Research Article

Paul Anglin* and Yanmin Gao

The Dynamics of Incentives, Productivity, and Operational Risk

DOI 10.1515/bejte-2014-0043 Published online September 17, 2015

Abstract: This paper develops a dynamic principal-agent model and applies it to understand changes in labor productivity and operational risk. Our analysis demonstrates the importance of matching the terms of the job contract to the technology. Such issues would be especially important in service industries and in the knowledge-based economy where discretionary effort tends to play a greater role. We show that the production technology needs to be characterized by at least two parameters: one parameter which measures output independent of the worker's effort and a second parameter which measures the effect of the effort. We solve for the Renegotiation-Proof Nash Equilibrium. We show that there can be a tension between increasing expected productivity and controlling costs per worker. Our analysis also adds to the growing interest in "operational risk", which is associated with human actions. The closed form solutions provided by our model provide a natural way to consider the impact and possibility of this type of risk. Our analysis demonstrates why the effect of a negative event should be considered relative to a concept of normal which is based on an equilibrium, that uncertainty in the external environment enables (but does not cause) operational risk events and that both the equilibrium and the effects vary with the production technology.

Keywords: dynamics, incentive contract, labor productivity, technological change, agency cost, operational risk

JEL Descriptors: D24, D82, M41

1 Introduction

This paper studies the effects of agency contracts on measured productivity and operational risk in dynamic settings. Conventional wisdom suggests that

Yanmin Gao, College of Business, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong, E-mail: yanmigao@cityu.edu.hk

^{*}Corresponding author: Paul Anglin, College of Management and Economics, University of Guelph, Guelph, ON, Canada, N1G 2W1, E-mail: panglin@uoguelph.ca

productivity growth and corporate profits are tied to the use of new technologies, and many examples can be used to confirm this wisdom. It is also understood that the effort of workers plays a role, but this role is studied less often and less formally. This vague understanding is unfortunate because measured productivity can vary for many reasons and a precise understanding often requires the use of ideas that are familiar in the principal-agent literature. Despite the common impression that productivity growth is purely a technological issue, we show that the effect of a technological change depends on how well the technology is matched with an appropriate job contract for workers. Thus, the effects of technology cannot be isolated from the effects of other aspects of the contracting environment. Further, this measurement problem implies that shareholders would have trouble allocating blame within the firm if the realized productivity is lower than forecast.

This measurement problem also affects an issue which is attracting increasing attention from international policy forums and in disclosures to shareholders: operational risk. It is defined as "the risk of loss resulting from inadequate or failed internal processes, people and systems or from external events. This definition includes legal risk, but excludes strategic and reputational risk" (Basel Committee on Banking Supervision 2011, fn. 5). As we discuss more fully in Section 5, small events are common and easy to associate with human foibles, such as imperfect memory and trivial carelessness. Large operational risk events are rare and significant in aggregate but their definition and the process of measurement are debated. More careful analysis sometimes measures it statistically, as though it were a mechanical process, despite the definition given above. We demonstrate that any explanation concerning both productivity growth and operational risk requires a principal-agent perspective. We argue that more familiar sources of risk, such as market risk, do not cause operational risk but enable it: if there were no external source of risk then the workers could not hide any mistakes or misbehavior. Our model offers closed form solutions which show how these issues are intimately linked, both in terms of precisely defining any concern and identifying the full implications of any resolution.

Some situations may illustrate the nature of the problem. For example, consider the banking industry and the introduction of computerized spreadsheets programs on a task such as projecting revenue and costs into the future. They were faster but, since they did not do anything that could not be done by hand, otherwise unremarkable. Even so, they had profound implications. The most important may be a simple operational issue: they reduced the number of mechanical mistakes in the arithmetic, such as adding instead of subtracting or shifting a decimal place in a computation or reversing the order

of digits in a two-digit number. With increased confidence in the accuracy, more and more complicated What If scenarios could be considered if there was a desire to do so.1

Or, consider a sales person. A good sales person tries to learn about their client in order to establish a relationship and, before signing a long term contract with a client, in order to determine whether they are a good client or not. Improvements in information technology make it easier to gather information about somebody more quickly and, in theory, that should help a sales person. In practice, the amount of extra information depends on the effort expended by the sales person: rather than increasing sales directly, this technology is a "force multiplier". The recent Credit Crisis offers many examples of mortgage loan officers acting as sales people issuing mortgages to clients who were obviously unsuitable after the Crisis, and that fact could have been discovered if they had done due diligence before the Crisis. The incentives facing the sales person may encourage them to build a relationship and to perform a reasonable due diligence, if the principal and agents were to agree to change the terms of the job contract. At the same time, mistakes can occur: e.g., people forget the birthdays of even their spouses or a search might confuse two people with the same name or information which is mostly reliable may not be updated. Even the managers of knowledge workers have limited understanding of the new technology.

These examples show how new technology increases potential output while also altering the effects of a worker's choices and "mistakes". In a sense, productivity and operational risk emphasize different dimensions of a change in the environment. Productivity analysis tends to focus on a mean while operational risk tends to focuses on *variability* (especially negative effects). This sense is too simple since, as we argue, a completely statistical summary of these tendencies would be unstable. An operational risk event is connected to human behavior, where a human may try to hide that connection by invoking uncertainty in the external environment selectively and depending on the technology of production.

We develop a two-period model in which a risk neutral principal hires a risk averse agent and solve for the unique Renegotiation-Proof Nash Equilibrium. This paper focuses on the implications of this equilibrium for changes in

¹ The introduction of computers also enabled opportunistic programmers to take advantage of the situation. For example, readers may remember stories of banking computers which could calculate interest payments to many significant decimal places and round the amount when reporting to a client while directing the positive fractions of a cent to an account owned by the programmer.

measured labor productivity and operational risk in a dynamic setting, when the effort of workers may be "hidden". In a hidden action setting, one way to make workers work harder or more carefully is to enforce tougher job standards, but monitoring those standards is costly even if workers accept them as part of the job contract. We provide closed form solutions for the equilibrium (linear) incentive contract, if the principal chooses to use incentives, and for the level of effort, if the principal chooses to monitor the workers. A complicating feature is that, in a dynamic setting, workers can also shift their income and consumption over time to mitigate the personal cost of risk in any one period. Our solution anticipates this behavior, which adds to the richness of the comparative statics analysis.

We find that expected productivity can differ between periods, even if the technology does not change. We find that distinguishing between different types of technological change adds a critical, but rarely discussed, insight: some types could increase expected output, but the effect varies with the agent's effort. If complemented by the equilibrium job contract then the effect of this type of technological change increases at an increasing rate.

Some broad facts from review papers may illustrate that productivity is not merely a matter of technology. Bloom and van Reenan (2011) note that the fraction of the labor force whose compensation is based on some kind of performance related pay system has been rising, despite the decline of the manufacturing sector, to include about 40–50% in the United States and now with comparable figures in the United Kingdom. Bloom and van Reenan link this fact to results repeated in Syverson (2011, 326) concerning an average manufacturing industry: "the plant at the 90th percentile of the productivity distribution makes almost *twice* as much output with the *same measured inputs* as the 10th percentile plant" (emphasis in the original; data based on four-digit SIC classification).

We are not the first researchers to recognize these issues. Jensen and Meckling (1976) note how incentives can affect output, and therefore productivity, by changing the behavior of an agent. Rajiv Banker and several co-authors offer more specific insights in a series of papers. Banker, Datar, and Mazur (1989) use a general model and focus on identifying a theoretically optimal measure of productivity which would be useful as part of a compensation system. They also test their hypothesis for a specific company and find that the company could have used a better alternative. Banker, Datar, and Rajan (1987) and Banker et al. (2002) use field tests to suggest the size of the effect of hidden effort. The first paper estimates a stochastic frontier model and concludes that introducing a "gain-sharing program" has no significant effect on the productivity of direct labor, which is likely to be constrained by machine

operating conditions, but that the program increases the productivity of workers whose actions are less constrained, such as supervisors and other forms of indirect labor. This program is noteworthy because, in percentage terms, half of the gains in productivity were passed onto the workers in the form of extra compensation. The second paper argues that the effects of a gain-sharing program are equivalent to 3.7% of costs.

Seshadri and Subrahmanyam (2005, 1) expressed a concern about "a lack of connection between research in operations management and finance." Incentives may represent a cost on a balance sheet but a well-designed incentive system aligns the interests of a principal and an agent. This broader perspective is important because, as Armitrage and Atkinson (1990) note, many workers oppose "productivity improvements" because they are seen as exhortations to "do more with less". In other words, the essential question is: if measured productivity were higher in one year relative to the previous year, does management deserve the credit for using better technology or do workers deserve the credit (and appropriate income) or was it the result of luck? We recognize the characteristics of this situation using a richer model which allows for renegotiation of the job contract to show how complementary changes in the technology of production with changes in the agency contract or operating procedures can generate a sustainable long term financial payoff.

Our paper differs from these papers because, where they seek to characterize a given technology in a single period or productivity after a change in agency relationship, we seek to understand the many implications of a change in technology in a more complex environment dynamically. We show that if technology can be summarized by a single parameter then production cost per unit tends to be inversely related to labor productivity. By considering a parameter which measures the marginal productivity of effort in a way that complements the agency model, our model facilitates insights into how a change in technology affects complementary variables that are often associated with operations, such as total cost, unit cost and the variation in productivity over time.

We extend this argument to show that the management of productivity should not be separated from the management of operational risk. The general topic of risk management is becoming more important to managers and, through disclosures in financial statements and other forms of communication, to the relationship between managers and shareholders. One of the least understood forms of risk is called "operational risk". In contrast to the better-known external sources of risk, such as market risk or credit risk, operational risk focuses on a failure of management to control or workers to implement the company's business strategy. The fact that the source of a negative event is human behavior implies that this risk factor differs from the risk associated with events external to the firm; a worker is not a machine and does not always do what they are ordered to do. One of the reasons why operational risk is difficult to understand is that "normal" behavior can vary for reasons which statistical or technical measures may not consider. Our model of an equilibrium provides a precise context to discuss "normal" outcomes. In this equilibrium, an external source of risk does not cause operational risk but is a necessary condition which enables behavior-based sources of risk.

