Assessing Three-Way Complementarities:

Performance Pay, Monitoring and Information Technology

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Abstract

We find evidence of three-way complementarities among information technology (IT), performance pay, and monitoring practices. We develop a principal-agent model examining how these practices work together as an incentive system that produces the largest productivity premium when the practices are implemented in concert. We assess our model by combining fine-grained data on Human Capital Management (HCM) software adoption over 11 years with detailed survey data on incentive systems and monitoring practices for 189 firms. As predicted, we find that the adoption of HCM software is greatest in firms that have also adopted performance pay and performance monitoring practices. Furthermore, HCM adoption is associated with a disproportionately large productivity premium when it is implemented as a system of organizational incentives, but has little or no benefit when adopted in isolation. Interestingly, pair-wise interactions are typically insignificant or even negative when the third practice is missing, highlighting the importance of including all three complements. In principle, performance pay can have effects on motivation (inducing employees to commit greater effort), selection (attracting and retaining higher quality employees) or both. Since our survey separately evaluates each of these mechanisms, we can also empirically distinguish which mechanism is responsible for the observed productivity premium. We find that the complementarities in our sample are entirely explained by talent selection, and not by changes in employee motivation.

Keywords: Incentive Systems, Information Technology, Monitoring, Complementarity, Enterprise Systems, ERP, Productivity, Production Function, Principal-Agent Model.

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Introduction

Substantial variation exists in the returns to information technology (IT) investments across firms (Brynjolfsson & Hitt 1995; Aral & Weill 2007). One reason for this variation may be differences in the adoption of complementary organizational practices (Bresnahan, Brynjolfsson and Hitt 2002; Ichniowski & Shaw 2003). As IT investments grew dramatically in the 1980s and 1990s, there was also a parallel up tick in the adoption of one potentially complementary practice—pay-for-performance incentive compensation policies (Ichniowski & Shaw 2003). As in the case of IT, there appears to be substantial variation in the effectivenessof such incentive plans. As a consequence, managers and economists alike continue to debate whether these new human resource practices have value (Ichniowski & Shaw 2003). In this paper we propose that these two phenomena are related and specifically that the returns to IT and incentive schemes depend on one another.

We argue that successful organizational incentive schemes rely on the ability to observe, measure, document and track performance accurately and transparently in order to appropriately reward those who excel and that information technologies designed to deliver such capabilities complement these incentive schemes. We develop an analytical model that illustrates this complementarity and demonstrate how the co-presence of IT and incentive schemes can explain variation in both the returns to IT and the effectiveness of performance pay contracts and performance monitoring.

In addition, we examine the underlying economic mechanisms that drive this complementarity. Two theories explain how incentive schemes may improve performance: 1) by motivating employees to contribute greater effort and 2) through a selection process whereby incentives help attract and retain high quality labor while eliminating underperformers (Lazear 2000, Paarsch and Shearer 2000, 2004). We observe variations in firm policy which allow us to distinguish which of these two effects contributes to the complementarities we observe. Further, we argue that effective incentive schemes are made up of a tightly knit incentive 'system' that combines performance pay with performance monitoring using information technology. We hypothesize that providing performance pay without technologies that enable effective performance monitoring creates adverse incentives or no incentive at all, and that monitoring technologies implemented without performance pay are also less effective. Our goals are two-fold: to examine the complementarities among IT, monitoring and performance pay in order to determine whether these practices can be effectively implemented piecemeal or rather must be introduced as a 'system of practices' (Milgrom & Roberts 1990), and to distinguish the mechanisms through which this system of incentives and technology impact productivity and performance.

To explore such fine-grained propositions, we narrow our investigation to the adoption of a specific technology—Human Capital Management (HCM) solutions found in typical Enterprise Resource Planning (ERP) systems. ERP systems provide an ideal test bed for studying IT business value as these "process-enabling technologies" represent firm-wide suites of business software and hardware designed to generate productivity and business value by supporting specific business processes (McAfee 2003). Aral, Brynjolfsson and Wu (2006) demonstrate the existence of a virtuous cycle of productivity and performance returns to enterprise systems. In this cycle, firms that invest in ERP experience greater productivity on average, motivating additional investments in extended enterprise systems such as Supply Chain

Management (SCM) and Customer Relationship Management (CRM), creating a cycle of escalating returns. In this paper, we examine the mechanisms driving this virtuous cycle.

The unique nature of our data also enables us to assess the direction of causality in relationships between adoption of HCM systems and higher performance. Simply identifying a correlation between adoption and performance is not sufficient to test the hypothesis that adoption *causes* performance, since the causality could go in the opposition direction, for instance if improved cash flows increased investments. It is also possible that unobserved factors might cause both adoption and higher performance. To help disentangle the causal relationships, we collected detailed data on the purchase and go-live decisions of 189 enterprise systems adopters from the sales database of a large enterprise systems vendor from 1995 to 2006. We were able to separate the purchase of IT from the actual use of IT, which for HCM systems may occur years later due to the time-consuming installation process. By doing so, we address the potential endogeneity of the relationship between IT and productivity. Specifically, if causality ran from productivity to adoption, then we would expect the strongest correlations between performance and the *purchase* of HCM, while if the causality ran from adoption to productivity, then we would expect that the strongest correlations would be between the *adoption (or use)* of HCM and performance (Aral, Brynjolfsson and Wu 2006).

In order to test three way complementarities between performance pay, monitoring and IT, we alsogathered a unique data set surveying the detailed human resource practices of these 189 firms in 2005, of which about half (90) adopted the HCM system. By focusing on a narrow set of technologies, we explore precisely how HCM systems complement the specific set of business processes they are designed to support. Combining data on technology adoption, financial performance, and human resource practices, we estimate how monitoring and performance pay complement HCM systems to generate a productivity premium. We also make a methodological contribution by devising tests for 3-way complementarities which can easily be extended to test for n-way complementarities.

Theory and Literature

Information Technology and Organizational Complementarities

Since the early 1990's, firm-level evidence has documented productivity and performance gains for IT-intensive firms (Brynjolfsson & Hitt 2002 provide a review). However, substantial variation exists in the returns to IT spending across firms (e.g. Brynjolfsson& Hitt 1995). A leading explanation for this variation is that firms with higher returns also adopt complementary organizational practices that produce productivity and performance premiums (Aral & Weill 2007, Bresnahan et al 2002; Caroli and Van Reenen 2002; Brynjolfsson, Hitt and Yang 1998, Bloom et. al. 2008). The value of IT investment is magnified by co-investment in organizational practices. For instance, estimating market value regressions, Brynjolfsson, Hitt and Yang (2002) find that one dollar of IT investment is associated with ten dollars of market value, where nine of those dollars can be attributed to complementary organizational investments. They find that markets reward firms that invest in IT only when they have also made appropriate organizational investments (Brynjolfsson, Hitt, and Yang, 2002). As information technology investments lower the cost of information transfer, it is hypothesized that IT adoption is especially beneficial for firms that use teamwork and decentralized decision-making (Bresnahan, Brynjolfsson, and Hitt 2002; Caroli and Van Reenen 2001). With a highly skilled workforce that can efficiently use information technology, firms can achieve higher productivity through increased efficiency and customization as line workers are empowered with more decision rights. Furthermore, IT and organizational investments such as those in innovative people management practices can help explain why the US has experienced sustained increases in productivity growth in the last decade while Europe has not (Bloom et al. 2008).

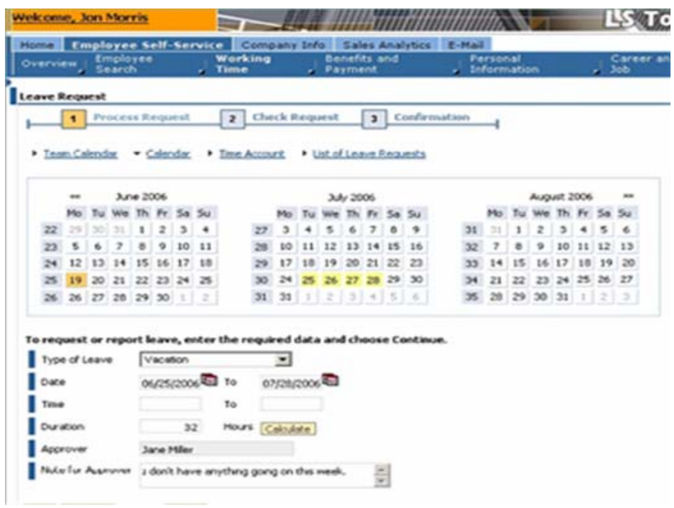
Most of the literature on IT and organizational co-investment has focused on general-purpose information technologies (Bresnahan & Trajtenberg, 1995). Given the general-purpose flexibility of IT, the predominant approach to measuring IT investment has simply been to count the number of IT employees or to estimate the total dollars spent on hardware purchases. However, prior research has shown that investments in different types of IT can have orthogonal and at times competing performance implications (Aral & Weill 2007). While aggregate measures of information processing capabilities inside firms are a good first step for understanding how IT-intensive firms experience greater productivity premiums, a more precise view of IT and organizational complementarity is possible with explorations of complementarities between particular technologies and the specific systems of practices they are intended to support (Aral & Weill 2007, Bartel et al 2007).

Human Capital Management Software

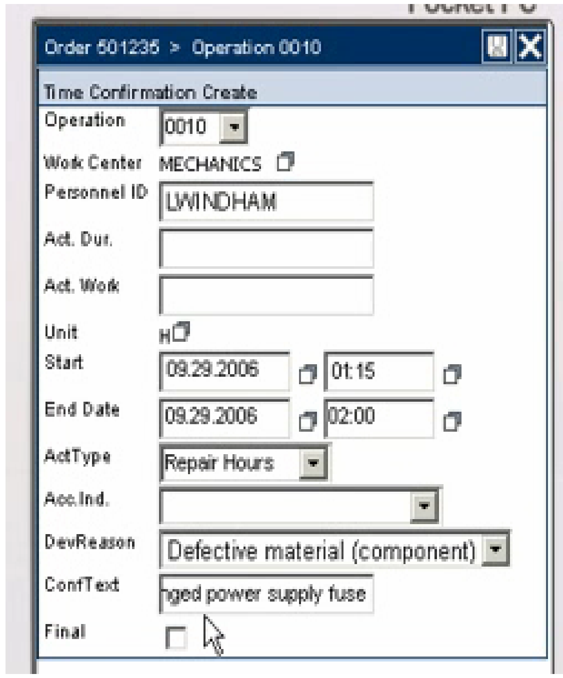
Human Capital Management (HCM) Software is a part of the Enterprise Resource Planning (ERP) suite of systems. It is an ideal choice for studying how a specific technology complements a specific set of organizational practices to improve productivity. The main purpose of HCM is to equip executives, HR professionals, and line managers with the specific information needed for workforce support, including accurate planning on performance pay, and the ability to continuously monitor work performance. By tightly linking human resource data with other operational and financial systems, HCM enables managers to understand the demand on human capital, track workforce costs, align the goals of employees with the organization's overarching business strategy, and to measure employee, division and firm performance.

