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Setting incentives for scientists who engage in research and other activities: an application of principal-agent theory

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Keywords
incentives, principal-agent model, multitasking, scientists, professors, repeat contracting, linear contracts

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Abstract

The objective of this paper is to develop an optimal incentive system for multitasking scientists in universities or professors under repeat contracting. With the aid of a principal-agent model under repeat contracting, we show that (i) when a second task is assigned to a professor and the two tasks are related, the size of the optimal incentive rate for the first task is reduced in some situations but not others relative to that of a single task, (ii) with an increase in the noise in the technical relationship of the second task or imprecision in output measurement, the optimal incentive rate for that task is reduced and for the first task may be reduced or increased , (iii) with greater efficiency of the professor in producing the second output, as reflected in ability relative to cost of effort, the optimal incentive rate for the first task generally decreases, (iv) if the output of the professor's two tasks are negatively correlated then the optimal incentive rate on the first task declines as the size of this correlation increases. The size of the guarantee is always reduced as the professor's ability for a task increases, but is increased as his cost of effort, noisiness of the technology or measurement of output, or correlation between the two outputs increases. It is also possible that, as a professor undertakes several difficult-to-measure tasks, the incentive rate will be reduced to the point that an optimal compensation system will involve only a guaranteed salary, which is a very weak incentive for effort. Selective audits may be useful in these situations.

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Introduction

The activity assignment of scientists in universities or professors typically consists of two or more major tasks, for example, research/teaching; research/outreach; or research/teaching/outreach. Huffman and Just (2000) have laid out the theory of optimal contracting by scientist with an administrator in the case of a single task. Following Holmstrom and Milgrom (1987) they show in a wide range of environments under repeat contracting that the optimal incentive is a linear contract with an incentive rate that depends on the productivity of effort and risk preferences of the scientist, and an optimal guarantee that depends on their reservation utility.

With multitasking, setting incentives is more difficult because unwanted outcomes are easy to generate. For example, if incentives are strong for research and weak for teaching, the professor will allocate effort primarily to research and skimp on effort allocated to teaching. In many institutions, this outcome is viewed as undesirable. Holmstrom and Milgrom (1991) emphasize that in the unitask principal-agent model the compensation system serves to reward effort and to allocate risk, but in a multitasking environment the compensation system also allocates the attention of agents among the tasks. They conclude that as agents are assigned more tasks, the strength of optimal incentives for effort will decline and might be characterized as fixed salary or guarantee. Clearly, multitasking adds an additional dimension of complexity to setting incentives.

The objective of this paper is to develop an optimal incentive system for multitasking scientists in universities or professors under repeat contracting. We show that (i) when a second task is assigned to a professor and the two tasks are related, the size of the optimal incentive rate for the first task is reduced in some situations but not others relative to that of a single task, (ii) with an increase in the noise in the technical relationship of the second task or imprecision in output measurement, the optimal incentive rate for that task is reduced and for the first task may be reduced or increased , (iii) with greater efficiency of the professor in producing the second output, as reflected in ability relative to cost of effort, the optimal incentive rate for the first task generally decreases, (iv) if the output of the professor's two tasks are negatively correlated then the optimal incentive rate on the first task declines as the size of this correlation increases. The size of the guarantee is always reduced as the professor's ability for a task increases, but is increased as his cost of effort, noisiness of the technology or measurement of output, or correlation between the two outputs increases. It is also possible that, as a professor undertakes several difficult-to-measure tasks, the incentive rate will be reduced to the point that an optimal compensation system will involve only a guaranteed salary, which is a very weak incentive for effort. Selective audits may be useful in these situations.

Background

Universities, relative to the corporate sector, are institutions with a modest hierarchy with vertically complementary coordination of the decision-making processes. Universities are organized into colleges composed of academic departments. Universities are administered by a president or chancellor at the head, with deans who administer colleges and department chairs or heads that administer departments. Professors have their appointments in academic departments, which are engaged in major activities of teaching (instruction), research (or creative works), and, in many, outreach (extension).

In the principal-agent framework, the university administration (principal) contracts with professors (agents) to conduct one or more major tasks. Professors are hired under a specified job description, which is often translated into a position responsibility statement. These statements specify that a professor will undertake one or more major activities. Appointments in many departments, particularly in colleges of agriculture, these statements assign ex ante weights to each, while in others the weights are determined implicitly by the tenure and promotion process. In addition, a small amount of administrative service is required of all professors in order to make a university function smoothly—committee work associated with hiring new professors, promotion and tenure decisions of existing professors, and overseeing various departmental and university programs. Hence, university professors are truly multitask agents in agency theory terminology.