The remainder of the paper proceeds as follows. Section 2 develops a twoperiod agency model with renegotiation between a principal and an agent, for a given technology of production. The two-period model allows us to consider more complex contracts and behaviors, including consumption smoothing by an agent without relying on their employer. Sections 3 and 4 characterize the equilibrium and analyze the effects of contracting on productivity measurement. We note that incentives can vary with other aspects of the contracting environment and, thus, that expected productivity can vary even if the technology of production does not change. Section 5 discusses the issue of operational risk in the context of an overall business strategy. The last section contains our concluding remarks.

2 A Dynamic Agency Model with Renegotiation

We develop a two-period agency model where the principal maximizes expected profit by hiring a group of workers (also referred to as the "agent") to produce output in each of the two periods. Both the principal and agent commit to stay for two periods. The principal offers the agent a compensation contract which is subject to renegotiation at the start of the second period. For mathematical tractability, we adopt a dynamic LEN model, i.e., Linear contract, Exponential utility, and Normally distributed performance measures.² The LEN model specifies the compensation contract as a linear function of the performance measures. Further, based on the concept of renegotiation-proofness of Fudenberg and Tirole (1990), we solve for a linear renegotiation-proof contract.

² It is well-known that LEN models provide a simpler mathematical representation, and are widely used in the literature. Several papers employ the LEN framework in dynamic settings, such as Christensen and Feltham (2005), Feltham, Indjejikian, and Nanda (2006), and Dutta and Reichelstein (2003).

The number of hours worked by an agent in period t is observable by the principal. Since this contribution is easily measured and has been widely investigated, we normalize the number of hours worked: $h_1 = h_2 = 1$. This normalization emphasizes the agent's second contribution: the hidden intensity or quality of effort a_t in period t.³ Effort represents a contribution to the level of output above and beyond the agent's input of time. Thus, output is

$$Q_t = \phi + \psi a_t + \varepsilon_t, \quad t = 1, 2$$
 [1]

where the technological parameters ϕ and ψ measure different aspects of productivity, ϕ measures the productivity per hour based on a minimal level of effort, i.e., $a_t = 0$, and ψ represents the added productivity per hour due to increased effort. ε_t , t=1,2, are Normally distributed noise terms with zero mean and covariance matrix

$$\Sigma = \begin{bmatrix} \sigma_1^2 & \rho \sigma_1 \sigma_2 \\ \rho \sigma_1 \sigma_2 & \sigma_2^2 \end{bmatrix} \quad \text{with} \quad \rho \in (-1, +1).$$
 [2]

Based on realized demand for the product, and the desire of the firm to produce more or fewer units, an assumption of constant returns to scale in hours implies that the firm can maintain efficiency by asking workers to work more or fewer hours without needing to change any other terms of the contract.

The fact that productivity does not grow smoothly over time suggests that short term random, hidden shocks are important enough for managers to be unsure of the precise cause of a low productivity outcome in a particular year:⁵ the situation displays asymmetric information. In such situations, an employer can be expected to offer a job contract which emphasizes incentives plus maybe monitoring and oversight.

If a firm sets a minimum standard of effort, and enforces this standard by monitoring workers, then agents who choose to work for this principal agree to

³ Since our model focuses on the role of an unobserved variable, we also abstract from the effects on other observable variables such as worker absenteeism and job turnover.

⁴ This linear representation of the effect of worker effort is not unreasonable, especially in aggregate settings (e.g., Arya, Fellingham, and Schroeder 2004).

⁵ Many methods of precise analysis have been suggested. Case studies are useful but must be conducted very carefully in order to separate the influence of uncertainty from the influence of technological changes from the behavioral effects of changes in uncertainty. Statistical techniques, such as data envelopment analysis (DEA) and benchmarking, are useful but rarely remove all uncertainty.

exert at least E_t units of effort in period t. If $a_t < E_t$ in a period then the firm has the right to impose a penalty according to the terms of the contract, where this penalty is sufficiently large that all workers exert the expected level of effort in equilibrium. This policy is consistent with the idea that the monitoring scheme is intended to get workers to work "hard enough" without imposing income risk or arbitrary penalties on the workers. The principal's cost of monitoring is assumed to be proportional to the standard, i.e., that cost is mE_t for some m>0. If a firm uses incentives, then an agent's compensation in period t includes a fixed payment, whose allocation between the periods may vary, and a payment, v_tQ_t which is proportional to output.

The following describes the timeline of the model which highlights the sequence of events and provides important assumptions concerning the agent's preferences, and the principal's preferences.

2.1 Timeline of the Model

Stage 1: At date zero, the principal designs an initial compensation contract $c^i(f^i, v_1^i, v_2^i)$, minimum effort standards for the two periods (E_1, E_2) and offers the job to the agent. f^i is the initial fixed payment paid at the end of the first period, and v_1^i, v_2^i are the initial incentive rates for the first and second period respectively.

Stage 2: At the start of the first period, the agent chooses her effort a_1 , which affects the first-period output Q_1 .

Stage 3: Since the principal cannot observe the agent's productive effort, the principal uses the output Q_1 to determine the agent's first-period compensation $\omega_1 = f^i + v_1^i Q_1$ if $a_1 \ge E_1$. If not, the agent is penalized.

Stage 4: At the start of the second period, based on the information from the first period, the principal may offer a renegotiated compensation contract $c^r(\Delta f^r, v_2^r)$, where Δf^r represents a change in the fixed payment, and v_2^r is the revised incentive rate for the second period. (The superscript i represents the initial offer and the superscript r represents the renegotiated offer.) The agent can accept or refuse the new contract. If she refuses, then the initial contract stays in effect. Based on Q_1 , the principal can also revise E_2 .

Stage 5: The agent chooses her second-period effort a_2 , which affects the second-period output Q_2 .

Stage 6: Based on Q_2 and the possibly renegotiated contract, the principal pays the agent second-period compensation $\omega_2 = \Delta f^r + v_2^r Q_2$ if $a_2 \ge E_2$. If not, the agent is penalized.

2.2 Agent's Preferences

The agent is assumed to be risk averse and effort averse. Her preferences for the contract period are represented by the following time-additive exponential utility function:

$$u^{a} = -\sum_{t=1}^{2} \beta^{t} \exp(-rc_{t})$$
 [3]

where r > 0 is the agent's risk aversion parameter and c_t represents consumption net of effort cost. $\beta = 1/R$ is the agent's discount factor and R represents the time value of money; since these parameters are necessary to account for inter-temporal tradeoffs but play no essential role in the comparative static analysis, we fix $\beta = 0.95$ and, approximately, R = 1.0526. Let $k(a_t)$ be the agent's labor cost where, as is commonly assumed in the agency literature, $k(a_t) = 1/2(1 + a_t^2)$ is a quadratic function. $k(a_t) > 0$ even if $a_t = 0$ to recognize the cost of a worker's time.

The agent can borrow and lend in financial markets. Let ℓ_t be the amount of borrowing or lending, where an agent's decision to substitute consumption over time affects the effective risk facing an agent (when measured in terms of consumption), their behavior and the kinds of incentives which are offered in equilibrium. After the agent has received her compensation and paid her labor cost, she has a cumulative-consumption bank balance:⁶

$$B_1 = \omega_1 - k(a_1) \equiv c_1 + \ell_1$$
 [4]

Similarly, at the end of the second period, the cumulative-consumption bank balance is

$$B_2 = R\ell_1 + \omega_2 - k(a_2)$$
 [5]

The agent is assumed to consume her bank balance at the end of the contract, i.e., $c_2 = B_2$, and, without loss of generality, we assume a zero reservation consumption: $c^0 = 0$.

2.3 Principal's Preferences

The principal is assumed to be risk neutral and the discount rate β used by the agent also applies to the principal. Setting the price of output equal to 1 as a

⁶ The agent is assumed to choose her consumption before accepting the contract at date zero.

numeraire, we let $Q \equiv Q_1 + \beta Q_2$ be the total gross payoff to the principal, $W \equiv \omega_1 + \beta \omega_2$ be the total compensation payment to the agent, both are stated in period 1 dollars and $CM \equiv mE_1 + \beta mE_2$ be the cost expended on monitoring. Thus, when negotiating a contract at t=0, the principal's preferences are summarized by:

$$EU_0^p = \beta E_0[Q] - \beta E_0[W] - \beta CM.$$
 [6]

That is, the principal's expected utility is the expected gross payoff minus expected compensation and monitoring costs.

3 Characterizing the Equilibrium

An equilibrium describes the terms of the contract as well as the actions of the agent and principal during the two periods. Measured costs, output and productivity are consequences of this equilibrium. To incorporate time in an essential way and to explore how productivity can change over time even if the technology does not, we use the concept of renegotiation-proof contracts in the equilibrium. According to Fudenberg and Tirole (1990), a contract is renegotiation-proof if the principal will not choose to alter it at the renegotiation stage. Given the LEN (e.g., Linear contract, Exponential utility, and Normally distributed performance measures) assumption in the model setting, we show why there is no loss of generality in restricting attention to *linear* renegotiation-proof incentive contracts.

The following two theorems offer closed form solutions for the key variables. An appendix offers a more complete proof, which is based on a backward induction argument and which contains some implications associated with these solutions, such as consumption smoothing behavior by the agent.

