down each level of ERP system scope into more detailed combinations of ERP modules. Appendix D

Table 6. Firm Risk and ERP System Modules

	Dependent Variable = Firm Risk			
	(1)		(2)	
ERP system functional and operational modules				
L1 (1 oper.)	-0.0762***	(0.0227)	-0.0888***	(0.0228)
L1 (1 func.)	-0.0767***	(0.0223)	-0.0911***	(0.0224)
L2 (2 oper.)	-0.0666**	(0.0247)	-0.0855***	(0.0251)
L2 (1 func. & 1 oper.)	-0.0746***	(0.0225)	-0.0874***	(0.0225)
L2 (2 func.)	-0.0808***	(0.0223)	-0.0953***	(0.0223)
L3 (1 func. & 2 oper.)	-0.0817***	(0.0223)	-0.0938***	(0.0229)
L3 (2 func. & 1 oper.)	-0.0843***	(0.0228)	-0.0968***	(0.0224)
Level 4 (L4)	-0.0832***	(0.0227)	-0.0912***	(0.0227)
Environmental uncertainty				
EU_PMV			0.0756***	(0.0175)
EU_PMV × L1 (1 oper.)			-0.0210	(0.0462)
EU_PMV × L1 (1 func.)			-0.0425*	(0.0188)
EU_PMV × L2 (2 oper.)			0.0510	(0.2071)
EU_PMV × L2 (1 func. & 1 oper.)			-0.0302	(0.0264)
EU_PMV × L2 (2 func.)			-0.0762***	(0.0178)
EU_PMV × L3 (1 func. & 2 oper.)			0.0767	(0.0648)
EU_PMV × L3 (2 func. & 1 oper.)			-0.0773***	(0.0176)
EU_PMV × L4			0.0777	(0.0445)
EU_ICR			0.0232	(0.0156)
EU_ICR × L1 (1 oper.)			0.0075	(0.0503)
EU_ICR × L1 (1 func.)			-0.0567*	(0.0221)
EU_ICR × L2 (2 oper.)			0.3821	(0.2250)
EU_ICR × L2 (1 func. & 1 oper.)			-0.0833**	(0.0281)
EU_ICR × L2 (2 func.)			-0.0444*	(0.0226)
EU_ICR × L3 (1 func. & 2 oper.)			-0.0440	(0.0416)
EU_ICR × L3 (2 func. & 1 oper.)			-0.0571**	(0.0203)
EU_ICR × L4			-0.0320	(0.0197)
Control variables				
PPE	-0.0069	(0.0053)	-0.0054	(0.0053)
SIZE	-0.0013	(0.0009)	-0.0011	(0.0009)
LEV	-0.0130**	(0.0046)	-0.0129**	(0.0045)
R&D	0.2678***	(0.0294)	0.2281***	(0.0307)
ADV	0.1083**	(0.0348)	0.0893**	(0.0345)
ROA	-0.2369***	(0.0117)	-0.2171***	(0.0121)
IMR	0.0388**	(0.0124)	0.0455***	(0.0125)
Year & industry fixed effects	Included		Included	
N	2,127		2,127	
Adj. R^2	0.333		0.354	

Note: Standard errors in parentheses; ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.
All variables are defined in Tables 2 and 3.

relates firm risk to such a detailed ERP-scope breakdown. Overall, Appendix D shows a pattern consistent with what was shown in Tables 5 and 6.

Controlling for IT Capital Investment: In Appendix E we added IT capital as an additional control. The results confirmed the prior finding that IT capital was positively related to firm risk (Dewan et al. 2007) and confirmed the post-implementation effect of ERP systems to reduce firm risk, as shown in our main analysis.

Controlling for Industry Effects: In Appendix F, we show the results controlling for industry effects using SIC two-digit industry codes (68 industry dummies). This helped better control for industry fixed effects. Adding a large number of controls, however, raised a stronger requirement on sample size. It was not surprising to see a weaker effect of ERP systems after including 68 industry dummies. For instance, the coefficient on *ERP_PRESENCE* became significant at the $p < 0.10$ level. Its interactions with the two uncertainty variables, however, were still significant at the $p<0.001$ and $p < 0.05$ levels, respectively.

Examining Outliers: First, in all tests reported above, we winsorized continuous variables at the top and bottom one percent to ensure reliable results (Kothari et al. 2002). Second, we checked the Cook's distance of each observation and excluded observations with a distance value greater than one (Saeed et al. 2005). Third, we checked studentized residuals for each observation and excluded observations with an absolute residual bigger than two (Belsley et al. 1980). All of these tests suggested that there were no extreme observations that would change our results.

Discussion

We theorized why ERP systems can help reduce firm risk and argued that, in order to reveal the risk reduction effect, a focus on the post-implementation stage is needed. Based on a sample of 2,127 firm-year observations, we found a reduction in firm risk after ERP system go-live, and the risk reduction effect increased with the scope of ERP system modules and particularly the number of functional modules installed. We further examined how environmental uncertainty would influence the risk reduction effect of ERP systems. We found that, in general, the risk reduction effect was stronger in more uncertain environments, while, interestingly, the risk reduction associated with fully deploying ERP system modules seemed to level off as environmental uncertainty increased.

