We present evidence on the three-way complementarities among information technology (IT), performance pay, and monitoring practices. We first develop a principal-agent model modeling how these practices work together as a tightly knit incentive system that produces the largest productivity premium when the practices are implemented in concert. We then assess our model by combining fine-grained data on Human Capital Management (HCM) software adoption with detailed survey data on incentive system for 90 firms over 11 years. We find that the adoption of HCM software is correlated with the use of performance pay, and performance monitoring. 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 generally 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, selection or both. Because our survey separately addresses each of these mechanisms, we can also address this question. We find that the complementarities in our sample can be entirely explained by talent selection policies, and not changes in motivation.

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

Substantial variation exists in the returns to information technology (IT) investments across firms (Brynjolfsson & Hitt 1995; Hitt & Brynjolfsson 1995, Aral & Weill 2007). One reason for this variation in outcomes 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 uptick in research of a potential complementary practice, such as pay-for-performance incentive compensation policies, by U.S. firms (Ichniowski & Shaw 2003). Economists have recently begun to examine the performance implications of such incentive compensation plans and, as in the case of IT, there is substantial variation in their effectiveness. 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 systems are linked.

We argue that organizational incentive systems 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 demonstrates this complementarity and argue that the co-presence of IT and incentive systems should explain variation in both the returns to IT and the effectiveness of performance pay contracts and performance monitoring. We hypothesize that firms derive benefits from well designed performance pay schemes primarily through talent selection that helps attract and retain high quality labor while eliminating underperformers (Lazear 2000, Paarsch and Shearer 2000). 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 to promote talent selection. We hypothesize that providing performance pay without effective performance monitoring creates adverse incentives or no incentive at all, and that monitoring without performance pay is less effective than with an performance pay scheme that promotes talent selection. Our goals are to examine the complementarities among IT, monitoring and an performance pay scheme that promotes talent selection, to determine whether practices can be effectively implemented piecemeal or must be introduced as a ‘system of practices’ (Milgrom & Roberts 1990), and finally to distinguish the mechanisms through which the 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 et. al. (2006) demonstrates 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) and thus creating a cycle of escalating returns. In this paper, we examine the mechanisms driving this virtuous cycle. We collected detailed data on the purchase, installation and go-live decisions of 189 enterprise systems adopters from the sales database of a large enterprise systems vendor from 1995 to 2006. We are able to separate the purchase of IT from the actual use of IT, which for ERP systems may occur years later. By doing
so, we address the potential endogeneity of the relationship between IT and productivity. We then gathered a unique data set surveying the detailed human resource practices of these 189 firms in 2005, of which half 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.

**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 (Hitt & Brynjolfsson 1995). A leading explanation for this variation is that firms with higher returns simultaneously 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. Using 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).

However, most of the literature on IT and organizational co-investment has focused on general-purpose information technologies and organizational practices (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 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 Software is a part of the Enterprise Resource Planning (ERP) systems. It is an ideal choice for studying how a specific technology complements a specific set of organizational practices to improve productivity. HCM is part of a large-scale, general-purpose, process-enabling enterprise technology that typically takes several years to
The main purpose of HCM is to equip executives, HR professionals, and line managers with a broad range of workforce support, including accurate planning on performance pay, and the ability to continuously monitor actual 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 strategies as well as measure employee, division and firm performance.

For example, HCM allows the firm to monitor work performance of its employees. It can keep a detailed record of employees’ attendance, such as time worked, overtime, illnesses and vacation time. The figure below captures a snapshot of what management’s view of a person’s time and attendance.

HCM can also track detailed work record. Using the HCM system, a worker can enter detailed records of each task they performed. The snapshot below shows a typical entry of 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 for the task.
Estimating returns on 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 et al. (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 et al (2006) provide an updated study using ERP adoption data on 698 firms from 1998-2005. By distinguishing the purchase of enterprise systems from their installation and use, this study offers some of the first evidence documenting a potential causal relationship between ERP adoption and firm productivity. The study illustrates the existence of a ‘virtuous cycle’ whereby successful ERP implementations prompt firms to invest 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.

Understanding how enterprise systems interact with organizational complements is especially important as these co-investments are instrumental for the success of enterprise systems such as the Human Capital Management (HCM) software. 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.’

**Human Capital Management 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 value created by employees. To fully leverage the monitoring capabilities provided by the HCM solution, we hypothesize that firms should simultaneously adopt an appropriate performance pay scheme. We use a principal-agent model with adverse selection to demonstrate that performance monitoring and performance pay form a system of organizational practices that complements HCM implementations.

Our theory confirms 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, Aral & Weill 2007). Firms realize the largest productivity gains by adopting clusters of complementary practices, but benefit little from individual practices alone. Our work is related to Ichniowski et al. (1997) who find that factories with a cluster of complementery 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. Similarly, Bartel (2004) documents similar findings in the banking sector. Through a large empirical study, Black and Lynch (2001, 2004) show how new technologies, human capital investments and changes in work practices combine to drive productivity.

In the set of papers most closely related to our work, Bartel, Ichniowski and Shaw (2007) analyze several plant-level mechanisms through which IT promotes productivity growth. By studying one narrowly defined industry—valve manufacturing—and 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 them. 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 that promotes talent selection, together act as a complementary system of technology and organizational practice.

We choose to focus our analysis at the firm level instead of within different departments in a single firm although we are aware that department-level analyses may be beneficial to explore fine-grained human resource practices. The advantage of analysis at the department level is that it can eliminate heterogeneity introduced at the firm level among different departments. However, the decision to adopt enterprise system such as HCM is generally determined at the
firm headquarters and the scope of these enterprise system implementation is usually firm-wide as well. 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, analysis at the firm level has more implications for firm strategies and bottom line business performance than at the department level.

**A Principal-Agent Model with Moral Hazard and Adverse Selection**

We use a basic principal-agent model with adverse selection to analyze the complementarity of HCM solutions and compensation systems that include monitoring and performance pay that promotes talent selection. 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 change the model by incorporating the costs of monitoring created by the adoption of HCM solutions. Second, we distinguish talents of workers by their disutility of work where skilled worker has a lower cost to exert the same level of effort than unskilled ones. We show that firms will profit more by hiring only the talented workers through an appropriate performance pay scheme if firms can 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. After all, it is in the agent’s interest to do so, given the incentive structure he faces. We model this 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, $a$, as follows:

$$q = a + \varepsilon_q$$

where $\varepsilon_q$ is normally distributed with mean 0 and variance $\sigma_q^2$. Similarly, we model the performance signal $p$ as 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 $\alpha$, while the true marginal productivity of effort is independent of $\alpha$. We assume $\alpha$ is normally distributed with mean 1 and variance $\sigma_\alpha^2$, where $\sigma_\alpha^2$ can be viewed as a direct measure of the degree to which the agent can game the compensation system (Baker, 1992). The error term $\varepsilon_p$ is also normally distributed with mean 0 and variance $\sigma_p^2$.

$$p = \alpha a + \varepsilon_p$$

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 $\Gamma(s)$.

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

where $\Gamma(sm) = ksm$, $\sigma_\alpha^2 = \frac{1}{sm}$

The cost of monitoring is a linear function of a constant $k$ and $s$, the effort of using technologies to monitor. To reduce the ability of the agent to game the compensation system or $\sigma_\alpha^2$, the principal must have the policy, $m$, as well as the ability to monitor employees, $s$. When the principal has the monitoring technology but without having explicit rules to monitor employees, information produced by the technologies will be of no use. Similarly, having the
policy to monitor the agent without having the right the tools, the principal would not experience any positive return from its monitoring effort. Only when a firm possess both the technology and the policy to monitor can it reduce $\sigma_a^2$.