Theorem 1

In an equilibrium with monitoring only

$$v_1 = v_2 = 0,$$
 $f = k(E_1) + \beta k(E_2)$ $a_1 = a_2 = E_1 = E_2 = \psi - m$

Theorem 2⁷

In equilibrium, with incentives only (assuming interior solutions)

$$v_{2} = \frac{\psi^{2}}{\psi^{2} + r(1 - \rho^{2})\sigma_{2}^{2}}$$

$$v_{1} = [\psi^{2}]/\Delta - \lambda[\beta v_{2}], \text{ where } \lambda \equiv rA_{1}\rho\sigma_{1}\sigma_{2}/\Delta, A_{1} = 1/(1 + \beta), \text{ and } \Delta \equiv \psi^{2} + rA_{1}\sigma_{1}^{2},$$

$$a_{2} = \psi v_{2}$$

$$a_{1} = \psi v_{1}$$

$$f = K(a_{1}, a_{2}) + RP_{0} - E_{0}[\omega_{1} + \beta\omega_{2}]$$

 $RP_0 = \frac{1}{2} \{ rA_1 [v_1 + \rho(\sigma_2/\sigma_1)\beta v_2]^2 \sigma_1^2 + r\beta [v_2]^2 (1 - \rho^2) \sigma_2^2 \}$ represents overall risk premium and $K(a_1, a_2) \equiv k(a_1) + \beta k(a_2)$ represents the total labor cost.

Theorem 2 shows that the solution for v_1 in an inter-temporal model varies with the variance of the first-period output σ_1 and is adjusted for the inter-period correlation ρ . The solution also varies with β because the agent's behavior in each period (and the effective degree of risk aversion) recognizes the effects of borrowing or lending as she attempts to smooth her consumption.

The equilibrium solution shows how the incentives vary with the technology of production. The realized profit of the principal depends on the agent's effort and this effort is anticipated as part of the equilibrium. The realized profit is also sensitive to unanticipated increases in productivity, ε_t , by affecting both revenue and the extra compensation paid to the agent. Regardless of the effect on the level of expected profit, an increase in ψ affects this profit sensitivity. More specifically, let $Q_t - W_t$ represent the realized profit to the principal in period t.

Corollary 1

Because an increase in ψ increases v_1 and v_2 in equilibrium, an increase in ψ decreases $\partial (Q_t - W_t)/\partial \varepsilon_t$.

⁷ The possibility of renegotiation implies that the equilibrium is not unique. The proof of Theorem 2 shows that, some differences between an initial contract for the second period and the renegotiated contract are possible but, since both sides know that initial contract will be renegotiated, the initial contract for the second period has no real effect. Therefore, without loss of generality, we focus on the equilibrium where the initial contract does not need to change.

Theorems 1 and 2 present solutions conditional on a type of job contract. In principle, a principal would make one of four types of job offers in a two period model:

to use incentives in both periods,

to monitor effort in both periods,

to monitor in the first period and to use incentives in the second period, or to use incentives in the first period and to monitor in the second period with the levels of incentives or standards determined by marginal conditions. Deriving conditions showing which of these four types of job offers a principal would offer in equilibrium is non-trivial computationally and, besides showing their existence, adds only a little insight. Fortunately, changes in the *type* of contract are rare and the marginal changes summarized by Theorems 1 and 2 are more relevant empirically. Therefore, an appendix contains a formal proof that an equilibrium exists unconditionally while the following comments note its characteristics informally and briefly.

If monitoring costs are low then a principal is likely to monitor workers. If the productivity of effort is high then the principal may or may not want to use incentives. Two special cases offer some insight: if ψ is low or if ψ and m increase equally.

At a low level of ψ , the cost of monitoring may be so high that the optimal incentives produce a higher level of effort than the optimal standard and only a "small" risk premium to the agent. Therefore, the principal's preferred contract shares the surplus generated by the agent's extra effort by offering an incentive contract. Suppose, instead, that ψ is large enough that the effort produced by an optimal effort standard is higher than the effort produced by an optimal incentive contract. In this case, the increase in total surplus as well as the reduction in agent's risk premium implies that it is more profitable to monitor. In intermediate cases, an optimizing principal must balance the increase in total surplus due to the extra effort against the increased costs due to either the cost of monitoring or the risk premium created by incentives. The participation constraint ensures that the agent is indifferent amongst all equilibria. Therefore, the effect of an increase in ψ on the type of job offer depends on the magnitudes of the different effects on cost of effort, production surplus and the risk premium.

Our second special case considers a situation where two of the parameters vary jointly: at the same time as new technology increases productivity the new technology can also change how workers shirk their effort and, therefore, the costs of monitoring workers. For example, older managers may struggle to keep up with the language of younger specialists or to be fully aware of their skills. Sometimes, the opposite is true: Hubbard (2000) studies an example where the primary effect of a technological change is to make it easier to monitor workers.

Consider a change in technology which increases ψ and m and has no effect on $\psi - m$. Theorem 1 shows that this change has no effect on the principal's preferred level of effort, if he uses a monitoring standard. Even so, the technological change increases output even if effort does not change. Theorem 2 shows that the change increases the optimal incentive, worker's effort, the worker's risk premium and the expected compensation. Therefore, the combined increase in (ψ, m) increases the likelihood that a principal offers a contract which includes monitoring of the agent's effort.

4 The Effects of Technology on Labor **Productivity with Incentive Contracts**

This section uses the equilibrium derived above to analyze the effects of incentive contracting on productivity measurement. In any period t, labor productivity is measured using a ratio of output to measurable input, such as hours of worker time:

$$P_t = Q_t/h_t. ag{7}$$

Since we normalize h_t to be 1, eq. [1] implies that

$$P_t = \phi + \psi a_t + \varepsilon_t.$$
 [8]

Since labor productivity is a well-known, widely-studied and commonly-used measure, this normalization helps to focus attention on the implications of variables which are harder to measure. The possibility or impossibility of measurement is an important aspect of our analysis because, if sufficient data were available, it is well-known that other measures (such as "total factor productivity" or "multi-factor productivity") are better able to account for issues not represented in our model of production: e.g., economies of scale and economies of scope (i.e., the production of a mix of types of output at a single production facility). It would also be possible to study whether multiple measurable inputs are being combined efficiently to produce any given type of output.8 Other authors, e.g., Banker, Datar, and Kaplan (1989), provide such an excellent

⁸ Since our model focuses on the role of hidden effort and since many researchers have studied issues related to combining measureable inputs, such as capital, energy and labor, we refer readers who are interested in the related issues to the papers cited in our bibliography, such as Syverson (2011) or Banker, Datar, and Kaplan (1989). The issue of capital is particularly important since it comes in many forms, including the human capital embodied in skilled labor which may represent a change in ψ .

insight into the differences between different measures that we choose to focus on the special implications of the principal not being able to measure one of the inputs into production.

In our model, measured productivity represents the combined effects of technological parameters (e.g., engineering specifications in a manufacturing context), behavioral choices and random shocks. In other words, if measured productivity were higher in one year relative to the previous year, one should determine whether the principal deserves the credit for using better technology, or whether the agent deserves the credit (and appropriate wages), or whether it increased because of luck. Using Theorems 1 and 2, we can express expected productivity based on the parameters of the model:

Proposition 1 i) $E[P_1] = \phi + \psi^2 v_1$ and $E[P_2] = \phi + \psi^2 v_2$ in equilibrium, if using incentives.

ii)
$$E[P_1] = \phi + \psi E_1$$
 and $E[P_2] = \phi + \psi E_2$ in equilibrium, if monitoring.

The traditional perception that productivity varies only if the technology varies is a special case of our model. Corollary 2 shows that this important special case has implications for the link between productivity and the average cost of producing a unit.

Corollary 2 i) If and only if $\psi = 0$, then $E[P_t] = \phi$.

ii) Define *UnitCost* as the ratio of total compensation paid to an agent over the two periods to the total production over the two periods, $Q_1 + Q_2$. If $\psi = 0$, then $E(UnitCost) > x/E(P_1)$ for some constant x that does not depend on ϕ .

This Corollary offers an significant benchmark because the discussion below, and especially the simulations, show that the qualified logic that "reduced cost is the corollary of increased productivity" is reasonable only in some circumstances: i.e., when $\psi=0$. The key difference between the effects of an increase in ψ or in ϕ is that the principal optimizes profit from the increase in ψ by changing the job offer made to an agent. Our model of hidden effort shows when basing decisions on costs alone would not fully exploit the improved technology. Trivially, the inequality in $E(UnitCost) > x/E(P_1)$ is due to Jensen's Inequality and would not be true if there was no randomness in output. Still, the randomness enables the principal-agent relationship and the case of $\psi=0$ represents a lower bound on $E(UnitCost)-x/E(P_1)$. An increase in ψ would increase output (since the agent would exert some effort in equilibrium) but the solution in Theorem 2 indicates that the multiplicative effect of changing effort declines as ψ rises. On the other hand, the cost per worker would increase in

equilibrium since both the cost of effort and the agent's risk premium would increase at an increasing rate. Without a clear accounting of the link between revenue and cost, uninformed senior managers in a firm may see the increase in total labor cost as an example of wasteful spending on inefficient workers.

The model also shows how the negotiated incentive varies with non-technological variables such as the environmental parameters $(\sigma_1, \sigma_2, \rho)$. The following Proposition explores the implications of these added variables.

Proposition 2 Suppose that $\psi > 0$ and that the principal uses incentives. In equilibrium, $E[P_2] > E[P_1]$ if and only if $A_1(\sigma_1^2 + \beta \rho \sigma_1 \sigma_2) - (1 - \rho^2)\sigma_2^2 > 0$.

Proposition 2 shows that expected productivity can differ between the periods even if the technology does not change. This result is true only with the use of incentives: Theorem 1 shows that effort and expected productivity would not change if the principal monitors effort in both periods. The extra condition on the exogenous parameters identifies conditions under which the agent's hidden effort is higher in the second period than in the first because the incentive is higher in the second period than in the first. What may appear to be the effects of learning-from-experience, i.e., an increase in productivity over time, tends to be true in the equilibrium to our model if ρ^2 is close to 1 or if σ_1^2 is large relative to σ_2^2 .

Propositions 3 and 4 help to understand the trade off facing a firm which must choose between two different types of technological change; one which increases output regardless of the effort of the agent and one whose effect depends on the hidden effort of the agent. If the cost of acquiring both types is the same, the relevant question is which has the bigger effect on expected productivity.