The nature of assigned multitasking can take one of several forms. First, a professor may be delegated the tasks of teaching several classes per year and discovery of knowledge leading to presentations at academic meetings and peer reviewed publications. Second, a professor may be delegated the tasks of research and outreach where the later activity is a form of public and largely off-campus education. Third, a professor may be delegated teaching, research, and outreach. Fourth, even if a professor is assigned only research, it has at least two dimensions: quantity (of papers published) and quality (academic ranking of the journals or citation rate). Frequently, research involves other complementary activities of supervising the training of graduate students or other scientists, and writing proposals for outside grant funding (Huffman and Just 2000).

The ability of the principal to measure these outputs accurately varies by task. For example, an administrator can easily count academic publications and the number of courses (or credit hours) taught, but it is more difficult to assess teaching and research quality. Further, units of measurement for research and classroom teaching output are likely better defined than for outreach.

For multitasking professors, an administrator may be naturally inclined to set strong incentives for those activities that have easily measureable and weak incentives for those that are difficult to measure. Under this reasoning, stronger incentives would be set for the numbers of publications and numbers of classes (or credit hours) taught per year, but weaker incentives for hard to quantify outreach. Also, because the quality dimension of output of a task is generally more difficult to measure than quantity, weaker incentives would be set for quality than for quantity. Consequently, under this structure of incentives, rational professors will allocate little attention to the hard-to-measure aspects of their tasks. Such as reward system could lead to a dysfunctional university.

The Principal-Agent Problem of Universities

To understand the implications of optimal incentive contracting for multitask scientists who are professors, a summary of the unusual attributes of tasks assigned to professors is useful. One important attribute relates to complementarities of tasks. The output from teaching is closely related to student-credit hours taught, but for research is most accurately described as the "best" of a professor's discoveries. Thus, university research requires a higher degree of creative activity than teaching. But research is frequently complementary with teaching because a thorough knowledge of a phenomenon is needed before one can expect to advance the frontiers of science. This knowledge, once obtained, can be transmitted to classroom students with relatively little added effort. Outreach has similarities to teaching, but is frequently conducted as an informal educational activity.

A second important attribute is uncertainty in technical effort-output relationships of precision in measurement of output. The payoff or value of research discoveries is unknown at the outset of a project. As a result, the output quantity and quality is non-contractible. However, the output from teaching and outreach are potentially contractible activities (as evidenced by paid extension arrangements and hiring of instructors to teach individual classes).

A third attribute is that asymmetric information exists on professors' allocation of effort in total and among tasks. An administrator has poorer information than a professor about the professor's total effort, allocation of effort among tasks, and ability to perform each task. Also, monitoring a professors' effort is impractical and prudent administrators do not attempt it. Given ex ante uncertainty in the research, teaching, and outreach production functions, an administrator cannot infer effort from observed payoffs. Hence, moral hazard arises in contracting professors' effort because the administrator cannot verify that contract terms have been met. The professor-administrator relation is thus largely one where contracts, at least for research, cannot be enforced by an impartial third party, such as a court.

Fourth, administrators are likely less risk averse than professors because they manage a much larger portfolio of activities. Each professor may have one or two research projects and two or three classes to teach per year, but a university administrator may have dozens or hundreds of professors. With different attitudes toward risk between administrators and professors, potential inefficiencies arise when professors are expected to bear a major share of the risk of their assigned tasks.

The primary focus of this paper is on setting incentives optimally when an administrator and scientist who is a professor have agreed to work together but all future contingencies cannot be specified. The principal-agent model is a tool for identifying optimal incentives because the joint surplus of the administrator (the principal) and the professor (the agent) is maximized. The optimal contract is an incentive compatible contract whereby the best private interests of both the administrator and professor are attained by voluntarily fulfilling the contract. This avoids the need for court enforcement as well as monitoring of professor's effort by university administrators.