Implications for Research

First, our research contributes to the understanding of the business value of ERP systems by revealing the risk reduction benefit of ERP systems. Although a long strand of research has examined ERP systems' business value (e.g., Appendix A), ours, to the best of our knowledge, is among the first to identify the risk reduction effect of ERP systems. Building on our findings, future studies that examine ERP system impacts on firm performance need to consider the risk reduction effect of ERP systems if the performance variables under investigation are related to firm risk. For instance, according to financial economics (Brealey and Meyers 2003), when the capital market values firms, it assesses not only firm profitability but also firm risk. As such, one way to extend the line of research on stock market reaction to ERP systems investments (e.g., Hendricks et al. 2007; Ranganathan and Brown 2006) would be to quantify the associated changes in firm risk and return. Lowering firm risk can increase a firm's risk-adjusted market value, because investors prefer lower risk at any given return.

Considering the critical role of risk management for contemporary firms, this work can serve as a stepping stone toward assessing how ERP systems influence performance volatility at various levels of an organization. Given that prior research has made a convincing argument that performance impacts of ERP systems at the firm level accrue with their impacts at more micro levels, such as processes and employee jobs (Sykes et al. 2014), our finding that ERP systems have impacts on performance volatility at the firm level implies possible impacts of ERP systems on performance volatility at more micro levels. Recent research on business impacts of information systems in general and ERP systems specifically has called for research to move beyond examinations that focus solely on the aggregated firm level to consider finer-grained levels where information systems are deployed and used. Rai and Tang (2014), for example, theorized how IT-enabled capabilities created by using IT in combination with business relationships affect firm performance. In the same vein, one could examine how ERP systems are deployed within business relationships and cope with risks that are related to such relationships. At the level of employee jobs, ERP systems have a potential to fundamentally reshape the characteristics of employee users' jobs (Morris and Venkatesh 2010). As such, one approach of future inquiry would be to examine the volatility of employee job performance following ERP systems implementations. Along the same line, an interesting direction for future research would be to conduct a multilevel analysis, for instance, investigating how more macro-level uncertainties (e.g., unexpected changes in the overall market or at the industry level) would influence the impact of ERP systems on micro-level performance volatility.

Second, by contributing new evidence of risk reduction of ERP systems to the more general literature on IT and firm risk, we have emphasized the importance of a post-implementation focus for identifying the risk reduction benefits of IT. To date, the primary evidence in the literature has supported that IT has a positive impact on firm risk. One possible reason could be that most prior studies examined IT investments or adoptions (e.g., Dewan et al. 2007; Dewan and Ren 2011). The current work is responsive to a suggestion that researchers move beyond and investigate how IT systems improve the quality of information, and thus reduce ingrained risks, in firm information processing and decision making to cope with uncertainty (Tanriverdi and Ruefli 2004). Extrapolating from our results to a broader theoretical perspective, our results, together with prior studies, suggest a dynamic view on the risk impacts of an IT across its entire life cycle, from adoption to post-implementation. To better theorize and estimate the risk impacts of IT, future research needs to identify the stage of the technology life cycle associated with the IT under investigation (e.g., adoption or post-implementation). The topic of IT impacts on firm risk continues to attract interest in the IS field. For instance, one risk-related performance variable is firms' costs of capital (Kim et al. 2013). Because investors generally expect higher returns to compensate for higher risk, a firm's risk is positively related to its costs of capital. Answering the question of whether there are information technologies in the post-implementation stage that can help lower costs of capital will generate implications that are economically important.

Third, showing differential risk effects associated with different levels of ERP system scope, as well as how ERP system scope interacts with environmental uncertainty in affecting firm risk, our study suggests that investigating ERP system modules can provide more in-depth insights into the risk effects of ERP systems. Our work makes a contribution to understanding how ERP systems create business value by uncovering that functional modules of an ERP system have the greater risk reduction effect. Our work is one of the first studies responsive to the call for research to investigate the differential impacts of functional and operational modules of an ERP system on organizational effectiveness and efficiency (Barki and Pinsonneault 2005). We hope that our findings will spur further research to advance our understanding of ERP system impacts at the more detailed level of modules, rather than the aggregated level of ERP systems as a whole. This direction for future research will generate actionable implications for practitioners, because, in practice, ERP system initiatives set out to deploy specific modules.