Proposition 3 Suppose that the principal uses incentives in both periods. If $(2\psi - 1)[\psi^2 + 2r(1 - \rho^2)\sigma_2^2]\psi^2 + [r(1 - \rho^2)\sigma_2^2]^2 > 0$, then $\partial E[P_2]/\partial \psi > \partial E[P_2]/\partial \phi$ in equilibrium.

Proposition 4 If an increase in ψ does not alter the choice between incentives and monitoring within a period then an increase in ψ increases $E[P_2]$ at an increasing rate.

Proposition 3 shows that the effect would vary across industries and market conditions. A unit increase in ψ would always have a bigger effect than a unit increase in ϕ if $\psi > 1/2$. This result implies that, when studying the kinds of technological advances used to improve productivity, industries where hidden effort is already a significant feature would tend to adopt technologies which exaggerate that feature. For example, methods of accounting for the cost and benefits of productivity change in a manufacturing industry, where engineering issues would tend to dominate and monitoring of effort is relatively easy, may be unsuitable in a service industry or in the knowledge-based economy, where the contribution of the discretionary behavior of an agent would be more significant.9

Proposition 5 Suppose that the principal uses incentives in period 2. An increase in σ_2^2 decreases $\partial E[P_2]/\partial \psi$. An increase in ρ increases $\partial E[P_2]/\partial \psi$ if and only if $\rho > 0$.

Proposition 5 reinforces the idea that the contract is negotiated based on the characteristics of the technology offered by the principal and the dynamic contracting environment in which both the principal and agent live. An increase in environmental risk discourages the risk averse agent. As the proof of Proposition 5 shows, the effect of an increase in ρ on the incentive depends on whether it reduces the conditional risk in the second period, i.e., $(1-\rho^2)\sigma_2^2$.

5 Operational Risk

This model emphasizes the idea that, in an environment of asymmetric information, the principal offers a contract and anticipates that agents will behave in a certain way in equilibrium. Reality shows that people do not always act as anticipated. Such deviations are identified as examples of "operational risk": "Operational risk is defined as the risk of loss resulting from inadequate or failed internal processes, people and systems or from external events. This definition includes legal risk, but excludes strategic and reputational risk." (Basel Committee on Banking Supervision 2011, fn. 5, emphasis added). Operational risk is distinguished from other sources of risk, such as market risk (evidence of which may be seen in flow measures, such as profit, revenue or costs) or credit risk (evidence of which may be seen in stock measures, such as the value of an asset).

Many readers may not be familiar with the term "operational risk". Increasingly, the financial statements offered by many companies report on risk

⁹ Despite the larger size of the service sector, reports on productivity in manufacturing industries are more common. Triplet and Bosworth (2008) reviewed how the state of the art has changed over the decades.

Conceptual problems remain because the service sector is almost defined by the idea of outputs being unmeasurable and this fact justifies different approaches to familiar questions. For example, Hsieh and Moretti (2003) showed how, in the context of the real estate brokerage industry, changes in the price of output can change productivity.

management issues in general and operational risk issues in particular to explain why the performance differed from last year's expectation. Comments in these statements include qualifiers such as "breakdown", "exceeding", "inadequate", "inappropriate", "misconduct", "errors", "interruptions", and "planned". These qualifications to an event indicate that whether an event is worthy of consideration depends on a comparison relative to some kind of persistent or normal solution.

Some evidence may give a sense of the problem. ¹⁰ The Basel Committee on Banking Supervision within the Bank for International Settlements (BCBS 2009) used reports from 119 banks in 17 countries during 8 years ("pre-2002" to 2008); they report on 172,000 events which were worth more than €20,000 individually and were worth €54,000 million in total. The Operational Riskdata eXchange Association (ORX 2014) report on the experience of about 60 large financial institutions during 2008-2013; they report on 241,000 events which were worth more than €20,000 individually and were worth €134,000 million in total. Both the BCBS and the ORX data show that the distribution of losses is highly skewed, with many medium value events (e.g., €20,000-€50,000) and very few high value operational risk events (e.g., more than 10 million euros). These events are in addition to many millions of small mistakes worth tens or hundreds of euros.

Looking into the data more deeply suggests our model is relevant to this situation. The examples in the Introduction note that mistakes happen, that workers do not always do what they are told. Obviously, there has been technological changes in banking sector that has led to changes in client expectations and, if only because it is so hard to convict misbehavior in a court of law, there is evidence that effort can be hidden. Fraud due to an internal and external activities (e.g., unauthorized transactions and bank robberies) is common in the retail banking sector, as expected, but events in the categories most closely associated with the activities of an "agent" (i.e., "Clients, products, and business practices", "Employee practices and workplace safety" and "Execution, delivery and process management") are more numerous and are much more expensive individually. If we assume that a "large" bank or financial institution has 50,000 employees, which is less than many large banks, then the average employee would make a mistake leading to a medium or large sized operational risk event less than once every 10 years (using the more recent ORX

¹⁰ When discussing these data, our goal is to give a sense of the problem. Many researchers and organizations are debating how best to define an event and how best to find patterns in these events which could be useful (e.g., BCBS 2011; Chavez-Demoulin, Embrechts, and Hofert 2015). We note that the ability to label an event as an operational risk does not necessarily identify an individual who could be held accountable. Thus, these reports do not necessarily invalidate our model of hidden action.

data). For these reasons, we think that our model is at least descriptively accurate, that the medium and high value events are rare relative to the day to day routine activities and that these types of events are significant enough in aggregate for the principal to worry about.

We suggest that the "normal solution" which is projected in a company's financial statement is an equilibrium. With this perspective, it makes sense that market risk and credit risk can create the asymmetry of information that leads to a principal-agent relationship, even if neither is a direct cause of an operational risk event. The closed form solutions derived from our model allow us to explore the significance of an operational risk event and its consequences for different players. We consider the effects of an operational risk event where effort is 10% less than the equilibrium.

This presentation is "ad hoc" in the most informative sense of the term: a good model should account for everything relevant and any departure from the model should be for a reason that is independent of the rest of the model. We observe that small, medium and large unanticipated deviations occur (e.g., BCBS 2009; ORX 2014) and, while we label the deviation as "ad hoc" in order to focus on the practical effects and to show how the contract varies with the technology, the deviations can be justified by appealing to any one of several theories. In addition to the ancient debates about whether it is possible to resolve conflicts of interest in a principalagent relationship and the growing literature on time-inconsistent decisions (e.g., O'Donoghue and Rabin 2015), large literatures can be interpreted as refining the idea of the "cost of effort": e.g., the literatures on "self-control", "temptation", "opportunistic behavior" and simple carelessness (e.g., Heidhues and Koszegi 2010; Belot and Schroder; 2013; Myrseth and Wollbrant 2013). The use of any specific theory does not affect our numerical analysis, since it emphasizes differences in production technology. To the extent that the principal and the agent anticipate these types of behavior on average by way of the incentive compatibility and participation constraints, they are already represented in the agency contract. Being able to anticipate the average does not eliminate the kinds of deviations that we consider below. Focusing on the effects of a 10% decrease is arbitrary. Fortunately, some of the important effects are linear in the size of the deviation: a 10% deviation is exactly 10 times larger than a 1% deviation. The costs of those effects tend to non-linear in the sense that an increase in the deviation increases the cost at an increasing rate since the deviation is a difference from an equilibrium. In this sense, 10% should be seen as big but not too big. 11

¹¹ As a side issue, we note a critical maintained assumption which seems to be rarely discussed. We assume that small operational risk events are common enough, within the scope of a principal-agent model, that they represent an ordinary "cost of doing business": i.e., we invoke a Central Limit

To estimate the effects and discuss them, we need to compute the equilibrium solution in a not-unrealistic scenario. Our model uses two parameters to describe the production technology, (ϕ, ψ) , and three variables describing the contracting environment, $(\sigma_1, \sigma_2, \rho)$. Other parameters (β, r) describe the agent's patience and degree of risk aversion. Our model offers closed form equilibrium solutions for the terms of the principal-agent contract and the choice of hidden effort by the agent as well as other derived measures such as measured productivity.

To provide a common benchmark, we focus mostly on the outcome for the second period. Most importantly, we normalize the level of measured productivity in the second period, $E(P_2) = 100$. We also use

$$ho = 0,$$
 $\sigma_1 = \sigma_2 = 5,$
 $r = 1.$

The condition on ρ offers a neutral starting point and the propositions above can be used to explore the significance of an alternative value. The condition on (σ_1, σ_2) is a conservative estimate for the variability facing a firm because the variability should be much greater at a more disaggregated level of industrial aggregation. This parameter reveals how much measured productivity can vary even if effort and technology do not change. The measure of risk aversion is chosen to represent a normal level of risk aversion. The value of β is reasonable given long term real interest rates but, as noted during the development of the model, changes in its value play no role in the following discussion: $\beta = 0.95$ implies that R = 1.0526 and that $A_1 = (1 + \beta)^{-1} = 0.5128$ approximately.

These conditions are not sufficient to uniquely identify the fundamental technology parameters. To avoid over-emphasizing the role of hidden effort, we deliberately choose parameter values where hidden effort appears to play a minor role on average: we set $\phi = 99.0$. Then, to reproduce the benchmark level of measured productivity in equilibrium, it must be true that

Theorem so that the relevant distribution is commonly known. For medium and large events, the data from BCBS and ORX support our idea that these events are possible but are sufficiently rare and highly skewed that the day to day considerations have the dominant effect on the terms of the job contract. While our numerical analysis can investigate the consequences of an event, interested researchers are encouraged to read the work of Gabaix (2011). In part, he argues that the sample size of events may need to be increased for the statistical properties of any estimate of the frequency to be stable enough to be useful. A more complete consideration of the distinction in theory between "small", "medium" and "large" value events is beyond the scope of this paper.

$$\psi = 2.3505,$$
 $a_2 = 0.4254,$
 $v_2^r = 0.1810$

As part of this solution, it is also true that $v_1 = 0.3012$, and $a_1 = 0.7079$.

Table 1: Effects of an operational risk event, when using an equilibrium incentive contract.