The agent or the employee is also risk neutral and has a linear utility as a function of wage and quadratic costs. The reservation utility is $\bar{V}$.

\[
w - \frac{1}{2} ca^2 \geq \bar{V}
\]

\[
w = t + bp = t + baa + b\varepsilon_p
\]

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

\[
a^* = \frac{ab}{c}
\]

Solving the principal’s maximization problem subject to the agent’s individual rationality (IR) and incentive compatibility (IC) constraints yields the following results.

\[
\pi^* = \frac{b}{c} - \frac{b^2}{2c}(1 + \sigma_a^2) - k \frac{1}{\sigma_a^2}
\]

If adopting an HCM system allows the principal to better monitor the work performance of the agent, we expect the firm to improve their profitability. Our interviews and surveys indicate that HCM can act as an instrument for reducing the magnitude of $\sigma_a^2$, the ability of the
agent 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 as HCM can take multiple years of planning and implementation before the systems “go live,” but once the HCM system is in place, the incremental costs of monitoring are minimal. By reducing the ability for employees to game the system (decreasing $\sigma^2$) through improved monitoring, firms should subsequently experience higher profits. This effect is characterized below.

$$\frac{\partial^2 \pi}{\partial \sigma \partial m} = \frac{1}{2c} b^2 \sigma^4 - k > 0$$

However, firms can obtain even greater profits if they increase the power of the incentive, $b$, at the same time as they increase their monitoring efforts, demonstrating the need to implement these organizational practices simultaneously as a system of IT complements. As the principal reduces the ability of the agent to game the compensation system through adopting monitoring policy and using the appropriate technology to monitor, increasing performance pay enables the principal to better align the overall organizational strategy with the goals of individual employees. Acting as a complementary system, performance pay, monitoring policy as well as the monitoring technology work together as a cluster of organizational practices to improve firm performance. Adopting them separately is less beneficial than adopting them in concert (Milgrom & Roberts, 1992, Aral & Weil 2007, Brynjolfsson & Milgrom, 2008).

$$\frac{\partial^3 \pi}{\partial b \partial \sigma \partial m} = \frac{1}{c} b \sigma^4 > 0$$

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

Both types participate using the same contract—Pooling equilibrium

$$t^* = \bar{V}_2 - \frac{(\theta(\frac{1}{c_1} - \frac{1}{c_2}) + \frac{1}{c_2})^2}{2c_2(2\theta(\frac{1}{c_1} - \frac{1}{c_2}) + \frac{1}{c_2})(1 + \sigma_\alpha^2)}$$

$$b^* = \frac{\theta(\frac{1}{c_1} - \frac{1}{c_2}) + \frac{1}{c_2}}{(2\theta(\frac{1}{c_1} - \frac{1}{c_2}) + \frac{1}{c_2})(1 + \sigma_\alpha^2)}$$

Only more able workers participate —Exclusive equilibrium

$$b_1^* = \frac{1}{1 + \sigma_\alpha^2}$$

$$t_1^* = \bar{V}_1 - \frac{1}{2c_1(1 + \sigma_\alpha^2)}$$
We can see the performance pay rate \( b \) under the exclusive equilibrium is greater than the performance pay when both types participate.\(^1\) As the firm raises performance pay rate, \( b \), less able workers drop out while talented workers still participate.

\[
b(c_1) > b(c_1, c_2) \\
t(c_1) < t(c_1, c_2)
\]

As the principal reduces the ability of the agent to game the compensation system, the principal is more likely to accurately observe and reward talented workers. Thus, implementing incentive scheme that retain talented workers can improve firm profits, since firms would no longer need to subsidize the low ability workers through offering them a higher fixed salary. Acting as a complementary system, performance pay contract that promote talent selection and monitoring policies and monitoring technology form a cluster of organizational practices to improve firm performance. Adopting them separately is less beneficial than adopting them together.

**Theories on Monitoring and Incentives**

The key characteristic that will affect whether monitoring should complement or substitute incentives is the extent to which technical changes facilitate the type of performance signals. As our model and Baker (1992) shows, monitoring technology improves the measurement of performance signal, \( p \), that proximate the actual output, \( q \). The monitoring capability comes primarily from reducing the noise of the performance signal and therefore prevents workers from gaming the compensation system. Under this model, as performance

\(^1\) We also show this to be true for a separating equilibrium in the Appendix.
signal, \( p \), can be more accurately observed, the firm should also create a higher level of incentives to achieve greater return on productivity.

Alternatively, the agency theory by Holmstrom (1979) shows the tradeoff between risks and incentives. When the monitoring technology eliminates risks, incentives are muted as well. For example, Baker and Hubbard (2004) have argued that the on-board computers used in trucks, can decrease the cost of monitoring a trucker’s level of care in driving. Consequently, compensation scheme shifts away from performance pay to rewarding on the level of care from driving, which is a signal they can observe well with the new technology. Thus, to understand the impact of information technology on firm incentives, it is important to understand what type of performance signal a particular technology can measure.

**Summary of Model Conclusions and Hypotheses**

The results of our analytical model demonstrate that there should be complementarities between monitoring and performance pay that promotes talent selection. As employees are compensated for stronger observed performance, the ability to monitor performance effectively (to reduce the error in the performance indicator’s 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 module is designed in part to help firms monitor key performance indicators in managing their workforce and that monitoring practices themselves are important for effective performance measurement, we expect there are positive effects of talent selection policies and performance monitoring on productivity and positive interaction effects of monitoring practices and HCM that supports monitoring activities, as well as positive interaction effects of talent selection policies, monitoring activities and adoption of the HCM module in concert.
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 solutions and are collected directly from the vendor’s sales database. Since these data record dates for purchase and go-live events, we can measure technology investment and use, as well as their associated impact on firm performance. We then 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. After removing private firms, government agencies and those with missing data, we were left with 90 firms over 11 years. In Table 1, we provide the descriptive statistics of the financial data from for these 90 firms.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Obs.</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales (MMS)</td>
<td>869</td>
<td>6644.68</td>
<td>12083.91</td>
<td>0</td>
<td>110789</td>
</tr>
<tr>
<td>Employees(M)</td>
<td>808</td>
<td>26.88</td>
<td>61.85</td>
<td>0</td>
<td>484</td>
</tr>
<tr>
<td>Capital(PPE Net) (MMS)</td>
<td>850</td>
<td>2454.86</td>
<td>4267.27</td>
<td>.01</td>
<td>29382</td>
</tr>
</tbody>
</table>

MM= Millions, MMS = 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 an independent and non-for-profit organization whose purpose is to share experiences of firms that adopt ERP to educate them about best practices. The organization is involved with 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 is high at 80%. The survey has more than 200 detailed questions about firm-level human resources management practices. 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 adopted the HCM module. We use survey responses to understand how the HCM module is used to monitor work performance, and how the current compensation system is implemented. Each question asks about the current coverage of a best practice that firms may have implemented. Participants rank the degree to which their firm has adopted a given practice from 1-5 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 from 9 survey questions that gauge how firms monitor their employees to obtain accurate performance signals. The questions are divided into three categories. The first category measures how firms use the HR system to monitor performance, to what degree these monitoring systems are integrated with financial reporting systems, sales systems and other relevant data, and whether these business processes support strategy formulation and scenario planning (M1-M5). Adopting these monitoring practices is beneficial as they deter employees from gaming the compensation system (reducing \( \sigma_a^2 \)). The second category measures the extent to which firms can directly monitor the effort level of employees 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 scales and dividing by the standard deviation, yielding a measure of performance monitoring with mean zero and a standard deviation of 1.