From a theoretical perspective, our finding of a nonlinear relationship between ERP system scope and the risk reduction effect (Figure 2B) suggests that *both economies of scope and diseconomies of scope may accrue with ERP system modules*. This implication could be a reason to reconcile the observations in prior studies of mixed relationships between ERP system scope and firm performance (e.g., Gattiker and Goodhue 2005; Ranganathan and Brown 2006). As such, we believe that the topic of economies/diseconomies of scope is worthy of a comprehensive examination by future research on ERP system impacts. An intriguing topic for examination would be *why diseconomies of scope sometimes happen*. One plausible explanation is that errors in information processing can propagate in a large-scope system, producing an adverse enterprise-wide impact (Hitt et al. 2002). Another plausible explanation, based on multiple case studies and field research, is that a greater scope of ERP system implementation is associated with barriers to organizational assimilation of new work processes (Robey et al. 2002; Sykes et al. 2014), thus impeding the realization of ERP system benefits. Such barriers include, for example, technical and managerial complexity in managing ERP system implementation (Maruping, Venkatesh, and Agarwal 2009; Venkatesh et al. 2010). Although we can only speculate about certain mechanisms likely at work, we hope that further research investigates the mechanisms that underlie economies and diseconomies of scope embedded in the relationship between ERP system modules and firm risk.

Finally, our results highlight the role played by environmental uncertainty in shaping economies of scope of an ERP system. Our results imply that, *for the purpose of reducing firm risk, certain levels of ERP system scope may better "fit" different degrees of environmental uncertainty*. As shown in Figure 2, the association of risk reduction with ERP system scope shifts toward a U-shape in highly uncertain environments. This implies that firms need to adopt certain levels of ERP system scope, but not necessarily the highest ones, to fit the various degrees of uncertainties in their environments. Below is one explanation grounded in the notion of ERP systems being an industry "standard" (Hanseth et al. 2006).[9] Today, many out-of-the-box ERP systems are designed based on common best practices in industry (Wagner et al. 2010). Deploying ERP systems thus imposes standards on organizational information processing, which, however, may have a side effect when environmental uncertainty is high (Hanseth et al. 2006). That is, common or standard best practices may not suit each of the ERP-deploying firms' requirements in their local environ-

[9]We thank an anonymous reviewer for his/her insightful comment leading to this explanation.

ments (Wagner et al. 2010; Wang et al. 2006). When firms operate in complex and dynamic environments, they typically need to customize ERP systems to make them flexible enough to handle shocks and turbulence that are idiosyncratic to the firms' operating environments and associated supply chains (Venkatesh and Bala 2012). Otherwise, an ERP system may not serve as an effective tool, but instead become a liability for information processing. Customization, however, can be particularly challenging when an ERP system embraces a large scope. Because an ERP system is an integrated platform and ERP system modules are not isolated from each other, customizing one module may entail corresponding adaptations in other modules as well. As a result, it would be difficult to customize ERP systems when the ERP system scope is large, and for this reason, the side effect (i.e., the possibility of ERP systems becoming liabilities in highly uncertain environments) tends to appear in ERP systems with a large scope. To sum up, opening up the black box of economies/diseconomies of scope associated with ERP system modules would be a useful avenue to furthering our understanding of ERP system impacts on firm performance in general and firm risk specifically. Importantly, future research along this line has a potential to unravel why and where diseconomies of scope in ERP systems implementations may happen, which, in turn, would shed light on how to enhance ERP system payoff.

Practical Implications

Our findings carry important implications for managers. Over the years, IT managers and chief information officers (CIOs) have been looking for evidence of ERP system payoff to justify their multimillion dollar investments. For these managers, perhaps the biggest takeaway from our work is that ERP systems can help reduce firm risk. This is an important message, as managing firm risk is among the top management tasks, especially in today's volatile business environments (Kaplan et al. 2009). Importantly, we have shown that the risk reduction effect of ERP systems is statistically significant and economically meaningful. Our findings can help managers justify firm investment in ERP systems. In particular, managers in certain industries and certain markets should act proactively to pursue ERP systems for risk reduction if their operating environments are characterized by high uncertainty.

Our findings should attract the interest of managers in other areas, including finance and operations, as well. Firm risk has significant impacts on firm financing, and our results suggest one proactive way that firms can leverage to reduce firm risk and thereby costs of financing. Environmental uncertainty and firm performance volatility are also in the scope of close monitoring by operations managers. Uncertainty makes production scheduling more challenging and, from an operations management perspective, performance volatility is often a signal of less efficient operations (e.g., overstock). Our study has suggested the benefit of an IT-enabled approach to smooth firm performance variation, even when firms operate in uncertain environments. As such, we believe that our findings have strong implications not just for IT managers but also for executives across business functions.

Our study has actionable implications for planning and preparing ERP systems implementations. Our findings suggest that managers can prioritize the deployment of functional modules of ERP systems to obtain better risk reduction benefits. At the same time, our results remind managers that they must choose the scope of ERP systems carefully. Managers must keep in mind that increasing ERP system scope may not always pay off (in terms of reducing firm risk). Our results, however, should not be interpreted as discouraging managers from progressively increasing the coverage of ERP systems along the entire enterprise value chain. Various operational modules are built over a unified ERP architecture, which greatly improves the *potential* to achieve seamless integration among operational modules. When choosing vendors or consulting firms that implement ERP systems, it is important to evaluate their capabilities of enterprise application integration for large-scope enterprise systems (Lam 2005). It is also critical for ERP system adoption firms to develop IT project management capability (Maruping, Venkatesh, and Agarwal 2009). This would help make it possible to customize large-scope ERP systems to increase their flexibility, so as to make them more useful when operating in more complex and uncertain environments. Our results also suggest that ERP system vendors should pay special attention to developing integration tools (e.g., systems adapters and master data management) that facilitate the integration of complex ERP systems with a large scope.