	$\phi=99.0$ $\psi=2.35$	$\phi = 99.0$ $\psi = 5.00$	$\phi=$ 119.0 $\psi=$ 2.35	$\phi=$ 119.0 $\psi=$ 5.00
a_2	0.43	2.50	0.43	2.50
$E(P_2)$	100.0	111.5	120.0	131.5
Δa_2	0.043	0.25	0.043	0.25
Change in Expected Output $= (\Delta a_2) \psi$	0.10	1.25	0.10	1.25
Change in Worker's Expected Compensation = $(\Delta a_2)\psi v_2^r$	0.018	0.625	0.018	0.625
Change in Expected Profit $= (\Delta a_2) \psi (1 - v_2^r)$	0.082	0.625	0.082	0.625

Table 1 shows the effects of a 10% decrease in effort in period 2, given an equilibrium incentive contract based on different values of the fixed technology parameters. The first row indicates the equilibrium level of a_2 , which changes with the technology, shown in each column and the second row shows the expected value of labor productivity in equilibrium based on the technology and the equilibrium level of worker's effort. The third row shows the size of a 10% decrease in the level of effort while the remaining rows show its consequences of that decrease for the expected output, expected compensation, and expected profit.

The cost or severity of an operational risk event is minor if ψ is small because a_2 would be small. Thus, if the agent exerts 10% less effort than the manager anticipates, and even though they would be penalized by it under the contract, then 10% of a small number is small. If ψ is larger, then the cost of a deviation is larger but, when using the equilibrium contract, the cost in terms of

¹² Our model does not allow (ϕ, ψ) to vary randomly: e.g., for a machine used by a worker to break down unexpectedly. It is easiest to interpret our results under the assumption that such breakdowns can be verified easily. Thus, they have no effect on the agent's compensation and represent some of the capital costs borne by the (risk-neutral) principal.

lost wages is higher for two reasons: because the change in output is larger and because the equilibrium incentive rate is higher. 13 Although the principal always loses if the agent exerts less effort, the fact that an equilibrium incentive contract is designed to be incentive-compatible means that the size of the loss varies with the technology.

The propositions above show how these conclusions can be applied to a wider range of scenarios. If using an incentive contract and if ϕ were higher, then columns 4 and 5 shows that (f, v_1, v_2) would not change. When using an incentive contract, an increase in (σ_1, σ_2) increases the worker's risk premium, and would cause the level of effort exerted in equilibrium to fall; in such cases, a 10% deviation from that equilibrium would have a smaller effect.

Some agency relationships are resolved by monitoring and oversight rather than incentives. The consequences of a 10% decrease in effort are easy to predict under this type of contract since the agent bears no risk due to external uncertainty: a worker who fails to meet the standard is easily identified and penalized. This rule may deter a worker enough that the possibility of accidental underperformance is minimal. The most relevant difference between the two types of job contracts is that, if a worker anticipates being fired for underperforming even a little then, rather than shirking a little or accidentally, they may not show up for work at all. Thus, the cost or severity of the event to a principal who monitors may depend on a worker's average productivity: i.e., both ϕ and ψ . Setting standards and monitoring workers may decrease the possibility of operational risk but increase its severity if a negative event happens. 14

An alternative perspective on monitoring would start by asking: if it could vary, what would the cost of monitoring need to be to reproduce an equivalent output as an incentive contract?¹⁵ The algebra in Theorem 1 shows that this question has a simple answer: $a_1 = a_2 = E_1 = E_2 = \psi - m$. Thus, in equilibrium, knowing ψ and the value of a_2 implied by an incentive contract makes it easy to solve for the value of *m* which produces an equivalent effort.

¹³ We also note that, independent of the issue of operational risk, the increase in ψ from 2.35 to 5.0 increases expected productivity by more than 10% in the benchmark because the equilibrium level of effort increases by so much.

¹⁴ This example illustrates several of the reasons why we are not able to fully answer the question raised by Hatzakis, Nair, and Pinedo (2010, 652) concerning whether there is a trade off between productivity and operational risk. In our model, the manager has only crude tools and the technology parameters cannot be varied at any cost. Intuition suggests that, in some cases, improving productivity would also reduce operational risk (such as if workers who work "harder" are more productive because the extra effort reduces carelessness) while, in other cases, there could be a trade off.

¹⁵ We thank an anonymous referee for this perspective.

Specifically, for the case of $\psi = 2.35$ the equivalent value of m is 1.92 and the total cost of monitoring is $1.92 \times 0.43 = 0.83$ or less than 1% of the benchmark output. If ψ increases to 5.00 then the equivalent value of m is 2.5 and the total cost of monitoring is 2.5*2.5 = 6.25 or more than 5% of expected output. Thus, an increase in ψ increases the cost of monitoring which is equivalent to an incentive contract, at an increasing rate. (Note that this cost is incurred by the principal but has no effect on the agent's payoff, since it is fixed by the participation constraint.)

The specification of the model suggests an additional scale which could be used to judging the magnitude or relevance of an operational risk event. The model characterizes the existence of a risky environment. Even though our discussion focuses on the expected outcome, the measured productivity would differ between periods without any deviation from the equilibrium behavior and would be less than expected with some probability: with no change in technology and using our assumption that random shocks are distributed Normally, there is a 16% probability that the measured productivity would be at least one standard deviation below its expectation. Our calculations assume that one standard deviation is approximately 5% of expected output (i.e., 5 units of output in Table 1). Therefore, this computation suggests that the effects of the operational risk events discussed in Table 1 are possible but that they are less serious than the negative "probable" events.

6 Concluding Remarks

This paper uses a dynamic agency model with renegotiation to study the relationships amongst incentives, monitoring, worker effort and productivity. We develop a two period model which shows how job offers vary with technology and how measured productivity can vary even if the technology does not. Since we are able to provide closed form solutions for critical variables, we are also able to discuss the impact of the issue of an operational risk event, where workers do not act as anticipated.

Our model uses *two* parameters to model the different types of technology. We show that increases in the marginal productivity of effort, ψ , have a nonlinear effect. Estimating these parameters separately may help to distinguish the productivity characteristics of a manufacturing industry (where the engineering processes and the presence of supervisors allow agents relatively little opportunity for discretionary effort) from the productivity characteristics of service industries. For a firm in the service sector or the knowledge-based economy, such as consulting or restaurants, hidden effort by its workers may be the source of its competitive advantage.

We show that an increase in ψ would increase productivity and increase total cost per worker in equilibrium. This finding differs from the traditional view of productivity, expressed in Corollary 2, where the percentage effect on unit cost of an increase in measured productivity is equal but in the opposite direction. While the technology-based model of increasing productivity focuses on the idea that the "boss" deserves the credit because he buys the better technology used by the agent, our model focuses on the idea that the agent deserves the credit for an increase in productivity because of hard work. These ideas are not mutually exclusive and our model of negotiations (followed by potential re-negotiations) should serve to remind readers that any productivity gain produces an expected surplus which can be bargained over: good management ensures that the terms of the job contract are appropriate to the technology. This idea is consistent with the conclusion of Bloom and van Reenan (2011) that the surprisingly large productivity dispersion amongst producers in a given industry may be due to the slow adoption of appropriate human resource management practices by some of them.

Other papers, e.g., Banker, Datar, and Mazur (1989), note that measurement is necessary before one can recognize whether productivity has changed and before one can institute policies to manage it. Our model shows that, even if the technology is fixed, productivity can appear to vary between periods, due to changes in the conditions, changes in behavior over time or luck (since the standard deviation of P_t equals σ). Therefore, while we do not offer any direct predictions concerning how productivity would evolve over time, our closedform solutions would be useful to anybody trying to determine whether a change in the measured value of P_t is statistically significant. We find that distinguishing between the different types of technological change adds insight since, if matched with the appropriate equilibrium job contract, the effect of a certain type of technological change increases expected productivity at an increasing rate.

¹⁶ Kahneman and Tversky (1973) note that luck and "regression to the mean" complicate the decisions of the principal in surprising ways. If an agent is praised when the outcome is above average and punished when below average then a simple argument about incentives may seem to be sufficient to explain why people who are punished will tend to improve their subsequent performance but it is not necessary. Alternative, and especially if randomness affects the outcome significantly, the evidence also suggests that giving praise lowers subsequent performance: i.e., when an above-average outcome in one period returns to the average later.

Beyond the issue of measuring productivity, we note that the significance of operational risk. The issue is not well understood. While many people agree that it exists although the events occur, researchers disagree about how best to measure it and about how common it is. Some people argue that good risk management aims to control the "possibility" and "impact" of an event. According to this definition, our paper argues that the analysis should recognize how the terms of the agency contract can alter the possibility of risks associated with human behavior. By proposing to study this phenomenon in a principalagent setting, we note that an external source of risk is a necessary feature of the situation: market risk is a natural candidate. Based on the environment, an incentive contract provides appropriate incentives and shares the risk. If an agent shirks and an operational risk event occurs then the impact on the principal varies with the negotiated terms of the job contract. Or, with an appropriate investment, the principal can choose to take on that risk by monitoring the work of the agent.¹⁷ In other words, the technology and the conditions determine an equilibrium which represents "normal" behavior. Therefore, the impact of an operational risk event on a company's profit would vary with the type of production technology as well as with the human dimensions of the operating environment.