Of particular relevance for our study, HCM allows the firm to monitor metrics of employee effort and performance. It keeps detailed records of employees' attendance, such as time worked, overtime, illnesses and vacation time. The figure below shows a managers' view of an employee's time and attendance displayed in the HCM system.

Management of Time and Attendance



HCM can also track detailed work records. Using the HCM system, workers enter records of each task they perform. The screen shot below shows a typical entry for a maintenance task. For this task, the worker provides a brief description of the work, the beginning and the end time of the task as well as any materials used.



Estimating returns to enterprise software

Although enterprise systems, such as HCM, constitute a large share of IT investments, especially for large and medium sized enterprises, empirical evidence examining the productivity and performance implications of these investments is sparse. In particular, we lack large-scale empirical evidence on complementarities between specific organizational practices and HCM or ERP investment in general. Hitt, Wu and Zhou (2002) provide one of the first large-scale statistical analyses of the productivity and performance impact of ERP adoption. By examining 350 publicly traded firms from 1986 to 1998, they demonstrate that ERP implementation is associated with positive productivity and performance gains. Aral, Brynjolfsson and Wu (2006) provide an updated study using ERP adoption data on 698 firms from 1998-2005. By separately estimating the effects of the purchase of enterprise systems from the effects of installation and use years later, this study addresses endogeneity concerns to document a potential causal relationship between ERP use and firm productivity. The study also illustrates the existence of a 'virtuous cycle' whereby successful ERP implementations prompt firms to invest subsequently in extended enterprise systems and to realize additional performance benefits. However, neither of these studies explicitly tests the complementarity between enterprise systems and organizational co-investments. In this paper, we test how HCM and a specific set of organizational complements—an incentive system comprised of performance monitoring and performance based compensation—combine to drive the 'virtuous cycle.'

Organizational Practices

Our interviews with HCM practitioners and survey results indicate that HCM solutions are used to provide performance monitoring capabilities, allowing managers to better understand work performance and employee contributions. To fully leverage the monitoring capabilities provided by the HCM solution, we hypothesize that firms should also have in place or adopt an appropriate performance pay scheme. We use a principal-agent model with moral hazard and adverse selection to determine whether performance monitoring and performance pay form a system of organizational practices that complements HCM implementations.

Our theory is consistent with existing frameworks demonstrating the importance of analyzing a firm's work policies not "in isolation but as a part of coherent systems" (Holmstrom & Milgrom 1994, Milgrom & Roberts, 1990, 1995; Kandel & Lazear, 1992). Firms realize the largest productivity gains by adopting clusters of complementary practices, but benefit little from individual practices alone. Our work is particularly consistent with Ichniowski, Shaw and Prennushi (1997) who find that factories with a cluster of complementary human resource practices are significantly more productive than those that implement the same practices separately. These practices include performance pay, teamwork, flexible job assignment, employment security and training. Bartel (2004) documents similar findings in the banking sector. Through a large-scale empirical study, Black and Lynch (2001, 2004) show how new technologies, human capital investments and changes in work practices combine to drive productivity.

Perhaps the paper most closely related to our work is Bartel, Ichniowski and Shaw's (2007) analysis of several plant-level mechanisms through which IT promotes productivity growth. By studying a specific technology that is used to improve valve-making processes, they find plants that adopt new IT-enhanced equipment improve productivity by lowering set up times for new product runs. They subsequently document that IT also shifts firms' business strategies to produce more customized goods. Furthermore, IT and the demands for customization prompt changes in skill requirements and work practices needed to implement the new business strategies. Although their work focuses on a specific technology and its associated impact on work practices, the authors do not directly test the complementarities between the two. Our work not only focuses on a specific technology and a set of organizational practices that the technology is designed to support, it also documents how performance monitoring, HCM adoption, and performance pay, together act as a complementary system of technology and organizational practice.

Although we are aware that department-level analyses may be beneficial to explore fine-grained human resource practices, we choose to focus our analysis at the firm level. Department or business unit level analysis can eliminate heterogeneity introduced at the firm level. However, the decision to adopt enterprise systems such as HCM is generally made at the firm headquarters, and the scope of enterprise system implementation is usually firm-wide. Furthermore, because intra-firm transfer pricing need not face a market test (if it even exists at all) the key performance metrics will be more meaningful and credible when assessed at the firm level. Finally, firm-level analysis has more direct implications for firm strategy and bottom line business performance than analysis conducted at the department or business unit level.

A Principal-Agent Model with Moral Hazard and Adverse Selection

We use a principal-agent model with both moral hazard and adverse selection to analyze the complementarity of HCM software and compensation systems that include monitoring policies and performance pay. Our model builds on the work of Baker (1992) and Prendergast (1999), who examine incentive systems in which both the principal and the agent are risk neutral, and the agent makes a single effort decision. We differ from these models in two ways. First, we incorporate changes in the costs of monitoring, such as those affected by HCM solutions, into the model. Second, we distinguish talents of workers by their disutility of work, whereby skilled workers have a lower cost to exert the same level of effort than unskilled workers. We show that firms profit more through the use of an appropriate performance pay scheme if they simultaneously improve their ability to monitor work performance and prevent employees from gaming the compensation system. In addition, we analyze the profitability impact of the compensation system and information technology when performance monitoring, performance pay and HCM systems are simultaneously adopted.

Following Baker (1992), we allow for a divergence between the socially optimal and privately optimal level of effort. For example, if the agent is rewarded on the total number of patents he produces, he may knowingly file patents that take little effort but have minimal value to the principal. We model such a scenario by assuming that the principal cannot contract with the agent on the actual output q. Instead, the principal observes a performance measure p, which he uses to reward the agent. We assume output is a function of the agent's effort, $\mathbf{a}$, as follows:

(1)

$$q = a + \varepsilon_q \qquad (1)$$

where ε_q is normally distributed with mean 0 and variance σ_q^2. The performance signal p is also a function of effort except that indicators of performance are noisy, such that the marginal effect of effort on the performance indicator depends on a scaling factor $\boldsymbol{\alpha}$, while the true marginal productivity of effort is independent of $\boldsymbol{\alpha}$. We assume α is normally distributed with mean 1 and variance σ_α^2, where σ_α^2 can be viewed as a direct measure of the degree to which the agent can game the compensation system (Baker, 1992). The error term ε_p is also normally distributed with mean 0 and variance σ_p^2.

$$p = \alpha a + \varepsilon_p \qquad (2)$$

The risk neutral principal maximizes the profit function, which is a function of output q, the agent's wage w, and the cost of monitoring $\Gamma(s)$.

$$\Pi = E\{q - w - \Gamma(s)\} \qquad (3)$$

$$\text{where } \Gamma(s) = ks\text{ , } \sigma_\alpha^2 = \frac{1}{sm} \qquad (4)$$

The cost of using the technology to monitor is a linear function of a constant k and the effort of using the technology to monitor, s. To discourage the agent from gaming the compensation system or to reduce σ_α^2, the principal must have both the *policy* (m) and the *ability* (s) to monitor employees. When the principal adopts a monitoring technology without explicit monitoring policies, information produced by the technologies will be of no use. Similarly, having the policy to monitor without the right technology to observe employees' actions would be equally ineffective. Thus, the principle can only reduce σ_α^2 when she possess both the technology and the policy to monitor.

The agent is also risk neutral with a linear utility as a function of wage and a quadratic cost of effort. The reservation utility is $\overline{V}$.

$$w - \frac{1}{2}ca^2 \geq \overline{V} \qquad (5)$$

$$w = t + bp = t + b\alpha a + b\varepsilon_p \qquad (6)$$

Wage *w* is a linear function of the performance measure, with a fixed wage *t* and a pay-for-performance component at a rate *b*. An agent receives higher compensation by signaling higher performance, *p*, to the principal. Given a contract (*t*, *b*), the agent chooses an optimal effort level *a* to maximize her utility. From the first order condition, we can solve for the optimal effort:

$$a^* = \frac{\alpha b}{c} \qquad (7)$$

Solving the principal's maximization problem subject to the agent's participation constraint and incentive compatibility constraint yields the following result:

$$\pi^* = \frac{b}{c} - \frac{b^2}{2c}(1 + \sigma_\alpha^2) - k\frac{1}{\sigma_\alpha^2} \qquad (8)$$

If adopting the HCM technology allows the principal to better monitor the agent's work performance, we expect the firm to improve its profitability. Our interviews and surveys indicate that HCM can act as an instrument for reducing the magnitude of σ_α^2, the ability to game the compensation system. We assume the value of *k* to be small such that the cost of monitoring is minimal once the HCM system is in place. Typically, HCM systems have large fixed costs with relatively low marginal costs because it takes multiple years of planning and implementation before the system can "go live." However, the incremental cost of using the system is small after it is fully implemented. By reducing the ability for employees to game the system (decreasing

σ_{α}^{2}) through improved monitoring, firms should experience higher profits. This effect is characterized by

$$\frac{\partial^2 \pi}{\partial s \partial m} = \frac{1}{2c} b^2 \sigma_{\alpha}^4 - k > 0 \qquad (9)$$

However, firms can obtain even greater profits if both the power of the incentive, *b*, and their monitoring efforts are high at the same time, demonstrating the need to implement these organizational practices together as a system of IT complements. As the principal reduces the ability of the agent to game the compensation system through effective use of monitoring technologies and policies, the introduction of performance pay can direct employees to exert more effort to produce. Acting as a complementary system, performance pay, monitoring policy and monitoring technologies work together as a cluster of organizational practices that improve firm performance. Adopting each separately is less beneficial than adopting them all in concert (Milgrom & Roberts, 1992, Brynjolfsson & Milgrom, 2008).

$$\frac{\partial^3 \pi}{\partial b \partial s \partial m} = \frac{1}{c} b \sigma_{\alpha}^4 > 0 \qquad (10)$$

The second outcome of this model is that performance pay contracts can have a selection effect, attracting and retaining more talented workers in the firm (Lazear 1994). To see this, we extend the model by assuming that workers privately know their disutility of effort, *c*. Under this adverse selection model, for any linear contract *w*, only those whose disutility of effort is smaller than c^* will choose to work for the firm. To demonstrate this, we assume that there are only two types of workers, high ability (Type 1) and low ability (Type 2), where the high ability type or the talented workers have a lower disutility of exerting effort than less able workers. Specifically, θ share of workers are talented with a cost of effort $c = c_1$ while $1-\theta$ share of workers are of low ability with cost of effort $c = c_2$, where $c_1 < c_2$. Assuming the Spence-Mirrlees single-crossing condition, talented workers always have a higher reservation utility than less able workers, $\overline{V}_1 > \overline{V}_2$ since the outside option for high ability workers is always better. The optimal contract under this model will differ from the original model with no adverse selection. We show that higher performance pay under adverse selection can lead to the participation of only talented workers. Specifically, we show that the performance pay rate when both types participate is less than the performance pay rate when only the high ability workers participate.