\[ \text{Monitor} = \text{Norm}(\text{Norm}(M_1) + \text{Norm}(M_2) + \ldots + \text{Norm}(M_9)) \]

<table>
<thead>
<tr>
<th>Performance Monitoring</th>
<th>Survey Question</th>
<th>obs.</th>
<th>avg.</th>
<th>sd.dev</th>
<th>min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>Compensation planning system integrates information with other relevant non HR systems, such as financial systems, OSHA, manufacturing, sales</td>
<td>61</td>
<td>2.13</td>
<td>1.16</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>M2</td>
<td>HR system allows for a Balanced Scorecard framework which is integrated into department and individual performance appraisal documents and supports benchmarking and continuous improvement</td>
<td>73</td>
<td>2.66</td>
<td>1.27</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>M3</td>
<td>HR System provides data analysis and reporting tools to support HR policy development and decision making</td>
<td>76</td>
<td>3.00</td>
<td>1.14</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>M4</td>
<td>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</td>
<td>72</td>
<td>2.38</td>
<td>1.01</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>M5</td>
<td>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</td>
<td>73</td>
<td>2.30</td>
<td>1.04</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>M6</td>
<td>Time worked routed automatically to project accounting/ resource planning systems: Coverage</td>
<td>71</td>
<td>2.97</td>
<td>1.43</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>M7</td>
<td>Time and attendance system has automated analysis and reporting capabilities to analyze KPIs such as lost time, productivity, cost of absence, overtime or illness</td>
<td>76</td>
<td>2.37</td>
<td>1.32</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>M8</td>
<td>Time and attendance system accounts for corrections, calculates the impact of the adjustment, and brings it forward to the current period</td>
<td>66</td>
<td>3.11</td>
<td>1.55</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>M9</td>
<td>Standardized job descriptions and evaluations are available online</td>
<td>75</td>
<td>2.43</td>
<td>1.38</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Monitor = Norm(Norm(m1)...+ Norm(m9))</td>
<td>47</td>
<td>0</td>
<td>-1.89</td>
<td>2.21</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Performance Pay</th>
<th>Survey Question</th>
<th>obs.</th>
<th>avg.</th>
<th>sd.dev</th>
<th>min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>I1</td>
<td>Compensation plans are designed to support overall corporate business strategy as well as strategies of individual divisions/departments</td>
<td>63</td>
<td>13.794</td>
<td>3.288</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>I2</td>
<td>Compensation plans are designed to align pay with performance, and are linked to easily understood KPIs (e.g., corporate, divisional, organizational profitability)</td>
<td>83</td>
<td>3.771</td>
<td>.941</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Motivation= Norm(Norm(I1)+Norm(I2))</td>
<td>84</td>
<td>0</td>
<td>-2.87</td>
<td>1.43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I3</td>
<td>Compensation plans are aligned with resource plans to attract and retain the desired skill set</td>
<td>74</td>
<td>3.19</td>
<td>1.09</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>I4</td>
<td>Employee performance expectations clearly communicated during Recruiting process.</td>
<td>68</td>
<td>3.43</td>
<td>1.14</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Selection= Norm(Norm(I3)+Norm(I4))</td>
<td>66</td>
<td>0</td>
<td>-2.88</td>
<td>1.81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Performance Pay= Norm(Motivation) + Norm(Selection)</td>
<td>65</td>
<td>0</td>
<td>-2.44</td>
<td>1.87</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Performance pay

The assessment of performance pay practices in the incentive system, constructed using survey response, assesses 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 can be roughly divided into two categories, monetary incentives that motivate employees to perform optimally and self-selection mechanisms designed to attract and retain high quality employees. Incentives using monetary rewards have the direct benefit of motivating workers to exert more effort and produce optimally. Self-selection, an indirect benefit of performance pay, enables firms to distinguish productive workers from unproductive ones. Performance pay is likely to help firms retain high performers as 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 they underperform. 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 the importance of performance pay in the current compensation system, and of the degree to which incentives are aligned with business goals \((I_1 \ I_2 \ I_3)\). The incentive compensation motivation variable is calculated by normalizing and summing the survey responses, yielding a measure with a mean zero and a standard error of 1.

\[
\text{Motivation} = \text{Norm}(\text{Norm}(I_1) + \text{Norm}(I_2) + \text{Norm}(I_3))
\]

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 retain the talent they need and eliminate ones they do not. To assess this
capability, we ask respondents to report the degree to which their firms use compensation plans to attract and retain talent (I4, I5).

\[
Selection = \text{Norm} (\text{Norm}(I_4) + \text{Norm}(I_5))
\]

We then construct the performance pay variable as the sum of motivation and self-selection as follows:

\[
PerfPay = \text{Norm}(\text{Motivation} + \text{Selection})
\]

In Figure 1, we show the distribution of firms who have adopted performance monitoring and talent selection practices. Since these variables are normalized with means valued at zero, we divide the graph into 4 quadrants with the X and Y axis valued at zero. Quadrant 1 contains firms that have both high levels of monitoring and performance pay practices, while quadrant 3 contains the opposite. Although firms are present in all four quadrants of the graph, the distribution is not entirely even. While a large proportion of the firms are located in quadrant 1, a few are located in quadrant 2 where firms have high level of performance monitoring but low levels of talent selection practices.
We then investigate how monitoring and performance pay measures vary across industries (Table 3). Industries, 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 precisely measure workers’ output. For construction, counting how many bricks were laid is not hard to do and reflect the 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 high level of performance pay but low level of monitoring practices.

<table>
<thead>
<tr>
<th>Industry</th>
<th># Firms</th>
<th>Monitor Average</th>
<th>Performance pay Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retail Trade: miscellaneous retail</td>
<td>4</td>
<td>1.56</td>
<td>2.83</td>
</tr>
<tr>
<td>Professional, Scientific, and Technical Services</td>
<td>3</td>
<td>1.67</td>
<td>3.42</td>
</tr>
<tr>
<td>Finance and Insurance</td>
<td>8</td>
<td>2.16</td>
<td>3.50</td>
</tr>
<tr>
<td>Real Estate and Rental and Leasing</td>
<td>2</td>
<td>2.28</td>
<td>3.50</td>
</tr>
<tr>
<td>Manufacturing: food &amp; textile</td>
<td>25</td>
<td>2.37</td>
<td>3.49</td>
</tr>
<tr>
<td>Manufacturing: material</td>
<td>8</td>
<td>2.61</td>
<td>2.71</td>
</tr>
<tr>
<td>Manufacturing: machinery &amp; electronic products</td>
<td>21</td>
<td>2.90</td>
<td>3.60</td>
</tr>
<tr>
<td>Administrative Support &amp; Waste Management &amp; Remediation Services</td>
<td>3</td>
<td>2.78</td>
<td>3.58</td>
</tr>
<tr>
<td>Retail Trade: general retail</td>
<td>1</td>
<td>3.00</td>
<td>3.25</td>
</tr>
<tr>
<td>Information</td>
<td>5</td>
<td>3.04</td>
<td>3.95</td>
</tr>
<tr>
<td>Utilities</td>
<td>1</td>
<td>3.22</td>
<td>3.00</td>
</tr>
<tr>
<td>Others</td>
<td>1</td>
<td>3.22</td>
<td>2.75</td>
</tr>
<tr>
<td>Construction</td>
<td>1</td>
<td>4.22</td>
<td>4.50</td>
</tr>
</tbody>
</table>

**Empirical Methods and Simultaneity Bias**

Having a set of longitudinal IT adoption and financial data as well as a cross-sectional survey on organizational practices allows us to test the complementarities hypothesis between IT
adoption and a system of human resource practices. Empirical tests of complementarity involve demonstrations of the clustering of complements across firms and positive effects of the co-presence of complements on performance (Milgrom and Roberts 1990, Bresnahan et al. 2002, Aral & Weill 2007). Brynjolfsson and Milgrom (2008) suggest two types of statistical tests to prove the existence of complementarities: correlations and performance differences. We first show the correlations among performance pay, monitoring practices and HCM adoption that enables effective monitoring. According to the model, we expect these three practices form a system of complements and we expect the pair-wise correlation between any two components of the system to be positive only when the third component is also present. In these set of regressions, we control for transitory shocks to performance by including a dummy variable for each year and industry controls for 15 industry groupings at the 1½ digit SIC level.

