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How Human Resource and Information Systems Practices Amplify the Returns on Information Technology Investments

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Abstract

This study examines the important roles that *human resources (HR) for information technology (IT) professionals* and *information systems (IS) practices for all workers* in an organization play in shaping returns on firms' IT investments. In particular, we consider how incentives, autonomy, and training for IT professionals can enable a firm to better leverage the value of its IT investments. We argue that well-trained, motivated, and empowered IT professionals can help firms make better strategic choices in allocating IT investments and implementing IT projects. We also demonstrate how this moderating relationship depends upon collaborative IS and autonomy-enhancing IS practices that affect other knowledge workers in the firm. We leverage archival data for 228 firms with 736 firm-year observations and document two key findings. We find (1) that *empowering HR practices for IT professionals* positively moderate the effect of IT investments on firm performance, and (2) that the alignment between *empowering HR practices for IT professionals* and *firm-wide collaborative IS practices* enhances the value that firms derive from IT investments. Our results suggest that the business value of IT investments is linked to the rewards and opportunities offered to IT professionals, who have a pivotal role in the effective deployment of IT in organizations.

Keywords: Information Technology, Human Resources, Knowledge Work, Productivity, Alignment, Governance

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1 Introduction

Creating value from information technology (IT) investments requires a mix of practices to train and incentivize IT professionals; these practices, in turn, align with the information systems (IS) practices that affect the general culture of productivity in the firm. The COVID-19 crisis has highlighted the importance of human resource (HR) practices applied to IT professionals, as well as IS practices in the firm more generally, in creating resilience to exogenous shocks. In the aftermath of the pandemic, firms have struggled to create an alignment between IT and HR (Loten, 2020), and the general view of HR has shifted from anonymous elements in the organizational hierarchy to a central aspect of an organization's value and identity, underscoring the importance of aligning HR and IS practices to empower employees (Higgins & Bianzino, 2020).

Because IT integrates various business functions (Bharadwaj et al., 2007), IT professionals are well positioned to understand the role of information-intensive business processes across a breadth of functional areas (Bassellier & Benbasat, 2004; Smaltz et al., 2006). Therefore, even though IT professionals represent a fraction of the overall workforce, their work has cross-functional and enabling effects across the entire organization because their core competencies involve the planning, implementation, and deployment of IT systems and IT integration. Beginning with Bharadwaj (2000, p. 73), who discussed the firm-performance implications of "human IT resources," several studies have highlighted the importance of studying IT human capital as a key focus in IS scholarship (Ang et al., 2011; Wattal et al., 2015). Although prior research has examined how HR practices and IT investments can be complementary from the point of view of IT users (Aral et al., 2012; Bresnahan et al., 2002; Tambe et al., 2012), we know very little about how practices that empower IT professionals enable firms to leverage greater business value from IT.

Our goal in this study is to examine how HR practices focused on IT professionals, together with IS practices applied organization-wide, can help firms enhance the business value of their IT investments. First, extending some implications of prior research (Agarwal & Ferratt, 1999; Ferratt et al., 2005; Josefek Jr. & Kauffman, 2003; Joseph et al., 2010), we argue that well-trained, motivated, and empowered IT professionals enable firms to make better strategic choices in allocating IT investments and implementing IT projects. We examine the complementarity between IT investments and HR practices for IT professionals in terms of firm performance. Second, we argue that the practices guiding IT use for the firm's non-IT employees can also either enable or inhibit IT professionals in their work. We posit that HR practices pertaining to training, autonomy, and incentives for IT professionals can help leverage IT business value, depending on how IS practices affect the general culture of productivity for the rest of the firm's employees.[1] In turn, IS practices can determine which HR or organizational practices will be effective; thus, the choice of technology practices can drive the complementary relationship between HR practices and IT investments. IT professionals can influence a firm's returns on IT investments through IS practices that enhance collaboration and worker autonomy.

We leverage rare archival data on IT investments and HR practices for 228 US firms using 736 firm-year observations for the period 2002-2006 to examine how empowering HR practices for IT professionals affect a firm's returns on IT investments. Next, we show that this complementary relationship depends upon the collaborative IS and autonomy-enhancing IS practices that affect the rest of the employees in the firm. By examining how HR and IT complementarities emerge with specific types of IS practices, we are better able to understand the circumstances under which managers can empower IT professionals to enhance firm-level returns on IT investments. This study provides new insight into the way in which incentives, autonomy, and training for IT professionals can enable firms to better leverage the value of their IT investments. Our focus on IT professionals has important implications for understanding the economic impacts of IT investments and for understanding IT's important role in firms (Ang et al., 2002), thereby bridging two major streams of IS scholarship. Our work also extends related work on work organization and IT investments (Aral et al., 2012; Bresnahan et al., 2002; Tambe et al., 2012). Together, the findings provide important implications for how HR and IT complementarities emerge with specific types of IS practices and how firms can leverage IT professionals and other employees to enhance firm-level returns on IT investments.

2 Theory and Hypotheses

We first discuss the complementarity between IT investments and HR practices for IT professionals, before discussing how this complementary relationship is contingent upon IS practices (e.g., collaborative-enhancing and autonomy-enhancing IS practices) for all employees in the firm.

2.1 How Empowering HR Practices for IT Professionals Complement IT Investments

Organizational practice, "an organization's routine use of knowledge for conducting a particular function that has evolved over time under the influence of the organization's history, people, interests, and actions" (Kostova & Roth, 2002, p. 216), often includes structures, programs, policies, and procedures that are adopted by the organization over time (Kogut & Zander, 1992; Kostova, 1999). Empowering HR practices, according to prior literature, comprise a set of managerial practices that enhance employees' self-determination and self-efficacy (Conger & Kanungo, 1988; Miles et al., 1978; Zimmerman, 2000). Conger and Kanungo (1988) define empowering practices as

[1] For example, in 1997, IBM encouraged employees to use the internet at a time when other firms were seeking to restrict their employees' internet access (Winman, 2011). More recently, IBM has made a series of investments in social computing to foster collaboration among its employees and to make subject matter experts within the firm more accessible to the general public; by contrast, many firms deliberately keep their employees' identities hidden behind the corporate firewall. https://www.ibm.com/developerworks/community/blogs/e874ec4d-2a29-41a2-8fdd-16babe9d4d21/entry/Happy_Social_Media_Day_IBM_s_social_business_transformation_journey?lang=en. Retrieved July 2016.

"a process of enhancing feelings of self-efficacy among organizational members through the identification of conditions that foster powerlessness and through their removal by formal organizational practices and informal techniques of providing efficacy information" (p. 474). According to this definition, the construct of empowerment goes beyond practices pertaining to delegating power or sharing resources with subordinates and includes motivational practices as well. We view empowering HR practices as those that reflect the potential role of managers as facilitators, insofar as they remove "the constraints that block organization members' search for ways to contribute meaningfully to their work roles" (Miles et al., 1978, p. 560).

Strategic HR management literature considers three broad dimensions of empowering HR practices: (1) *training HR practices,* or practices that influence employees' knowledge and abilities; (2) *incentive HR practices,* or practices that influence employees' motivation and effort; and (3) *autonomy HR practices*, or practices that influence employees' participation (Lepak et al., 2006). The concept of empowerment aligns with innovative HR management (in contrast to traditional HR management) and implies the removal or reduction of barriers, such as barriers to information sources or barriers between people or functional units within a firm. Tafti et al. (2007) argue that such HR practices foster (1) worker autonomy, (2) connectedness among workers through collaboration and information sharing, (3) a culture of learning in the organization, (4) a culture of valuing individuals, (5) an environment of trust, and (6) greater flexibility in work structures.

We draw on prior work that shows the importance of organizational commitment to IT, in terms of verbal support and providing supporting resources, in a firm's ability to reap the benefits of IT investments (Steelman et al., 2019), and we apply this literature to gain insights into how the management of IT professionals might enhance the firm-wide effectiveness of IT investments. In particular, we draw on Adler and Borys's (1996) description of three features of empowering management practices for our approach to empowering practices. First, empowering practices provide employees with insights into local processes (i.e., those with which employees are directly involved), thus enabling workers to solve problems as they arise. Second, these practices give employees greater insight into the "broader system within which they are working," thus enabling them to find opportunities for improvement and provide suggestions to upper management (Adler & Borys, 1996, p. 73). Third, on both a small and a large scale, these practices give workers more flexibility to initiate changes in business processes. Central to Adler and Borys's (1996) distinction between enabling and coercive methods of management is whether workers are being empowered to fully leverage their capabilities, which is possible when employees have insight into firm processes and when the firm is amenable to employees' insights.

We draw on the existing literature on the strategic management of IT and argue for a complementary relationship between IT investments and HR practices. Prior research has suggested that firms need to create complementary resources and capabilities to enhance the value they gain from their IT resources, including human capital (Melville et al., 2004). Related research has shown that IT investments might have a complementary or substitutive relationship with different aspects of firms' capabilities (Havakhor et al., 2019; Sabherwal et al., 2019). For example, Sabherwal et al. (2019) revealed evidence of heterogeneities in the effect of strategic IT alignment on firms' gains from IT under environmental uncertainty. Havakhor et al. (2019) demonstrated that firms' research and development (R&D) and advertising capabilities might interact differently with their IT investments under various environmental conditions. Theoretical arguments from prior research, as well as anecdotal examples, support the idea that IT investments and HR practices can be complementary (see Table 1).

We argue that the complementarity between IT investments and HR practices for IT professionals allows firms to obtain higher gains because this relationship (1) improves IT use in the organization, (2) motivates organization-wide IT innovations, and (3) enhances business-IT alignment. First, empowering HR practices for IT professionals are likely to amplify the effect of IT investments on productivity by enhancing IT use within the firm. Bresnahan et al. (2002) found that IT investments accompanied by work reorganization investments and a highly skilled workforce contribute to firm-level productivity. Bresnahan et al. (2002) used the term *innovative work organization* practices to include a combination of practices that encourage teamwork and decentralize decision-making authority among employees. Tambe et al. (2012) employed a similar construct. For Prennushi et al. (1997), *innovative human resource management* systems include "incentive pay, teams, flexible job assignments, employee security, and training" (p. 291).

This literature highlights how implementing empowering HR practices enhances employee authority, and this stronger sense of authority, combined with new IT resources, improves the use of IT systems. For example, Black and Lynch (2001) showed that among innovative HR practices, the practice of allowing greater employee input in important decisions has a substantial positive effect on the use of a specific IT system for plant productivity.

Table 1. Studies on Complementarities of HR, IT, and Effects on Firm Productivity: Main Variables

Study	Sample	HR practice variables	IS practice variables	IT investment variables
Bresnahan et al. (2002)	Survey of organizational practices conducted in 1995-1996; panel of IT capital levels from CII matched to Compustat database from 1987-1994 period.	Decentralization (e.g., teamwork and autonomy)	---	IT hardware capital stocks (excluding software, applications, and personnel)
Tambe et al. (2012)	Survey of 253 firms in 2001 matched with IT employment data.	External focus (e.g., competitive benchmarks, recruiting) Decentralization (e.g., teamwork and autonomy)	----	Pct. of workers using PCs and email IT employment
Aral et al. (2012)	Survey in 2005-2006 of 189 firms that adopted HCM systems, 90 of which were matched with performance data from Compustat (firm-years 1995-2006).	Performance pay incentives (e.g., compensation aligned with business objectives)	Adoption of the human capital management (HCM) software module of a major ERP systems vendor HR analytics (e.g., functionality of HR analytics IS system)	----
This study	*Panel of surveys on IS practices from 2002 through 2006, survey of HR practices in 2003, matched to Compustat.*	*Training, autonomy, and incentives of IT professionals*	*Collaborative IS* *Autonomy-enhancing IS*	*Comprehensive global IT budget as a percentage of revenue*

Further, empowering HR practices allow for a more collaborative environment and decentralized decision-making practices, both of which contribute to better use of IT resources. Black and Lynch (2001) showed that an implemented IT system has positive effects on productivity, especially when employees have been engaged in regular group decision-making meetings. In another example, Bartel et al. (2007) examined the relationship between IT and new HR management practices, which include the use of employee teams, shop floor meetings (a proxy for information sharing), and training in technical skills. In general, what these HR constructs have in common is that they include dimensions related to flexible work organization, teamwork, information sharing, decentralized decision-making, employee autonomy, and training.