A Model of Incentives with Risk, Asymmetric Information, and Multiple Tasks

Our model is obtained by generalizing the model of Huffman and Just (2000) for a unitask scientist. The university administrator is assumed to observe the payoff from the assigned tasks at the end of the period, say an academic year or contract period, and to be able to aggregate the value of the professor's output from multiple tasks into a single indicator, perhaps with random error. The administrator's objective is to maximize the expected payoff across multiple tasks net of the professors' compensation.

Scientists who are professors are assumed to obtain utility from income and disutility from effort or work, to be risk averse, and to have a reservation utility. The reservation utility reflects a shadow value of a professor's effort from using it in non-university activities such as home production, leisure, consulting, or other outside activities. Professors are assumed to differ in abilities and output by task as well as in other attributes such as the cost of effort, risk aversion, and reservation utility. While a university has many professors, we assume that each of them engages in research and teaching independently.

In order to provide penetrating insights on incentives, a scientist's effort e is assumed to be allocated to two activities, $e = e_1 + e_2$, which are the only sources of asymmetric information. That is, effort devoted to these tasks is unobservable to the university administration but known to the scientist. However, the payoff from research and teaching are assumed to be observable to both the administrator and the scientist, but only at the end of the contract period.

Specifically, each scientist who is a professor is assumed to have a semi-quadratic cost function, $c = (k_1 e_1^2 + k_2 e_2^2)/2,$ which generates a positively sloped supply of effort for each task. Each professor is also assumed to have a unique constant absolute risk aversion φ and fixed certainty-equivalent reservation utility $\bar{u}$. Professors choose effort levels for the two tasks to maximize individual expected utility subject to attaining at least their respective reservation utilities. Subscripts denoting differences in these and other parameters among professors are omitted for convenience.

Each scientist is assumed to work alone (although the model can be adapted to working in teams on a single task) and to undertake one project per period that produces one indivisible unit of output in each task.[1] However, the quality of output in each task is related positively to the professor's effort. The production function for quality of output y_j in task j is

(1) $$y_j = a_j e_j + \mu_j,\ j = 1, 2,$$

where a_j is the expected marginal product of effort in activity j and μ_j is a random disturbance. Differences in a_j across professors reflect differing abilities for various tasks such as research

[1] We acknowledge that scientists sometimes work together or in teams, but we leave the explicit consideration of incentives in teams for later work. See for example, Corts (2007) and Huffman (2010).

(e.g., creativity, efficiency of mental processes, and work routine) and teaching (organization, efficiency of delivery, rapport with students), each of which depends on the available stock of relevant public knowledge. As is plausible, the production function in (1) reflects complementarity of effort and ability.

The technology for each task is stochastic where the random component, μ_j, has mean $E(\mu_j) = 0$ and variance $V(\mu_j) = \sigma_j^2$, $j = 1,2$. The covariance between the two activities is denoted by $\sigma_{12} = \rho\sigma_1\sigma_2$ where ρ is the correlation of unanticipated variation of outputs or measurement of outputs between the two tasks. The two tasks are stochastic complements if their correlation is negative, stochastic substitutes if their correlation is positive, and unrelated if their correlation is zero.[2]

Optimal Compensation of Scientists who are Professors

An important administrative policy question is: What is the optimal compensation scheme for a university professor and how does it depend on the characteristics of the professor, assignments to various tasks, and the environment. To convey basic results about optimal compensation and the associated payoffs, we consider contracting between a university administrator and a single professor. According to principal-agent theory, when contracting is repeated many times and the agent has discretion in actions including the level and timing of effort and allocation of effort among multiple tasks, the structure of the optimal pay scheme is linear in the observed principal's payoffs (Holmstrom and Milgrom 1987). This implies a linear contract consisting of two parts: (i) a guaranteed salary, α, that is independent of the observed payoffs, and (ii) an incentive payment for each task that amounts to positive share of the payoff, β_1 and β_2, respectively,

(2) $w = \alpha + \beta_1 y_1 + \beta_2 y_2.$

[2] A more general specification of the input-output relations for the two activities creates needless complexities in later developments.

A large β_j implies a "higher powered" incentive scheme for task *j*. Substituting (1) into (2) reveals the linear structure of the pay scheme for the professor's effort,

(3) $$w(e_1, e_2) = \alpha + \beta_1 a_1 e_1 + \beta_2 a_2 e_2 + \beta_1 \mu_1 + \beta_2 \mu_2.$$

Equation (3) reflects, for example, how ex ante uncertainty in research and teaching production processes is transmitted into ex ante uncertainty for the pay of the professor. From equation (3), the expected wage conditional on effort is $E[w(e_1, e_2)] = \alpha + \beta_1 a_1 e_1 + \beta_2 a_2 e_2$ and the wage variance is $V(w) = \beta_1^2 \sigma_1^2 + \beta_2^2 \sigma_2^2 + 2\beta_1 \beta_2 \sigma_{12}$.