Both types participate using the same contract—Pooling equilibrium

$$t^* = \overline{V_2} - \frac{(\theta(\frac{1}{c_1} - \frac{1}{c_2}) + \frac{1}{c_2})^2}{2c_2(2\theta(\frac{1}{c_1} - \frac{1}{c_2}) + \frac{1}{c_2})(1+\sigma_\alpha^2)} \quad b^* = \frac{\theta(\frac{1}{c_1} - \frac{1}{c_2}) + \frac{1}{c_2}}{(2\theta(\frac{1}{c_1} - \frac{1}{c_2}) + \frac{1}{c_2})(1+\sigma_\alpha^2)} \qquad (11)$$

Only more able workers participate —Exclusive equilibri (12)

$$b_1^* = \frac{1}{1+\sigma_\alpha^2} \qquad (13)$$

$$t_1^* = \overline{V_1} - \frac{1}{2c_1(1+\sigma_\alpha^2)} \qquad (14)$$

We can see the performance pay rate under the exclusive equilibrium, $b(c_1)$ is greater than the performance pay rate when both types participate, $b(c_1, c_2)$. As the firm raises the performance pay rate, b, less able workers drop out while talented workers continue to participate.

$$b(c_1) > b(c_1, c_2) \qquad (15)$$

$$t(c_1) < t(c_1, c_2) \qquad (16)$$

As the principal reduces the ability of the agent to game the compensation system, the principal is more likely to accurately observe and reward high ability workers. Thus, implementing an incentive scheme that retains talented workers can improve firm profits, since firms would no longer need to subsidize low ability workers by offering them a higher fixed salary. Acting as a complementary system, performance pay, monitoring policies and monitoring technologies form a coherent system of organizational practices that improve firm performance. Adopting each separately is less beneficial than adopting them in concert.

Summary of Model Conclusions and Hypotheses

The results of our analytical model demonstrate that there should be complementarities between monitoring (having both the technology and policies to monitor) and performance pay. As employees are compensated for stronger observed performance, the ability to monitor performance effectively (to reduce the error in the performance indicators' signal of actual output) should improve the appropriate assignment of rewards for performance, reduce the ability of employees to game the system, and improve the firm's ability to distinguish top performers from weak performers. Since the HCM software is designed in part to help firms monitor key performance indicators in managing their workforce and because monitoring practices themselves are important for effective performance measurement, we expect *there are positive interaction effects of performance pay, monitoring practices and adoption of the HCM software in concert, and that adoption of any two components of this system without the third forgoes the benefits of this complementarity*. Thus, we do not necessarily expect to observe complementarities between any two components of the system, like HCM and performance pay, unless the third component, in this case monitoring policies, is also present.

Data and Survey Methods

We collected detailed data on the enterprise system purchase and go-live decisions of 189 firms that adopted HCM systems from 1995 to 2006. The data include the U.S. sales of a major vendor's HCM software and are collected directly from the vendor's sales database. Since these data record separate dates for purchase and go-live events, we can separately measure technology investment and use, as well as the associated impact of each on firm performance. We matched these firms with data on their financial performance. Of the 189 firms in our survey, 90 firms are publicly traded with performance data in the COMPUSTAT database. In Table 1, we provide descriptive statistics of the financial data from for these 90 firms.

Table 1: Descriptive Statistics on Firm Financials

Variable	**Obs.**	**Mean**	**Std Dev**	**Min**	**Max**
Sales (MM$)	869	6644.68	12083.91	0	110789
Employees(M)	808	26.88	61.85	0	484
Capital(PPENet) (MM$)	850	2454.86	4267.27	.01	29382
MM$ = Millions of Dollars, M= thousands Source: Compustat 1995-2006					

Our human resource practice data is collected from a survey administered to the 189 firms between 2005 and 2006. We obtained the survey from a not-for-profit organization whose purpose is to share experiences of firms that adopt ERP to educate them about best practices. The organization is composed of 1750 member corporations and 50,000 individual members. The survey was sent to all the customers of this major ERP vendor that provided HCM adoption data. Since the majority of these customers are also members of this independent user organization, the response rate for the survey was high at 80%[1]. All surveyed firms have adopted some form of ERP from the same major vendor that provided the adoption data, but only half of these firms have specifically adopted the HCM software. We use survey responses to understand how the

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[1] The survey is a multi-year effort and is conducted on the Web. As this organization has a close relationship with most ERP users and also provides a report comparing the practice of each firm to its peers as well as reports of best practices and lesson learned, the survey response rate is high at 80%. The survey is often completed by a team from the responding firm whose members range from senior management to the rank and file of the organization depending on who has the expertise to answer a particular question. A senior executive from the human resource department typically coordinates this effort.

HCM software is used to monitor work performance, and how the current compensation system is implemented. Each question asks about the current coverage of a practice that firms may have implemented. Participants rank the degree to which their firm has adopted a given practice on a scale from 1 to 5 with a value of 1 indicating that there is no coverage and a value of 5 indicating that the practice is fully adopted by the organization. Definitions and descriptive statistics for all the survey questions are listed in Table 2. To test our hypotheses, we use the survey to construct variables on the level of performance monitoring and performance pay currently implemented by the firms in our sample.

Performance Monitoring

The performance-monitoring variable is constructed by combining nine survey questions that gauge how firms monitor workers to obtain more accurate performance signals. The questions are divided into three categories. The first category measures how firms monitor performance, to what degree the monitoring systems are integrated with other relevant systems such as financial reporting and sales systems, and whether these business processes support overall firm strategy (M1-M5). Adopting these monitoring practices is beneficial as they deter employees from gaming the compensation system (by reducing σ_α^2). The second category measures the extent to which firms can directly monitor employees' effort using detailed attendance and overtime records, and the ability of the firm to verify the productivity impact of these signals (M6-M8). The third category measures transparency (M9). When management clearly communicates the evaluation criteria to employees, it leaves no room for employees to misinterpret where they should exert effort. To construct the performance monitoring variable, we combine all these factors into a single measure where each factor is first normalized (Norm) by subtracting the mean of the responses and dividing by the standard deviation, yielding a measure of performance monitoring with mean zero and a standard deviation of 1.

$$Monitor = Norm(Norm(M_1) + Norm(M_2) + ... + Norm(M_9))$$

Correlations among individual constructs are shown in Appendix A. The correlations are positive but the survey questions are not strongly correlated and the Cronbach's alpha is 0.30. The low value is due to multidimensionality of monitoring practices since there is little reason to believe that firms adopting any one monitoring practice will necessarily adopt all others. Firm and industry characteristics can also lead to divergent monitoring practices. For example, attendance may be more important for a manufacturing firm than a software engineering firm, since the former requires workers to show up on time to operate machinery while software engineers can potentially work from anywhere. Therefore, we may expect manufacturing firms to implement monitoring policies that log detailed records of workers' attendance, such as practices in M6-M8 while software engineering firms are more likely to focus on other types of monitoring practices, such as aligning to the overall firm strategy. Our goal in this paper is not to identify which practices are most beneficial, but to evaluate the overall extent to which a firm monitors its workers. As long as firms monitor work performance, they may reap the economic rewards from monitoring regardless of the specific monitoring practices they choose to use. To test the validity of including all nine measures into a single component, we have separately introduced these measures into our main regression and find that we cannot reject the hypothesis that all nine practices have the same coefficients. Consequently, for simplicity of analysis and interpretation, we combined them into a single measure of monitoring.

Table 2: Human Resource Practices Survey Variables						
Performance Monitoring						
	Survey Question	Obs	Avg	Std Dev	Min	Max
M 1	Compensation planning system integrates information with other relevant non HR systems, such as financial systems, OSHA, manufacturing, sales	61	2.13	1.16	1	5
M 2	HR system allows for a Balanced Scorecard framework which is integrated into department and individual performance appraisal documents and supports benchmarking and continuous improvement	73	2.66	1.27	1	5
M 3	HR System provides data analysis and reporting tools to support HR policy development and decision making	76	3.00	1.14	1	5
M 4	HR system allows to analyze workforce data; design, implement and monitor corporate strategies to optimize the workforce; and continuously evaluate how various courses of action might affect business outcomes	72	2.38	1.01	1	4
M 5	HR system enables HR professionals to develop cost effective resource strategies, by supporting accurate the planning process, allowing to monitor actual performance relative to plan and allowing to simulate multiple planning scenarios or analyze the financial impact of head count changes	73	2.30	1.04	1	5
M 6	Time worked routed automatically to project accounting/ resource planning systems: Coverage	71	2.97	1.43	1	5
M 7	Time and attendance system has automated analysis and reporting capabilities to analyze KPIs such as lost time, productivity, cost of absence, overtime or illness	76	2.37	1.32	1	5
M 8	Time and attendance system accounts for corrections, calculates the impact of the adjustment, and brings it forward to the current period	66	3.11	1.55	1	5
M 9	Standardized job descriptions and evaluations are available online	75	2.43	1.38	1	5
	Monitor = Norm(Norm(m1)…+ Norm(m9))	47	0	1	-1.89	2.21
Performance Pay						
I1	Compensation plans are designed to support overall corporate business strategy as well as strategies of individual divisions/departments	63	13.79	3.29	1	5
I2	Compensation plans are designed to align pay with performance, and are linked to easily understood KPIs (e.g., corporate, divisional, organizational profitability)	83	3.77	.941	1	5
	Motivation= Norm(Norm(I1)+Norm(I2))	84	0	1	-2.87	1.43
I3	Compensation plans are aligned with resource plans to attract and retain the desired skill set	74	3.19	1.09	1	5
I4	Employee performance expectations clearly	68	3.43	1.14	1	5

	communicated during Recruiting process.					
	Selection= Norm(Norm(I3)+Norm(I4))	66	0	1	-2.88	1.81
	Performance Pay= Norm(Motivation) + Norm(Selection)	65	0	1	-2.44	1.87

Performance Pay

Our measures of performance pay practices assess the degree to which firms reward employees for their work performance. Five questions pertaining to performance pay are used to construct the variable. These questions are classified into two groups, monetary incentives that motivate employees, and self-selection mechanisms designed to attract and retain high quality employees. Incentives using monetary rewards can have the direct benefit of motivating workers to exert more effort and produce optimally. Self-selection is another potential benefit of performance pay, helping firms to attract and retain productive workers. Performance pay is likely to help firms retain high performers since they derive higher income as a function of their performance. At the same time, incentive compensation systems can induce poor performers to leave as their relative income is reduced. As incentive compensation takes on a greater share of the overall wage, these effects should be magnified.