Second, empowering HR practices for IT professionals are likely to amplify the effect of IT investments on productivity by enabling organization-wide IT innovations within the firm. Powell and Dent-Micallef (1997) examined the relationship between IT and HR practices, taking the perspective that IT is a technological resource that leverages other firm resources. Scholars have argued that IT capabilities are generated through investments complementary to IT, resulting in assets that are both intangible and difficult for competitors to replicate (Bharadwaj, 2000; Melville et al., 2004; Saunders and Brynjolfsson, 2016). Prior research findings have also suggested that firms can cultivate their strategic advantages and improve their performance by engaging in IT investments simultaneously with HR practices (Bresnahan et al., 2002). Accordingly, we argue that HR practices and IT investments have a complementary relationship, such that empowering HR practices help the firm's IT professionals identify innovative uses for the acquired IT resources, which, in turn, enhance the firm's productivity. This argument is also consistent with the findings of Steelman et al. (2019), who showed that new IT resources have a higher positive effect on a firm's performance when IT staff members are better supported through greater involvement in organization-wide decision-making and more access to organizational resources.

Third, empowering HR practices for IT professionals are likely to amplify the effect of IT investments on productivity by enhancing business-IT alignment. One reason for the disconnect between IT departments and business departments in large firms may be the social isolation of IT professionals from business issues (Prahalad & Krishnan, 2008). Because IT professionals are focused on technology in their work, their depth of understanding of the broader business context and their opportunities to connect IT solutions to business problems may be limited. We argue that the HR practices discussed here can enable IT professionals to connect better with their business counterparts, thus deepening their understanding of business issues and expanding the effectiveness of the IT solutions they develop. IT professionals have substantial control over the value that firms derive from IT investments. When empowered with training, autonomy, and incentives, IT professionals may be in a position to make better strategic choices with regard to IT investments and effectively implement and execute IT projects. Therefore, we hypothesize:

H1: Empowering HR practices for IT professionals positively moderate the effect of IT investments on firm productivity.

2.2 Role of Firm-Wide Collaborative and Autonomy-Enhancing IS Practices: Three-Way Complementarities

Thus far, we have discussed the complementarity between IT investments and HR practices for IT professionals. We next consider how this complementary relationship is contingent upon IS practices (e.g., collaborative-enhancing and autonomy-enhancing IS practices) that influence all employees in the firm.

We posit that firm-wide IS practices determine the extent to which the management of IT professionals can enhance the value of IT investments, thereby influencing the firm's general culture of productivity. The digitization of business processes through IT investments has led to the greater complexity and visibility of information, resulting in a greater demand for knowledge-intensive labor (Bresnahan et al., 2002; Levy & Murnane, 2004; Zuboff, 1988). Such knowledge-intensive labor requires worker autonomy, information seeking, and interpersonal collaboration (Davenport, 2005; Drucker, 1999). When firms and employees adapt to new IT, they also change their organizational routines, work processes, and work habits (Bresnahan et al., 2002; Dubé, 2014; Levy & Murnane, 2004). IT enhances collaboration and coordination among knowledge workers who might otherwise be separated by geographical, departmental, or organizational boundaries (Apte & Mason, 1995; Mithas et al., 2006; Mithas & Whitaker, 2007; Ravichandran et al., 2017; Saldanha et al., 2020). Further, IT enhances social processes that facilitate virtual teamwork among knowledge workers (Havakhor & Sabherwal, 2018). As this research shows, the notion of IS practices is inclusive and broad in that the term includes practices such as email, internet use, and IT-enabled collaboration, whether involving multiple or individual users.[2]

IS practices play a major role in moderating the firm-performance impact of IT professionals for several reasons. First, IS practices define the role of IT professionals in their service to the firm's remaining employees. That is, IS practices reflect the capacity of IT professionals to influence the firm's general culture of productivity and capture the cross-functional role of the firm's digital business practices (e.g., Bharadwaj et al., 2013). Second, IS practices affecting the firm's non-IT employees fall under the purview of the chief information officer or the highest-level IT executives, as do the training, autonomy, and incentivizing of IT professionals. Prior research has suggested that the decisions and practices of a firm's leadership can influence the firm's overall performance (e.g., Banker et al., 2011); in particular, the firm's returns on IT investments are often a criterion for evaluating the performance of top IT executives. Thus, firms need to consider how firm-wide practices under the purview of IT executives influence the value that firms derive from IT investments. Third, the explanations for prior theory on complementarities were based implicitly on the notion that IT can enhance autonomy and collaboration among workers (e.g., Bresnahan et al., 2002); thus, identifying and measuring specific IS capacities is critical to developing this theory further. Specifically, implicit in the prior research on the complementary relationship between IT investments and HR practices is the notion that IT investments are channeled toward tools and technologies that facilitate communication, collaboration, and information access, even though firms' use of these IS practices has sometimes remained an unobserved variable (e.g., Bresnahan et al., 2002).

We consider two salient categories of IS practices: *collaborative* and *autonomy-enhancing*. Collaborative IS practices include the use of collaborative hardware such as videoconferencing equipment, collaborative software such as intranet or email tools, instant messaging applications, and voice-over IP (VoIP) applications. All of these tools enable employees to connect with one another and collaborate at a distance. Video conferencing, internet-enabled telephones, and other collaborative hardware allow for seamless interactions among computers and telephones, thus supporting more flexibility in synchronous communication. The literature suggests that

[2] IS practices, in this sense, capture organizations' use and deployment of related IS-technology practices, although neither our theoretical arguments nor our empirical analysis will comprehensively address *every* aspect of a firm's strategic, necessary, or basic IT capabilities. However, firms have historically exhibited substantial heterogeneity in their use and deployment of the IS-technology practices salient to both our theoretical discussion and empirical analysis. Moreover, we consider a number of specific aspects of IS practices in order to derive more insight from the underlying theoretical mechanisms.

collaborative tools also include computer-aided software engineering (CASE) tools that enable knowledge sharing across functional units within a firm (Alavi & Leidner, 2001).[3] For example, document repositories, enterprise applications, and archived case reports allow employees to strengthen their expertise in their own task-specific domains and learn about how their jobs interface with other task or knowledge domains (Kang et al., 2007; Takeishi, 2002).

Autonomy-enhancing IS practices, meanwhile, give employees greater access to information through greater internet access, mobile information access, and decentralized decision-making tools. This description aligns with the framework by Bloom et al. (2014). Autonomy-enhancing IS practices are distinct from collaborative IS practices because they refer to policies aimed at enhancing employees' ability to independently access and process information, rather than policies that facilitate collaboration and information sharing among groups of employees. Besides independent information access, autonomy-enhancing IS practices can also include policies that permit or encourage telecommuting. Further, autonomy-enhancing IS practices can be linked to a reduction in monitoring IS practices that reinforces managers' ability to precisely track employees' activities with aims that are coercive or manipulative: "Techniques of control are used for monitoring, surveillance, detection, and record-keeping … offer[ing] ways to shore up or circumvent the imperfections of imperative control" (Zuboff, 1988, p. 313). Despite progressive management strategies that advocate for worker autonomy, the use of IT for monitoring has been on the rise (Dunn, 2006; Maher, 2003), a trend foreseen in prior organizational scholarship (Sewell, 1998; Zuboff, 1988). Some firms, such as Proctor & Gamble, have at times chosen to impose strict controls, requiring employees to obtain permission from managers to access internet web pages other than a certain list of pre-approved sites (Glazer, 2012). Telecommuting, too, has incited controversy in terms of its benefits and drawbacks. Yahoo!, for example, phased out telecommuting, while other firms have installed software to track employees' online behavior during telecommuting work (Shellenbarger, 2012).

Considerable variation exists in terms of how a firm uses IS practices to manage worker autonomy and collaboration (D'Arcy et al., 2014). Firms have historically adopted different levels of information exchange and collaboration through IS technologies and practices and allowed different levels of autonomy in their employees' access to IS technologies and information. While firms often support highly collaborative IS practices, they also often seek to reduce employees' autonomy through practices such as closely monitoring employees' IT use and other activities during work hours or limiting employees' flexibility to choose the time and location of their work activities. Recently, the COVID-19 crisis has compelled employers to embrace a culture of flexibility in accommodating work-from-home arrangements enabled by online collaboration systems to mitigate the otherwise negative performance effects of the pandemic. At the same time, however, many employers have combined the shift to online collaboration tools with draconian limits on employees' autonomy in their efforts to maintain high levels of productivity for employees working at home (Scalerandi, 2020). Some employers have adopted intrusive techniques such as constant monitoring of employees' computer and mobile phone screens, internet activity, and physical location (Satariano, 2020).

2.2.1 Collaborative IS Practices, Empowering HR Practices for IT Professionals, and IT Investments

We offer two theoretical arguments for how collaborative IS practices can create positive synergies with empowering HR practices and IT investments. First, collaborative IS practices complement empowering HR practices in a successful organization-wide adoption of acquired IT resources. Collaborative IS practices promote the use of tools that are instrumental in the free exchange of ideas, coordination, and collaboration in organizations. They allow employees to collectively adopt IS technologies, and therefore complement empowered IT professionals in implementing and operationalizing the firm's IT investments. IT professionals not only provide and support IT tools but also often provide training for their use (Ahuja & Thatcher, 2005; Kankanhalli et al., 2005). Together, the combination of

[3] Vessey and Sravanapudi (1995) describe in detail how CASE tools support the collaborative process in software engineering and help make that process more collaborative. CASE tools make it easier for teams to collectively surmount challenging technical hurdles, and thus they facilitate collaborative IT development overall. As Vessey and Sravanapudi (1995) argue, "at the team level the [CASE] tool must facilitate information sharing and provide monitoring capabilities" (p. 85). CASE tools manage the workflow among IT practitioners and make it more transparent to each team member what others in the team are doing. Such tools facilitate storing and retrieving modules of work from a centralized repository, making it easy for team members to view and access multiple versions of a document checked into the repository. As computer networking tools have become even more ubiquitous since the publication by Vessey and Sravanapudi (1995), CASE tools have become more collaboration-oriented, with many explicit and implicit mechanisms for the exchange of information built directly into the technologies.

training, autonomy, and incentive practices that empower IT professionals and organization-wide collaborative practices can help create an organizational culture that rewards information sharing and encourages creative and exploratory behavior among other employees. Researchers have found that the use of collaborative tools helps build connectedness and trust among employees, especially where efforts to create a team-oriented culture with supportive informal relationships complement substantive, collaborative work (Bos et al., 2002; Moore et al., 1999; Zheng et al., 2002). Such supportive informal relationships can enable a firm's employees to better assimilate the know-how required for effective IS use and, therefore, enhance the value of the firm's IT investments. For example, Gust et al. (2017) showed that a weak data-sharing culture and lack of interfunctional collaborations in a utility company resulted in the implementation failure of an innovative data analytics system. In another example, collaboration through Lotus Notes failed to gain traction in one particular firm, in part because managers failed to provide adequate training for its use (Orlikowski, 1992). These two examples illustrate the mutually reinforcing effects of and the complementarities between empowering practices for IT professionals and collaborative organization-wide IS practices for optimizing IT investments.

Second, collaborative IS practices help empowered HR professionals implement and operationalize the acquired IT systems in the organization through connecting functions within the organization. Collaborative software tools facilitate knowledge sharing and information access; these include issue-tracking tools, distributed project software, document source repositories, and enterprise applications (Grudin, 1994; Tafti et al., 2007). By actively encouraging the use of such tools to foster a culture of sharing, a firm can help its IT professionals in their efforts to operationalize the firm's IT investments. Further, collaborative IS practices make employees more self-sufficient and enable them to transition to other functional areas as needed, thus complementing a flexible work structure (Ulrich, 1998). Collaborative IS practices bring transparency into the complexity of interdependent organizational processes, thus enabling firms to better leverage their IT investments. For example, Yeow et al. (2018) demonstrated how organization-wide collaborative IS practices that facilitated cross-business unit collaborations, combined with empowering HR practices for IT professionals (i.e., using a process modeling tool), helped a large corporation in the design, realization, and operationalization phases of implementing an enterprise system. Yet collaborative IS practices enable such positive outcomes only if combined with empowering HR practices that provide high levels of support for firms' IT personnel (Boughzala & De Vreede, 2015; Olson & Olson, 2000). When IT professionals are empowered through incentives and practices that foster a culture of learning and worker autonomy, they can help promote and enable collaborative IS practices more effectively among the firm's other employees.

Therefore, we posit that IS practices that foster a culture of collaboration can help amplify complementarities between IT investments and HR practices that empower IT professionals.

H2a: Collaborative IS practices have a positive effect on the complementary relationship between IT investments and empowering HR practices for IT professionals.