Next, we use performance differences to demonstrate 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 that support them 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 $HCM$ are dummy variables which equal 1 after HCM is ‘live’ in
the firm. As shown in our theoretical model, we expect better monitoring capabilities to improve firm performance.

\[
\ln(Sales) = \alpha + \beta_1 \ln(K) + \beta_2 \ln(L) + \beta_3 \text{HCM} + \beta_4 \text{Monitor} + \beta_5 \text{PerfPay} \\
+ \sum_j \beta_j \text{Industry}_j + \sum_k \beta_k \text{Year}_k + \varepsilon
\]

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 forms a system of complements, we expect the three way interaction, \(HCMLive \times \text{Monitor} \times \text{PerfPay}\), to be positive.

\[
\ln(Sales) = \alpha + \beta_1 \ln(K) + \beta_2 \ln(L) + \beta_3 \text{HCMLive} + \beta_4 \text{Monitor} \\
+ \beta_5 \text{PerfPay} + \beta_6 (\text{HCMLive} \times \text{Monitor}) + \beta_7 (\text{HCMLive} \times \text{PerfPay}) \\
+ \beta_8 (\text{Monitor} \times \text{PerfPay}) + \beta_9 (\text{HCMLive} \times \text{Monitor} \times \text{PerfPay}) \\
+ \sum_j \beta_j \text{IndustryControls}_j + \sum_k \beta_k \text{Year}_k + \varepsilon
\]

**Addressing Simultaneity Bias**

There are two sources of endogeneity that may hamper the potential causal interpretation in this empirical model. First, HCM adoption may be endogenous. While we hypothesize that HCM adoption drives firm performance, the reverse causality is also possible in which firms choose to adopt HCM when they are expected to perform well or they experience exogenous shocks to productivity that inspires HCM adoption. To address this potential simultaneity bias, we took advantage of a unique feature in enterprise technology adoption. To adopt an enterprise system such as HCM, firms often experience a lag of several months or years between the time they decide to install the system and the time when the system finally go live. Figure 2 shows a typical time line of HCM adoption. In this particular firm, there is a five year gap between the beginning of installation and the final use of HCM. We also provide the summary statistics for
the gaps below. On average, it takes a firm 2.71 years to complete an implementation of an HCM system.

<table>
<thead>
<tr>
<th>HCM System install</th>
<th>HCM System Go-live</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>2002</td>
</tr>
</tbody>
</table>

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 installation of HCM and the go-live event to distinguish firms’ decisions to invest 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 installation of the technology, we could reasonably assume that technology drives the performance instead of performance drives the technology adoption. Adding HCM Install variable in the model leads in the following regression. Similarly we would assume HCM Live to be the part of the complementary system instead of HCM install

\[
\ln(Sales) = \alpha + \beta_1 \ln(K) + \beta_2 \ln(L) + \beta_3 HCM\text{Install} + \beta_4 HCM\text{Live} + \beta_5 \text{Monitor} \\
+ \beta_6 \text{PerfPay} + \beta_7 (HCM\text{Install} * \text{Monitor}) + \beta_8 (HCM\text{Install} * \text{PerfPay}) \\
+ \beta_9 (\text{Monitor} * \text{PerfPay}) + \beta_{10} (HCM\text{Install} * \text{Monitor} * \text{PerfPay}) \\
+ \beta_{11} (HCM\text{Live} * \text{Monitor}) + \beta_{12} (HCM\text{Live} * \text{PerfPay}) \\
+ \beta_{13} (HCM\text{Live} * \text{Monitor} * \text{PerfPay}) \\
+ \sum_j \beta_j \text{IndustryControls}_j + \sum_k \beta_k \text{Year}_k + \varepsilon
\]

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 (Brynjolfsson and Hitt 1996). Thus, our regressions test how cross-firm differences in human resource practices influence the productivity return from investing in HCM.

Under the quasi-fixed assumption, firms that have already implemented performance pay and monitoring practices are more likely to invest in HCM which can empower the effectiveness of these practices. Adopting HCM to monitor employees enables these firms to quickly reap the rewards of using the technology, and consequently, early adoption of HCM for these firms is more likely to be beneficial. Conversely, firms that do not have the appropriate performance pay practices and monitoring policy are less likely to reap rewards from adopting HCM. Consequently, their demand for HCM would also be lower. To test this hypothesis, we estimate a logistic regression of adopting HCM as a function of the existing human resource practices and firm performance.

\[
\ln\left(\frac{P(Y_{i} = 1)}{1 - P(Y_{i} = 1)}\right) = \alpha + \sum \beta X + \epsilon
\]

Lastly, 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 interacts with the HCM variable. The fixed-effect specification gives more credibility to our result since it eliminates influence from any time-invariant characteristics that are unobservable to us.

**Results**

**Assessing Complementarities**

**The Correlation Test**

Our first task is to examine the evidence for complementarities between HCM and a cluster of human resource practices. Table 4, 5 and 6 show the pair-wise correlations among
monitoring, performance pay and HCM adoption, after 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 monitoring practices using logistic regressions, since the dependent variable, HCM, is binary variable. There is an overall positive correlation between performance monitoring and HCM (β = .460, p < .05; Model 1) when we use the full sample of firms. This is consistent with the hypothesis that performance monitoring practices complement HCM adoption. However, after we separate firms by their use of performance pay, the resulting correlations vary. When firms use performance pay in compensation, the correlation between performance monitoring and HCM adoption is positive and significant (β = .175, p < .1; Model 2), suggesting that HCM and performance monitoring practices are complement when performance pay is simultaneously adopted. On the other hand, when performance pay is not used, the correlation between monitoring and HCM is still positive but becomes insignificant (β = .5, p > .1; Model 3), providing a much weaker evidence of complementarities than when performance pay is used in compensation.

In Table 5, the negative coefficient for 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 (β = -.30, p < .1; Model 1). In fact they seem to be substitutes instead. However, after separating the sample into firms that have adopted monitoring practices from those that do not monitor their employees, the correlations significantly vary. When firm have performance monitoring practices, the correlation coefficient between HCM adoption and performance pay is positive and significant (β = .289, p < .1; Model 2). This suggests that performance pay and HCM are part of complementary system only when the firm
simultaneously adopts policies to monitor employees. On the other hand, when a firm does not monitor employees, performance pay is actually negatively correlated with HCM adoption, albeit not significant. This suggests that performance pay and HCM may actually be substitutes when there is no policy to monitor employees. Together, these results demonstrating the importance of examining the system of complements together, as even pair-wise correlations between elements in the system can be misleading.