We measure the impact of motivation and self-selection separately. To calculate the extent to which direct monetary rewards are used to motivate employees, we ask firms to report the importance of performance pay in their current compensation systems, and the degree to which incentives are aligned with business goals (I1 I2). The incentive compensation motivation variable is calculated by normalizing and summing the survey responses, yielding a measure with mean zero and a standard deviation of 1. Cronbach's alpha for the set of motivation measures is 0.64.

$$Motivation = Norm(Norm(I_1) + Norm(I_2))$$

Finding the right people and putting their talent to good use is one of the most important goals in any human resources department. Through self-selection, the appropriate compensation plan enables firms to hire and retain the talent they need. To assess this capability, we ask respondents to report the degree to which their firms use compensation plans to attract and retain talent (I3, I4). Cronbach's alpha for these measures is 0.59.

$$Selection = Norm(Norm(I_3) + Norm(I_4))$$

We construct the performance pay variable as the sum of motivation and self-selection and show the correlation matrix for perforce pay variables in Appendix A. The correlations are strongly positive.

$$PerfPay = Norm(Motivation + Selection)$$

Correlations between Monitoring and Performance Pay Practices

In Figure 1, we show the distribution of firms who have adopted performance monitoring and performance pay practices, along with our associated industry codes. Because the monitoring and performance pay variables are normalized, we divide the graph into four quadrants with the X and Y-axis valued at zero. Quadrant 1 contains firms that have both high levels of monitoring practices and performance pay practices, while quadrant 3 contains the opposite. Although firms are present in all four quadrants, the data are not evenly distributed. Specifically, a majority of firms are located in quadrants 1 or 3, relatively few are located in quadrants 2 or 4 where firms have high levels of performance monitoring but low levels of performance pay practices, or vice-versa.

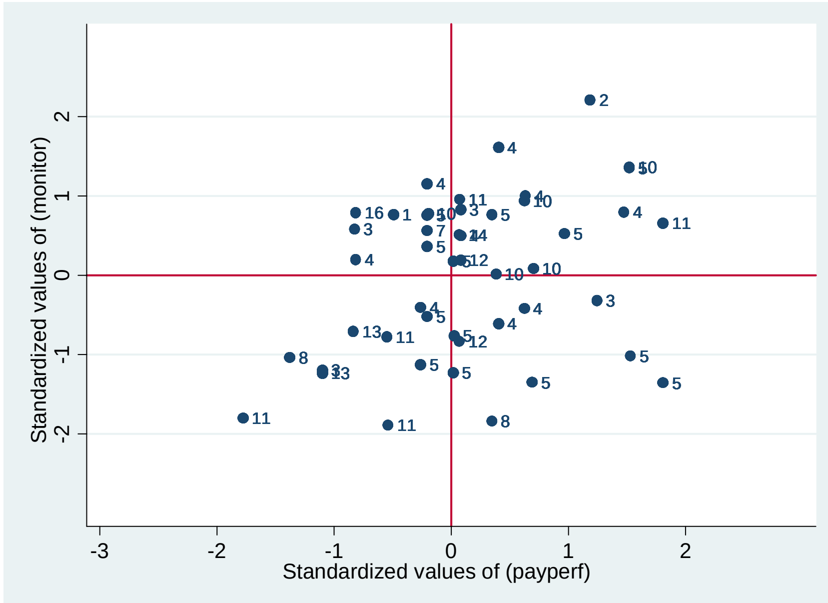

Figure 1: The Distribution of Monitoring and Performance Pay Practices for All Firms.

We also investigate how monitoring and performance pay practices vary across industries (see Table 3). We find that industries in involving physical work, such as construction and general retail, tend to have high levels of performance pay and monitoring practices, perhaps because firms in these traditional industries are able to measure workers' output more precisely.For example, construction output is easily observed; counting the number of bricks laid per unit time is easy and an accurate measure of actual worker productivity. For the same reason, industries such as professional, scientific and technical services, where it is hard to measure outputs generated by individual workers, tend to have relatively lower levels of monitoring practices.

Table 3: Monitoring and Performance pay practices by Industry

Industry	# Firms	Monitor Avg.	Performance PayAvg.
Retail Trade: miscellaneous retail	4	1.56	2.83
Professional, Scientific, and Technical Services	3	1.67	3.42
Finance and Insurance	8	2.16	3.50
Real Estate and Rental and Leasing	2	2.28	3.50

Manufacturing: food & textile	25	2.37	3.49
Manufacturing: material	8	2.61	2.71
Manufacturing: machinery & electronic products	21	2.90	3.60
Administrative Support & Waste Management & Remediation Services	3	2.78	3.58
Retail Trade: general retail	1	3.00	3.25
Information	5	3.04	3.95
Utilities	1	3.22	3.00
Others	1	3.22	2.75
Construction	1	4.22	4.50

Non-adopters vs. adopters of HCM Software

Next, we examine if there is any systematic difference between HCM adopters and non-adopters. We list the summary statistics for the two samples below.

Summary Statistics for HCM adopters

Variable	Obs	Mean	Std. Dev.	Min	Max
lnSales (MM$)	437	8.228691	1.490413	-.5108256	11.61539
lnEmployees(M)	442	6.846093	2.163024	-4.60517	10.28814
lnCapital(PPE Net) (MM$)	423	2.439552	1.712473	-4.961845	5.92135
Std Dev Monitor	288	0.0456761	0.9370652	-1.839183	1.354015
Std Dev PayPerf	348	0.0262813	0.8991296	-1.940735	1.808172

Summary Statistics of HCM non-adopters

Variable	Obs	Mean	Std. Dev.	Min	Max
Sales (MM$)	421	7.252376	1.441403	2.290816	10.87827
Employees(M)	408	5.580497	1.695459	1.182034	9.676786
Capital(PPE Net) (MM$)	374	1.767751	1.419896	-1.555897	5.872118
Std Dev Monitor	276	-0.047662	1.06132	-1.88891	2.210379
Std Dev PayPerf	432	-0.0211711	1.074962	-2.882619	1.808172

HCM adopters and non-adopters are not statistically different from one another in terms of firm revenue, the number of employees and physical plant, property and equipment. We also examine the industry distribution for HCM adopters and non-adopters and find the distributions for the two groups to be similar.

In contrast, HCM adopters and non-adopers differ significantly in their use of monitoring and performance pay practices. Compared to non-adopters, HCM adopters tend to have higher level of monitoring as well as more use of performance pay. This is consistent with the theoretical prediction that firms that monitor employee and use performance pay practices are more likely to adopt HCM software.

Empirical Methods and Simultaneity Bias

As we have a set of longitudinal IT adoption and financial performance data as well as a cross-sectional survey on organizational practices, we can test for complementarities between IT adoption and a system of human resource practices. In their review of organizational complementarities, Brynjolfsson and Milgrom (2008) describe two specific types of statistical tests to assess the existence of complementarities: correlations (adoption or demand equations) and performance differences (productivity equations). The first test determines if a cluster of practices is more likely to be adopted jointly rather than separately. The second test examines whether the hypothesized complements are more productive when adopted together rather than separately (Milgrom and Roberts 1990, Ichniowski, Shaw and Prennushi 1997, Athey and Stern 1998, Bresnahan, Brynjolfsson and Hitt 2002).

We first examine the correlations among performance pay, monitoring practices and HCM adoption. According to the model, we expect these three practices to form a system of complements in which any pair-wise correlation between two components of the system is positive when the third component is also present, but not necessarily otherwise. In assessing these correlations, we control for transitory shocks to adoption or performance by including a separate dummy variable for each year and industry controls for 15 industry groupings.

Next, we use performance differences to test the complementarities between HCM and an incentive system that includes performance pay and monitoring. If monitoring, performance pay and use of HCM are complements, we would expect firms that use these practices and technologies in concert to be the most productive. We test this hypothesis using a production function framework. Following the literature on IT-productivity (Brynjolfsson and Hitt 1996, 2000; Hitt, Wu and Zhou, 2002; Aral, Brynjolfsson and Wu, 2006), we adopt a Cobb-Douglas specification. In addition to Labor and Capital inputs, we embed HCM adoption and HR practices into the model to show how firms convert these inputs to outputs.

We first test whether performance monitoring, HCM adoption and performance pay separately impact productivity using the specifications below, where *K* represents capital, *L* is the number of employees and *HCM* represents dummy variables which equal to 1 each year after HCM is 'live' in the firm. As shown in our theoretical model, we expect better monitoring capabilities to improve firm performance. We then test whether monitoring, performance pay and HCM adoption form a system of complements that provides additional performance improvements when used together. From our theoretical model, if these practices form a system of complements, we expect the three way interaction, $HCMLive * Monitor * PerfPay$, to be positive.

$$\begin{aligned}
\ln(Sales) &= \alpha + \beta_1 \ln(K) + \beta_2 \ln(L) + \beta_3 HCMLive + \beta_4 Monitor \\
&+ \beta_5 PerfPay + \beta_6 (HCMLive * Monitor) + \beta_7 (HCMLive * PerfPay) \\
&+ \beta_8 (Monitor * PerfPay) + \beta_9 (HCMLive * Monitor * PerfPay) \\
&+ \sum_j \beta_j IndustryControls_j + \sum_k \beta_k Year_k + \varepsilon
\end{aligned}$$

Addressing Simultaneity Bias

Endogeneity may hamper the potential causal interpretation in this empirical model. Of particular concern, HCM adoption may be endogenous. While we hypothesize that HCM adoption drives firm performance, the reverse is also possible – firms may choose to adopt HCM when they perform well or experience exogenous shocks to productivity that inspire HCM adoption. The best way to do this is to separately measure the *decision to invest* versus the *actual investment* itself. In our data set, we are able to do exactly that.

Specifically, to address this potential simultaneity bias, we take advantage of an important feature in enterprise technology adoption. When adopting an enterprise system such as HCM, firms typically experience a lag of up to several years between the time they decide to invest in the system and the time when the system finally goes live. This reflects the complex implementation process requiring redesign of business processes, software customization and extensive training. Figure 2 shows a typical time line of HCM adoption as represented by one of the manufacturing firms in our sample. In this particular firm, the purchase of HCM software in 1997 initiated a five-year implementation sequence, which made it possible to actually use the system in 2002. On average, it takes a firm 2.71 years to complete an implementation of an HCM system from the initial purchase to use of the system,

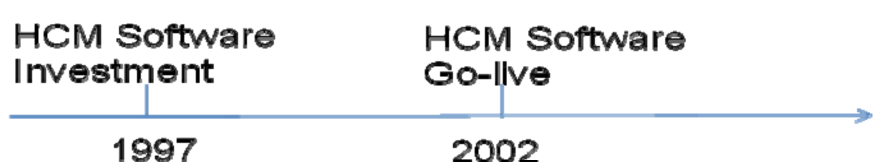

Figure 2: The time line of HCM adoption of a firm in the manufacturing industry for producing machinery and electronic product.