2.2.2 Autonomy-Enhancing IS Practices, Empowering HR Practices for IT Professionals, and IT Investments

We offer two theoretical arguments for how autonomy-enhancing IS practices can create positive synergies with empowering HR practices and IT investments. First, autonomy-enhancing IS practices enable employees to make their own decisions, access information, and perform a multitude of tasks without direct mediation of their superiors (Ahuja & Thatcher, 2005). They also empower employees to act creatively, initiate contacts, and find sources of information beyond the confines of the organizational hierarchy. Empowered by collaborative IS practices, employees can prepare for challenging tasks (Bandura, 1977). In addition, such practices enhance employees' self-efficacy when it comes to adopting new IS technologies (Thatcher & Perrewe, 2002). For IT professionals specifically, such empowerment and enhanced self-efficacy can help them support other employees when adopting IS technologies, transitioning to automated business processes, or coping with other workplace changes resulting from the implementation of IS technologies (Compeau & Higgins, 1995; Lewis et al., 2003). For example, analyzing the implementation of Sales Force Automation, Porter and van den Hooff (2020) showed that combining the new system with the provisioning to employees of laptops, internet access, and other mobile technologies facilitates the adoption of the system. In another example, Beaudry and Pinsonneault (2005) analyzed the implementation of a new IT system for account managers at two large North American banks and showed that perceived autonomy over the technology and work system—provided by combining the new IT system with laptops and internet access—together with support and training from IT staff, encouraged a benefit-maximizing adoption behavior among employees. Therefore, autonomy-enhancing IS practices can complement the attempts of empowered IT professionals to realize the benefits of firms' IT investments.

Second, autonomy-enhancing IS practices can encourage creative, independent, and exploratory behavior (Ahuja & Thatcher, 2005). Since IT is a general-purpose technology that serves as a lower-cost substitute for routine or manual unskilled labor, the demand for labor has shifted toward tasks that require flexibility, innovation, information processing, and decentralized decision-making (Autor et al., 2003; Bresnahan et al., 2002). As data and information become widely accessible within the organization, their value is more likely to be realized when employees are empowered to leverage IT capabilities. Evidence suggests that enabling information access and decentralized decision-making among employees is a critical factor in the success of teams and can allow employees to apply greater levels of creativity and motivation in achieving professional goals that also benefit the firm (Autor et al., 2003; Bresnahan et al., 2002). For example, Beaudry and Pinsonneault (2005) revealed that combining the implementation of a new IT system with enhanced autonomy—achieved by providing laptops and internet access to employees—allowed employees to find innovative and unintended beneficial uses for the system. Analyzing the adoption of a new IT system for account managers in a large bank, Beaudry and Pinsonneault showed that by taking advantage of the complementarities between the new system, enhanced autonomy, and IT staff support, account managers could use the system for analyzing competitors' activities and benchmarking their activities against them, even though this was not an explicit function of the system. Since IT professionals are empowered with training, autonomy, and incentives, they can better encourage and support the adoption of autonomy-enhancing IS practices among other employees; thus, the complementary relationship between IT investments and empowering practices for IT professionals should be enhanced as firms adopt such IS practices.

H2b: Autonomy-enhancing IS practices have a positive effect on the complementary relationship between IT investments and empowering HR practices for IT professionals.

3 Research Design and Methodology

3.1 Data

This study uses data from several sources. The measures of IT investments and IS practices are based on a series of surveys administered by InformationWeek from 2002 through 2006, enabling us to build a panel dataset. The InformationWeek surveys were conducted using the same process that was used for other surveys, such as the InformationWeek's IW500 Rankings and the InformationWeek Annual Salary Reports, which have been used in many prior studies (Havakhor et al., 2019; Mithas & Krishnan, 2008; Whitaker et al., 2010; Whitaker et al., 2019). The surveys targeted the senior-level IT managers of major corporations (e.g., senior IT managers, vice presidents, e-commerce directors, and C-level executives), collecting data on IT department operations, as well as on general firm operations and investments that might be relevant to understanding the role of IT initiatives in the firm (Whitaker et al., 2007). In 2003, InformationWeek included an additional multi-item survey question upon which the measures of HR are based. We combined this panel of survey data with panels of archival data from Compustat and the Bureau of Economic Analysis (BEA). We compiled an initial panel on IS practices consisting of 457 firms between 2002 and 2006, accounting for 1,111 observations from the set of InformationWeek surveys. We then matched the firm-year observations from these surveys to Compustat and BEA datasets to obtain variables pertaining to firm performance and associated controls, resulting in a final unbalanced panel dataset of 228 firms with 736 firm-year observations.

Table 2a reports summary statistics and correlations of primary variables in this final sample, and Table 2b reports the number of observations in each year for the final sample. The length of the panel is such that it contains enough longitudinal variation to correct for firm-level unobserved heterogeneity through a fixed-effects panel analysis while also remaining short enough that it is reasonable to impose the *quasi-fixed assumption* in factors related to organizational practices, an important imposition in this context because we assume that the HR-related constructs are constant over the length of the panel. As with several other prior studies, Aral et al. (2012) employed a similar assumption pertaining to organizational variables. Our analysis exploits the changes in IT investments and IS practices over time within firms in the panel dataset.

To assess the representativeness of our sample, we used the larger population of 9,000 firms from Compustat that publicly reported the same financial items used in our models in the same year of 2003. We found no significant difference in profitability, firm size, industry conditions (turbulence, market size growth, annual change in concentration), or industry average IT capital intensity (measured using BEA data) between firms in our sample and those in the larger population. We also compared the mean of the main variables for the firms that were included in our sample and those that were excluded due to missing values (reported in Table 6).

Table 2a. Correlation and Summary Statistics (N = 736)

Variable	Abbreviation	VA	HR	Auton IS	Collab IS	Incent HR	Train HR	Auton HR	IT	L	K
Value-added	VA	1.00									
General empowering HR practices	HR	0.12	1.00								
Autonomy IS	Auton IS	0.05	0.40*	1.00							
Collaborative IS	Collab IS	0.09*	0.23*	0.35*	1.00						
Incentives HR	Incent HR	0.06	0.85*	0.26*	0.13*	1.00					
Training HR	Train HR	0.12	0.77*	0.34*	0.19*	0.49*	1.00				
Autonomy HR	Auton HR	0.09	0.60*	0.33*	0.20*	0.24*	0.24*	1.00			
IT investment	IT	0.67*	0.18*	0.03	0.07	0.14*	0.13*	0.14*	1.00		
Labor	L	0.96*	0.09	0.06	0.08*	0.05	0.10	0.05	0.63*	1.00	
Capital	K	0.67*	0.12	0.02	0.09*	0.08	0.10	0.11	0.43*	0.59*	1.00
M		27444.3	8.85	3.01	1.82	3.42	2.76	2.67	344.1	16155.68	8356.8
SD		43006.5	1.40	1.51	1.15	0.78	0.57	0.51	726.7	25201.11	18700.1
Min		909.1	0.00	0.00	0.00	0.00	0.00	0.00	3.2	194.65	46.3
Max		332748.3	10.00	5.00	5.00	4.00	3.00	3.00	8155.5	182395.5	176932.2

Note: $*p < 0.05$. Dollar figures are in tens of thousands for IT investment (IT), and in thousands for value-added (VA), labor (L), and capital (K).

Table 2b. Number of Observations for Each Year

Year	2002	2003	2004	2005	2006	Total
Frequency	148	224	154	123	87	736
Percent	20.11	30.43	20.92	16.71	11.82	100

We utilized the unbalanced structure of the panel data to test for the possibility of selection bias due to attrition using a version of the Nijman-Verbeek test (Wooldridge, 2002). If selection bias due to attrition influences firm performance beyond factors already accounted for in the model, then a forward selection indicator—with a value of 1 when a firm present in year t of the sample period is also present in year $t + 1$, and 0 otherwise—would have a significant coefficient estimate. The results of the Nijman-Verbeek test in our empirical models show no evidence for selection bias stemming from the structure of the unbalanced panel. Further, the results of the Nijman-Verbeek test show that variables are comparable across years despite firms entering and exiting the sample. After describing the main measures and empirical model below, we provide details about the identification strategy and additional evidence revealing how expected complementarities drive firms' simultaneous adoption of IT investments, HR practices for IT professionals, and IS practices for all employees.

3.2 Variables

We introduce the primary variables here and detail the entire list of variables in Appendix A. The measure of *empowering HR practices for IT professionals* (HR) incorporates practices that foster a team environment, offer balanced performance incentives, provide training programs, offer higher levels of worker autonomy, and generally improve worker conditions. This measure is based on a multi-item survey question in 2003 in which respondents were asked the following: "Which of the following opportunities and rewards do you provide to your IT staff? (Choose ALL that apply.)" Here, we interpret the adoption of opportunities and rewards extending over multiple years. The measure of HR practices for IT professionals comprises the following items: (1) potential for promotion, (2) e-learning, (3) encouragement for innovative new IT solutions, (4) opportunities to earn cash or stock bonuses, (5) stock options, (6) permission to telecommute, (7) career path planning, (8) company-paid educational or training opportunities, (9) recognition for work well done, and (10) increased responsibilities to keep the work challenging. As mentioned in the survey question, these measures only capture specific IT staff-related practices (such as encouragement for innovative new IT solutions) in addition to more general practices (such as stock options) as they relate to the IT staff of the organization only and not to employees more generally. Thus, these practices pertain to the management of IT staff and are hence entirely distinct from technology-related IS practices directed at the entire organization.

The HR construct is then disaggregated into more specific components: incentives HR practices (*Incent HR),* training HR practices (*Train HR*), and autonomy-enhancing HR practices (*Autonomy HR*). Incentive-enhancing practices are motivational and, as a result, are considered an important aspect of empowering HR practices (Lepak et al., 2006; Zimmerman, 2000). For example, the distribution of ownership rights to employees through stock incentives empowers employees by giving them a sense of psychological ownership and investment in the fruits of their labor— and, in turn, contributes to their psychological empowerment (Zimmerman, 2000). Opportunities for promotion and receiving recognition for achievements enhance employees' self-determination (Conger & Kanungo, 1988). Accordingly, we measured incentives HR practices as the combination of the following: (1) potential for promotion, (2) opportunities to receive cash or stock bonuses, (3) stock options, and (4) recognition for work well done. Training practices, such as mentoring employees on their career path, and autonomy-enhancing practices, such as promoting more flexibility in work structures, capture the components of empowering HR practices related to delegation and self-efficacy (Conger & Kanungo, 1988). Training HR practices comprise the following: (1) company-paid educational or training opportunities, (2) career path planning, and (3) e-learning. Finally, autonomy-enhancing HR practices include (1) encouragement for innovative new IT solutions, (2) permission to telecommute, and (3) increased responsibilities to keep the work challenging.[4]

To measure IS practices for all workers, we used InformationWeek panel data from 2002 to 2006. Respondents were asked to select from among a list of effective technology-related steps that managers across the entire organization implemented to raise worker productivity in the 12 months leading up to the annual survey. We classified IS practices into two groups. First, some IS practices enable autonomous access to information, such that data, knowledge, and information become more accessible to workers (*Auton IS*). These practices include allowing more workers to access the internet, outfitting workers with laptops and supporting mobile access, and using tools to support decentralized decision-making and personal productivity. The next category of IS practices enables collaboration and information sharing (*Collab IS*). These technology-related practices facilitate collaboration and communication among workers through deploying collaborative hardware, collaborative software development tools, instant messaging, internet-enabled telephones, and enterprise applications.

We also constructed alternative measures for *Auton IS* and *Collab IS* that leave out specific measurement items to conduct a sensitivity analysis. These alternate measures are discussed below in the results section (see Footnote 8). The survey question for these constructs reads: "Which of the following are the most effective technology steps managers in your organization have made in the past 12 months to raise worker productivity? (Choose ALL that apply.)" The collaborative IS construct comprises the following: (1) deploying collaborative hardware such as videoconferencing, (2) deploying collaborative software such as intranet or email, (3) using instant messaging, (4) deploying VoIP applications, (5) modeling business processes using CASE or related tools, and (6) implementing enterprise-level applications such as enterprise resource planning (ERP). The autonomy IS construct includes (1) allowing more workers to access the internet, (2) supplying workers with laptop computers, (3) deploying wireless devices such as handheld PCs and cell phones, (4) upgrading desktop productivity software, and (5) upgrading desktop operating systems. The components and aggregation method of the measures are detailed in Appendix A.