The logistic regression in Table 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, Table 4 supports the hypothesis that a firm is more likely to adopt HCM when firms already have policies to monitor work performance and simultaneously use performance pay to motivate employees and self-select top talents (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 4). Conversely, when a firm does not monitor employees, HCM is less likely to be adopted despite having implemented performance pay policies that promotes talent selection (Model 3, Table 5). Again, this is consistent with the existence of ‘three-way complementarities’ among IT, incentives and performance monitoring.
### Table 4. 3-way correlations: Logit regression between HCM and Monitor

<table>
<thead>
<tr>
<th>Dep. Var.</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCM</td>
<td>Monitor</td>
<td>Perf Pay &gt; 0</td>
<td>Perf Pay ≤ 0</td>
</tr>
<tr>
<td>All obs.</td>
<td>.460** (.235)</td>
<td>.175* (.131)</td>
<td>.500 (.765)</td>
</tr>
<tr>
<td>Control Variables</td>
<td>Industry</td>
<td>Industry</td>
<td>Industry</td>
</tr>
<tr>
<td></td>
<td>Year</td>
<td>Year</td>
<td>Year</td>
</tr>
<tr>
<td>Firm size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>263</td>
<td>169</td>
<td>45</td>
</tr>
<tr>
<td>χ²(D.F.)</td>
<td>56.5</td>
<td>44.25</td>
<td>5.22</td>
</tr>
<tr>
<td>Pseudo-R²</td>
<td>.404</td>
<td>.626</td>
<td>.806</td>
</tr>
</tbody>
</table>

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

### Table 5. 3-way correlations: Logit regression between HCM on Selection

<table>
<thead>
<tr>
<th>Dep. Var.</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCM</td>
<td>Performance Pay</td>
<td>Monitor &gt; 0</td>
<td>Monitor ≤ 0</td>
</tr>
<tr>
<td>All obs.</td>
<td>-.30* (.080)</td>
<td>.289* (.150)</td>
<td>-1.03 (.967)</td>
</tr>
<tr>
<td>Control Variables</td>
<td>Industry</td>
<td>Industry</td>
<td>Industry</td>
</tr>
<tr>
<td></td>
<td>Year</td>
<td>Year</td>
<td>Year</td>
</tr>
<tr>
<td>Firm size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>461</td>
<td>333</td>
<td>45</td>
</tr>
<tr>
<td>χ²(D.F.)</td>
<td>-221.50</td>
<td>77.30</td>
<td>-21.06</td>
</tr>
<tr>
<td>Pseudo-R²</td>
<td>.244</td>
<td>.225</td>
<td>.30</td>
</tr>
</tbody>
</table>

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

### Table 6. 3-way correlations: Linear regression Monitor and Selection

<table>
<thead>
<tr>
<th>Dep. Var.</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitor</td>
<td>Performance pay</td>
<td>Monitor</td>
<td>Monitor</td>
</tr>
<tr>
<td>All obs.</td>
<td>.433*** (.080)</td>
<td>.127* (.080)</td>
<td>.528*** (.120)</td>
</tr>
<tr>
<td>Control Variables</td>
<td>Industry</td>
<td>Industry</td>
<td>Industry</td>
</tr>
<tr>
<td></td>
<td>Year</td>
<td>Year</td>
<td>Year</td>
</tr>
<tr>
<td>Firm Size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>396</td>
<td>222</td>
<td>174</td>
</tr>
<tr>
<td>R²</td>
<td>0.404</td>
<td>.626</td>
<td>.806</td>
</tr>
</tbody>
</table>

*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 are used. After we separate the sample by firms’ decision to purchase HCM, monitoring and performance pay remain positively correlated, suggesting that they may be complements regardless of HCM.

**The Productivity Test**

Table 7 shows the results from productivity regressions examining our main hypothesis that the combination of performance pay, monitoring practices and monitoring technology drives productivity. Model 1 uses the standard Cobb-Douglas production function framework, correlating the log of annual sales with the logs of physical capital and labor. The coefficients for labor and capital are both statistically significant and within the ballpark 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 the time-invariant variables and added seasonality controls for time-specific changes, such as firms tend to perform poorly in a recession. To address the simultaneity bias in estimating the return from adoption HCM, we separately estimate the installation of HCM from the go-live event, since examining both the go-live and the installation variables provides a valuable technique for assessing causality. Because HCM solutions, a module with the ERP system, can typically take months or even years to implement, we can estimate these effects separately. If firm performance is correlated with the actual use of HCM instead of mere installation, we can reasonably assume that the HCM technology drives firm performance instead of performance driving the investment in information technology.
Table 7. Productivity Effects of HCM, Monitor and Performance Pay

<table>
<thead>
<tr>
<th>Fixed Effect</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln(capital)</td>
<td>.254***</td>
<td>.253***</td>
<td>.257***</td>
<td>.279***</td>
<td>.257***</td>
<td>.282***</td>
<td>.265***</td>
<td>.266***</td>
<td>.401***</td>
<td>.263***</td>
<td>.398***</td>
</tr>
<tr>
<td></td>
<td>(.026)</td>
<td>(.026)</td>
<td>(.038)</td>
<td>(.025)</td>
<td>(.038)</td>
<td>(.025)</td>
<td>(.037)</td>
<td>(.037)</td>
<td>(.035)</td>
<td>(.037)</td>
<td>(.035)</td>
</tr>
<tr>
<td>ln(labor)</td>
<td>.520***</td>
<td>.528***</td>
<td>.695***</td>
<td>.631***</td>
<td>.695***</td>
<td>.635***</td>
<td>.661***</td>
<td>.664***</td>
<td>.436***</td>
<td>.667***</td>
<td>.434***</td>
</tr>
<tr>
<td></td>
<td>(.036)</td>
<td>(.036)</td>
<td>(.031)</td>
<td>(.028)</td>
<td>(.031)</td>
<td>(.028)</td>
<td>(.031)</td>
<td>(.031)</td>
<td>(.049)</td>
<td>(.030)</td>
<td>(.049)</td>
</tr>
<tr>
<td>HCM Install:</td>
<td>.032</td>
<td>.031</td>
<td>.122**</td>
<td>.033</td>
<td>.132**</td>
<td>-.004</td>
<td>-.002</td>
<td>.021</td>
<td>.028</td>
<td>.029</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(.039)</td>
<td>(.070)</td>
<td>(.061)</td>
<td>(.071)</td>
<td>(.062)</td>
<td>(.069)</td>
<td>(.070)</td>
<td>(.045)</td>
<td>(.083)</td>
<td>(.049)</td>
<td></td>
</tr>
<tr>
<td>HCM Live:</td>
<td>.056*</td>
<td>.104</td>
<td>.171***</td>
<td>.100</td>
<td>.187***</td>
<td>.124*</td>
<td>.129*</td>
<td>.090**</td>
<td>.134*</td>
<td>.093**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(.033)</td>
<td>(.066)</td>
<td>(.056)</td>
<td>(.065)</td>
<td>(.056)</td>
<td>(.066)</td>
<td>(.068)</td>
<td>(.037)</td>
<td>(.069)</td>
<td>(.037)</td>
<td></td>
</tr>
<tr>
<td>monitor</td>
<td>.123***</td>
<td>.120***</td>
<td>.084**</td>
<td>.075**</td>
<td>--</td>
<td>.070*</td>
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<td></td>
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<tr>
<td></td>
<td>(.034)</td>
<td>(.036)</td>
<td>(.036)</td>
<td>(.037)</td>
<td>--</td>
<td>(.039)</td>
<td>--</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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*p<.1, **p<.05, ***p<.001. Huber-white robust standard errors are shown in parentheses.

Our result in Model 2 shows that the estimated parameter of the go-live variable is positive and significant while the installation 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 (β = .056, p < .10; Model 2). The magnitude of the HCM go-live parameter has an intuitive economic interpretation—firms that adopt the HCM module produce approximately 5.6% greater output holding inputs constant. However, it could be that HCM adoption is highly correlated with adopt of the full ERP suite and that we are picking up some of...
the productivity effects of ERP adoption as a whole in this estimate. In particular, 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 leads 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, and a selection effect. We added lagged HCM adoption variable into the model and it does not fundamentally change our results.