Using similar methodologies as in Aral, Brynjolfsson and Wu (2006), we separately estimate the regressions based on the HCM *purchase* event and the *go-live* event to distinguish firms' decisions to purchase in new technology from the impact of actually using the technology. If firm performance is correlated with the actual use of the technology but uncorrelated with the purchase decision, we can reasonably infer that technology drives performance instead of performance driving technology adoption.

Including the HCM *purchase* variable in the model leads in the following regression. The model predicts HCM *Live* to be part of the complementary system but not necessarily HCM *purchase*.

$$\begin{aligned}
&\ln(Sales) = \alpha + \beta_1 \ln(K) + \beta_2 \ln(L) + \beta_3 HCMPurchase + \beta_4 HCMLive + \beta_5 Monitor \\
&+\beta_6 PerfPay + \beta_7 (HCMPurchase * Monitor) + \beta_8 (HCMPurchase * PerfPay) \\
&+\beta_9 (Monitor * PerfPay) + \beta_{10} (HCMPurchase * Monitor * PerfPay) \\
&+\beta_{11} (HCMLive * Monitor) + \beta_{12} (HCMLive * PerfPay) \\
&+\beta_{13} (HCMLive * Monitor * PerfPay) + \sum_j \beta_j IndustryControls_j + \sum_k \beta_k Year_k + \varepsilon
\end{aligned}$$

In addition to the potential endogeneity of the purchase decision, a second potential source of endogeneity is that human resource practices such as performance pay and monitoring may be endogenous. Because our human resource practice data is cross-sectional, we cannot directly assess the level of HR practices before and after the HCM adoption. However, we take the advantage of the fact that organizational practices are often quasi-fixed (Applegate, Cash and Mills 1988, Brynjolfsson and Hitt 1996, Milgrom and Robert 1990, Murnane, Levy and Autor 1999; Bresnahan, Brynjolfsson and Hitt, 2001). Thus, our regressions can be interpreted as assessing whether pre-existing cross-firm differences in human resource practices influence the productivity return from using HCM.

Under the quasi-fixed assumption, firms that have already implemented performance pay and monitoring practices are more likely to invest in HCM because it can enhance the effectiveness of these organizational practices. HCM enables firms to improve the monitoring of employees and make their performance pay more salient. Firms that have already implemented performance pay and monitoring practices are in a better position to quickly reap the rewards of using HCM. In fact, the earlier these firms adopt HCM the more likely can they reap rewards from using HCM. Consequently, the demand for HCM should be higher for firms that have already implemented performance pay and monitoring practices. To test this hypothesis, we estimate a logistic regression, estimating the adoption of HCM as a function of existing organizational practices and firm performance.

$$\ln\left(\frac{P(Y_i = 1}{1 - P(Y_i = 1}\right) = \alpha + \sum \beta X + \varepsilon$$

A third source of endogeneity may arise from omitted third variables that drive HCM adoption, human resource practice adoption and performance. In order to mitigate against possible omitted variables we include industry and time dummies to capture any industry or exogenous temporal shocks to performance or organizational change. We also employ fixed-effects specifications to control for time invariant characteristics of each firm. For example, if good management is an omitted variable that confounds our results, fixed effects specifications are likely to soak up most of the variance from this variable. Although our organizational factors are cross-sectional, the HCM adoption variables are longitudinal, allowing us to use a fixed-effects specification to estimate coefficients on all time varying variables including those that interact with the HCM variables. The fixed-effect specifications give more confidence in our results since they eliminate the influence of any unobservable time-invariant characteristics of firms. However, there is also the risk that fixed effects will over-control for firm specific factors that are legitimately part of the complementarity system we are examining. Thus, the coefficient estimates from those specifications may underestimate the true effects of the complements.

Results

Assessing Complementarities

As discussed above, both correlations and productivity differences can be used to test for complementarities (Athey and Stern, 1998; Brynjolfsson and Milgrom, 2008). In fact, each test tends to be strongest when the other is weakest. If a particular set of complementary practices is a well-known phenomenon, we would expect all firms to adopt this system of complementarities and the correlations for the co-presences of these practices should be near perfect. However, precisely because every firm adopted the complementarities, there would not be any performance differentiations and the productivity test would not show any benefit from adopting the system. On the other hand, when firms are still assessing what makes a system of complementary practices, the co-presence of these practices would not be perfect but there should be detectable differences in productivity between firms that adopt the system of complements and those that do not.

The Correlation Test

We first examined the evidence for complementarities between HCM and the cluster of human resource practices. Tables 4, 5 and 6 show the pair-wise correlations among monitoring policies, performance pay and HCM adoption, controlling for the number of employees, industries and years. The results show broad support for the simultaneous adoption of a system of incentives and human capital management technologies.

Table 4, shows pair-wise correlations between HCM adoption and performance pay practices using logistic regressions (since HCM adoption is binary). The negative coefficient on the pair-wise correlation between performance pay and HCM adoption using the full sample seems to indicate that performance pay and HCM are not a part of the complementary system ($\beta = -.057$, $p < .1$; Model 1). However, after separately examining the sub sample of firms that have adopted monitoring practices, we see that the correlation between HCM Live and performance pay is positive and significant ($\beta = .058$, $p < .1$; Model 2), suggesting that performance pay and HCM are part of a complementary system only when firms simultaneously adopt policies to monitor employees. On the other hand, when a firm does not monitor employees, performance pay is negatively correlated with HCM adoption (albeit not significantly). Together, these results suggest the importance of examining the complete system of putative complements together. In contrast, pair-wise correlations between elements of the system can be misleading.

Table 5 shows pair-wise correlations between HCM adoption and monitoring practices using logistic regressions. Again, we see a similar pattern where the correlation between HCM adoption and monitoring policies is statistical significant only when firms also adopt performance pay policies. When firms use performance pay in compensation schemes, the correlation between performance monitoring and HCM adoption is positive and statistically significant at the 10% level ($\beta = .033$, $p < .1$; Model 2), suggesting that HCM and performance monitoring practices are complements in the presence of performance pay. On the other hand, when performance pay is not used, the correlation between monitoring practices and HCM is not different from zero, suggesting that monitoring policies and HCM are not complements in the absence of performance pay schemes.

Table 4. 3-way correlations: Logistic Regression: HCM and Performance Pay			
	(1)	**(2)**	**(3)**
	All obs.	Monitor >0	Monitor ≤0
Dep. Var.	**HCM**	**HCM**	**HCM**
Performance Pay	-.057* (.032)	.058* (.03)	-.221 (.212)
Control Variables	Industry Year Firm size	Industry Year Firm size	Industry Year Firm size
Obs.	461	333	45
log likelihood	-221.50	77.30	-21.06
χ^2(D.F.)	109.40	-166.39	21.20
Pseudo-R^2	.244	.225	.30
*p<.1, **p<.05, ***p<.001, Huber-White robust standard errors are shown in parentheses. Coefficients are marginal effects.			

The logistic regression in Tables 4 and 5 can also be used to estimate the probability of adopting HCM as a function of firm performance and human resource practices. Assuming a firm's organizational practices are quasi-fixed, these tables support the hypothesis that a firm is more likely to adopt HCM when it already has policies in place to monitor work performance and simultaneously uses performance pay to motivate employees (Model 2, Table 4; Model 2, Table 5). When a firm does not use performance pay, implementing monitoring practices alone does not increase the likelihood of adopting HCM (Model 3, Table 5). Conversely, when a firm does not monitor employees, it is less likely to adopt HCM despite having performance pay policies in place (Model 3, Table 4). Again, this is consistent with the existence of 'three-way complementarities' among IT, incentives and performance monitoring.

Table 5. 3-way correlations: Logistic Regression: HCM and Monitoring Policy			
	(1)	**(2)**	**(3)**
	All obs.	Perf Pay> 0	Perf Pay ≤ 0
Dep. Var.	**HCM**	**HCM**	**HCM**
Monitor	.102** (.053)	.033* (.015)	.124 (.178)
Control Variables	Industry Year	Industry Year	Industry Year

	Firm size	Firm size	Firm size
Obs.	263	169	45
log likelihood	-125.80	-75.88	-28.95
χ^2(D.F.)	56.5	44.25	5.22
Pseudo-R^2	.404	.626	.806
*p<.1, **p<.05, ***p<.001, Huber-White robust standard errors are shown in parentheses. Coefficients are marginal effects.			

Table 6. 3-way correlations: Linear Regression - Monitoring and Performance Pay			
	(1)	(2)	(3)
	All obs.	HCM Live =1	HCM Live =0
Dep. Var.	**Monitor**	**Monitor**	**Monitor**
Performance pay	.433*** (.080)	.127* (.080)	.528*** (.120)
Control Variables	Industry Year Firm Size	Industry Year Firm Size	Industry Year Firm Size
Obs.	396	222	174
R^2	0.404	.626	.806
*p<.1, **p<.05, ***p<.001, Huber-White robust standard errors are shown in parentheses.			

Lastly, Table 6 shows the pair-wise correlations between monitoring and performance pay practices. The correlation between the two sets of practices is positive and significant (β =.433, p<.001; Model 1) when the full sample of firms is used. In the split sample, monitoring and performance pay practices remain positively correlated whether or not the firm has invested in HCM, suggesting that they may be complements regardless of HCM.

Collectively, the pattern of correlations is consistent with three-way complementarities among HCM, monitoring and performance pay practices, and supports predictions from the economic model. However, we cannot rule out the existence of unobservable factors which, given just the right set of correlations, could mimic the correlation patterns resulting from true complements.

The Productivity Test

Table 7 shows the productivity regressions examining our main hypothesis that the combination of performance pay, monitoring practices and monitoring technology drives productivity. We also performed several outlier tests and detect a single firm that has an unusually large influence on all the regressions.[2] We show the results in Table 7 after eliminating this outlier. The results do not change qualitatively due to outliers as shown in Appendix B, although the statistical significance falls in some specifications. All models are either using clustered standard errors or fixed effect at the firm level. Model 1 uses the standard Cobb-Douglas production function framework, correlating the log of annual sales with the logs of capital and labor inputs in a fixed-effect specification. Coefficients for labor and capital are statistically significant and are within the range of theoretical predictions.

Next we estimate the impact of HCM adoption (defined as the "go-live" date) on performance. To precisely estimate the impact of HCM, we use a fixed-effect specification to eliminate influence from all time-invariant unobservables and add seasonality controls for time-specific changes. To address the simultaneity bias in estimating the return from HCM adoption, we separately estimate the purchase of HCM from the go-live event. If firm performance is correlated with the actual use of HCM rather than with purchase of the technology, we can infer that the HCM technology drives firm performance instead of performance driving the purchase of HCM software.

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[2] The residual is more than 3 times the standard deviation; Cook's D> 4/n where n is the number of observations; Dfit is 3 times the value of the cut-off.