Our formal model emphasizes ideas which are more familiar to financial analyses and that fact may seem to limit the insights into models which are more descriptively accurate of the operational processes. For example, Hatzakis, Nair, and Pinedo (2010) offer a number of insights based on specific features of the financial industry. They, as well as the descriptive data from the BCBS (2009) and ORX (2014), note certain issues with using the Normal distribution to describe uncertainty about operational risk. While there are many small events which could be considered as a cost of doing business, most of the attention focuses on the distribution of medium and large value events which tends to

¹⁷ One possible extension of our model would be to consider the effect of imperfect monitoring. With imperfect monitoring, the agency contract would likely change since imperfections would create risk for workers: they could be penalized even if exerting the appropriate effort. To the extent that the monitors are imperfect, because they are human, it might be interesting to consider a hierarchical model of agency where the principal gives incentives to a supervisor to monitor production-level workers. As part of this extension, it would be important to fully understand the nature of the "imperfection" in the monitoring technology. The findings of our model might complement such a study because intuition suggests that the most appropriate incentives given to the supervisor would vary with the production technology and with the monitoring technology. The costs and relevance of these imperfections are likely to vary from industry to industry. Rahman (2012) offers more insight on this issue.

have fatter tails and to be skewed toward a few catastrophic events. Incorporating such issues into the analysis coherently would need to consider the extra effects of the preferences of a principal and an agent with respect to higher moments of a distribution, such as "skewness-loving" or "kurtosis-aversion" or even uncertainty aversion and ambiguity aversion. We conjecture that the basic insights of our comparative statics analysis with respect to the technology would remain valid. Having fat tails would have little direct effect on the mean productivity but the cost of a risk, and the associated consumption smoothing behavior, would become a more significant consideration when the worker and manager negotiate the terms of the job contract. If an agent has limited liability, it may not be possible to impose the penalty implied by a linear incentive contract in the event of a catastrophe. If true then a principal may prefer to use some kind of costly monitoring system. In all cases, the choice of contract needs to be matched with the technology. The match affects the expected productivity, the agent's anticipated level of effort as well as affecting how the losses are distributed between principal and agent when people do not behave as anticipated.

Acknowledgements: This paper has benefited from discussions with Tom Ross, Xiaopeng Yin, Kam Yu, seminar audiences at the University of Alberta, University of British Columbia, University of California - Los Angeles, University of Illinois- Urbana Champaign, Peking University, University of Toronto, the CAAA Annual Conference, the Canadian Economics Association Annual Meeting and the AAA FARS Midyear Conference and the comments of two referees. We gratefully acknowledge the financial support from City University of Hong Kong.

Appendix: Proofs

Proof of Theorem 1: Behavior with Monitoring Only

Workers who exert the required effort know that the monitoring technology is accurate enough to confirm that they are doing the job as agreed in the contract. Therefore, they have no reason to work any less hard than the standard. Without incentives, i.e., $v_1^i = v_1^r = 0$, workers have no reason to exert more than the minimum set by the standard. Thus, $a_1 = E_1$ and $a_2 = E_2$. Knowing this, the principal pays $f = k(E_1) + \beta k(E_2)$ to workers and incurs the cost of monitoring separately.

The principal can increase (E_1, E_2) and the effect on output varies with the technology. In our model, ψ represents the incremental benefit of effort and a profit maximizing principal would set the effort standard at a point where the incremental benefits of an increase balance the incremental costs. Given $k(a_t) = \frac{1}{2}(1 + a_t^2)$, the first order condition showing the optimum to eq. [6] implies that the optimal (E_1, E_2) satisfies

$$E_1 = \psi - m = E_2 \tag{9}$$

(if there is an interior solution, else $E_i = 0$). This solution depends on the fixed parameters; it would not be renegotiated at the beginning of the second period based on output in the first period or on any change in the worker's bargaining position between the first and second period. **Q.E.D.**

Proof of Theorem 2: A Renegotiation-proof Incentive Contract

Solving for the appropriate incentives is more complex because the possibilities for a worker's behavior are more varied and complex. As is commonly done in dynamic models, we construct an equilibrium solution using backward induction, as follows. Since the agent is assumed to consume all the remaining bank balance at the end of the second period, the second-period consumption c_2 is not a decision variable (i.e., $c_2 = B_2$) and we can start by characterizing the agent's second-period effort choice a_2 and the principal's renegotiated incentive rate v_2^r at t = 2. Given these solutions, we can characterize the agent's first-period consumption decision c_1 , and first-period effort a_1 . Finally, we solve for the principal's incentive contract at t = 0, described by (f, v_1) .

The initial linear compensation contract is $c^i(f^i, v_1^i, v_2^i)$ and, at the *start* of t=2, (i.e., stage 4 in the time line), f^i and v_1^i are irrevocable. At this stage, the principal can offer a renegotiated linear compensation contract $c^r(\Delta f^r, v_2^r)$ with an (additional) fixed payment Δf^r and a revised incentive rate for the second period v_2^r . If the agent accepts the new contract, then her second-period compensation will be $\omega_2(c^r) = \Delta f^r + v_2^r Q_2$. The LEN assumption implies that, conditional on the information at the end of t=1, her expected compensation net of labor cost is

$$E_1[\omega_2 - k(a_2)] = \Delta f^r + v_2^r[\phi + \psi a_2 + \rho(\sigma_2/\sigma_1)(Q_1 - \phi - \psi a_1)] - \frac{1}{2}(1 + a_2^2)$$
 [10]

and that the risk premium for the net compensation based on the posterior variance of Q_2 is

$$RP_1 = \frac{1}{2}r[v_2^r]^2(1-\rho^2)\sigma_2^2.$$
 [11]

Therefore, the agent's certainty equivalent with respect to the net compensation, conditional on the information at the end of the first period, is

$$CE_1(c^r) = \beta E_1[\omega_2 - k(a_2)] - \beta RP_1$$
 [12]

The agent is assumed to consume her bank balance at the end of t=2, i.e., her second-period consumption $c_2 = B_2$, and $B_2 = R(B_1 - c_1) + \omega_2 - k(a_2)$. Thus, the agent's utility maximization decision with respect to her second-period effort a_2 is

$$\arg\max_{a_2} E_1[-\beta \exp(-rc_2)] = \arg\max_{a_2} \{B_1 - c_1 + CE_1\}$$
 [13]

The first-order condition for the problem yields $a_2^r = \psi v_2^r$. This condition indicates that the agent chooses her second-period effort optimally based on the revised incentive rate v_2^r .

Given the initial contract, the output Q_1 , and the principal's conjecture of the agent's first-period effort \hat{a}_1 , the principal chooses Δf^r and v_2^r so as to maximize his second-period expected utility, subject to acceptance by the agent. Formally, the principal solves

$$\max_{\Delta^{f'}, \psi'_{1}} EU_{1}^{p}(c^{r}) = \beta \{\phi + \psi \alpha_{2}^{r} - E_{1}[\omega_{2}(c^{r})]\}$$
 [14]

subject to
$$CE_1(c^r) \ge CE_1(c^i)$$
 [15]

$$a_2^r = \psi v_2^r \tag{16}$$

If the participation constraint, eq. [15], is binding then

$$\begin{split} \Delta f^r &= \frac{1}{2}\{[a_2^r]^2 - [a_2^i]^2\} + \frac{1}{2}r(1-\rho^2)\sigma_2^2\{[v_2^r]^2 - [v_2^i]^2\} \\ &- \{v_2^r[\phi + \psi a_2^r + \rho(\sigma_2/\sigma_1)(Q_1 - \phi - \psi \hat{a}_1)] - v_2^i[\phi + \psi a_2^i + \rho(\sigma_2/\sigma_1)(Q_1 - \phi - \psi \hat{a}_1)]\} \end{split}$$

Substituting eqs [17] and [16] into the objective function [14], the principal's decision problem becomes an unconstrained optimization problem:

$$\begin{split} \max_{v_{2}'} \Pi_{1}^{p} &= \beta \{ \phi + \psi^{2} v_{2}^{r} - \frac{1}{2} \{ \psi^{2} [v_{2}^{r}]^{2} - [a_{2}^{i}]^{2} \} - \frac{1}{2} r (1 - \rho^{2}) \sigma_{2}^{2} \{ [v_{2}^{r}]^{2} - [v_{2}^{i}]^{2} \} \\ &- v_{2}^{i} [\phi + \psi a_{2}^{i} + \rho (\sigma_{2}/\sigma_{1}) (Q_{1} - \phi - \psi \gamma \hat{a}_{1})] \} \end{split}$$
 [18]

The first-order condition with respect to v_2^r is

$$\beta[\psi^2 - \psi^2 v_2^r - r(1 - \rho^2)\sigma_2^2 v_2^r] = 0$$
 [19]

Therefore, the revised incentive rate is

$$v_2^r = \frac{\psi^2}{\psi^2 + r(1 - \rho^2)\sigma_2^2}$$

The solution indicates that Δf^r is a *linear* function of (Q_1, \hat{a}_1) . Furthermore, if the initial contract specifies $v_2^i = v_2^r$, then $\Delta f^r = 0$. For any optimal initial *linear* contract $c^i(f^i, v_1^i, v_2^i)$ that is subject to renegotiation, there exists an equivalent initial *linear* contract that is renegotiation-proof $c^{rp}(f, v_1, v_2^r)$.

At the end of t = 1 and before the contract might be renegotiated, the agent decides on her consumption c_1 to maximize her expected utility over the two-period consumption, conditional on the information available at this time. Borrowing and lending opportunities are available to the agent. Given $c_2 = B_2 = R\ell_1 + \omega_2 - k(a_2)$ and $\ell_1 \equiv B_1 - c_1$, the agent's decision problem with respect to c_1 is

$$\max_{c_1} \{-\exp(-rc_1) - \beta E_1[\exp(-rc_2)]\}$$

$$= \{-\exp(-rc_1) - \beta \exp[-r(R(B_1 - c_1) + R CE_1)]\}$$
[20]

The first-order condition for this problem is satisfied by $c_1 = R(B_1 - c_1 + CE_1)$. Rearranging it and using the annuity amortization factor $A_1 \equiv (1+\beta)^{-1}$ gives $c_1 = A_1(B_1 + CE_1)$. Because the agent smoothes consumption over time, it is optimal for the agent to consume an amount equal to an annuity based on the sum of first-period bank balance and second-period certainty equivalent. Relative to a one-period model of the principal-agent relationship, consumption smoothing alters the effectiveness of incentives within a period by reducing the agent's utility of a good outcome in that period and increasing the utility of a bad outcome in that period. Consumption smoothing also implies that the conditions anticipated in the future and the terms of the contract at that time can affect behavior in the current period.