Models 5, 6 and 7 assess the pair-wise interactions among HCM, performance monitoring, performance pay. 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 that can self-select talents, performance monitoring and HCM Live 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), demonstrate that monitoring policy and performance pay are not complements if the firm lacks the appropriate tool to monitor. There is weak evidence of a pair-wise complementarity between performance and HCM (Model 6). The coefficient 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 terms 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 does not necessarily complement each other without considering all components in the system.

Model 8 applies a test of the three-way complementarities between HCM, monitoring practices and performance pay. 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 of 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 talent selection is not significantly different from zero. It could be that without appropriate IT systems that make monitoring effective, the performance pay alone does not produce greater productivity. Although the interaction of performance pay and HCM is positive and statistically significant in Model 6, it lost its statistical power in Model 8 after adding all the two-way and three-way interaction terms, demonstrate that performance pay and HCM are only complements when monitoring policies are also implemented.

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 HCM go-live 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 HCM and without, including variation across firms and 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. Although our formal model predicts that the interaction effect between HCM Live and performance monitoring to be positive, it is not
evident in Model 8. However, the interaction of HCM Live and an incentive system that includes performance monitoring and performance practices \((HCM\text{Live} \times\ Monitor \times\ Perf\text{Pay})\) is positive and significant \((\beta=.266, p<.01; \text{Model 8})\). 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 effects of a one-standard-deviation increase in the degree to which firms have adopted incentive system practices are 26.6% higher in firms that have also adopted HCM compared to firms that have not adopted HCM. These results suggest that firms with HCM have more effective incentive systems practices on average, controlling for a host of other factors.

Model 9 is similar to Model 8 except we use a fixed-effect specification. As a fixed-effect specification eliminates influence from all time invariant characteristics including cross-sectional organizational practice variables, the coefficients in Model 4 are generally smaller than in Model 3. \textit{HCM Live} continues to be positive and significant \((\beta = .085, p < .05; \text{Model 4})\). The interaction effect between performance monitoring and \textit{HCM Live} becomes positive and significant \((\beta = .086, p < .001; \text{Model 4})\), supporting our model that monitoring and \textit{HCM Live} are complements. The interaction of HCM and the system of incentives is positive but just short of being statistically significant at conventional thresholds.

Model 10 and 11 incorporated install variables and its interaction with monitor and performance pay variables. As we expected, only the three-way interaction with the go-live variable has any statistical significance, demonstrate again that only when the system is in use to monitor, can it be a part of the complementary system with performance pay and monitoring.
We also performed several outlier tests and detect a single firm that has an extraordinarily large influence on all the regressions (Table 8). After estimating all models in Table 7 without the outliers, we find that the magnitude and direction of the estimates in all 9 models are generally similar to Table 7, with the exception that the interaction effect of \((HCM\text{Live}*\text{Monitor}^*\text{PerfPay})\) has become even more positive and significant \((\beta = .445, p < .001; \text{Model } 8, \beta = .165, p < .01; \text{Model } 9)\), providing further evidence of the complementarities between the system of organizational practices that implement the incentive system and the

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*P<.1, **P<.05, ***P<.001. Huber-white robust standard errors are shown in parentheses.
HCM technology. The interaction effect between performance monitoring and HCM adoption is positive and significant ($\beta = .108$, $p < .032$; Model 9), supporting our theoretical model. The coefficient of the interaction between HCM Live and performance pay is negative and statistically significant, demonstrating that firms implementing a partial system could actually experience a negative return on productivity.

Finally, we introduce a “cube view” version of complementarities among performance monitoring, HCM, and performance pay practices. In Figure 4, 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 of 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 being a high level of implementation. For example, the coordinate (1, 1, 1) indicates that a firm...
has HCM and implement performance pay and monitor practices. Based on the theory of complementarities, we expect firms located at coordinate (1,1,1), where they adopted 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 use performance pay to select for top talents nor have policies to monitor work performance. Similarly coordinate (1, 1, 0) represents firms that have adopted HCM and implemented performance pay but choose not to monitor performance of their employees. Using the production function framework, we first determine whether firms that monitor employees and implement compensation schemes that promote talent selection reaps 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 (p=0.039; HCM test), demonstrating that firms reap greater benefits from HCM when they already have a complementary system of incentives that includes performance monitoring and performance pay that promotes talent selection.

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 contract to retain talent. Our analyses find evidence that firms reap a greater reward from monitoring their employees when firms use performance pay and simultaneously adopt HCM to monitor employees (p=0.041; Selection test). In the third test (Monitoring test), we determine whether firms experiences greater returns from using an performance pay when it choose to use the
technology to monitor employees. Contrary to previous tests of complementarities, we do not find evidence supporting this claim.

Lastly, we perform the full test of three-way complementarities by comparing if 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. We find evidence supporting this claim through a t-test that demonstrates the difference to be highly significant at p=0.0038 (System test). This finding is difficult to explain without a reliance on the three-way complementarities between incentives, monitoring and information technology.

These results together provide evidence that technology adoption is complementary to a system of organizational practices that includes monitoring and performance pay that retains talent. We find that firms experience greater productivity gains from HCM when they practice performance monitoring and adopt talent selection policies, demonstrating that these organizational practices act as ‘a system of complements’ to HCM adoption. These results highlight the essential nature of systems of complements. As Aral & Weill (2007: 767) note “[a] variety of individual capabilities, practices, and processes may complement IT; however, we expect systems of practices and competencies working in concert to enable greater business value generation per IT dollar.” 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).

Testing the mechanisms through which incentives affect performance: Motivation or Selection?

Having found that performance monitoring and performance pay work as a cluster of organizational practices that complement the adoption of HCM solutions, we now explore two theoretical mechanisms through which incentive pay drives 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 individual rationality (IR) constraint. On the other hand, high performers are more likely to stay as they can earn more under performance pay compensation systems. Self-selection is particularly beneficial to firms by allowing them to sort workers by ability. 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 cheaply identify talents 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 piece-rate plan in a windshield installation factory. He finds that productivity rose 35% due to this
change, and uses the factory’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 sort workers by talent. Under our moral hazard model with self selection, we expect performance pay to complement monitoring policy and monitoring technology primarily through talent selection. In our empirical analysis, we also quantifies 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) align compensation plan to attract and retain desired talents (self-selection). Clearly, these proxies for distinguishing the two theoretical mechanisms behind the performance effects of performance pay will be measured with some error. 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 9 shows the empirical results estimating proxies for motivation and self-selection. Model 1 and Model 2 separately test the effect of motivation and self-selection respectively. The results demonstrate that selection has a stronger individual effect on productivity. While one-standard-deviation of motivation is associated with 8.7% increase in productivity, the interaction effect of motivation, performance monitoring and HCM adoption (HCMLive*Monitor*Motivation) is not significantly different from zero (Model 1). However, both self-selection and its interaction term with performance monitor and HCM adoption are all positive and statistically significant (βSelection = .145, p < .001; Model 2; βSelection*Monitor*HCM = .185, p<0.1; Model 2), lending evidence that self-selection is the primary driver for improved productivity. In Model 3, we include 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 ($\beta_{\text{Selection}} = 0.079$, $p<0.1$, $\beta_{\text{Selection} \times \text{Monitor} \times \text{HCM}} = .373$, $p < .05$; Model 3), while none of the parameter estimates relating to motivation is significantly different from zero, demonstrating that HCM and performance monitoring are shown to complement the selection mechanism. The t-tests for ($\beta_{\text{Selection}} < \beta_{\text{Motivation}}$) and ($\beta_{\text{Motivation} \times \text{Monitor} \times \text{HCM}} < \beta_{\text{Selection} \times \text{Monitor} \times \text{HCM}}$) both reject at $p<0.001$ level. Firms that adopt HCM see greater returns from the system of incentives primarily through selection. We suspect that HCM enhances firm’s monitoring abilities such that motivation based incentives are heightened, and that as HCM improves monitoring poor performers are more motivated to leave firms that identify them accurately as poor performers and therefore pay them less.