Our results in Model 2 using a fixed-effect specification show that the estimated parameter of the go-live variable is positive and significant while the purchase variable is not significantly different from zero. This implies that the decision to purchase HCM is uncorrelated with productivity, while the actual use of the system is correlated with productivity ($\beta = .069$, $p < .05$; Model 2). The magnitude of the HCM go-live parameter has an intuitive economic interpretation—firms that adopt the HCM software produce approximately 6.9% greater output holding inputs constant. However, it could be that HCM adoption is correlated with adoption of a broader suite of ERP software and process changes and that we are picking up some of the productivity effects of ERP adoption as a whole in this estimate.

These estimates imply that simultaneity bias is not affecting our results and lend credibility to the argument that HCM adoption drives performance, rather than higher performance leading firms to adopt HCM. While this result gives us some confidence that the relationship between HCM adoption and productivity is causal, we are aware there could be alternate explanations for this pattern of results including lagged performance effects of enterprise systems adoption. When we add lagged HCM adoption into the model the results do not fundamentally change.

Models 5, 6 and 7 assess the pair-wise interactions among HCM, performance monitoring, and performance pay, using clustered standard errors. Model 5 estimates the pair-wise interaction between monitoring and HCM (for the *go-live* event). We find that the interaction between monitoring and HCM is not statistically different from zero. This suggests that in the absence of performance pay practices, performance monitoring and HCM are not complements. Similarly, we do not find evidence that performance pay and monitoring practices are complements in the absence of HCM, since the coefficient of their interaction term is not statistically different from zero (Model 7). This result suggests that monitoring policies and performance pay are not as strongly complementary when firms lack the appropriate technologies to monitor. There is weak evidence of a pair-wise complementarity between performance pay and HCM (Model 6). The coefficient of their interaction is positive, demonstrating they might be complements. However, this could be due to the fact that firms that have adopted both performance pay and HCM may also tend to monitor their employees. Thus this two-way interaction term may pick up the effect of the missing three-way interaction variable among monitoring, performance pay and HCM, as shown in Model 8.

Overall, these results largely support earlier results from the correlation tests. Both sets of tests illustrate the importance of examining the 'system of complements' as a whole since any subset of the system– two of three practices without the third – does not necessarily create complementarities without simultaneous adoption of all the system's components.

Model 8 applies a test of the three-way complementarities between HCM, monitoring practices and performance pay using clustered standard errors. The coefficients for *HCM Live*, monitoring and performance pay are positive and significant, consistent with estimates in earlier models. Similar to what we found in Models 3, 4, and 5, there is no evidence of an interaction effect for a partial system where only two out of the three components are used. For example, the coefficient of the interaction term between performance monitoring and performance pay is not significantly different from zero. It could be that without appropriate IT systems that make monitoring effective, performance pay alone does not enhance productivity. We compare the productivity effects of the system of incentive practices in firms that adopt HCM with the effect of similar firms that do not adopt HCM. As the *HCMlive* variable is a dummy variable indicating whether a firm is actually using the technology, the three-way interaction variable estimates the difference in the coefficients of the incentive system variable in firms with and without HCM, including variation across firms as well as variation within firms over time as they go from being non-adopters to adopters. As shown in Model 8, the interaction of any individual organizational practice (performance monitoring or performance pay) and *HCM live* is not significantly different from zero. However, the interaction of *HCM Live* and an incentive system that includes performance monitoring and performance practices $(HCMLive * Monitor * PerfPay)$ is positive and statistically significant. This result provides strong evidence for complementarities between the complete incentive system and the HCM technology that supports it. The parameter estimate for the three-way interaction indicates that the productivity of firms that have adopted the full set of incentive system practices are substantially higher in firms that have also adopted HCM compared to firms that have not adopted HCM.

Table 7. Productivity Effects of HCM, Monitor and Performance Pay											
	1	2	3	4	5	6	7	8	9	10	11
Dep.Var: Output	ln(Y)	ln(Y)	ln(Y)	ln(Y)	ln(Y)	ln(Y)	ln(Y)	ln(Y)	ln(Y)	ln(Y)	ln(Y)
Specification	FE	FE	Cluster	Cluster	Cluster	Cluster	Cluster	Cluster	FE	Cluster	FE
ln(capital)	.257*** (.0266)	.265*** (.0256)	.248** (.0985)	.277*** (.0677)	.247** (.0984)	.280*** (.0678)	.254*** (.0931)	.256*** (.0923)	.428*** (.0360)	.254*** (.0918)	.429*** (.0365)
ln(labor)	.517*** (.0369)	.579*** (.0340)	.712*** (.0845)	.638*** (.0804)	.713*** (.0843)	.643*** (.0823)	.683*** (.0780)	.689*** (.0754)	.400*** (.0514)	.692*** (.0751)	.394*** (.0522)
HCM Purchase:		.0430 (.0406)	.0480 (.155)	.136 (.130)	.0501 (.156)	.148 (.134)	.0172 (.147)	.0171 (.148)	-.0106 (.0464)	.0587 (.146)	-.0102 (.0510)
HCM Live:		.0689** (.0341)	.117 (.158)	.179 (.129)	.110 (.157)	.199 (.127)	.143 (.154)	.125 (.155)	.0570 (.0393)	.130 (.155)	.0562 (.0403)
monitor			.150 (.0942)		.145 (.0993)		.114 (.0983)	.103 (.0984)		.101 (.102)	
Perf Pay				.010 (.0764)		-.0224 (.0877)	.0868 (.149)	.102 (.118)		.116 (.119)	
Monitor* HCM live					.0305 (.105)			.0193 (.109)	.108*** (.0321)	.0202 (.115)	.122*** (.0352)
Perf Pay * HCM live						.124 (.133)		-.235 (.326)	-.129** (.0506)	-.250 (.351)	-.134** (.0627)
Monitor* Perf Pay							.0859 (.104)	.0617 (.105)		.0623 (.124)	
Monitor* Perf Pay* HCM live								.445* (.242)	.165** (.0687)	.445* (.247)	.143** (.0722)
Monitor * HCM Purchase										-.0523 (.174)	.0634 (.0663)
Perf Pay * HCM Purchase										-.173 (.328)	.000999 (.104)
Monitor* Perf Pay* HCM Purchase										.153 (.303)	-.0767 (.102)
Control Variables	Year Firm	Year Firm	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Industry Year	Year Firm	Industry Year	Year Firm
Obs.	772	772	384	552	384	552	384	384	384	384	384
R-squared	.817	.821	.932	.916	.932	.917	.934	.936	.876	.936	.877
*p<.1, **p<.05, ***p<.001. Huber-white robust standard errors are shown in parentheses.											

The estimation of the three-way interaction appears to be larger than expected, leading us to believe there are still other unobserved organizational practices that are correlated with monitoring and performance pay but missing in our data. However, true organizational complementarities may be far more than a 2-way or 3-way complementarities, but a composition of a large set of interlocking firm practices that complement each other.

The Cube View of Three-Way Complementarities

A graphical framework - the "Cube View" - is useful for understanding the complementarities among three-way systems of technology and organizational practices. In Figure 3, we present a 1x1x1 cube with the X-axis representing HCM, the Y-axis representing use of performance pay, and the Z-axis representing the extent to which a firm monitors employees. The binary version of the variable is used to label the coordinates in the cube, with 0 indicating a low level of implementation and 1 indicating a high level of implementation. For example, the coordinate (1, 1, 1) indicates that a firm has an HCM system installed, fully implements performance pay, and fully implements the monitoring practices.

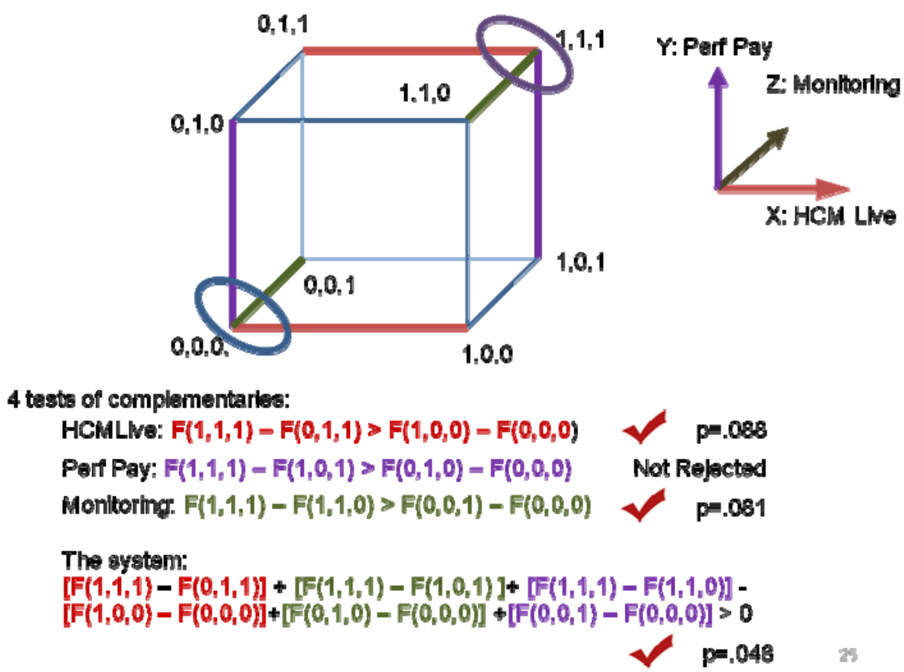

Figure 3: Cube View of Complementarities

Based on the theory of complementarities, we expect firms located at coordinate (1,1,1), where they adopt HCM and simultaneously implement high levels of performance monitoring and performance pay policies to be disproportionately more productive than firms that have implemented partial systems like coordinate (1, 0, 0) where firms have implemented HCM but adopt neither performance pay nor monitoring policies. Similarly, coordinate (1, 1, 0) represents firms that have adopted HCM and implemented performance pay but choose not to actively monitor employee performance.

Using the production function framework, we first determine whether firms that monitor employees and implement compensation schemes reap greater productivity gains from HCM than firms that do neither. We find this to be true by comparing the magnitude of parameter estimates for firms at the edge from (0,1,1) to (1,1,1) with those at the edge from (0,0,0) to (1,0,0). The difference between the edges is statistically significant at the 10% threshold (p=.088; HCM test), suggesting that firms reap greater benefits from HCM when they already have a complementary system of incentives that includes performance monitoring and performance pay.

Similarly, we determined whether firms that already have HCM and use performance pay reap greater productivity benefits from adopting performance monitoring policies than firms that have neither the technology to monitor employees nor the performance pay contracts to hire, retain and motivate talent. Our analyses find evidence that firms reap a greater reward from monitoring their employees when they use performance pay and simultaneously adopt HCM to monitor employees (p=.081; *Monitoring test*). In the third test (*PerfPay test*), we determine whether firms experience greater returns from using performance pay when they choose to use the technology to monitor employees. In contrast to the previous tests of complementarities, we do not find evidence supporting this claim.