IT Expenditure (IT) is the firm's worldwide IT budget in the prior fiscal year, including capital and operating expenses for infrastructure such as telecommunications, networking, hardware, applications (maintenance and development and packaged), internet-based costs, salaries and recruitment, IT services/outsourcing, and training. Respondents provided this figure in terms of percentage of revenue, which was then multiplied by annual sales to get the total value of IT capital. Our choice of a flow-type IT investment measure is in-line

[4] To construct the aggregated and disaggregated HR practices variables, as done in Aral et al. (2012) and Bresnahan et al. (2002) for multidimensional measures, we normalized each measure by subtracting the mean of each response and dividing by the standard deviation, and then we normalized the sum of normalized items. The Kaiser-Meyer Olkin measures of internal consistency are provided in Table A1 (see Appendix A for further details).

with other literature that uses the flow of IT investments to explain flow-type dependent measures, such as firms' financial or market performance (Aral & Weill, 2007; Bharadwaj et al., 1999; Mithas et al., 2017; Rai et al., 1997). Rai et al. (1997) argue that flow-type measures of IT investments are appropriate in rapidly changing environments, where current investments can have a short-term profit-enhancing effect and past investments might rapidly become obsolete. In addition, the use of a flow-type measure of IT investments can help prevent potential measurement errors in cumulative stock measures (Kleis et al., 2012).[5]

Our primary dependent variable is firm productivity, measured as *Value Added* (VA), which is the difference between annual sales and material costs, similar to the measure used in Bresnahan et al. (2002), Brynjolfsson and Hitt (2003), and Brynjolfsson et al. (2002). We also incorporate the standard control variables used in a production function that include labor expenses (L), capital (K), indicator variables for each year, and (for non-fixed-effects models) industry segment indicators at the two-digit North American Industry Classification System (NAICS) level. Our production function models use control variables similar to those used in Bresnahan et al. (2002); Brynjolfsson and Hitt (2003); and Brynjolfsson et al. (2002).

3.3 Empirical Framework

To test the main hypotheses, we used a common production function framework (e.g., Aral et al., 2012; Bresnahan et al., 2002; Tambe et al., 2012).

$$\log(VA) = \log(S - M) = f(L, K, IT, HR; \text{controls}) \quad (1)$$

The dependent variable, log(VA), is a measure of firm-level productivity; S is sales; M is materials; L and K are labor investment and capital investment, respectively; and IT represents total firm IT expenditure. For firm *i*, in year *t*:

$$\log(VA)_{i,t} = \beta_0 + \beta_1 \log(L)_{i,t} + \beta_2 \log(K)_{i,t} + \beta_3 \log(IT)_{i,t-1} + \beta_4 \log(IT)_{i,t-1} \times HR_i + \Sigma\beta_t \, Year_t + u_i + \varepsilon_{i,t} \quad (2)$$

After establishing the baseline complementarities, we expanded the model to complementarities between HR and IS practices in order to test H2a and H2b:

$$\log(VA)_{i,t} = \beta_0 + \beta_1 \log(L)_{i,t} + \beta_2 \log(K)_{i,t} + \beta_3 \log(IT)_{i,t-1} + \beta_4 (\log(IT)_{i,t-1} \times HR_i \times \text{Collab IS}_{i,t}) + \beta_5 (\log(IT)_{i,t-1} \times HR_i \times \text{Auton IS}_{i,t}) + \beta_6 \, \text{Collab IS}_{i,t} + \beta_7 \, \text{Auton IS}_{i,t} + \mathbf{X_C} \boldsymbol{\beta_C} + \Sigma\beta_t Year_t + u_i + \varepsilon_{i,t} \quad (3)$$

For brevity in writing the above equation, we represent the matrix of controls $\mathbf{X_C} \boldsymbol{\beta_C}$ to include all two-way interaction terms that are implied by the three-way interaction terms, which we estimate and discuss in our presentation of results.

3.4 Identification

One challenge in assessing production complementarities is the potential endogeneity of inputs—in particular, their correlation with the error term (Cassiman & Veugelers, 2006). For example, shocks in firm cash flow (in the form of unexpected windfalls) would encourage the firm to invest more in IT, which could bias both the estimated output elasticity of IT and the interaction effect with HR.[6] Thus, we conducted a number of baseline tests with an instrumental variables approach using industry-level estimates from the BEA as instruments.

BEA provides annual estimates at the three-digit NAICS industry level of investments in personal computers, mainframes, computer terminals, systems integrators, prepackaged software, custom software, and in-house software (Fox, 2011). We divided each of these items by total annual investment in equipment to obtain separate industry-level instruments for each component of industry-level IT intensity, and we also used three-year lagged levels as well as three-year changes of these measures. These figures are part of BEA's publicly available data on investment in fixed assets reported at two- and three-digit NAICS levels. The data comes from a combination of mandatory surveys of firms conducted by the US Census Bureau and the Bureau of Labor Statistics (Fox, 2011). We used three-year lag values for a number of components of industry IT intensity estimates and prior three-year changes in the same variables from the BEA data source. We note that using one- or two-year lags and one- or two-year changes in industry IT intensity delivers similar results.

BEA's industry-level estimates have a number of attributes as exogenous instruments. Since BEA's estimates are derived from a separate population of

[5] Note that we are using a fixed-effects panel framework; hence, even if we were to use accurate estimates of IT capital stock instead of IT investment flows, the differences between these measures would not be very meaningful in this econometric framework, which extracts the deviations in levels from a baseline level over the sample time period. Because IT capital exhibits steep rates of depreciation, which, as Jorgenson (2001) discusses, creates additional estimation problems in a production function, we do not believe it would provide any improvement over using IT investment flows in our setting.

[6] As a robustness check, we also conducted reverse-causality tests that showed that prior values of firm productivity and their interactions with HR or IS practices have no significant effect on the demand for IT investments (see Table C3 in Appendix).

representative US firms in each industry, errors in measurement should be uncorrelated with our firm-level measures of IT investment. The US Census Bureau conducts a number of mandatory surveys of firms periodically, resulting in a representative sample for each NAICS industry classification (Fox, 2011). BEA reports annual industry-level estimates of detailed IT investment categories based on this data, and these estimates are unlikely to be influenced by the investments of any single firm in our dataset. By contrast, prior research suggests a number of mechanisms by which industry-level IT investments, and also changes in IT investments by a firm's industry peer group, can serve as an exogenous shock that influences the firm's own IT investments (Mithas et al., 2013). By reacting to industry levels of IT investments, the firm's own IT investments will mediate any effect of the industry's IT investments on the firm's performance.[7] While we cannot reject the possibility outright, we find it difficult to identify a specific economic mechanism by which idiosyncratic shocks to performance of firms in our sample could affect the industry-level IT estimates for the BEA's firm population. This possibility is further mitigated by the three-year lags in the instruments, though one-year lags and one-year prior levels of BEA's industry IT estimates yield similar results when used as instruments. Forman et al. (2012) use a similar instrument.[8]

A potential limitation in our instruments is that a firm in our sample might provide IT technology spillovers to the rest of its industry; however, to do so, the firm would have to be an extraordinary technological leader in its industry. Further, any unobserved firm or managerial capabilities that are stable for a period of four years and change slowly are accounted for as fixed effects, which, in addition to the control variables and interaction variables of interest, form what is known as the *quasi-fixed* assumption, discussed in Aral et al. (2012). We used the fixed-effects panel model with robust clustered standard errors as the primary method of hypothesis testing in our study because it is parsimonious and addresses the most serious sources of unobserved firm heterogeneity; we conducted a sensitivity analysis to examine the consistency of our main model results with a number of alternative generalized method of moments (GMM) estimators using the instrumental variables discussed here. We also explored the potential role of input endogeneity and its potential influence on the results.

4 Results

4.1 Results of Hypotheses Tests

Table 3 presents the results of two-way complementarities between IT investments and HR practices for IT professionals in their effects on firm productivity.[9] We found support for H1, which predicts that HR practices that empower IT professionals positively moderate the effect of IT investments on firm productivity. Consistent with H1, we found a positive and statistically significant coefficient estimate for HR × IT across multiple models.

We assessed the sensitivity of our coefficient estimates to potential sources of endogeneity using alternative sets of instrumental variables and variants of GMM to compare with the fixed-effects panel model. Column 1 shows the panel fixed-effects results without HR or IT interactions.[10] Column 2 takes the interaction of HR and IT to be endogenous and uses three-year lagged levels and three-year changes in BEA's industry IT estimates as instruments. In Column 3, we added an instrument of one-year prior value of the firm's projected IT investments (based on managers' forecasts in the prior year). As Columns 1-3 show, the results are similar with and without the lagged projected value of IT investments as an instrument.[11] In Columns 4-7, we show the cross-sectional instrumental variables results for the year 2003.

[7] We conducted tests of weak instruments and find Cragg-Donald statistics in the range of 13-15, suggesting that the instruments are not weak. The correlations between these instruments and annual IT investments are shown in Table A4 of the Appendix.

[8] This approach is common in prior econometric studies. Angrist and Pischke (2008) explain how the aggregation of theoretical constructs at a broader level (and from separate sources) can serve as an exogenous instrument; this point is echoed in Angrist and Pischke (2010) and demonstrated in Card and Krueger (1992a, 1992b). In their comments about the studies by Card and Kreuger (1992a, 1992b), Angrist and Pischke (2010) articulate support for the use of aggregate constructs for instrumental variables if individuals in the main sample do not affect the aggregate level variables. This is the same spirit in which we employ the industry-level IT data from the BEA.

[9] Note that because our independent variables of interest are mutually reinforcing in a causal sense, in that IT investments can influence the effect of IS practices and vice-versa, our models use a moderation logic (i.e., individual main effect coefficients should not be interpreted as total effects), in contrast to a mediation logic that may be appropriate in other contexts. We thank a reviewer for this discussion.

[10] The coefficient estimate on IT (0.0306) in this column corresponds to an economic interpretation: An increase in IT investments of $1 corresponds to an increase in value-added of $2.5 (=0.0306(27.4)/0.34), roughly consistent with the economic interpretation in all alternative models in this study.

[11] Using the lag of IT as an instrument mitigates the effect of cash flow shocks and better reflects a "long-run iteration of complements moving together" (Bresnahan et al., 2002, p. 363). Since it is a measure of projected and not actual investments, its effect on current year performance is heavily mediated by the actual IT investments in the following year, consistent with its role as an exogenous instrument.

Table 3. Tests of Hypothesis 1: Firm Productivity Effects of Two-way Interactions Between HR Practices for IT Professionals and IT Investments

	(1) Fixed-effects (FE) panel	(2) Panel FE instrumental variables	(3) Panel FE instrumental variables	(4) GMM	(5) GMM	(6) 2SLS	(7) GMM
H1: HR × log(IT)		0.103**	0.115**	0.185***	0.187***	0.242**	0.124***
		(0.050)	(0.046)	(0.034)	(0.031)	(0.094)	(0.034)
HR				-0.805***	-0.812***	-1.06***	-0.535***
				(0.153)	(0.139)	(0.409)	(0.150)
log(labor)	0.625***	0.720***	0.651***	0.718***	0.718***	0.700***	0.792***
	(0.069)	(0.022)	(0.027)	(0.029)	(0.029)	(0.035)	(0.030)
log(IT)	0.031***	0.029***	0.045***	0.133***	0.133***	0.100**	0.068***
	(0.010)	(0.010)	(0.014)	(0.019)	(0.018)	(0.040)	(0.025)
log(capital)	0.127***	0.055**	0.079***	0.037**	0.037**	0.054**	0.052***
	(0.039)	(0.023)	(0.029)	(0.016)	(0.016)	(0.024)	(0.014)
Constant	2.79***	2.45***	2.78***	2.06***	2.07***	2.25***	1.50***
	(0.411)	(0.176)	(0.225)	(0.258)	(0.256)	(0.317)	(0.252)
2-digit NAICS industry dummies	Not needed	Not needed	Not needed	Included	Included	Included	Included
Year dummies	Included	Included	Included	Not needed	Not needed	Not needed	Not needed
Observations	1,209	721	533	139	139	139	139
Firms	387	223	205	139	139	139	139
F-statistic	60.80***						
Chi-squared		15046541***	11255679***	16091***	17898***	2618***	17061***

Note: Dependent variable is log(VA), the log of value-added as a measure of firm productivity. The estimate for the direct effect of HR does not exist for models reported in Columns 1-3 because they report fixed-effects results, and HR values in our sample do not vary over time. Robust clustered standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Column 1: Fixed-effects panel with robust standard errors.
Column 2: Exogenous instruments are three-year lag and three-year change in industry intensity in PCs, mainframes, printers, data storage devices, computer terminals, tape drives, systems integrators, pre-packaged software, custom software, and in-house software, as well as the firm's projected IT investments from the prior year. HR × IT is treated as endogenous.
Column 3: HR and HR × IT are treated as endogenous; same instruments as Column 2 with the addition of the one-year prior value of firm's projected IT investments.
Column 4: Year 2003 only. Same instruments and endogenous variables as Column 3.
Column 5: Current year levels of instruments are used in place of three-year lagged levels. Otherwise, the same instruments and endogenous variables as Column 3.
Column 6: Same instruments and endogenous variables as Column 5 except 2SLS-style errors are used.
Column 7: HR, IT, and HR × IT are treated as endogenous. The same instruments as Column 5.