**Discussion and Conclusion**

Previous research has found complementarities between information technology and organizational capital. We move this stream of inquiry from a broad perspective of IT as a general-purpose technology, toward examination of a 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 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 show how incentives affect observable performance. In particular we examine performance monitoring and performance pay
that promotes talent selection as a set of organizational practices that complements HCM. Using a detailed human resource practice survey 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, talent selection, and monitoring practices are mutually correlated. In particular, the demand for HCM is greatest in firms that have adopted the other two practices. Second, HCM implementations are correlated with higher productivity, echoing previous ERP productivity studies (Hitt et al 2002, Aral et al 2006), as are talent selection and performance monitoring, when measured separately. Third, these practices generate a disproportionate productivity premium when they are implemented simultaneously as a tightly knit system of organizational incentives. These results provide evidence of a three-way complementary system of organizational practices that enable greater productivity returns to enterprise IT. Our results are consistent with the hypothesis that complementary systems of organizational practices enable greater returns to enterprise IT.
References


APPENDIX: DETAILED DERIVATION OF THE MODEL

Definitions of variables:

- $q$: the level of output
- $p$: the observed performance signal that is used to contract
- $a$: Agent’s effort level
- $\alpha$: a random variable normally distributed with mean 0 and variance $\sigma^2_\alpha$.
- $w$: Agent’s wage level
- $t$: fixed wage
- $b$: pay-for-performance rate
- $s$: dummy variable indicating if technology is used to monitor
- $m$: monitoring policy
- $sm$: the level of the monitoring effort
- $\Gamma(sm)$: the cost of monitoring
- $\Pi$: Principle’s utility
- $V$: Agent’s utility

All $\epsilon$’s are random variables, normally distributed with mean 0.

Model Setup

$$q = a + \epsilon_q$$  \hspace{1cm} (1)

$$p = \alpha a + \epsilon_p$$  \hspace{1cm} (2)

$$w = t + bp = t + b\alpha a + b\epsilon_p$$  \hspace{1cm} (3)

$$\Gamma(sm) = k(sm) = \frac{k}{\sigma^2_\alpha}$$  \hspace{1cm} (4)

$$\Pi = E\{q - w - \Gamma(sm)\} = E\left(a - t - b\alpha a - \frac{k}{\sigma^2_\alpha}\right)$$  \hspace{1cm} (5)

$$V = w - \frac{1}{2}ca^2$$  \hspace{1cm} (6)

Given a contract $(t, b)$, Agent maximizes its utility by choosing an effort level, $a$.

$$\max E(V) = \max E\left(W - \frac{1}{2}ca^2\right)$$  \hspace{1cm} (7)

$$\max \left(t + b\alpha a - \frac{1}{2}ca^2\right)$$  \hspace{1cm} (8)

$$\frac{\partial}{\partial a} \Rightarrow b\alpha = ca$$  \hspace{1cm} (9)

$$a^* = \frac{b\alpha}{c}$$  \hspace{1cm} (10)
Now the principal determine the contract \((t, b)\) subject to agent’s IR constraint

\[
\max E \left( a - t - b a - \frac{k}{\sigma^2} \right) \quad (11)
\]

\[
E(V) = E \left( t + b a a - \frac{1}{2} c a^2 \right) \geq V \quad (12)
\]

\[
b^* = \frac{1}{1 + \sigma^2_a} \quad (13)
\]

\[
t^* = V - \frac{b^*^2}{2c} (1 + \sigma^2_a) \quad (14)
\]

Under the incentive contract \((t, b)\), firms derive profits to be

\[
\pi^* = \frac{b}{c} - \frac{b^2}{2c} (1 + \sigma^2_a) - k \left( \frac{1}{\sigma^2_a} \right) \quad (15)
\]

for small enough \(k\), marginal increase in profit from increasing monitoring policy and simultaneously adopt technology to monitor is positive

\[
\frac{\partial^2 \Pi}{\partial m \partial s} = \frac{1}{2c (sm)^2} - k > 0 \quad (16)
\]

Firms experience greater profit gain when they increase monitoring and simultaneously increase performance pay.

\[
\frac{\partial^3 \Pi}{\partial m \partial s \partial b} = \frac{1}{c (sm)^2} \quad (17)
\]

Next we show that performance pay also provides a sorting mechanism that self-select talents.

**Proposition:** *Increase in performance pay results in higher ability workers to retain in the firm while driving out the less able workers.*

Assuming there are two types of workers, where Type 1 workers has a lower disutility to work than Type 2. \(\theta\) share of the population are of Type 1 with a disutility of work of \(c = c_1\), \(1 - \theta\) share of the population are Type 2 workers and has a disutility of work of \(c = c_2\), and \(c_1 < c_2\). We use \(i\) to denote the type of the worker where \(i \in 1, 2\).

\[
V_i = w_i - \frac{1}{2} c_i a_i^2 \quad (18)
\]

Assuming the Spence-Mirrlees single-crossing condition, the reservation utilites for the two types of workers, \(V_1, V_2\), are different where, \(V_1 > V_2\).

**Find the Separating Equilibrium and the Exclusive Equilibrium and**
show that incentive pay is higher under Exclusive Equilibrium than the Separating Equilibrium where both types of workers are hired.

**Proof:** 1. Find the optimal effort under a contract \((t, b)\)

\[
\max E \left( V_i \right) = \max E \left( W - \frac{1}{2} c_i a_i^2 \right) \tag{19}
\]

\[
\max \left( t + b \alpha a_i - \frac{1}{2} c_i a_i^2 \right) \tag{20}
\]

\[
\frac{\partial}{\partial a_i} \Rightarrow b \alpha = c_i a_i \tag{21}
\]

\[
a_i^* = \frac{b_i \alpha}{c_i}, \; i \in 1, 2 \tag{22}
\]

Assuming \exists a separating equilibrium where a Type 1 worker with \(c = c_1\) chooses a contract with \((t_1, b_1)\) and a Type 2 worker with \(c = c_2\) chooses a contract with \((t_2, b_2)\), the optimal effort for each type of workers is

\[
a_1 = \frac{b_1 \alpha}{c_1} \tag{23}
\]

\[
a_2 = \frac{b_2 \alpha}{c_2} \tag{24}
\]

If a Type \(i\) worker with \(c = c_i\) wants to immitate a Type \(j\) worker where \(j \in 1, 2\) with \(c = c_2\), the optimal effort for immitation for each type is

\[
\tilde{a}_i = \frac{b_j \alpha}{c_i} \tag{25}
\]

**Exclusive Equilibrium:** Find the condition for an exclusive equilibrium where only Type 1 or talented workers are retained. Firm offers \((t_1, b_1)\)

\[
E \left[ \Pi^*_c \right] = \max E \left( \frac{a_1 - t_1 - b_1 \alpha a_1 - \frac{k}{\sigma^2}}{\sigma^2} \right) \tag{26}
\]

subject to IR, IC constraints. IR constraint is binding

\[
E \left[ t_1 + b_1 \alpha a_1 - \frac{1}{2} c_1 a_1^2 \right] \geq V_1 \quad \text{IR} \tag{27}
\]

\[
E \left[ t_1 + b_1 \alpha \tilde{a}_2 - \frac{1}{2} c_2 \tilde{a}_2^2 \right] \geq V_2 \quad \text{IC} \tag{28}
\]