Lastly, we develop and estimate a full test of three-way complementarities. The *system test* has greater statistical power than any of the previous tests and assesses whether firms that can complete the system of complements (1,1,1), by adopting just one of the three practices—HCM, monitoring and performance pay—experience a greater productivity gain than firms that choose to adopt the same practice but in isolation (i.e. starting from (0,0,0) and adding one practice). We find evidence supporting this claim through a t-test that demonstrates the difference to be highly significant at p=.048 (*System test*). A straightforward explanation of this result is the existence of three-way complementarities between incentives, monitoring and information technology.

Thus, the system test offers a unique and powerful way to assess the presence of a complementary system that may not be obvious from the regression results alone (Table 7). In Table 7, the three-way interaction among monitoring, performance pay and HCM adoption is positive and statistically significant compared to the null in which no components of the system is adopted. However, strictly speaking, this is neither necessary nor sufficient to identify complementarities. Instead, it is necessary to show that the benefits of implementing the full system are greater than sum of the benefits of the individual parts. Specifically, complementarities imply that the benefits to adopting the full system of practices together are greater than adopting those same practices in isolation. This is precisely what the system test does.[3]

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[3] In the analysis of the HCM system, we assess a 3-way system, In principle, systems with 4, 5 or more dimensions could be estimated using a generalized version of the system test we estimate here.

When applied to our sample, we find that the productivity gains from completing a full system of complementarities using all three practices is greater than sum of gains from adopting any one of the three practices in isolation. These results together provide evidence that technology adoption is complementary to a system of organizational practices that includes monitoring and performance pay. We find that firms experience greater productivity gains from HCM when they practice performance monitoring and adopt performance pay schemes, indicating that these organizational practices act as ‘a system of complements’ to HCM adoption.

Although we have found evidence of significant complementarities among information technology, monitoring practices and performance pay practices, we interpret the exact coefficient estimates of the three-way interaction terms with caution. Depending on the empirical method used and whether we exclude outliers, the coefficient estimates vary. These coefficients are often larger than expected, leading us to believe there are still other unobserved organizational practices that are correlated with monitoring and performance pay but missing in our data. This is likely since true organizational complementarities may be far more than a 2-way or 3-way complementarities, but a composition of a large set of interlocking firm practices that complement each other. Econometricians and even the managers themselves may not understand the full set of complements involved.

Milgrom and Roberts (1990) formally analyze how non-convexities can exist in a firm’s decision to adopt any or all of a set of organizational characteristics that together complement new technology. As the marginal benefit of adopting any one of a complementary set of activities increases with the adoption of the others, adoption of systems of practices (what Milgrom and Roberts 1990 call “groups of activities”) “may not be marginal decision[s].” They argue “exploiting such an extensive system of complementarities requires coordinated action between traditionally separate functions" (Milgrom and Roberts 1990, p. 515). Because such discovery and coordination is difficult, it is not surprising that we find a non-empty set of firms at each of the eight vertices of the 3-way complements cube. As expected, a disproportionate, but not universal, subset of them is in the higher performing clusters.

Does Performance Pay Affect Performance Via Motivation or Talent Selection?

Having found evidence that performance monitoring and performance pay work as a cluster of organizational practices that complement the adoption of HCM solutions, we end by examining two theoretical mechanisms which may enable these complementarities and through which incentive pay may drive productivity gains—employee motivation and self-selection. The first effect, employee motivation, is the direct effect of monetary rewards that motivate workers to exert more effort and produce more output. The second effect, self-selection, is the effect of performance pay on the likelihood that more talented and productive workers are likely to take and keep jobs in which they are disproportionally rewarded, while less productive workers are likely to turn over. When compensation is tied to performance, poor performers whose cost of effort is relatively high are likely leave as performance pay decreases their total compensation and makes the job difficult to justify from the perspective of their Participation Constraint. On the other hand, high performers are more likely to stay as they can earn more under performance pay compensation systems.

Self-selection allows firms to sort workers by ability even if they cannot observe that ability *a priori*. True abilities are a part of workers' private information and are generally unobservable to the employer especially at the beginning of the employment period. Although firms can update their beliefs about a worker's ability over time, the process is costly and the information obtained may still be inaccurate and incomplete. Acting as a selection device, incentive pay helps firms more cheaply identify talent and replace unproductive workers with more productive ones as less talented employees leave voluntarily.

Past empirical work has documented evidence of the dual effects of performance pay. For example, Lazear (1996) shows the impact of changing compensation from a fixed rate to a piece-rate plan in a windshield installation company. He found that productivity rose 35% due to this change, and uses the company's turnover rate to attribute a third of the productivity benefits to self-selection. Our theoretical model shows that performance pay can directly motivate employees as well as helping firms sort workers by talent. Under our moral hazard model with adverse selection, we expect performance pay to complement monitoring policies and monitoring technology primarily through talent selection. In our empirical analysis, we also quantify the differential effects of motivation and self-selection by separately measuring the effects of organizational practices designed to a) align pay with performance (motivation), and b) use compensation plans to attract and retain talent (self-selection). These proxies for distinguishing the two theoretical mechanisms behind the performance effects of performance pay may be measured with some error. For example, the act of aligning pay with performance will support self-selection, and the articulation of incentive policies will motivate employees, contaminating our results and biasing the differences in performance effects between the two to zero. If we do find differences across these distinct aspects in our proxy measures, it will be in spite of this measurement error.

Table 8. Employee Motivation or a Selection Effect?		
	1	**2**
Dep. Var.	**ln(output)**	**ln(output)**
Model	Cluster	FE
ln(capital)	.292*** (.0825)	.399*** (.0351)
Ln(labor)	.648*** (.0994)	.439*** (.0494)
HCM Invest	-.0212 (.147)	.0186 (.0454)
HCM Live	.0998 (.118)	.0833** (.0378)
Monitor	.0743 (.103)	
Monitor * HCM Live	.0477 (.111)	.0907*** (.0312)
Motivation	.0634 (.113)	
Motivation * HCM Live	-.433 (.259)	-.0363 (.0438)
Motivation* Monitor	.0258 (.152)	
Motivation* Monitor*HCM Live	-.229 (.319)	-.00572 (.0669)
Selection	.0790 (.111)	
Selection * HCM Live	.0555 (.194)	-.0661 (.0448)
Selection* Monitor	.00332 (.181)	
Selection* Monitor*HCM Live	.373* (.202)	.115 (.0855)
Control Variables	Industry Year	Firm Year
R^2	.93	.87
Obs.	384	384
*p<.1, **p<.05, ***p<.001, Huber-white robust standard errors are shown in parentheses.		

Table 8 shows the empirical results estimating proxies for motivation and self-selection. Model 1 includes both motivation and self-selection variables in a single regression. The effect from self-selection and its three-way interaction with performance monitoring and HCM is even stronger ($\beta_{Selection}$ = .079, p<0.1, $\beta_{Selection*Monitor*HCM}$ = .373, p < .05; Model 1), while none of the parameter estimates relating to motivation are significantly different from zero. The results suggest that HCM and performance monitoring are complements primarily due to the selection mechanism. The t-tests for ($\beta_{Selection} < \beta_{Motivation}$) and ($\beta_{Motivation*Monitor*HCM} < \beta_{Selection*Monitor*HCM}$) are both rejected at the p<.01 level. Firms that adopt HCM see greater returns from the system of incentives primarily through talent selection and retention effects. We suspect that HCM enhances firms' monitoring abilities such that motivation based incentives are heightened, and that as HCM improves monitoring, poor performers are more motivated to leave firms when they are identified accurately as poor performers and therefore paid less. We applied a fixed-effect specification to Model 2. As all the organizational practice variables such as monitoring and performance pay are cross-sectional and they are dropped from the estimation. The three-way interaction among self-selection, monitoring and HCM live is positive but falls short of being significant. However ($\beta_{Motivation*Monitor*HCM} < \beta_{Selection*Monitor*HCM}$) continues to be rejected at the p<.05 level, demonstrating that talent selection is the predominant mechanism driving the three-way complementary system.

Conclusion

Previous research has found evidence of complementarities between general investments in information technology and broad metrics organizational capital. We move this stream of inquiry from an expansive perspective of IT as a general-purpose technology, toward examination of specific process-enabling technologies designed to support human resource management and specifically incentive management. By studying a specific type of enterprise system, the Human Capital Management solution within the ERP suite, we are able to examine very specific, theory-driven predictions about *how* information technology complements a narrow set of business practices focused on designing and implementing effective incentive contracts.

We use a principal-agent model with adverse selection to model the way that incentives affect observable performance. In particular, we examine performance monitoring and performance pay as a set of organizational practices that complements HCM. Using a detailed survey of human resource practices and comprehensive objective enterprise IT adoption data, we provide some of the first firm-level evidence on *how* clusters of human resource practices complement a specific type of information technology.

Our analysis uncovers three key results. First, we find that HCM, performance pay, and monitoring practices are mutually correlated. In particular, the demand for HCM is significantly higher in firms that have adopted the other two practices. Second, these practices generate a disproportionate productivity premium when they are implemented simultaneously as a tightly knit system of organizational incentives. We develop and assess a cube view of complementarities, which illustrates the increased productivity from completing the triad of complements as compared to introducing one of its elements in isolation. Lastly, we find evidence that the complementarities in our sample can be entirely explained by talent selection, and not by changes in employee motivation. An important feature of our data is that we can rule out reverse causality between high productivity and HCM adoption. We do this by exploiting separate measures for purchase and go-live events,—allowing us to infer a causal explanation for the complementarities we find.

These results provide support the theoretical prediction of a three-way complementary system of organizational practices and suggest a path to greater productivity from technology innovations such as enterprise IT. At the same time, these three-way complementarities may be only part of an even larger complementary system, highlighting the complexity of successful technology-enabled organizational change.

References

Aral and Weill (2007) "IT Assets, Organizational Capabilities & Firm Performance: How Resource Allocations and Organizational Differences Explain Performance Variation", Organization Science, 18(5), September-October: 1-18.

Aral, Brynjolfsson and Wu (2006) "Which Came First, IT or Productivity? The Virtuous Cycle of Investment & Use in Enterprise Systems", International Conference on Information Systems 2006, December, 2006

Attewell, P. and Rule, J. "Computing and Organizations: What We Know and What We Don't Know", *Communications of the ACM* (27:12), 1984, pp. 1184-1192.

Baker, (1992). "Incentive Contracts and Performance Measurement," Journal of Political Economy, 100, pp. 598-614.

Bartel, A., Ichniowski, C., and Shaw, K. "How Does Information Technology Affect Productivity? Plant-Level Comparisons of Product Innovation, Process Improvement, and Worker Skills", *Quarterly Journal of Economics* (122:4), 2007, pp. 1721-1758.

Black, Sandra E. and Lynch, Lisa M. "How to Compete: The Impact of Workplace Practices and Information Technology on Productivity." Review of Economics and Statistics, 2001, 83(3), pp. 434-45.