Our findings have implications to industrial consortia and policymakers as well. They have advocated enterprise IT applications as a digital firm infrastructure for the better control of firm risk (e.g., COSO 2013). A digital firm infrastructure ensures "availability of information necessary to carry out day-to-day activities" (PCAOB 2013), which feeds various stakeholders and decision makers (e.g., senior managers, directors, external monitoring and advising experts such as auditors) and is essential for controlling endogenous risks in business activities. While these suggestions were made by industrial consortia based mainly on case studies, our work offered evidence (that ERP systems reduce firm risk) by using a systematic research design and a large dataset from Fortune 1000 firms. Our study has thus offered strong evidence corroborating the advice by the industrial consortia.

Limitations and Future Research

There are some limitations concerning our sample and data. First, our sample includes large firms (i.e., Fortune 1000). Future research could use samples including smaller firms to examine the risk reduction effect of ERP systems across firms with different sizes so that we can obtain a better understanding of the risk effect of ERP systems in a more generalizable setting. Second, as explained earlier, the CI database documents whether firms had ERP systems installed or not. With these data, we were unable to investigate the quality of ERP systems. In reality, ERP systems may vary in a set of indicators for information systems success (e.g., information quality, system quality, etc.), while such information about the quality of ERP systems was lacking in our data. Performance impacts of information systems also depend on the actual usage of the systems. It would be desirable if future research could investigate variations in the quality of ERP systems and their actual usage. Third, given the nature of our data, our analysis mainly took a technology-centric view on ERP systems. Recent research has recommended that researchers pay attention to the coevolutionary changes in organizational structures, business processes, and job designs (Morris and Venkatesh 2010). It would be interesting for future research to examine what organizational change strategies would interact with ERP system initiatives to better manage firm risk. Finally, although our arguments and theory tapped into the impact of ERP systems on firm risk, our statistical analysis showed only associations between ERP systems and firm risk, and not a causal effect of ERP systems on firm risk. Future research could employ different methodologies, such as in-depth case studies or longitudinal field research (Venkatesh et al. 2013), to draw more refined conclusions regarding how ERP systems affect firm risk.

Conclusion

Our finding of reduced firm risk associated with ERP systems in the post-implementation stage uncovered one dimension of ERP system business value. Although prior researchers have examined ERP system impacts on firm performance, the new evidence of ERP system impacts on firm performance *volatility* extends our understanding of the business value of ERP systems. Our results revealed how the risk reduction effect of ERP systems varied across systems consisting of different scopes of modules, and how environmental uncertainty moderated the risk reduction effect of ERP systems. Situated in the broader literature of firm risk and IT investment, our findings highlighted the view that, after go-live, IT in general and enterprise systems in particular can be instrumental in reducing firm risk.

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RESEARCH ARTICLE

HOW DO ENTERPRISE RESOURCE PLANNING SYSTEMS AFFECT RISK? POST-IMPLEMENTATION IMPACT

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Appendix A

Key Findings of Illustrative Empirical Studies on ERP Business Value

Study	Measures of ERP Business Value: Process Performance	Profitability	Firm Value	Data and Sample	Findings
Anderson et al. (2006)			√ (market value)	Firm filings on IT spending, with a large overlap with ERP system investment (62 firms during 1999-2000)	IT spending is associated with a significant increase in firm value. The association varies across industries: positive in transform industries, insignificant in automate industries, negative/insignificant in informate industries.
Aral et al. (2006)	√ (productivity, inventory, asset utilization, collection efficiency)	√ (ROA, ROE, margin)	√ (Tobin's q)	Vendor (SAP) data on ERP purchases (623 unique firms during 1986-2005)	ERP "purchase" events lead to no improvements in process performance and profitability; ERP "go live" events lead to improvements in process performance, but not in profitability.
Cotteleer and Bendoly (2006)	√ (order lead-time)			Field research (a manufacturing firm that had implemented an ERP system)	There is a significant improvement in order fulfillment improvement after ERP system implementation.
Dehning et al. (2007)	√ (operations, logistics, and support processes)	√ (ROA, ROS)		Event study (123 adoption announcements of IT-based supply chain management systems; during1994-2000)	Comparing pre-implementation and post-implementation periods suggest: (1) improvements in logistics and support processes; (2) an increase in ROS, and (3) no increase in ROA. The overall post-implementation financial performance (ROA/ROS) decreases in the scope of implementation.
Dorantes et al. (2013)	√ (forecasting quality)			Event study (enterprise systems "go-live" announcements, N = 353, during 1995-2008)	Enterprise systems lead to higher management forecast quality.