Column 4 reports a GMM model in which HR and its interaction with IT are taken as endogenous with the same instruments as Column 3. In Column 5, we present a GMM model in which the current year values of BEA's industry-level IT intensity instruments are used in place of the three-year lagged values from the same source. Column 6 of this table shows the results of a two-stage least squares (2SLS) model.[12] In the last column, in addition to HR and HR-IT interaction, IT investment is taken as endogenous. The Hansen *J* test statistic (25.4 at 18 degrees of freedom) is insignificant ($p > 0.1$), suggesting that second-stage errors are uncorrelated with the instrumental variables. All first-stage models have significant *F*-statistics. Controls for each two-digit NAICS industry are included in the cross-sectional models (Columns 4-7) and are unnecessary (i.e., automatically accounted for) in the fixed-effects models (Columns 1-3). Controls for each

[12] The only difference from the single-equation GMM is that 2SLS employs the assumption of conditional homoscedasticity on the error terms (Hayashi, 2000).

year indicator are included in the fixed-effects models (Columns 1-3) and are unnecessary in the cross-sectional models (Columns 4-7). These indicators are omitted from Table 3 for brevity. Overall, our results suggest strong support for complementarities between IT investments and HR practices that empower IT professionals, in line with prior studies (e.g., Bresnahan et al., 2002). The results and sensitivity analysis in Table 3 provide the confidence needed to proceed with the more parsimonious fixed-effects panel estimates.

We also found support for H2a, which predicts that collaborative IS practices have a positive effect on the complementary relationship between IT investments and HR practices. The hypothesis is modeled as a three-way complementary system (*IT* × *HR* × *Collab IS*) shown in the panel production model coefficients in Columns 1 and 2 of Table 4. Column 1 shows fixed-effects results and Column 2 shows random-effects results that control for all two-digit NAICS indicators. All models include indicators for each year. As both columns of Table 4 show, the positive coefficient estimate of the interaction term *IT* × *HR* × *Collab IS* is significant at $p < 0.05$.

We did not find support for H2b, which predicts that autonomy-enhancing IS practices have a positive effect on the complementary relationship between IT investments and HR practices. Among the potential reasons for this result, factors such as identity formation in organizational culture may supersede explicit incentive schemes (Akerlof & Kranton, 2005), as discussed later.[13]

4.2 Additional Analyses

We conducted additional analyses to explore more refined mechanisms behind the three-way complementarities driving the positive and significant interaction term *IT* × *HR* × *Collab IS* by disaggregating the measure of HR into three specific sets of practices: incentives (*Incent HR*), autonomy (*Autonomy HR*), and training (*Train HR*). In particular, we considered whether collaborative IS practices strengthen the complementary relationship between IT investments and training practices. We found support for this three-way complementary system (*IT* × *Train HR* × *Collab IS*) in the fixed-effects model (see Table 5). Columns 1 and 2 show fixed-effects and random-effects results, respectively. The models in Table 5 use the same industry and year controls as those in Table 4 and include all two-way and three-way combinations of interactions among HR, IT, and IS practices. As Columns 1 and 2 of Table 5 show, the positive coefficient estimate of the triple interaction term *IT* × *Training HR* × *Collab IS* is significant at $p < 0.10$.[14]

Given our study's focus on how the combination of HR practices and IS practices influences a firm's returns on IT investments, the magnitude of some negative interaction effects is worth considering. As seen in Columns 1 and 2 of Table 4, we observe an unexpected negative two-way interaction between collaborative IS and general HR practices; however, this effect disappears at a more refined level of analysis in which the HR measures in the results shown in Columns 1 and 2 are separated into training HR, autonomy HR, and incentive HR practices after also taking into account the magnitude of the estimates in Table 5. Within the expanded models in Table 5, the apparently negative two-way interaction of *Collab IS* × *Train HR* represents the effect at the (practically implausible) level of zero IT investments, which is in line with our overall thesis. To understand how this two-way interaction changes with IT investments, we consider the three-way interaction term in Column 1 of Table 5, of 0.00837, which suggests that the interaction of *Collab IS* × *Train HR* becomes positive at a threshold of (0.0399/0.00837) = 4.77, representing a value of $\exp(4.77) \times 10{,}000$ = \$1.18 million in IT investments.[15]

This threshold is below our reported sample mean of \$3.4 million in annual IT investments. We also observe a substitution effect between *Collab IS* and log(IT), which is expected because general monetary IT investments can be channeled to other productivity-enhancing mechanisms that might substitute for collaborative IS practices.

Because work practices and IT investments may entail a number of unobservable adjustment costs (Bresnahan et al., 2002), we took steps to account for unobserved differences between firm capabilities and adjustment costs using a fixed-effects panel and a number of GMM-based instrumental variables models. We also used an alternative but common approach that studies the source of correlations between sets of practices and investments (Arora & Gambardella, 1990; Cassiman & Veugelers, 2006). In Appendix C, we present the results of an analysis with that framework to better understand how firms choose to undertake different investments or practices together.

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[13] Results in Appendix C suggest that autonomy IS practices play a role in adoption complementarities (see Section 4.2).

[14] We also conducted a sensitivity analysis to address potential measurement concerns regarding specific items used in the constructs *Collab IS* and *Autonomy IS.* In particular, we constructed *Collab IS Alt, Auton IS Alt 1*, and *Auton IS Alt 2* by omitting the items related to enterprise/ERP applications, laptop computer, and support for desktop operating systems, respectively. Empirical results using these alternative constructs are shown in Table B1 of Appendix B and are consistent with the main results.

[15] We use coefficients estimated at five decimal places for this calculation, although coefficients appearing in Table 5 are rounded to three decimal places.

Table 4. Tests of Hypothesis 2, Full Specification of Three-way Interactions Between IS Practices, HR Practices for IT Professionals, and IT Investments

	(1) Fixed effects	(2) Random effects
H2a: Collab IS × HR × log(IT)	0.008* (0.004)	0.008** (0.004)
H2b: Auton IS × HR × log(IT)	-0.004 (0.004)	-0.003 (0.004)
log(capital)	0.066 (0.042)	0.082*** (0.027)
log(labor)	0.709*** (0.063)	0.742*** (0.046)
log(IT)	0.040*** (0.011)	0.056*** (0.013)
Collab IS	0.035** (0.015)	0.036** (0.0149)
Auton IS	0.001 (0.014)	-0.006 (0.014)
HR		0.030 (0.034)
log(IT) × HR	0.001 (0.007)	0.001 (0.007)
Collab IS × log(IT)	-0.008*** (0.003)	-0.008*** (0.003)
Auton IS × log(IT)	-0.000 (0.003)	0.001 (0.003)
Collab IS × HR	-0.042** (0.021)	-0.042** (0.021)
Auton IS × HR	0.016 (0.024)	0.009 (0.023)
F-statistic	43.8***	
Chi-squared		13848***

Note: Panel regression results with 736 observations, 228 firms. Dependent variable is log(VA), the log of value-added as a measure of firm productivity. The estimate for the direct effect of HR does not exist for the model reported in Column 1 because it reports fixed-effects results, and HR values in our sample do not vary over time. All models also include indicators for each year and indicators for each two-digit NAICS industry (the latter are automatically accounted for in the fixed-effects models). Huber-White robust clustered standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

After adjusting for a number of common driving factors, we found that empowering HR practices for IT professionals are associated with the adoption of autonomy-enhancing IS practices (Appendix Table C1) while the combination of collaborative IS and training HR practices is associated with the demand for IT investments (Appendix Table C2). Even though our results do not support hypothesis H2a with respect to complementarities involving autonomy IS practices, we found evidence of two-way complementarities in adoption, which is not surprising because managers sometimes undertake combinations of practices or investments that are not optimal for performance.

5 Discussion

Our goal in this research was to study how HR practices for training and incentivizing IT professionals and IS practices that affect all employees enable firms to derive greater value from their IT investments. We found that (1) *empowering HR practices for IT professionals* positively moderate the effect of IT investments on firm productivity, resulting in a two-way complementary relationship; and (2) *collaborative IS practices* have a positive influence on the complementary relationship between IT investments and HR practices, forming a three-way complementary relationship. These results suggest that the business value of IT is linked to the rewards and opportunities offered to IT professionals, who have a pivotal role in the effective deployment of IT in organizations.

Upon disaggregating HR practices further, we found that collaborative IS practices positively influence the complementarities between training HR practices and IT investments on firm performance. The support for this three-way interaction effect is consistent with how training, learning, and the distribution of knowledge have become an increasingly decentralized, collaborative, and technology-supported undertaking in firms.

Table 5. Expanded Specification of Three-way Interactions Between Training/Incentive HR Practices for IT Professionals, IS Practices, and IT Investments

Variables	(1) Fixed effects	(2) Random effects
Collab IS × Train HR × log(IT)	0.008** (0.004)	0.007* (0.004)
Collab IS × Autonomy HR × log(IT)	0.003 (0.003)	0.002 (0.003)
Collab IS × Incentive HR × log(IT)	-0.002 (0.005)	-0.001 (0.005)
Autonomy IS × Training HR × log(IT)	-0.002 (0.004)	-0.001 (0.004)
Autonomy IS × Autonomy HR × log(IT)	0.005 (0.004)	0.007* (0.004)
Autonomy IS × Incentive HR × log(IT)	-0.004 (0.005)	-0.004 (0.005)
Collab IS × log(IT)	-0.006** (0.003)	-0.006** (0.003)
Incentive HR × log(IT)	0.001 (0.014)	0.001 (0.012)
Collab IS × Incentive HR	0.009 (0.023)	0.004 (0.023)
Autonomy IS × log(IT)	-0.002 (0.003)	-0.001 (0.003)
Autonomy IS × Incentive HR	0.018 (0.022)	0.020 (0.022)
Autonomy HR × log(IT)	-0.011 (0.014)	-0.014 (0.010)
Collab IS × Autonomy HR	-0.013 (0.015)	-0.007 (0.014)
Autonomy IS × Autonomy HR	-0.020 (0.016)	-0.031** (0.016)
Training HR × log(IT)	0.001 (0.011)	0.005 (0.009)
Collab IS × Training HR	-0.040** (0.019)	-0.033* (0.018)
Autonomy IS × Training HR	0.004 (0.020)	0.002 (0.020)
log(Labor)	0.706*** (0.020)	0.743*** (0.016)
log(Capital)	0.066*** (0.020)	0.079*** (0.014)
log(IT)	0.045*** (0.010)	0.061*** (0.009)
Collab IS	0.028** (0.014)	0.030** (0.014)
Autonomy IS	0.009 (0.015)	0.003 (0.015)
Incentive HR		-0.021 (0.059)
Autonomy HR		0.094* (0.049)
Training HR		0.016 (0.040)
Constant	2.485*** (0.164)	2.046*** (0.183)
Observations	736	736
R-squared	0.835	
Number of gvkey	228	228
F-statistic	93.55	
F-test	0	
Chi-squared		6452

Note: Panel regression results with 736 observations, 228 firms. Dependent variable is log(VA), the log of value-added as a measure of firm productivity. All models also include indicators for each year and indicators for each two-digit NAICS industry (the latter are automatically accounted for in the fixed-effects models). Huber-White robust clustered standard errors in parentheses. The estimate for the direct effect of HR does not exist for the model reported in Column 1 because it reports fixed-effects results, and HR values in our sample do not vary over time. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Table 6. Comparison of Main Variable Averages Between Firms in Sample and Firms Excluded Due to Missing Variables or Nonrepresentation in the *InformationWeek* Survey

Variable	Mean: excluded	Mean: included	*p*-value	*t*-stat
VA	9.368	9.538	0.104	-1.628
Capitol	7.445	7.702	0.089	-1.705
Labor	8.705	8.907	0.070	-1.816
IT	4.832	4.817	0.916	0.1056
Collaborative IS	0.027	-0.008	0.592	0.5366
Autonomy IS	-0.011	0.229	0.000	-3.844***
HR	-0.163	0.034	0.214	-1.246
Incentive HR	-0.221	0.046	0.093	-1.684
Training HR	-0.004	0.001	0.975	-0.031
Autonomy HR	-0.176	0.0364	0.182	-1.339

Collaborative IS practices enable the formation of "communities of practice," wherein "joint sense-making and problem solving enhances the formation of strong interpersonal ties" (Wasko & Faraj, 2005, p. 27). These practices enhance and reinforce the degree to which training programs leverage IT investments. For example, collaborative IS practices can enable peers to refer to one another for questions. They can also enable multichannel systems of feedback that enhance relationships among employees and foster supportive environments for experimentation, learning, and supportive feedback. Training programs such as career path advising and employer-sponsored training can help develop a common ground among employees that sets the stage for effective collaboration (Olson & Olson, 2000). As collaborative IS practices take place across the organization, they drive a synergy between IT professionals and other functional business areas, creating a three-way system of complementarity between training practices, IT investment, and collaboration-enhancing IS practices.