Black, Sandra E. and Lynch, Lisa M. "Measuring Organizational Capital in the New Economy," 2005.

Black, Sandra E. and Lynch, Lisa M. "What's Driving the New Economy?: The Benefits of Workplace Innovation." Economic Journal, 2004, 114(493), pp. F97-F116.

Bloom, Nicholas; Sadun, Raffaella and Van Reenen, John. "It Ain't What You Do It's the Way That You Do It-Testing Explanations of Productivity Growth Using US Affiliates," mimeo Centre for Economic Performance, London School of Economics, 2005.

Bloom, Nicholas; Sadun, Raffaella and Van Reenen, John. "Americans do I.T. Better: US Multinationals and the Productivity Miracle," mimeo Centre for Economic Performance, London School of Economics, 2008.

Bradley, S.P. and R. Nolan, Sense and Respond: Capturing Value in the Network Era, Harvard Business School Press, 1998.

Bresnahan, T., Brynjolfsson, E. and Hitt, L. M. "Information Technology, Workplace Organization and the Demand for Skilled Labor: Firm-level Evidence", Quarterly Journal of Economics (117:1), 2002, pp. 339-376.

Bresnahan, T. and Trajtenberg, M. "General Purpose Technologies: Engines of Growth?", Journal of Econometrics (65:1), 1995, pp. 83-108.

Brynjolfsson, E. and L. Hitt (1995) "Information Technology As A Factor Of Production: The Role Of Differences Among Firms" Economics of Innovation and New Technology, 3(3): 183 – 200

Brynjolfsson, E. and Hitt, L. M. "Beyond the Productivity Paradox", Communications of the ACM (41:8), 1998, pp. 49-55.

Brynjolfsson, E and Yang, S. "Intangible Benefits and Costs of Computer Investments : Evidence from the Financial Market." Proceedings of the International Conference on Information Systems, 1999.

Brynjolfsson, Erik and Lorin M. Hitt (1993) "Is Information Systems Spending Productive? New Evidence and New Results," Proceedings of the 14th Annual International Conference on Information Systems, Orlando, FL. December: 47-64.

Brynjolfsson, E. and Hitt, L. M. "Paradox Lost? Firm-Level Evidence on the Returns to Information Systems", Management Science (42:4), 1996, pp. 541-558.

Brynjolfsson, E. and Hitt, L. M. "Computing Productivity: Firm-Level Evidence", Review of Economics and Statistics (85:4), 2003, pp. 793-808.

Brynjolfsson, E., Hitt, L. M. and Yang, S. "Intangible Assets: Computers and Organizational Capital, " Brookings Papers on Economic Activity (1), 2002, pp. 137-199.

Brynjolfsson, E., Hitt, L. M. and Yang, S. (1998) "Intangible Assets: How the Interaction of Computers and Organizational Structure Affects Stock Market Valuations", Proceedings of the 19th Annual International Conference on Information Systems, Helsinki, Finland: pp. 8-29.

Brynjolfsson, E., Milgrom, R. (2008) “Complementarities in Organizations”, NBER Workshop on Economics of Organization

Caroli, E. and Van Reenen, J. “Skill-Biased Organizational Change: Evidence from a Panel of British and French Establishments”, Quarterly Journal of Economics, 116:4, pp: 1449-1492.

Cappelli, P., The New Deal at Work: Managing the Market Driven Workforce, Harvard Business School Press, Cambridge, USA, 1993.

Griliches, Z and Mairesse, “Productivity and R&D at the Firm level”(pp339-374) in Z. Griliches (Ed.) *R&D Patent and Productivity* (Chicago: University of Chicago Press, 1984

Hitt, L.M., Wu, D. J., and Zhou, X. “Investment in Enterprise Resource Planning: Business Impact and Productivity Measures,” Journal of Management Information Systems (19:1), 2002, pp. 71-98

Holmstrom, Bengt and Milgrom, Paul. "The Firm as an Incentive System." American Economic Review, September 1994,84'(4), pp. 972-91.

Hubbard, Thomas N., “Information, Decisions and Productivity: On-Board Computers and Capacity Utilization in Trucking,” American Economic Review, XCIII (2003), 1328-1353.

Ichniowski, Casey and Shaw, Kathryn. "Beyond Incentive Pay: Insiders' Estimates of the Value of Complementary Human Resource Management Practices." Journal of Economic Perspectives, 2003, 17(1), pp. 155-8.

____. "The Effects of Human Resource Management Systems on Economic Performance: An International." Management Science, 1999, 45(5), pp. 704-721.

Ichniowski, Casey; Shaw, Kathryn and Prennushi, Giovanna. "The Effects of Human Resource Management Practices on Productivity: A Study of Steel Finishing Lines." American Economic Review, 1997, 87(3), pp. 291-313.

Jorgenson, Dale W., Mun C. Ho and Kevin Stiroh, “Growth of U.S. Industries and Investments in Information Technology and Higher Education,” in Carol Corrado, John Haltiwanger, and Daniel Sichel, eds., Measuring Capital in the New Economy (Chicago, IL: University of Chicago Press, 2005).

Kandel, Eugene and Lazear, Edward P. "Peer Pressure and Partnerships." Journal of Political Economy, 1992, 100(4), pp. 801-817.

Lazear, E. (2000) a “Performance Pay and Productivity”, The American Economic Review, Vol. 90, No. 5 (Dec., 2000), pp. 1346-1361

Lazear, E. (2000) b, “The Power of Incentives.” American Economic Review, Vol. 90, No. 2,410-414.

Mendelson, H. “Organizational Architecture and Success in the Information Technology Industry,” Management Science (46:4), April 2000, pp. 513-529.

Mendelson, H. and Pillai, R. “Clockspeed and Informational Response: Evidence from the Information Technology Industry”, Information Systems Research (9:4), 1998, pp. 415-433.

McAfee, A. 2004. “Do You Have Too Much IT?" MIT Sloan Management Review 45, no. 3: 18-22.

Milgrom, Paul and John Roberts, “The Economics of Modern Manufacturing: Technology, Strategy and Organization” American Economic Review, LXXX (1990), 511-528.

Oliner, Stephen, and Daniel Sichel, "Computers and Output Growth Revisited: How Big is the Puzzle?'Brookings Papers on Economic Activity 2 (1994), 273-317.

Paarsch, H., andShearer, B.(2000), “Piece Rates, Fixed Wages, and Incentive Effects: Statistical Evidence from Payroll Records,” International Economic Review 41, no. 1 (2000): 59-92.

Paarsch, H., andShearer, B., (2004), “Piece Rates, Fixed Wages and Incentives: Evidence from a Field Experiment,” Review of Economic Studies 71, no. 2 (2004): 513-534.

Prendergast (1999) “The Provision of Incentives in Firms”, Journal of Economic Literature, Vol. XXXVII, March 1999

Swanson, E.B., and Wang, P. “Knowing Why and How to Innovate with Packaged Business Software,” Working Paper, The Anderson School at UCLA, Los Angeles, CA, 2003.

APPENDIX [NOT FOR PUBLICATION]

A. Correlation matrix for monitoring and performance pay practices

Table A.1 Correlations for survey questions used to construct the monitoring practice variable

	M1	M2	M3	M4	M5	M6	M7	M8	M9
M1	1								
M2	.2417	1							
M3	.3253	.3491	1						
M4	.3642	.0114	.5428	1					
M5	.1879	.1765	.5713	.6517	1				
M6	.5236	.1914	.1984	.1384	.0411	1			
M7	.3098	.371	.2686	.1047	.0687	.4604	1		
M8	.4322	.0501	.2596	.1878	.013	.6655	.5205	1	
M9	.4298	.1064	.1458	.2336	.1418	.5066	.3645	.6857	1

Table A.2 Correlations for survey questions used to construct performance pay variable

	I1	I2	I3	I4
I1	1			
I2	.6312	1		
I3	.6886	.5973	1	
I4	.42	.2603	.3754	1

B. Productivity Effects of HCM, Monitoring and Performance Pay including the Outlier Firm.

Table 7b. Productivity Effects of HCM, Monitor and Performance Pay

	1	2	3	4	5	6	7	8	9	10	11
dep.var: output	ln(Y)	ln(Y)	ln(Y)	ln(Y)	ln(Y)	ln(Y)	ln(Y)	ln(Y)	ln(Y)	ln(Y)	ln(Y)
model	firm-FE	firm-FE	cluster	cluster	cluster	cluster	cluster	cluster	firm-FE	cluster	firm-FE
ln(capital)	.254***	.253***	.257***	.279***	.257***	.282***	.265***	.266***	.401***	.263***	.398***
	(.026)	(.026)	(.038)	(.025)	(.038)	(.025)	(.037)	(.037)	(.035)	(.037)	(.035)
ln(labor)	.520***	.528***	.695***	.631***	.695***	.635***	.661***	.664***	.436***	.667***	.434***
	(.036)	(.036)	(.031)	(.028)	(.031)	(.028)	(.031)	(.031)	(.049)	(.030)	(.049)
HCM Invest:		.032	.031	.122**	.033	.132**	-.004	-.002	.021	.028	.029
		(.039)	(.070)	(.061)	(.071)	(.062)	(.069)	(.070)	(.045)	(.083)	(.049)
HCM Live:		.056*	.104	.171***	.100	.187***	.124*	.129*	.090**	.134*	.093**
		(.033)	(.066)	(.056)	(.065)	(.056)	(.066)	(.068)	(.037)	(.069)	(.037)
monitor			.123***		.120***		.084**	.075**	--	.070*	--
			(.034)		(.036)		(.035)	(.037)	--	(.039)	--
Perf Pay				.020		-.010	.142***	.162***	--	.174***	--
				(.025)		(.029)	(.045)	(.039)	--	(.043)	--
Monitor* HCM live					.021			-.003	.086***	-.002	.096***
					(.046)			(.047)	(.031)	(.049)	(.034)
Perf Pay * HCM live						.117**		-.152	-.064	-.165	-.048
						(.055)		(.132)	(.045)	(.134)	(.054)
Monitor* Perf Pay							.044	.023	--	.020	--
							(.040)	(.042)	--	(.051)	--
Monitor* Perf Pay* HCM live								.266***	.074	.268**	.051
								(.102)	(.060)	(.105)	(.063)
Monitor * HCM Invest										-.022	.038
										(.079)	(.066)
Perf Pay * HCM Invest										-.181	.079
										(.194)	(.100)
Monitor* Perf Pay* HCM Invest										.168	-.142
										(.178)	(.099)
Control Variables	year	Year	industry year	industry year	industry year	industry year	industry year	industry year	year	industry year	year
R^2	.86	.86	.93	.93	.92	.92	.93	.93	.97	.93	.97
Obs.	396	396	396	396	396	396	396	396	396	396	396

*p<.1, **p<.05, ***p<.001. Huber-white robust standard errors are shown in parentheses