Study	Measures of ERP Business Value: Process Performance	Profitability	Firm Value	Data and Sample	Findings
Gattiker and Goodhue (2005)	√ (coordination improvement and task efficiency)			Survey (111 manufacturing plants where ERP systems had gone live)	Manufacturing plants obtain such benefits as task efficiency and coordination improvements after ERP implementation. The benefits from ERP are moderated by interdependence and differentiation among subunits of an organization.
Hayes et al. (2001)			√ (stock market return)	Event study (347 announcements of ERP adoption; during 1990-1998)	There is a positive market reaction to ERP system adoption. The market reaction is most positive for small/healthy firms. And the reaction to PeopleSoft and SAP systems is positive, while the reaction to other vendors is not significant.
Hendricks et al. (2007)		√ (ROA, ROS)	√ (stock market return)	Event study (186 announcements of ERP adoption; during 1991-1999)	There is moderate evidence for post-implementation improvement in profitability, but no evidence for improvement in stock returns. The post-implementation improvements in profitability are stronger for early adopters (1997 and before).
Hitt et al. (2002)	√ (productivity, inventory, asset utilization, collection efficiency)	√ (ROA, ROE, margin)	√ (Tobin's q)	Vendor (SAP) data on ERP purchases (350 unique firms during 1986-1998)	Firms that invest in ERP systems show an increase in Tobin's q, productivity, ROA, inventory turn, margin, asset utilization, and collection efficiency, but a decrease in ROE.
Karimi et al. (2007)	√ (process efficiency, effectiveness, and flexibility)			Survey of manufacturing firms that have implemented ERP projects (N = 148; 2002-2003)	The extent of ERP implementation is positively related to business process outcomes of ERP implementation. The magnitude of the positive association increases in IS resources.
Ranganathan and Brown (2006)			√ (stock market return)	Event study (116 announcements of ERP adoptions; 1997-2001)	There is a positive abnormal return to ERP system implementation for the overall sample. The abnormal return is most positive for the highest ERP system scope while negative for the lowest ERP system scope.
Sykes et al. (2014)	√ (user work performance)			Survey of ERP system users (N = 255)	Peer advice network improves users' post-implementation job performance.

Appendix B

Robustness Check: Environmental Uncertainty

Panel A: Uncertainty Measured by *EU_PMV*						
	Dependent Variable = Firm Risk					
	(1)		(2)		(3)	
ERP_PRESENCE	-0.0900***	(0.0223)				
ERP system scope						
Level 1 (L1)			-0.0932***	(0.0223)		
L1 (1 oper.)					-0.0883***	(0.0227)
L1 (1 func.)					-0.0910***	(0.0223)
Level 2 (L2)			-0.0949***	(0.0223)		
L2 (2 oper.)					-0.0783**	(0.0247)
L2 (1 func. & 1 oper.)					-0.0878***	(0.0225)
L2 (2 func.)					-0.0954***	(0.0223)
Level 3 (L3)			-0.0991***	(0.0223)		
L3 (1 func. & 2 oper.)					-0.0947***	(0.0229)
L3 (2 func. & 1 oper.)					-0.0961***	(0.0223)
Level 4 (L4)			-0.0947***	(0.0227)	-0.0914***	(0.0227)
Environmental uncertainty						
EU_PMV	0.0723***	(0.0174)	0.0779***	(0.0173)	0.0827***	(0.0174)
EU_PMV × ERP_DEPLOY	-0.0725***	(0.0174)				
EU_PMV × L1			-0.0452*	(0.0185)		
EU_PMV × L1 (1 oper.)					-0.0233	(0.0461)
EU_PMV × L1 (1 func.)					-0.0500**	(0.0187)
EU_PMV × L2			-0.0782***	(0.0175)		
EU_PMV × L2 (2 oper.)					-0.0782	(0.1948)
EU_PMV × L2 (1 func. & 1 oper.)					-0.0389	(0.0263)
EU_PMV × L2 (2 func.)					-0.0835***	(0.0176)
EU_PMV × L3			-0.0798***	(0.0174)		
EU_PMV × L3 (1 func. & 2 oper.)					0.0666	(0.0640)
EU_PMV × L3 (2 func. & 1 oper.)					-0.0845***	(0.0174)
EU_PMV × L4			0.0692	(0.0442)	0.0704	(0.0441)
Controls	Included		Included		Included	
Panel B: Uncertainty Measured by *EU_ICR*						
	Dependent Variable = Firm Risk					
	(1)		(2)		(3)	
ERP_PRESENCE	-0.0770***	(0.0221)				
ERP system scope						
Level 1 (L1)			-0.0782***	(0.0223)		
L1 (1 oper.)					-0.0785***	(0.0229)
L1 (1 func.)					-0.0790***	(0.0223)
Level 2 (L2)			-0.0798***	(0.0223)		
L2 (2 oper.)					-0.0759**	(0.0251)
L2 (1 func. & 1 oper.)					-0.0764***	(0.0225)
L2 (2 func.)					-0.0830***	(0.0223)
Level 3 (L3)			-0.0845***	(0.0223)		
L3 (1 func. & 2 oper.)					-0.0856***	(0.0229)
L3 (2 func. & 1 oper.)					-0.0847***	(0.0224)
Level 4 (L4)			-0.0857***	(0.0226)	-0.0849***	(0.0227)