5.1 Research Implications

Our results demonstrate the significance of HR practices for IT professionals in alignment with IS practices to realize greater firm-level productivity returns from investments in IT and have several implications for IS research. First, our study generates new insights into the interaction between HR and IT in the context of a specific form of knowledge work—the work of IT professionals. We build on and extend the existing IS literature exploring how complementary resources and capabilities enhance the value that firms gain from their IT resources (Aral et al., 2012; Bharadwaj et al., 2007; Melville et al., 2004; Saldanha et al., 2020). In particular, our work here extends prior studies examining complementarities between organizational practices and IT investments (Aral et al., 2012; Tambe et al., 2012). In addition, our finding that the effect of IT investments on firm productivity increases with training and incentives for IT professionals shows that the business value of IT is linked to the rewards and opportunities offered to IT professionals, employees who are instrumental to the effective deployment of IT in organizations. This finding further shows that while IT is an organization-wide asset, IT professionals are essential to fully realizing the potential benefits of IT investments. By considering empowering HR policies pertaining specifically to IT professionals, our results suggest that if IT professionals are well-trained, motivated, and empowered, they will be well-positioned to make better strategic choices when allocating IT investments and implementing IT projects.

Further, we explore a theoretical connection between the business value of IT literature (Bresnahan et al., 2002; Brynjolfsson & Hitt, 2003) and the literature on HR practices for IT professionals (Ang et al., 2002; Ferratt et al., 2005; Venkatesh et al., 2017; Whitaker et al., 2019). Using the categories of technology practices, our results build on the prior empirical research on work organization and IT investments (Aral et al., 2012; Bresnahan et al., 2002; Tambe et al., 2012). Finally, our results contribute to the ongoing conversation around the changing nature of work. For example, Khazanchi et al. (2018) investigate the effect of enhanced employee autonomy as a result of greater access to IS technologies—internet access, laptops, and smartphones—on employee relationships at work. In another example, Claggett and Karahanna (2018) study the effect of IS-enabled coordination mechanisms on performance. Our results complement this stream of research by offering a novel mechanism through which technology-related workplace transformations could boost business value.

Beyond our hypotheses, our examination of more granular categories of empowering HR practices—training, autonomy, and incentive—and their complementarity with IT investments suggests that collaborative IS practices can support the formation of communities of practice. Collaborative IS practices can do this by enhancing the alignment between information-intensive knowledge work settings and peer-group-driven training practices that characterize the increasingly decentralized and flattened organizational structures in modern firms. Specifically, our analysis reveals a three-way complementarity of collaborative IS practices, training HR practices, and IT investments. This extends prior work on the concept of "fit" in the organization (e.g., Han et al., 2019; Venkatesh et al., 2017). For example, Han et al. (2019) show that the benefit of autonomy, incentive, and training HR practices is enhanced with the internal consistency of individual practices across domains. Building on these findings, our results point to higher dimensions of fit among IT and human capital variables in performance assessment.

At the same time, our results do not support other granular complementarities that we would have expected based on prior theories. For example, prior theory would have predicted a positive three-way complementarity between autonomy-enhancing IS practices, incentive HR practices, and IT investments; the lack of support for this relationship despite prior theory suggests a need for more nuance in understanding worker autonomy. For example, identity formation can serve as a powerful motivator in organizations (Akerlof & Kranton, 2005; Kryscynski, 2021) and can perhaps also complement practices supporting worker autonomy, thus reducing the need for explicit incentive schemes. Moreover, the combination of autonomy and high-powered incentives may be more salient in specific industries such as high technology, where front-line employees need to be empowered to act quickly and make independent decisions. Further research might consider how standardized work processes can bring discipline and balance to the flexibility enabled by autonomy-enhancing IS practices (e.g., Kude et al., 2019; Mithas & Kude, 2017).

Overall, our findings underscore the role of human IT resources in generating firm value, specifically by enhancing returns on monetary IT investments. Human IT resources encompass technical and managerial IT skills, rent-generating resources that are difficult for competitors to imitate (Bharadwaj, 2000). Moving forward, our findings suggest the contribution of human IT resources to firm performance depends upon digital business practices across functional areas, such as IT-enabled collaboration. This implication underscores the growing need to understand digital business capabilities, including human IT capabilities, as *transcendent* of traditional functional areas (Bharadwaj et al., 2013). For example, future studies could reexamine HR practices as an integrated—rather than separate or complementary—part of IT practices.

Our findings are distinct from prior studies on work organization and IT complementarities and have broader relevance beyond the context of IT professionals for two reasons. First, we expect HR practices for IT staff to be generally aligned with HR practices for other employees in the firm. Second, IS practices are also likely to be aligned with the firm's general HR culture. Since HR practices for IT staff and general IS practices that affect the firm's other employees are within the purview of the CIO or other top IT executives, IT executives are often evaluated on the basis of the productivity or value of their overall monetary investments in IT. While the role and function of IT is evolving in many corporations, creating value from IT investments is not just a matter of allocating monetary investments in IT in conjunction with various disparate managerial practices. Rather, the managerial practices must be geared towards the effective implementation, management, and oversight of IT, including practices under the purview of the CIO that empower IT professionals and enhance productivity for the entire firm. On the whole, we believe that HR practices for IT staff, and their role in generating business value from IT investments merits further study. Future studies could also examine the effect of IS practices on the business value generated by various functions of the organization.

5.2 Managerial Implications

Among managerial implications, our results suggest that HR practices designed to empower IT professionals may have limited impact without adequate technology tools that enable collaboration, knowledge-sharing, and information access among the rest of the firm's employees. Likewise, collaborative or autonomy-enhancing IS practices may have little impact on productivity without HR practices that empower IT professionals with greater autonomy, flexibility, and an environment that fosters trust and makes employees feel valued. Therefore, empowering HR practices for IT professionals not only encourage the use of collaborative or autonomy-enhancing IS by other employees, but also help ensure the effectiveness of these IS practices. When seeking to maximize the value of monetary IT investments, IT executives should consider adopting HR practices that enable IT professionals to contribute to a work environment that aligns with broader IT objectives to enhance the general culture of productivity for all employees in the firm. IT executives should also take a systematic approach to using technology infrastructure and IS practices to align their firm's information architecture with the firm's social architecture through HR-driven initiatives for worker productivity (Prahalad & Krishnan, 2008).

Further, although our measures for empowering HR practices exclusively pertain to IT professionals, IT professionals are unlikely to be the exclusive beneficiaries of such practices. If such practices were also applied to other employees to some extent, organization-wide empowering HR practices regarding autonomy, incentives, and training could be considered a factor that enhances the value of IT investments when paired with organization-wide IS practices.

Examining the role of IT professionals enabled us to consider in more precise terms how the interaction of IT and HR practices can affect a firm's productivity. We found that certain innovative HR practices positively moderate the effect of IT investments on firm productivity. This suggests that firms are able to derive greater value from IT investments (which include hardware, software, and compensation to IT professionals) by implementing HR practices that empower IT professionals. Given what we know about the potential for IT professionals to act as drivers of organizational innovation (Bassellier & Benbasat, 2004; Ferratt et al., 2005; Swanson, 1994), managers should consider more seriously the rewards and opportunities they provide their IT employees and how such practices may enable firms to leverage value from IT investments.

In addition, our results provide important practical contributions in the aftermath of the COVID-19 crisis. According to our results, the long-lasting organization-wide shifts towards IS-oriented collaboration and enhanced autonomy resulting from more flexible work-from-home practices need to be complemented with empowering HR practices. We provide two specific recommendations for the post-COVID-19 workplace in terms of its greater reliance on collaboration and autonomy-enhancing IS practices. First, we highlight the importance of training IT professionals to enhance the business value of firms' investments in collaborative IS technologies and organization-wide collaborative IS practices. Our results show that strong training practices for IT professionals have a pivotal role in realizing business value from IT investments. This is salient especially given that many firms have failed to adequately enhance their online collaboration practices as needed for the post-COVID-19 era. Second, we argue that autonomy-enhancing practices for IT professionals complement autonomy-enhancing IS practices for other employees in the organization. By contrast, many firms have chosen to decrease employees' autonomy through enhanced monitoring of their activities at home, an attempt to deal with issues arising in the post-COVID-19 work environment (Mortensen & Gardner, 2021). Our results show that empowering IT professionals by supporting their autonomy can be crucial for firms that aim to enhance the autonomy of all their employees. Media and practitioners have recently focused on organizational transformations involving collaborative IS and autonomy IS practices for employees. Our results highlight the importance of training-, autonomy-, and incentives-oriented policies specifically designed for IT professionals who carry the responsibility for organization-wide transformation projects.

5.3 Limitations and Suggestions for Further Research

We point to some limitations of our study and provide suggestions for further research. First, the system of HR practices we considered are specifically management practices that influence IT professionals' work practices and behavior, such as information sharing, autonomy, and benefits. Future studies might consider other aspects of HR, such as employee sourcing, deployment, hiring, and retention practices. Second, our focus was on IT professionals, although the implications of our results may also extend readily to other knowledge workers (Tafti et al., 2007). Future studies could use alternative constructs to operationalize knowledge work and compare the alignment of IT and HR practices for other types of knowledge work. Third, while our measures capture the reality of employee collaboration and autonomy in the workplace in the time frame when the data were collected, future research might consider new generations of technology that support both collaboration and autonomy. Finally, future work could consider how certain elements of corporate strategy, such as strategies of competition or innovation, shape firms' IT and HR practices. Differences in firms' HR and IT practices may reflect variations in corporate culture, values, structure, or strategy, and our framework could likely be extended to account for this variety.

The continued expansion of the services and technology sectors of the economy, as well as the digitization of business processes, has influenced the nature of work and the necessary skill sets needed by knowledge workers, including IT professionals (Wattal et al., 2015). Given that IT is transforming desirable employee skill sets, this study suggests that HR-IT alignment can be effective at leveraging the capabilities of workers in the knowledge economy. We develop and empirically validate a theory of complementarity regarding two sets of practices under the purview of IT executives. Our findings suggest that specific categories of HR and IS practices under the direction of IT executives can moderate the effect of IT investments on overall firm-level productivity. We also examine the interaction between IT and HR practices in their effects on firm performance and find that empowering practices for IT professionals have a positive moderating influence on the effect of IT investments on firm productivity. In addition, we find that the use of specific collaborative IS practices positively moderates the effect of HR practices—training HR practices, in particular—on firm productivity. Furthermore, collaborative IS practices explain a substantial portion of the complementarity of IT investments and HR practices. Together, these findings show that implementing certain HR and IS practices together can help leverage the contribution of knowledge workers for enhanced firm productivity.

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Appendix A: Description of Measures

Dependent Variable

Value Added (VA): This measure of productivity was used in Bresnahan et al. (2002), Brynjolfsson and Hitt (2002), and Brynjolfsson et al. (2003). This measure is computed as *VA = Sales - Materials*. *Sales* is the *Sales (Net)* as reported in Compustat item #29. Materials quantity is calculated as *Total Expenses - Labor Expenses*. *Total Expenses* are calculated as *Sales (Compustat item #12) - Operating Income Before Depreciation (Compustat item #13)*.

IS Practices

From the set of InformationWeek questionnaires administered from 2002 to 2006, respondents were asked to select from among a list of effective technology steps that managers across the entire organization made in the 12 months leading up to the survey to raise worker productivity. STD(•) denotes a standardized quantity. Unless otherwise noted, each component of the composite measures are binary responses. As specific technologies might not be included in every year of the survey, in order to make the scores comparable across different years, we standardized the scores of firms within each year in the sample.

The question reads as follows:

"Which of the following are the most effective technology steps managers in your organization have made in the past 12 months to raise worker productivity? (Choose ALL that apply.)"

The full list of technologies and actions includes the following: implement enterprise applications such as ERP, wireless devices such as handheld PCs and cell phones, upgrade desktop PCs with newer models, deploy business-intelligence tools, deploy customer-relationship management or front office solutions, e-learning, deploy collaborative software tools such as intranet or email, moving legacy processes to e-business applications, train workers to master key software programs, upgrade desktop productivity software, allow more workers Internet access, upgrade desktop operating systems, outfit workers with laptop PCs, call-center software, deploy collaborative hardware such as video conferencing, boost network bandwidth or performance, other (please specify), and none of these.

We indicate in brackets the years in which each item was featured in the survey:

Collaborative IS Practices (Collab IS): Respondents were asked to select from among a list of effective technology steps that managers across the entire organization made in the 12 months leading up to the survey in order to raise worker productivity: (1) Deployed collaborative hardware such as videoconferencing (VIDEOCONF) (2002, 2004-2006), (2) deployed collaborative software such as intranet or email (COLLAB_SW) (2002-03, 2005-06), (3) used instant messaging (IM) (2004-2006), (4) deployed voice-over-IP applications (VOIP) (2004-2006), (5) modeled business processes using CASE or related tools (CASE) (2004-2006), and (6) implemented enterprise applications such as ERP (ENT_APPS) (2002-2003).