The solution to the maximizing problem is:

\[
b_1^* = \frac{1}{1 + \sigma^2} = \frac{1}{1 + \frac{1}{m}} \tag{29}
\]
\[ t_1^* = \overline{V}_1 - \frac{1}{2c_1(1 + \sigma_2^2)} \]  
\[ E(\Pi_1^*) = \frac{1}{2c_1(1 + \sigma_2^2)} - \overline{V}_1 - \frac{k}{\sigma_2^2} \]  
\[ \frac{\partial E(\Pi_1^*)}{\partial m} = \frac{dE(\Pi_1^*)}{dm} = \frac{1}{2c_1m(1 + 1/m)^2} - k = \frac{1}{2m_1c_1} - k > 0 \]  

Again, for sufficiently small \( k \),  
\[ \frac{\partial E(\Pi_1^*)}{\partial m} > 0 \]  

**Separating Equilibrium:** To obtain the separating equilibrium, Principle wants to maximize its profit, \( \Pi \), subject to IR and IC constraints  
\[ \max \sum_{i=1}^{2} E \left( a_i - t_i - b_i\alpha a_i - \frac{k}{\sigma_2} \right) \]  
\[ E(V_1) = E \left( t_1 + b_1a_1\alpha - \frac{1}{2}c_1a_1^2 \right) \geq \overline{V}_1 \quad \text{IRH} \]  
\[ E(V_2) = E \left( t_2 + b_2a_2\alpha - \frac{1}{2}c_2a_2^2 \right) \geq \overline{V}_2 \quad \text{IRL} \]  
\[ E \left( t_1 + b_1a_1\alpha - \frac{1}{2}c_1a_1^2 \right) \geq E \left( t_2 + b_2a_2\alpha - \frac{1}{2}c_2a_2^2 \right) \quad \text{ICH} \]  
\[ E \left( t_2 + b_2a_2\alpha - \frac{1}{2}c_2a_2^2 \right) \geq E \left( t_1 + b_1a_1\alpha - \frac{1}{2}c_1a_1^2 \right) \quad \text{ICL} \]  

IRL and ICH bind. The solution to the maximization problem is  
\[ b_1^* = \frac{1}{1 + \sigma_2^2} \]  
\[ b_2^* = \frac{1 - \theta}{c_2(1 + \sigma_2^2) \left( \frac{\theta}{\alpha} - \frac{2\theta - 1}{c_2} \right)} = \frac{b_1^*(1 - \theta)}{c_2 \left( \frac{\theta}{\alpha} - \frac{2\theta - 1}{c_2} \right)} > b_1^* > 0 \]  
\[ b_2^* \leq b_1^* \]  
\[ t_1^* = \overline{V}_2 - \frac{b_2^2(1 + \sigma_2^2)}{2c_2} \]
$t_2^* = V_2 - \frac{b_2^*(1 + \sigma_2^2)}{2c_2} + \frac{(b_1^2 - b_2^2)(1 + \sigma_2^2)}{2c_1}$  \hspace{1cm} (43)

$t_2^* \geq t_1^*$  \hspace{1cm} (44)

Under the separating equilibrium contract, Principal gives a higher fixed wage to the low type to satisfy the IR constraint. It also provides a higher piece rate for the high type so the high type would not want to imitate the low type who receives a higher fixed pay.

The profit function under the separating equilibrium is

$$E(\Pi_s^*) = \frac{\theta}{2(1 + \sigma_2^2)}c_1 + \frac{(1 - \theta)^2}{2c_2^2(1 + \sigma_2^2)} \left( \frac{\theta}{c_1} - \frac{2\theta - 1}{c_2} \right) - \frac{k}{\sigma_2^2}$$  \hspace{1cm} (45)

The marginal benefit of monitoring is

$$\frac{\partial E(\Pi_s^*)}{\partial m} = \frac{dE(\Pi_s^*)}{dm} = \frac{1}{2m^2} \left[ \left( \frac{1 - 2\theta}{c_2} + \frac{\theta}{c_1} \right) b_2^2 + \frac{b_1^2 \theta}{c_1} \right] - k$$  \hspace{1cm} (46)

$k$ is usually small since the marginal costs of using the technology to monitor is typically minimal, therefore

$$\frac{\partial E(\Pi_s^*)}{\partial m} > 0$$  \hspace{1cm} (47)

Now we show that as performance pay increase, exclusive equilibrium will dominate over the separating equilibrium where both types participate.

$$b^*_{\text{exclusive equilibrium}} > b_2^*_{\text{separating equilibrium}}$$  \hspace{1cm} (48)

$$b^*_{\text{exclusive equilibrium}} = b_1^*_{\text{separating equilibrium}}$$  \hspace{1cm} (49)

For the talented workers, Principal will always provide the highest performance pay

**Pooling Equilibrium:**

Next we find the pooling equilibrium if it exists. And show that as performance pay increases, only talented workers will participate.

$$\max E(\pi_p) = \max E \left( \theta(a_1 - t - b_0a_1) + (1 - \theta)(a_2 - t - b_0a_2) - \frac{k}{\sigma_0^2} \right)$$  \hspace{1cm} (50)

such that

$$E \left[ t + b_0a_1 - \frac{1}{2}c_1a_1^2 \right] \geq V_1 \hspace{1cm} \text{IR1}$$  \hspace{1cm} (51)
\[ E \left[ t + boa_2 - \frac{1}{2}c_2a_2^2 \right] \geq V_2 \quad \text{IR2} \quad (52) \]

IR2 is binding.

Under (t,b) contract, employee will choose effort to maximizes its utilities

\[ a_1 = \frac{b\alpha}{c_1} \quad (53) \]
\[ a_2 = \frac{b\alpha}{c_2} \quad (54) \]

solving the maximization problem yields:

\[ b^* = \frac{\theta(\frac{1}{c_1} - \frac{1}{c_2}) + \frac{1}{c_2}}{(2\theta(\frac{1}{c_1} - \frac{1}{c_2}) + \frac{1}{c_2})(1 + \sigma_a^2)} \quad (55) \]
\[ t^* = V_2 - \frac{(\theta(\frac{1}{c_1} - \frac{1}{c_2}) + \frac{1}{c_2})^2}{2c_2(2\theta(\frac{1}{c_1} - \frac{1}{c_2}) + \frac{1}{c_2})(1 + \sigma_a^2)} \quad (56) \]

\[ E[\Pi_p] = b^*(\frac{\theta}{c_1} - \frac{1}{e_2} - \frac{\theta}{e_2}) + b^*(1 + \sigma_a^2)(\frac{\theta}{c_1} - \frac{1}{e_2} - \frac{\theta}{2e_2}) - V_2 - \frac{k}{\sigma_a^2} \quad (57) \]
\[ E[\Pi_p] = b^*(\frac{\theta}{c_1} - \frac{1}{e_2} - \frac{\theta}{e_2}) + b^*(1 + \frac{1}{m})(\frac{\theta}{c_1} - \frac{1}{e_2} - \frac{\theta}{2e_2}) - V_2 - km \quad (58) \]

\[ \frac{\partial E(\Pi_p)}{\partial m} = \frac{dE(\Pi_p)}{dm} = \frac{(s + \frac{1}{e_2})^2}{2s + \frac{1}{e_2}} \frac{1}{m^2(1 + \frac{1}{m})^2} - k > 0 \quad (59) \]

for small k

\[ b^* \mid \text{exclusive equilibrium} > b^* \mid \text{pooling equilibrium} \quad (60) \]
\[ t^* \mid \text{exclusive equilibrium} < t^* \mid \text{pooling equilibrium} \quad (61) \]