	Dependent Variable = Firm Risk					
	(1)		(2)		(3)	
Environmental uncertainty						
EU_ICR	0.0274	(0.0156)	0.0265	(0.0156)	0.0278	(0.0156)
EU_ICR × ERP_DEPLOY	-0.0496**	(0.0167)				
EU_ICR × L1			-0.0538*	(0.0213)		
EU_ICR × L1 (1 oper.)					-0.0046	(0.0507)
EU_ICR × L1 (1 func.)					-0.0619**	(0.0222)
EU_ICR × L2			-0.0597**	(0.0205)		
EU_ICR × L2 (2 oper.)					0.3272	(0.2135)
EU_ICR × L2 (1 func. & 1 oper.)					-0.0911**	(0.0283)
EU_ICR × L2 (2 func.)					-0.0534*	(0.0227)
EU_ICR × L3			-0.0616**	(0.0198)		
EU_ICR × L3 (1 func. & 2 oper.)					-0.0380	(0.0414)
EU_ICR × L3 (2 func. & 1 oper.)					-0.0656**	(0.0204)
EU_ICR × L4			-0.0302	(0.0196)	-0.0316	(0.0196)
Controls	Included		Included		Included	

Note: Standard errors in parentheses; ***p < 0.001, **p < 0.01, *p < 0.05.
All variables are defined in Tables 2 and 3.

Appendix C

Robustness Check: Sample-Split Analysis

Panel A: Four Levels of ERP System Scope

	Dependent Variable = Firm Risk							
	(1)		(2)		(3)		(4)	
	No ERP (N = 356) & Level 1 (N = 382)		No ERP (N = 356) & Level 2 (N = 464)		No ERP (N = 356) & Level 3 (N = 490)		No ERP (N = 356) & Level 4 (N = 435)	
L1	-0.0805*	(0.0374)						
L2			-0.0879*	(0.0346)				
L3					-0.1019**	(0.0328)		
L4							-0.0674*	(0.0308)
EU_PMV	0.0650**	(0.0220)	0.0730***	(0.0217)	0.0642**	(0.0203)	0.0802***	(0.0215)
EU_PMV × L1	-0.0359	(0.0231)						
EU_PMV × L2			-0.0739***	(0.0219)				
EU_PMV × L3					-0.0664**	(0.0203)		
EU_PMV × L4							0.0927	(0.0511)
EU_ICR	0.0166	(0.0193)	0.0151	(0.0190)	0.0138	(0.0179)	0.0227	(0.0186)
EU_ICR × L1	-0.0415	(0.0259)						
EU_ICR × L2			-0.0397	(0.0245)				
EU_ICR × L3					-0.0451*	(0.0222)		
EU_ICR × L4							-0.0356	(0.0229)
Controls	Included		Included		Included		Included	

Panel B: Combinations of ERP Modules						
	Dependent Variable = Firm Risk					
	(1)		(2)		(3)	
	No ERP (N = 356) & Level 1 (N = 382)		No ERP (N = 356) & Level 2 (N = 464)		No ERP (N = 356) & Level 3 (N = 490)	
L1 (1 oper.)	-0.0823*	(0.0386)				
L1 (1 func.)	-0.0825*	(0.0376)				
L2 (2 oper.)			-0.0763*	(0.0382)		
L2 (1 func. & 1 oper.)			-0.0793*	(0.0354)		
L2 (2 func.)			-0.0850*	(0.0347)		
L3 (1 func. & 2 oper.)					-0.1015**	(0.0333)
L3 (2 func. & 1 oper.)					-0.1037**	(0.0327)
EU_PMV	0.0671**	(0.0223)	0.0772***	(0.0218)	0.0676***	(0.0204)
EU_PMV × L1 (1 oper.)	-0.0246	(0.0556)				
EU_PMV × L1 (1 func.)	-0.0379	(0.0235)				
EU_PMV × L2 (2 oper.)			0.0775	(0.2443)		
EU_PMV × L2 (1 func. & 1 oper.)			-0.0357	(0.0314)		
EU_PMV × L2 (2 func.)			-0.0787***	(0.0219)		
EU_PMV × L3 (1 func. & 2 oper.)					0.0986	(0.0721)
EU_PMV × L3 (2 func. & 1 oper.)					-0.0697***	(0.0203)
EU_ICR	0.0176	(0.0194)	0.0181	(0.0190)	0.0152	(0.0179)
EU_ICR × L1 (1 oper.)	0.0141	(0.0604)				
EU_ICR × L1 (1 func.)	-0.0497	(0.0271)				
EU_ICR × L2 (2 oper.)			0.3862	(0.2643)		
EU_ICR × L2 (1 func. & 1 oper.)			-0.0798*	(0.0338)		
EU_ICR × L2 (2 func.)			-0.0307	(0.0273)		
EU_ICR × L3 (1 func. & 2 oper.)					-0.0428	(0.0458)
EU_ICR × L3 (2 func. & 1 oper.)					-0.0480*	(0.0229)
Controls	Included		Included		Included	

Note: Standard errors in parentheses; ***p < 0.001, **p < 0.01, *p < 0.05.
All variables are defined in Tables 2 and 3.