The variable is standardized within each year. Hence, for year *t*,

$$\textit{Collaborative IS}_t = \text{STD}(\text{STD}(\text{VIDEOCONF}_t) + \text{STD}(\text{COLLAB\_SW}_t) + \text{STD}(\text{IM}_t) + \text{STD}(\text{VOIP}_t) + \text{STD}(\text{CASE}_t) + \text{STD}(\text{ENT\_APPS}_t))$$

For a sensitivity analysis, we also constructed an alternative measure *Collaborative IS Alt* that leaves out the ENT_APPS measure.

Autonomy IS Practices: Technologies and policies belong to this category because they enable workers greater freedom in access to information and decentralized tools for autonomous decision-making. This measure is comprised of the following items from the set of InformationWeek questionnaires, and we indicate in brackets the years in which each item was featured in the survey: (1) the allowance of more workers to access the internet (IA) (2002-2005), (2) outfit workers with laptop computers (LAPTOP) (2002-2003, 2006), (3) deployed wireless devices such as handheld PCs and cell phones (WIRELESS) (2002-2006), (4) upgraded desktop productivity software (DESK) (2002-2006), and (5) upgraded desktop operating systems (DESKOS) (2002-2006).

The variable is standardized within each year. Hence, for year *t*,

$$\textit{Autonomy IS}_t = \text{STD}(\text{STD}(\text{IA}_t) + \text{STD}(\text{LAPTOP}_t) + \text{STD}(\text{WIRELESS}_t) + \text{STD}(\text{DESK}_t) + \text{STD}(\text{UPGRADE\_OS}_t))$$

Over the years, minor changes in wording occurred in some questions, such as using the terms "notebook PCs" in 2003 and "laptops with wi-fi or other wireless connectivity" in 2006 to refer to laptop computers. For a sensitivity analysis, we also constructed an alternative measure *Autonomy IS Alt 1* that leaves out the LAPTOP measure and *Autonomy IS Alt 2* that leaves out the DESKOS measure.

HR Practices for IT Professionals

This measure is from the InformationWeek questionnaire administered in 2003. We describe the aggregate measures and all items that comprise each measure. Unless otherwise noted, the components of the composite measures are each binary responses. *R*espondents were asked to select from among a list of rewards and opportunities managers provided to their IT staff in order to raise worker productivity. STD(•) denotes a standardized quantity.

The question reads as follows, which we interpret as a level of adoption that may extend over multiple years.

"Which of the following opportunities and rewards do you provide to your IT staff?" (Choose ALL that apply.)

The full list of opportunities and rewards includes the following: potential for promotion, e-learning, encouragement for innovative new IT solutions, opportunities to achieve cash or stock bonuses, stock options, telecommuting, career path planning, company-paid educational or training opportunities, recognition for work well done, increased responsibilities to keep the work challenging, other (please specify), and none of these.

Empowering HR Practices for IT Professionals (HR): This class of workplace innovations fosters greater worker autonomy, teamwork, and collaboration, investing in workers' skills and knowledge, and other practices that motivate workers by making them feel more valued. Respondents were asked to select from among a list of effective *non-technology* steps that managers across the entire organization made in the 12 months leading up to the survey in order to raise worker productivity. The measure of HR practices comprises the following items from the survey administered by InformationWeek in 2003: (1) potential for promotion (PROMOTE), (2) e-learning (ELEARNING), (3) encouragement for innovative new IT solutions (INNOVIT), (4) opportunities to achieve cash or stock bonuses (BONUS), (5) stock options (STOCKOPT), (6) permit telecommuting (TELECOMMUTE), (7) career path planning (CAREERPATH), (8) company-paid educational or training opportunities (TRAIN), (9) recognition for work well done (RECOG), and (10) increased responsibilities to keep the work challenging (RESPONSIB). This measure of HR practices was formed using the same method of standardizing the sum of standardized components.

HR = STD(STD(PROMOTE) + STD(EDUC) + STD(INNOVIT) + STD(BONUS)+ STD(STOCKOPT) + STD(TELECOMMUTE) + STD(CAREERPATH) + STD(TRAIN) + STD(RECOG) + STD(RESPONSIB))

The following disaggregated measures were also constructed as standardized sums of the specified standardized measures:

Incentives HR Practices (Incent HR): This measure comprises the following items from the survey administered by *InformationWeek* in 2003: (1) potential for promotion (PROMOTE), (2) opportunities to achieve cash or stock bonuses (BONUS), (3) stock options (STOCKOPT), and (4) recognition for work well done (RECOG).

Training HR Practices (Train HR): This measure comprises the following items from the survey administered by *InformationWeek* in 2003: (1) company-paid educational or training opportunities (TRAIN), (2) career path planning (CAREERPATH), and (3) e-learning (ELEARNING).

Autonomy HR Practices (Autonomy HR): This measure comprises the following items from the survey administered by *InformationWeek* in 2003: (1) encouragement for innovative new IT solutions (INNOVIT), (2) permit telecommuting (TELECOMMUTE), and (3) increased responsibilities to keep the work challenging (RESPONSIB).

IT Investment

IT Expenditure (IT): This is the firm's worldwide IT budget in the prior fiscal year, including capital and operating expenses for infrastructure such as telecommunications, networking, hardware, applications (maintenance and development and packaged), Internet-based costs, salaries and recruitment, IT services/outsourcing, and training. Respondents provided this figure in terms of a percentage of revenue, which was then multiplied by annual sales to compute the total value of IT capital.

Projected IT Expenditure (IT Projected): Managers provided their projected IT budget for the coming year, including capital and operating expenses for infrastructure such as telecommunications, networking, hardware, applications (maintenance and development and packaged), Internet-based costs, salaries and recruitment, IT services/outsourcing, and training. Respondents provided this figure in terms of a revenue percentage, which was then multiplied by annual sales to compute the total value of IT capital.

Control Variables

Related Diversification (Rel. Diversification):$\sum_t P_t \log({}^1/_{P_t}) - \sum_u P_u \log({}^1/_{P_u})$, where P_t = percentage of sales in each four-digit NAICS industry and P_u = percentage of sales in each two-digit NAICS category.

Capital Intensity: This is the ratio of physical capital investment over net income.

Industry Concentration: We measured industry concentration (a proxy for industry competitiveness) with the Herfindahl Hirschman index (HHI). The HHI for industry j is measured as follows:

$HHI_j = \sum_i s_{ij}^2$, where s_{ij} is the market share of firm i in industry j.

R&D Intensity (R&D): This is the portion of sales spent on R&D. If this value was missing in Compustat, we used the three-digit NAICS industry average.

Labor Expenses (L): Following Bresnahan et al. (2002), Brynjolfsson and Hitt (2003), and Brynjolfsson et al. (2002), we used *Labor* and *Related Expenses* as reported in Compustat (item #42) if that amount was available.

If *Labor* and *Related Expenses* were not reported in Compustat, we used the following method to determine industry-weighted labor expenses: First, we used Bureau of Labor Statistics (BLS) data to obtain the hourly cost of workers (including benefits) for ten sectors of the economy. We multiplied this by the number of employees in the firm (Compustat item #29) and an estimated number of work hours per year. As several of the firms in our sample are multi-industry conglomerates, we computed the firm's *weighted* industry average labor expense using the percentage of the firm's sales from each industry segment (using the Compustat Segments database):

$Weighted\ Industry\ Average\ Labor\ Expense = Employees \times \sum_j \bar{L}_j P_j$, where $\bar{L}_j$ is the average labor expense for industry j and P_j is the portion of the firm's revenue in industry j.

Capital (K): We followed the procedure described in Bresnahan et al. (2002). We used the total value of physical assets—"*Property, Plant, & Equipment (Total - Gross)*," Compustat item #7—which was deflated using the implicit gross domestic product fixed investment deflator, applied at the average age of capital. The average age of capital was calculated as the three-year average of the ratio of total accumulated depreciation—"*Property, Plant, & Equipment (Total - Net)*," (Compustat item #8)—over the current depreciation: "*Depreciation and Amortization*," (Compustat item #14).

Table A1. Principal Component Analysis Results for Empowering HR Practices for IT Professionals, Collaborative IS, and Autonomy-enhancing IS: Loadings onto the First Unrotated Principle Component

Item/HR Category	PC	Collab IS	PC	Auton IS	PC
LEARN/Train HR	0.42	VIDEOCONF	0.46	IA	0.50
CAREERPATH/Train HR	0.23	COLLAB_SW	-0.33	LAPTOP	0.25
TRAIN/Train HR	0.32	VOIP	0.42	WIRELESS	0.34
PROMOTE/Incent HR	0.17	CASE	0.40	DESK	0.54
RECOG/Incent HR	0.17	ENT_APPS	0.29	DESKOS	0.54
STOCKOPT/Incent HR	0.33				
BONUS/Incent HR	0.46				
Kaiser-Meyer-Olkin measure[a]	0.72		0.81		0.65

Note: The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy indicates the degree to which variables belong together by virtue of their correlations and partial correlations (Kaiser, 1970). KMO values above .60 indicate that the variables are suitable for factoring.

Table A2. Representation of Industries in the Final Sample

NAICS-2 digit	Name	Frequency	Pct.
21	Mining	11	1.49
22	Utilities	57	7.74
23	Construction	25	3.4
31	Manufacturing—perishables	44	5.98
32	Manufacturing—durables	102	13.86
33	Manufacturing—metals	193	26.22
42	Wholesale trade	39	5.3
44	Retail trade	32	4.35
45	Retail trade	16	2.17
48	Transportation and warehousing	24	3.26
49	Transportation and warehousing	8	1.09
51	Information	43	5.84
52	Finance and insurance	40	5.43
53	Real estate rental and leasing	10	1.36
54	Professional, scientific, and technical services	15	2.04
56	Administrative and support and waste management and remediation services	26	3.53
62	Health care and social assistance	19	2.58
72	Accommodation and food services	25	3.4
99	Unclassified	7	0.95

Note: Industry names are from http://www.naics.com/

Table A3. Summary Statistics of Control and Alternative Measure Variables

Variable	N	Mean	Std Dev	Min	Max
Autonomy IS Alt 1	736	0.28	0.89	-1.43	1.22
Autonomy IS Alt 2	736	0.31	0.93	-1.43	1.60
Collaborative IS Alt	736	-0.02	0.93	-1.22	2.81
Rel. diversification	714	0.19	0.23	-0.25	1.38
Capital intensity	736	0.29	0.20	0.01	0.89
Industry concentration (HHI)	736	0.08	0.09	0.01	0.92
Industry mainframe investment*	721	0.66	1.66	0.00	11.39
Industry PC investment*	721	2.59	1.59	0.38	14.27
Industry pre-packaged software investment*	721	7.09	3.17	0.95	16.73
Industry custom software investment*	721	8.20	5.37	0.44	21.44
Industry in-house software investment*	721	10.08	6.69	0.48	26.22

Note: Industry IT intensity levels are obtained from the BEA. They are calculated as percentages over general equipment.