At the beginning of t = 1, and based on a given compensation contract, the agent chooses a_1 to maximize her expected utility over the two periods. This is equivalent to maximizing her total certainty equivalent CE_0 under the LEN assumption,

$$\max_{a_1} CE_0 = \beta E_0[W - K(a_1, a_2^r)] - \beta RP_0$$
 [21]

 $W \equiv \omega_1 + \beta \omega_2$ is the total compensation payment to the agent, stated in period 1 dollars, and $K(a_1, a_2) \equiv k(a_1) + \beta k(a_2)$ represents the total labor cost.

$$RP_0 = \frac{1}{2} \{ rA_1 [v_1 + \rho(\sigma_2/\sigma_1)\beta v_2]^2 \sigma_1^2 + r\beta [v_2]^2 (1 - \rho^2) \sigma_2^2 \}$$
 [22]

represents the agent's total risk premium, which takes account of the effect of inter-temporal correlation, captured by ρ , and the effective risk aversion parameter, rA_1 . The first-order condition for the problem implies that $a_1 = \psi v_1$.

Finally, we consider the compensation terms of the incentive contract, (f, v_1) , offered by the principal at t = 0. Anticipating the optimal solutions in the next two periods, the principal chooses (f, v_1) to maximize his expected utility at date zero subject to the agent's participation and incentive constraints. That is, the principal solves the following problem

$$\max_{f,v_0} EU_0^p = \beta E_0[Q] - \beta E_0[W]$$
 [23]

subject to
$$CE_0 = \beta E_0[W - K(a_1, a_2)] - \beta RP_0 \ge c^0$$
 [24]

$$a_1 = \psi v_1 \tag{25}$$

$$a_2 = \psi v_2 \tag{26}$$

where $Q \equiv Q_1 + \beta Q_2$ represents the expected gross payoff stated in period 1 dollars and $W \equiv \omega_1 + \beta \omega_2$, represents the expected compensation payment stated in period 1 dollars.

The fixed wage f is sufficient to induce the agent to accept the job offer, i.e., the participation constraint is binding. Without loss of generality, we assume a zero reservation consumption: i.e., $c^0 = 0$. This condition implies that

$$f = K(a_1, a_2) + RP_0 - E_0[\omega_1^{\nu} + \beta \omega_2],$$
 [27]

where $\omega_1^{\nu} = \nu_1 Q_1$ is the variable component of the first-period compensation. Using the binding participation constraint enables us to express the principal's decision problem as the following unconstrained optimization problem:

$$\max_{V_0} \Pi_0^p = \beta E_0[Q] - \beta [K(a_1, a_2) + RP_0]$$
 [28]

Ex ante, the principal chooses v_1 so as to maximize his expected gross payoff net of the agent's total labor cost and total consumption risk premium. The first derivative of Π_0^p with respect to v_1 is:

$$\frac{\partial \Pi_0^p}{\partial v_1} = \beta \frac{\partial E_0[Q]}{\partial a_1} \frac{\partial a_1}{\partial v_1} - \beta \left[\frac{\partial K(a_1, a_2)}{\partial a_1} \frac{\partial a_1}{\partial v_1} + \frac{\partial RP_0}{\partial v_1} \right]
= \beta \left\{ \psi^2 - \left[\psi^2 v_1 + rA_1 \sigma_1^2 (v_1 + \rho(\sigma_2/\sigma_1)\beta v_2) \right] \right\}$$
[29]

Setting this derivative equal to zero in order to characterize the optimal solution yields $v_1 = [\psi^2]/\Delta - \lambda [\beta v_2]$, where $\lambda \equiv rA_1 \rho \sigma_1 \sigma_2/\Delta$ and $\Delta \equiv \psi^2 + rA_1 \sigma_1^2$.

In a Nash equilibrium, $\hat{a}_1 = a_1$ by definition. To characterize an equilibrium, we focused on the case where the initial contract does not need to be renegotiated (i.e., $v_2^r = v_2^i = v_2$). Substituting these equalities in the equations above produces the Theorem stated in the main text. **Q.E.D.**

Proof of the Existence of an Equilibrium

Theorem 2 identifies algebraic solutions for the appropriate renegotiation-proof contract $c^{rp}(f, v_1, v_2)$ if using an incentive contract and Theorem 1 identified solutions for the appropriate monitoring standard if using a monitor. This proof shows that the principal-agent equilibrium exists unconditionally.

A key step in the argument is that the monitoring standard imposes a *lower* bound on effort and, if the contract creates an incentive to work harder then the standard has no other effect. If the standard is binding in either period in equilibrium, then using incentives also adds income risk for the agent and the agent would demand compensation. Thus, the principal would use either a binding standard of effort in a period or an incentive contract in that period (with $E_t = 0$) but not both. The essential question is to identify conditions under which each is used in equilibrium.

We note that there is no benefit and some cost to a principal who both monitors workers and introduces income risk by using incentives. Due to the LEN assumptions and our consideration of renegotiation, the choice of incentives vs. monitoring in the first period has no effect on the choice of incentives vs. monitoring in the second period. If the principal chooses to monitor in the second period then this choice has no effect if the principal chooses to monitor in the first period. Any effect of this choice on the level of incentives in the first period, if the principal chooses to monitor in the second period, depends on the total risk faced by a worker and the effective degree of risk aversion (which varies with the worker's decision to smooth income over time). Therefore, for any given set of parameters, it is possible for the principal to choose their best contract in period 2. Given that choice and the parameters, it is possible for the principal to choose their best contract in period 1. Thus, an equilibrium exists.

Q.E.D.

Proof of Corollary 2ii)

Corollary 2: ii) Define *UnitCost* as the ratio of total compensation paid to an agent over the two periods to the total production over the two periods, $Q_1 + Q_2$.

If $\psi = 0$, then $E(UnitCost) > x/E(P_1)$ for some constant x that does not depend on ϕ .

Proof: Jensen's Inequality implies that E(1/z) > 1/E(z) for any random variable z. Therefore, $E(UnitCost) = E\big((f + E_0(\omega_1^{\rm v} + \beta\omega_2))/(Q_1 + Q_2)\big) > E(f + E_0(\omega_1^{\rm v} + \beta\omega_2))/E(Q_1 + Q_2)$. If $\psi = 0$ is the agent's cost of effort minimal and, with $v_t = 0$, there is no risk premium: $E(f + E_0(\omega_1^{\rm v} + \beta\omega_2)) = K(0,0)$ in equilibrium. If $\psi = 0$ then $E(Q_1 + Q_2) = 2\phi = 2E(P_1)$ in equilibrium. Therefore, $E(UnitCost) > K(0,0)/2E(P_1)$ in equilibrium. **Q.E.D.**

Proof of Proposition 2

Proposition 2: $E[P_2] > E[P_1]$ if and only if $A_1(\sigma_1^2 + \beta \rho \sigma_1 \sigma_2) - (1 - \rho^2)\sigma_2^2 > 0$.

Proof: In equilibrium, $E[P_1] = \phi + \psi^2 v_1$ and $E[P_2] = \phi + \psi^2 v_2$, where

(i)
$$v_1 = \frac{1}{\Lambda} [\psi^2] - \lambda [\beta v_2^r]$$
, where $\Delta = \psi^2 + rA_1\sigma_1^2$, $\lambda = \frac{1}{\Lambda} rA_1\rho\sigma_1\sigma_2$, and $A_1 = (1 + \beta)^{-1}$;

(ii)
$$v_2^r = \frac{\psi^2}{\psi^2 + r(1-\rho^2)\sigma_2^2}$$

Therefore, $E[P_2] > E[P_1]$ if and only if $v_2^r > v_1$. The equilibrium incentive rates give

$$\frac{\psi^2}{\psi^2 + r(1 - \rho^2)\sigma_2^2} > \frac{1}{\Delta} [\psi^2] - \lambda \beta \frac{\psi^2}{\psi^2 + r(1 - \rho^2)\sigma_2^2}$$
 [30]

Substituting $\Delta \equiv \psi^2 + rA_1\sigma_1^2$ and $\lambda \equiv \frac{1}{\Delta}rA_1\rho\sigma_1\sigma_2$, it follows that

$$\frac{\psi^2}{\psi^2 + r(1 - \rho^2)\sigma_2^2} [\psi^2 + rA_1\sigma_1^2 + rA_1\beta\rho\sigma_1\sigma_2] > \psi^2$$
 [31]

Thus, we have

$$A_1(\sigma_1^2 + \beta \rho \sigma_1 \sigma_2) - (1 - \rho^2)\sigma_2^2 > 0$$
 Q.E.D.

Proof of Proposition 3

Proposition 3: If $(2\psi - 1)[\psi^2 + 2r(1 - \rho^2)\sigma_2^2]\psi^2 + [r(1 - \rho^2)\sigma_2^2]^2 > 0$, then $\partial E[P_2]/\partial \psi > \partial E[P_2]/\partial \phi$.

Proof: Using the equilibrium incentive rates in the expected productivity expressions, and differentiating with respect to ϕ and ψ give

$$\frac{\partial E[P_2]}{\partial \phi} = 1 \tag{32}$$

$$\frac{\partial E[P_2]}{\partial \psi} = 2\psi V_2^r + \psi^2 \frac{\partial V_2^r}{\partial \psi}$$
 [33]

Since $\frac{\partial v_2^r}{\partial \psi} = \frac{2\psi r (1-\rho^2)\sigma_2^2}{\left[\psi^2 + r (1-\rho^2)\sigma_2^2\right]^2}$, it follows that

$$\frac{\partial E[P_2]}{\partial \psi} = \frac{2\psi^3 [\psi^2 + 2r(1 - \rho^2)\sigma_2^2]}{[\psi^2 + r(1 - \rho^2)\sigma_2^2]^2}$$
[34]

Hence, $\frac{\partial E[P_2]}{\partial \psi} > \frac{\partial E[P_2]}{\partial \phi}$ if the following condition is satisfied

$$(2\psi - 1)[\psi^2 + 2r(1 - \rho^2)\sigma_2^2]\psi^2 + [r(1 - \rho^2)\sigma_2^2]^2 > 0$$
 Q.E.D.