Appendix D

Robustness Check: ERP System Scope Breakdown

	Dependent Variable = Firm Risk	
ERP system scope breakdown		
L1	-0.0882***	(0.0223)
L2A	-0.0937***	(0.0222)
L2B	-0.0859***	(0.0226)
L2C	-0.0904***	(0.0263)
L2OTHER	-0.0909***	(0.0235)
L3A	-0.0908***	(0.0224)
L3B	-0.0963***	(0.0226)
L3OTHER	-0.0927***	(0.0229)
L4	-0.0901***	(0.0227)
Environmental uncertainty		
EU_PMV	0.0746***	(0.0175)
EU_PMV × L1	-0.0409*	(0.0187)
EU_PMV × L2A	-0.0752***	(0.0177)
EU_PMV × L2B	-0.0251	(0.0266)
EU_PMV × L2C	-0.4982	(0.2653)
EU_PMV × L2OTHER	0.0081	(0.1441)
EU_PMV × L3A	0.0259	(0.0396)
EU_PMV × L3B	-0.0765***	(0.0175)
EU_PMV × L3OTHER	0.0766	(0.0647)
EU_PMV × L4	0.0805	(0.0444)
EU_ICR	0.0228	(0.0156)
EU_ICR × L1	-0.0484*	(0.0212)
EU_ICR × L2A	-0.0433	(0.0226)
EU_ICR × L2B	-0.0765*	(0.0384)
EU_ICR × L2C	-0.0769	(0.0455)
EU_ICR × L2OTHER	-0.0214	(0.0515)
EU_ICR × L3A	-0.0531*	(0.0213)
EU_ICR × L3B	-0.0646*	(0.0336)
EU_ICR × L3OTHER	-0.0438	(0.0415)
EU_ICR × L4	-0.0316	(0.0196)
Controls	Included	

Note: Standard errors in parentheses; ***p < 0.001, **p < 0.01, *p < 0.05.
All variables are defined in Tables 2 and 3.
L2OTHER = L2D + L2E + L2F; L3OTHER = L3C + L3D.
We combine Levels 2D, 2E, and 2F and use the combined group (labeled as *L2OTHER*) in the regression. The reason is that the number of firms in each of the three groups (Levels 2D, 2E, and 2F) is small; in order to carry out the regression, we need to combine them. For the same reason, we combine Levels 3C and 3D to form a combined group (*L3OTHER*) in our regression. We have conducted a further robustness check by excluding *L2OTHER* and *L3OTHER*, which yields highly consistent results.

Appendix E

Robustness Check: Controlling for IT Capital

	Dependent Variable = Firm Risk					
	(1)		(2)		(3)	
ERP_PRESENCE	-0.0854***	(0.0223)				
ERP system scope						
Level 1 (L1)			-0.0892***	(0.0223)		
L1 (1 oper.)					-0.0873***	(0.0228)
L1 (1 func.)					-0.0891***	(0.0223)
Level 2 (L2)			-0.0913***	(0.0223)		
L2 (2 oper.)					-0.0872***	(0.0250)
L2 (1 func. & 1 oper.)					-0.0854***	(0.0225)
L2 (2 func.)					-0.0934***	(0.0223)
Level 3 (L3)			-0.0966***	(0.0223)		
L3 (1 func. & 2 oper.)					-0.0928***	(0.0229)
L3 (2 func. & 1 oper.)					-0.0956***	(0.0223)
Level 4 (L4)			-0.0932***	(0.0227)	-0.0910***	(0.0227)
Environmental uncertainty						
EU_PMV	0.0747***	(0.0180)	0.0809***	(0.0181)	0.0877***	(0.0182)
EU_PMV × ERP_DEPLOY	-0.0670***	(0.0176)				
EU_PMV × L1			-0.0387*	(0.0187)		
EU_PMV × L1 (1 oper.)					-0.0198	(0.0460)
EU_PMV × L1 (1 func.)					-0.0434*	(0.0188)
EU_PMV × L2			-0.0757***	(0.0178)		
EU_PMV × L2 (2 oper.)					-0.0274	(0.2077)
EU_PMV × L2 (1 func. & 1 oper.)					-0.0301	(0.0263)
EU_PMV × L2 (2 func.)					-0.0822***	(0.0179)
EU_PMV × L3			-0.0722***	(0.0176)		
EU_PMV × L3 (1 func. & 2 oper.)					0.0865	(0.0647)
EU_PMV × L3 (2 func. & 1 oper.)					-0.0769***	(0.0176)
EU_PMV × L4			0.0703	(0.0446)	0.0707	(0.0445)
EU_ICR	0.0178	(0.0158)	0.019	(0.0157)	0.0219	(0.0157)
EU_ICR × ERP_DEPLOY	-0.0386*	(0.0170)				
EU_ICR × L1			-0.0449*	(0.0213)		
EU_ICR × L1 (1 oper.)					0.0127	(0.0503)
EU_ICR × L1 (1 func.)					-0.0553*	(0.0220)
EU_ICR × L2			-0.0485*	(0.0204)		
EU_ICR × L2 (2 oper.)					0.3815	(0.2246)
EU_ICR × L2 (1 func. & 1 oper.)					-0.0813**	(0.0281)
EU_ICR × L2 (2 func.)					-0.0431*	(0.0226)
EU_ICR × L3			-0.0509*	(0.0199)		
EU_ICR × L3 (1 func. & 2 oper.)					-0.0408	(0.0419)
EU_ICR × L3 (2 func. & 1 oper.)					-0.0561**	(0.0203)
EU_ICR × L4			-0.0287	(0.0198)	-0.0312	(0.0197)
IT_CAP	0.3550**	(0.1353)	0.4454**	(0.1369)	0.4667***	(0.1353)
IT_CAP × EU_PMV	1.7951	(0.9300)	2.1237	(1.2862)	2.5665*	(1.3017)
IT_CAP × EU_ICR	-0.0692	(0.9221)	0.0099	(0.9231)	-0.0300	(0.9261)
Controls	Included		Included		Included	