Table A4. Correlations of Industry-wide IT Investments and Firm IT investments

Instrumental variable	Pearson correlation with log of annual firm IT investments (year *t*)
Industry mainframe investment (*t*-3)	0.06 (p = 0.05)
Industry PC investment (*t*-3)	0.26 (p = 0.00)
Industry pre-packaged software investment (*t*-3)	0.20 (p = 0.00)
Industry custom software investment (*t*-3)	0.31 (p = 0.00)
Industry in-house software investment (*t*-3)	0.32 (p = 0.00)

Appendix B: Sensitivity Analysis with Alternative Construction of Variables

Table B1. Firm Productivity Effects of Three-way Interactions Between IS Practices, HR Practices for IT Professionals, and IT Investments

	(1)	(2)		(3)	(4)	(5)
Alternative construction of Collab IS Alt (without ERP/Enterprise applications)				**Collab IS Alt**	**Auton IS Alt 1 (without laptop)**	**Auton IS Alt 2 (without desktop OS)**
	Fixed effects	**Random effects**		**Fixed effects**	**Fixed effects**	**Fixed effects**
log(capital)	0.064 (0.049)	0.082*** (0.027)	log(capital)	0.066*** (0.020)	0.067*** (0.020)	0.066*** (0.020)
log(labor)	0.709*** (0.063)	0.742*** (0.046)	log(labor)	0.707*** (0.020)	0.707*** (0.020)	0.706*** (0.020)
log(IT)	0.040*** (0.012)	0.056*** (0.013)	log(IT)	0.040*** (0.009)	0.040*** (0.009)	0.041*** (0.009)
H1a: Collab IS Alt × HR × log(IT)	0.007* (0.004)	0.007* (0.004)	Collab IS [Alt] × Train HR × log(IT)	0.008** (0.004)	0.008* (0.005)	0.008* (0.004)
H1b: Auton IS × HR × log(IT)	-0.002 (0.004)	-0.001 (0.004)	Auton IS [Alt] × Incent HR × log(IT)	-0.003 (0.004)	-0.005 (0.005)	-0.004 (0.005)
Collab IS Alt	0.028* (0.015)	0.031** (0.015)	Collab IS [Alt]	0.030** (0.013)	0.040*** (0.009)	0.037*** (0.014)
Auton IS	0.007 (0.013)	0.001 (0.014)	Auton IS [Alt]	0.004 (0.014)	-0.002 (0.015)	0.003 (0.014)
HR		0.033 (0.035)				
F-statistic	45.8***		*F*-statistic	116.7***	116.4***	116.5***
Chi-squared		14123***				

Note: Panel regression results with 736 observations, 228 firms. Dependent variable is log(VA), the log of value-added as a measure of firm productivity. Estimation models include all three-way and two-way interactions between HR, IS and IT practices, and a constant term not shown here for brevity. All models also include indicators for each year and indicators for each two-digit NAICS industry (the latter are unnecessary in the fixed-effects models). Huber-White robust clustered standard errors in parentheses. The complete table of coefficient estimates with all interaction terms is available from the authors. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Appendix C: Evidence of Adoption Complementarities

We examine evidence of *adoption complementarities*—the source of correlations between sets of practices and investments (Aral et al., 2012; Arora & Gambardella, 1990; Bresnahan et al., 2002; Cassiman & Veugelers, 2006; Tambe et al., 2012). The framework of adoption complementarities is useful for understanding how firms choose to undertake different investments or practices together. Thus, we examine whether IT investments are made in conjunction with IS practices encouraging autonomy and collaboration. A number of common factors might incline firms to make investments in different sets of practices simultaneously. Beyond such common factors, the presence of complementarities in adoption can reveal itself in mutually reinforcing aspects of these practices. Two factors x_1 and x_2 are complementary if the derivative $\partial^2 V/\partial x_1 \partial x_2$ is positive, where V is the firm's payoff function (Arora & Gambardella, 1990). Both x_1 and x_2 are conditional on a common set of exogenous factors Θ_i. Assuming that the firm chooses x_1 and x_2 to maximize the payoff function, Arora and Gambardella (1990) formally link payoff maximization, assuming optimal investment choices, to a variant of the following expression for adoption complementarities between two sets of practices that we apply to IT investments and IS practices (i.e., autonomy IS or collaborative IS):

$$E[[IT - E(IT|\Theta)][IS\ Practices - E(IS\ Practices\ |\Theta)]] \geq 0 \quad \text{(C-1)}$$

The term Θ comprises common drivers of practice or investment adoption, including many industry and firm characteristics. These include industry-level measures of multiple components of IT intensity from the BEA, relative diversification, physical capital intensity, industry concentration, and R&D (e.g., Dewan et al., 1998). After regressing on common factors that would simultaneously affect the adoption of different sets of firm practices or investments, a correlation persisting in the residuals suggests the existence of mutually reinforcing factors between IT and IS practices (Cassiman & Veugelers, 2006).

Table C1 shows the coefficient estimates resulting in residuals ε_1 through ε_6, which are used to test the degree to which HR practices explain the correlation between specific types of IS practices and IT investments, after accounting for common drivers. Column 2 shows the Spearman correlation between the residual $\varepsilon_1 = [IT - E(IT|\Theta)]$, resulting from the regression of IT on common factors, and $\varepsilon_2 = [\textit{Collab IS} - E(\textit{Collab IS}\ |\Theta)]$, resulting from the regression of *Collab IS* on common factors. Column 3 shows the correlation between the residual $\varepsilon_1 = [IT - E(IT|\Theta)]$ and $\varepsilon_3 = [\textit{Auton IS} - E(\textit{Auton IS}\ |\Theta)]$. We also show correlations among residuals from the year 2003 only, showing that the year 2003 is not idiosyncratic in IS practice and IT residual correlations. Columns 5 and 6 show a reduction in the residual correlation for the single year of 2003, which controls for industry fixed effects at the two-digit NAICS level and introduces coefficient estimates for *incentives HR*, *autonomy HR*, and *training HR* practices. While residual correlations with ε_1 decline when incentives, autonomy, and training are introduced in Columns 5 and 6, support for adoption complementarities between HR practices and IS practices is limited to the model predicting *Autonomy IS* in Column 6.

Despite controlling for relevant common factors, certain unobserved factors related to incentives, autonomy, or training may still account for some of the residual correlations. Controlling for the same industry and firm fixed effects in a panel regression model with the same control variables as above, and adding a control for prior-year investments, we consider how HR and IS practices interact to influence the *projected* IT investment for the following year. Projected IT demand is measured as the managers' intended IT investments at the beginning of the year; implementation issues and unforeseen events may cause eventual IT spending in that year to veer from the projected demand level. Based on their current information set, firms must decide each year the IT investments they plan to make. Since many unexpected events can influence what is ultimately spent, actual spending levels may not fully capture demand within the model of adoption complementarities, which relies on the notion of investments made in anticipation of returns. Hence, for the measurement of adoption complementarities we capture IT investments in light of managers' anticipated returns and investments:

$$\begin{aligned} \text{IT Projected}_{i,t+1} &= \beta_0 + \beta_1 \text{ Incent HR}_i \times \text{Auton IS}_{i,t} + \beta_2 \text{ Incent HR}_i \times \text{Collab IS}_{i,t} + \beta_3 \text{ Autonomy HR}_i \times \\ &\text{Auton IS}_{i,t} + \beta_4 \text{ Autonomy HR}_i \times \text{Collab IS}_{i,t} + \beta_5 \text{ Train HR}_i \times \text{Auton IS}_{i,t} + \beta_6 \text{ Train HR}_i \times \text{Collab IS}_{i,t} + \\ &\beta_7 \text{ IT}_{i,t-1} + \boldsymbol{\Theta_c \beta_c} + u_i + \varepsilon_{i,t} \end{aligned} \quad \text{(C-2)}$$

Controls represented by the term $\boldsymbol{\Theta_c}$ in equation (C-2) include the one-year lag intensity level of investment in PCs, pre-packaged software, in-house software, and communications equipment. All main effects and two-way interactions are taken into account to calculate the final marginal effects, as is the case for all subsequent estimation models presented in this paper. Coefficient estimates in Table C2 suggest that collaborative IS and training HR practices interact positively in their influence on demand for IT investments, as measured by survey respondents' projected IT investments in the coming year. The results suggest that incentive programs reduce the effect of collaborative IS practices on the demand for IT investments. The statistical significance and direction of coefficient estimates remain similar when a control for the prior year value of IT investments is included in the estimation model. As a robustness check, we also conducted reverse-causality tests that showed that prior values of firm productivity and their interactions with HR or IS practices have no significant effect on the demand for IT investments (Table C3).

Overall, we find that collaborative IS and training HR practices interact positively in their effects on the demand for IT, which is evidence of three-way complementarities in adoption. While providing some insight into common adoption practices, this auxiliary analysis assumes that firms choose the optimal combination of inputs; otherwise, the assumption is that their misallocations are not systematically correlated with any other observable firm-level factors.

Table C1. Common Factors Driving Managers' Projected Estimates of IT Investment and IS Practices

	(1) Projected IT investment	(2) Collab IS	(3) Autonomy IS	(4) Projected IT investment	(5) Collab IS	(6) Autonomy IS
Residual term	ε_1 Fixed effects	ε_2 Fixed effects	ε_3 Fixed effects	ε_4 OLS	ε_5 OLS	ε_6 OLS
Spearman correlation of residual with ε_1: 2002-2006	1.00	0.37***	0.37***			
Spearman correlation of residual with ε_1: 2003 only	1.00	0.38***	0.41***	1.00	0.14**	0.09
Industry mainframes (t-1)	-0.008* (0.004)	0.157 (0.099)	-0.025 (0.094)	0.000 (0.011)	-0.000 (0.107)	-0.065 (0.158)
Indus. PCs (t-1)	-0.0142 (0.017)	-0.283 (0.310)	-2.139*** (0.257)	0.006 (0.007)	0.030 (0.065)	-0.077 (0.096
Indus. pre-pkg software (t-1)	-0.014** (0.006)	-0.356*** (0.108)	-0.025 (0.100)	-0.007 (0.005)	-0.003 (0.051)	0.004 (0.076)
Indus. custom software (t-1)	0.010* (0.006)	0.083 (0.135)	0.310** (0.123)	0.0389 (0.056)	0.412 (0.542)	0.526 (0.805)
Indus. in-house software (t-1)	0.008* (0.004)	0.577*** (0.139)	0.230** (0.093)	-0.034 (0.048)	-0.345 (0.464)	-0.454 (0.689)
Indus. communications (t-1)	-0.020 (0.013)	0.307** (0.146)	0.416*** (0.118)	0.010*** (0.002)	0.044** (0.020)	0.011 (0.029)
R&D	0.000 (0.001)	-0.032 (0.025)	0.004 (0.024)	0.008 (0.006)	0.061 (0.056)	0.064 (0.083)
Related divers.	0.012 (0.014)	0.684* (0.350)	-0.794*** (0.282)	-0.042 (0.039)	-0.286 (0.382)	0.413 (0.567)
Capital intensity	-0.033 (0.046)	2.370** (1.070)	3.310*** (0.926)	-0.263*** (0.053)	-0.799 (0.517)	-0.752 (0.766)
Industry concentration	0.150 (0.144)	-11.20*** (3.677)	-10.53*** (2.792)	0.069 (0.081)	0.470 (0.793)	0.864 (1.177)
Autonomy HR				0.005 (0.004)	0.064 (0.041)	0.157** (0.061)
Incent HR				0.005 (0.005)	0.014 (0.047)	0.145** (0.070)
Train HR				-0.006 (0.005)	0.056 (0.045)	0.132** (0.066)
Constant	0.104* (0.060)	-5.081** (2.432)	-0.124 (1.809)	0.143*** (0.052)	-0.0167 (0.504)	0.522 (0.748)
Two-digit NAICS industry dummies	Not needed	Not needed	Not needed	Included	Included	Included
Observations	944	1,111	1,111	238	238	238
Firms	403	457	457	238	238	238
F-statistic	6.8***	7.3***	34.6***	3.9***	1.6***	2.8***

Note: OLS models included for each two-digit NAICS industry; these are unnecessary in the fixed-effects models. Huber-White robust clustered standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table C2. Interaction Effects of HR and IS Practices on Demand for IT Investments

	(1)	(2)
Collab IS × Train HR	0.002** (0.001)	0.001* (0.001)
Collab IS × Incent HR	-0.003** (0.001)	-0.002** (0.001)
Collab IS × Auton HR	-2.82e-05 (0.000953)	-0.000364 (0.000809)
Collab IS	-0.004*** (0.001)	-0.004*** (0.001)
Auton IS × Train HR	-0.001 (0.001)	-0.001 (0.001)
Auton IS × Incent HR	0.001 (0.002)	0.000 (0.001)
Auton IS × Auton HR	0.00140 (0.00114)	0.00131 (0.000847)
Auton IS	-0.001 (0.001)	-0.000 (0.001)
IT (t-1)		0.618*** (0.212)
F-statistic	4.3***	7.0***

Note: Fixed-effects panel regression with 791 observations, 274 firms. Dependent variable is the survey respondents' projected IT investments in the coming year. Estimation models include the one-year lag intensity level of investment in PCs, pre-packaged software, in-house software, and communications equipment. Huber-White robust clustered standard errors in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

Table C3. Drivers of Demand for IT: Reverse-causality Tests with Panel Fixed Effects

	(1) Projected IT (t) Interactions with VA (t-1)		(2) Projected IT (t) Interactions with VA (t-2)
Collab IS	0.003 (0.013)	Collab IS	0.005 (0.018)
Auton IS	0.007 (0.016)	Auton IS	0.010 (0.018)
log(VA) (t-1)	0.008 (0.014)	log(VA) (t-2)	-0.003 (0.012)
Collab IS × log(VA) (t-1)	-0.008 (0.001)	Collab IS × log(VA) (t-2)	-0.001 (0.002)
Auton IS × log(VA) (t-1)	-0.001 (0.002)	Auton IS × log(VA) (t-2)	-0.008 (0.002)
Incent HR × log(VA) (t-1)	0.006 (0.011)	Incent HR × log(VA) (t-2)	-0.015 (0.017)
Training HR × log(VA) (t-1)	-0.007 (0.003)	Training HR × log(VA) (t-2)	-0.003 (0.024)
Constant	-0.061 (0.14)	Constant	0.071 (0.11)
Observations	751	Observations	727
Firms	251	Firms	252

Note: Significant at *10%, **5%, and ***1% levels for two-tailed *t*-tests.

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