Proof of Proposition 4

Proposition 4: If an increase in ψ does not alter the choice between incentives and monitoring within a period then an increase in ψ increases $E[P_2]$ at an increasing rate.

Proof: In equilibrium, the first derivative of the expected productivity with respect to ψ is

$$\frac{\partial E[P_2]}{\partial w} = 2\psi v_2^r + \psi^2 \frac{\partial v_2^r}{\partial w}$$

Since
$$\frac{\partial v_2^r}{\partial \psi} = \frac{2\psi r (1-\rho^2)\sigma_2^2}{[\psi^2 + r(1-\rho^2)\sigma_2^2]^2} > 0$$
, so $\frac{\partial E[P_2]}{\partial \psi} > 0$.

Further, the second derivative with respect to ψ is

$$\frac{\partial^2 E[P_2]}{\left[\partial \psi\right]^2} = 2v_2^r + 4\psi \frac{\partial v_2^r}{\partial \psi} + \psi^2 \frac{\partial^2 v_2^r}{\left[\partial \psi\right]^2}$$
 [35]

Substituting $\frac{\partial^2 v_2^r}{[\partial \psi]^2} = \frac{2r(1-\rho^2)\sigma_2^2[r(1-\rho^2)\sigma_2^2-3\psi^2]}{[\psi^2+r(1-\rho^2)\sigma_2^2]^3}$ into [35] gives

$$\frac{\partial^2 E[P_2]}{[\partial \psi]^2} = \frac{2\psi^2 \{M^2 + r(1 - \rho^2)\sigma_2^2[\psi^2 + 5r(1 - \rho^2)\sigma_2^2]\}}{M^3} > 0$$

where $M = \psi^2 + r(1 - \rho^2)\sigma_2^2$.

If the principal monitors effort, then an increase in ψ increases E_1 and E_2 . Since $E[P_1] = \phi + \psi E_1$ and $E[P_2] = \phi + \psi E_2$ when the principal monitors, an increase in ψ increases $E[P_t]$ at an increasing rate.

Therefore an increase in ψ increases $E[P_t]$ at an increasing rate independent of whether the principal monitors or uses incentives within a period. **Q.E.D.**

Proof of Proposition 5

Proposition 5: An increase in σ_2^2 decreases $\partial E[P_2]/\partial \psi$. An increase in ρ increases $\partial E[P_2]/\partial \psi$ if and only if $\rho > 0$.

Proof: From the last proof, we have

$$\frac{\partial E[P_2]}{\partial \psi} = 2\psi V_2^r + \psi^2 \frac{\partial V_2^r}{\partial \psi}$$
 [36]

Differentiating the above with respect to σ_2^2 and ρ respectively, yields

$$\frac{\partial^2 E[P_2]}{\partial \sigma_2^2 \partial \psi} = 2\psi \frac{\partial v_2^r}{\partial \sigma_2^2} + \psi^2 \frac{\partial^2 v_2^r}{\partial \sigma_2^2 \partial \psi}$$
 [37]

$$\frac{\partial^2 E[P_2]}{\partial \rho \partial \psi} = 2\psi \frac{\partial v_2^r}{\partial \rho} + \psi^2 \frac{\partial^2 v_2^r}{\partial \rho \partial \psi}$$
 [38]

Since
$$\frac{\partial v_2'}{\partial \sigma_2^2} = -\frac{\psi^2 r (1-\rho^2)}{M^2}$$
 and $\frac{\partial^2 v_2'}{\partial \sigma_2^2 \partial \psi} = \frac{2\psi r (1-\rho^2)[\psi^2 - r (1-\rho^2)\sigma_2^2]}{M^3}$, it follows that $\frac{\partial^2 E[P_2]}{\partial \sigma_2^2 \partial \psi} = -\frac{4\psi^3 [r (1-\rho^2)]^2 \sigma_2^2}{M^3} < 0$, where $M \equiv \psi^2 + r (1-\rho^2)\sigma_2^2$.

Substituting $\frac{\partial^2 v_2^r}{\partial \rho \partial w} = \frac{-4 \psi r \sigma_2^2 \rho [\psi^2 - r(1-\rho^2) \sigma_2^2]}{M^3}$ and $\frac{\partial v_2^r}{\partial \rho} = \frac{2 \psi^2 r \sigma_2^2 \rho}{M^2}$ into [38], we have

$$\frac{\partial^2 E[P_2]}{\partial \rho \partial w} = \frac{8\psi^3 [r\sigma_2^2]^2 (1-\rho^2)}{M^3} \rho$$

Therefore, the sign of $\frac{\partial^2 E[P_2]}{\partial \rho \partial \psi}$ depends on the sign of ρ . Q.E.D.

References

- Armitrage, H. M., and A. A. Atkinson. 1990. *The Choice of Productivity Measures in Organizations: A Field Study in Seven Canadian Firms*. Hamilton: Society of Management Accountants in Canada.
- Arya, A., J. Fellingham, and D. Schroeder. 2004. "Aggregation and Measurement Errors in Performance Evaluation." *Journal of Management Accounting Research* 16:93–105.
- Banker, R. D., S. Datar, and R. Kaplan. 1989. "Productivity Measurement and Management Accounting." *Journal of Accounting, Auditing and Finance* 4 (4):528-54.
- Banker, R. D., S. Datar, and M. Mazur. 1989. "Testing the Optimality of a Performance Evaluation Measure for a Gain Sharing Contract." *Contemporary Accounting Research* 6 (2):809–24.
- Banker, R. D., S. Datar, and M. Rajan. 1987. "Measurement of Productivity Improvements: An Empirical Analysis." *Journal of Accounting, Auditing and Finance* 2 (4):319-47.

- Banker, R. D., S. Devaraj, R. G. Schroeder, and K. Sinha. 2002. "Performance Impact of the Elimination of Direct Labor Variance Reporting: A Field Study." Journal of Accounting Research 40 (4):1013-36.
- Basel Committee on Banking Supervision. 2009. Results from the 2008 loss data collection exercise for operational risk. Working paper, Bank for International Settlements, available at: http://www.bis.org/publ/bcbs160a.pdf. Accessed July 15, 2013.
- Basel Committee on Banking Supervision. 2011. Principles for the sound management of operational risk. Working paper, Bank for International Settlements, available at http://www.bis.org/publ/bcbs195.pdf.
- Belot, M., and M. Schröder. 2013. "Sloppy Work, Lies and Theft: A Novel Experimental Design to Study Counterproductive Behaviour." Journal of Economic Behavior and Organization 93:233-8.
- Bloom, N., and J. van Reenan. 2011. "Human Resource Management and Productivity." Handbook of Labor Economics 4 (part B):1697-767.
- Chavez-Demoulin, V., P. Embrechts, and M. Hofert. 2015. "An Extreme Value Approach for Modeling Operational Risk Losses Depending on Covariates." Journal of Risk and *Insurance.* available on-line at doi:10.1111/jori.12059.
- Christensen, P. O., and G. A. Feltham. 2005. Economics of Accounting: Volume II Performance Evaluation. New York: Springer.
- Dutta, S., and S. Reichelstein. 2003. "Leading Indicator Variables, Performance Measurement and Long-Term Versus Short-Term Contracts." Journal of Accounting Research 41 (3): 837-66.
- Feltham, G. A., R. Indjejikian, and D. Nanda. 2006. "Dynamic Incentives and Dual-Purpose Accounting." Journal of Accounting and Economics 42 (3):417-37.
- Fudenberg, D., and J. Tirole. 1990. "Moral Hazard and Renegotiation in Agency Contracts." Econometrica, Econometric Society 58 (6):1279-319.
- Gabaix, X. 2011. "The Granular Origins of Aggregate Fluctuations." Econometrica 79 (3):733-76.
- Hatzakis, E. D., S. K. Nair, and M. L. Pinedo. 2010. "Operations in Financial Services-an Overview." Production and Operations Management 19 (6):633-64.
- Heidhues, P., and B. Koszegi. 2010. "Exploiting Naivete About Self-Control in the Credit Market." American Economic Review 100 (5):2279-303.
- Hsieh, C.-T., and E. Moretti. 2003. "Can Free Entry Be Inefficient? Fixed Commissions and Social Waste in the Real Estate Industry." Journal of Political Economy 111 (5):1076-122.
- Hubbard, T. 2000. "The Demand for Monitoring Technologies: The Case of Trucking." Quarterly Journal of Economics 115 (2):533-60.
- Jensen, M., and W. Meckling. 1976. "Theory of the Firm: Managerial Behavior, Agency Costs and Ownership Structure." Journal of Financial Economics 3:305-60.
- Kahneman, D., and A. Tversky. 1973. "On the Psychology of Prediction." Psychological Review 80:237-51.
- Myrseth, K. O. R., and C. E. Wollbrant. 2013. "A Theory of Self-Control and Naivete: The Blights of Willpower and Blessings of Temptation." Journal of Economic Psychology 34:8-19.
- Operational Riskdata eXchange, 2014. 2014 ORX report on operational risk loss data. https://www.orx.org/pages/ORXData.aspx. Accessed on April 14, 2015.
- O'Donoghue, T., and M. Rabin. 2015. "Present Bias: Lessons Learned and To Be Learned." American Economic Review: Papers & Proceedings 105 (5):273-9. http://dx.doi.org/10. 1257/aer.p20151085.

- Rahman, D. 2012. "But Who Will Monitor the Monitor?." *American Economic Review* 102 (6):2767–97. http://dx.doi.org/10.1257/aer.102.6.2767.
- Seshadri, S., and M. Subrahmanyam. 2005. "Introduction to the Special Issue on "Risk Management in Operations." *Production and Operations Management* 14 (1):1–4.
- Syverson, C. 2011. "What Determines Productivity." *Journal of Economic Literature* 49 (2): 326–65.
- Triplett, J., and B. P. Bosworth. 2008. "The State of Data for Services Productivity Measurement in the United States." *International Productivity Monitor* 16:53–70.