Note: Standard errors in parentheses; ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.
All variables are defined in Tables 2 and 3.
IT_CAP = IT capital (scaled by total assets).

Appendix F

Robustness Check: Controlling for SIC Two-Digit Industry Fixed Effects

	Dependent Variable = Firm Risk					
	(1)		(2)		(3)	
ERP_PRESENCE	-0.0423	(0.0244)				
ERP system scope						
Level 1 (L1)			-0.0448	(0.0247)		
L1 (1 oper.)					-0.0460	(0.0251)
L1 (1 func.)					-0.0450	(0.0247)
Level 2 (L2)			-0.0465	(0.0247)		
L2 (2 oper.)					-0.0405	(0.0271)
L2 (1 func. & 1 oper.)					-0.0415	(0.0249)
L2 (2 func.)					-0.0498*	(0.0247)
Level 3 (L3)			-0.0511*	(0.0248)		
L3 (1 func. & 2 oper.)					-0.0489	(0.0251)
L3 (2 func. & 1 oper.)					-0.0508*	(0.0247)
Level 4 (L4)			-0.0457	(0.0252)	-0.0448	(0.0251)
Environmental uncertainty						
EU_PMV	0.0576***	(0.0174)	0.0617***	(0.0173)	0.0660***	(0.0173)
EU_PMV × ERP_DEPLOY	-0.0577***	(0.0174)				
EU_PMV × L1			-0.0303	(0.0185)		
EU_PMV × L1 (1 oper.)					-0.0236	(0.0455)
EU_PMV × L1 (1 func.)					-0.0340	(0.0186)
EU_PMV × L2			-0.0620***	(0.0175)		
EU_PMV × L2 (2 oper.)					0.0502	(0.2037)
EU_PMV × L2 (1 func. & 1 oper.)					-0.0272	(0.0260)
EU_PMV × L2 (2 func.)					-0.0667***	(0.0176)
EU_PMV × L3			-0.0634***	(0.0173)		
EU_PMV × L3 (1 func. & 2 oper.)					0.0862	(0.0636)
EU_PMV × L3 (2 func. & 1 oper.)					-0.0676***	(0.0174)
EU_PMV × L4			0.0408	(0.0449)	0.0438	(0.0448)
EU_ICR	0.0059	(0.0206)	0.0083	(0.0205)	0.0094	(0.0205)
EU_ICR × ERP_DEPLOY	-0.0416*	(0.0174)				
EU_ICR × L1			-0.0471*	(0.0219)		
EU_ICR × L1 (1 oper.)					0.0168	(0.0503)
EU_ICR × L1 (1 func.)					-0.0562*	(0.0227)
EU_ICR × L2			-0.0442*	(0.0209)		
EU_ICR × L2 (2 oper.)					0.3719	(0.2210)
EU_ICR × L2 (1 func. & 1 oper.)					-0.0786**	(0.0284)
EU_ICR × L2 (2 func.)					-0.0364	(0.0232)
EU_ICR × L3			-0.0458*	(0.0203)		
EU_ICR × L3 (1 func. & 2 oper.)					-0.0469	(0.0421)
EU_ICR × L3 (2 func. & 1 oper.)					-0.0484*	(0.0208)
EU_ICR × L4			-0.0424*	(0.0208)	-0.0440*	(0.0208)
Controls	Included		Included		Included	

Note: Standard errors in parentheses; ***p < 0.001, **p < 0.01, *p < 0.05.
All variables are defined in Tables 2 and 3.

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