Under the assumption of constant absolute risk aversion for each professor, a professor's expected utility can be expressed as a certainty equivalent,

(4) $$\begin{aligned} E[u_1(e_1, e_2)] = \alpha + \beta_1 a_1 e_1 + \beta_2 a_2 e_2 - (k_1 e_1^2 + k_2 e_2^2)/2 \\ - (\varphi/2)(\beta_1^2 \sigma_1^2 + \beta_2^2 \sigma_2^2 + 2\beta_1 \beta_2 \sigma_{12}). \end{aligned}$$

The administrator's payoff net of the professor's compensation is $\pi = (1 - \beta_1) y_1 + (1 - \beta_2) y_2 - \alpha.$ Therefore, the expected net administrator payoff is

(5) $$E(\pi) = (1 - \beta_1) a_1 e_1 + (1 - \beta_2) a_2 e_2 - \alpha.$$

Clearly if $0 \leq \beta_1, \beta_2 < 1$ then the expected net payoff of the university administrator is positively related to professor's total effort and allocation of effort among tasks as well as the professor's ability for each task. However, the administrator's net payoff is negatively related to the professor's guaranteed salary α.

The administrator chooses the parameters of the incentive scheme, α, β_1, and β_2, to maximize expected net payoff subject to constraints that (i) the professor maximizes utility through choices of level and allocation of effort and (ii) the professor's reservation utility is met,

(6) $$\max_{\alpha, \beta_1, \beta_2} (1 - \beta_1) a_1 e_1 + (1 - \beta_2) a_2 e_2 - \alpha.$$

subject to

(7) $$\{\hat{e}_1, \hat{e}_2) = \arg\max_{e_1, e_2} \alpha + \beta_1 a_1 e_1 + \beta_2 a_2 e_2 - (k_1 e_1^2 + k_2 e_2^2)/2 - (\varphi/2)(\beta_1^2 \sigma_1^2 + \beta_2^2 \sigma_2^2 + 2\beta_1\beta_2\sigma_{12}).$$

and

(8) $$\alpha + \beta_1 a_1 \hat{e}_1 + \beta_2 a_2 \hat{e}_2 - (k_1 \hat{e}_1^2 + k_2 \hat{e}_2^2)/2 - (\varphi/2)(\beta_1^2 \sigma_1^2 + \beta_2^2 \sigma_2^2 + 2\beta_1\beta_2\sigma_{12}) \geq \bar{u}.$$

These conditions recognize that the professor will choose a privately beneficial effort level and allocation of effort among tasks in response to the compensation scheme (incentive compatibility), and must be offered a compensation package that is acceptable (meets the reservation constraint). If the administrator to offer a compensation scheme that the professor rejects, then the administrator's expected payoff is zero because $E(y_1 + y_2) = 0$.

Because risk associated with each task is independent of effort in this model (an assumption that can be relaxed with added complexity), the optimization problem in equations (6)-(8) can be solved sequentially. First, the optimal solution to the professor's effort decisions in equation (7) is

(9) $$\hat{e}_j = \beta_j a_j / k_j,\ j = 1,2,$$

which depends positively on the professor's marginal product of effort (a_j) and inversely on the marginal cost of effort (k_j). Second-order conditions obviously hold if $k_j > 0$, $j = 1,2$.

Second, substituting equation (9) into (6) and (8), Kuhn-Tucker conditions (or direct examination) generate a boundary solution with $E[u_1(e_1, e_2)] = \bar{u}$ in (8) implying

(10) $$\begin{aligned}\alpha &= \bar{u} - \beta_1^2 a_1^2/(2k_1) - \beta_2^2 a_2^2/(2k_2) + (\varphi/2)(\beta_1^2\sigma_1^2 + \beta_2^2\sigma_2^2 + 2\beta_1\beta_2\sigma_{12}) \\ &= \bar{u} - (\beta_1^2 p_1 + \beta_2^2 p_2)/2 + (\beta_1^2 r_1 + \beta_2^2 r_2 + 2\beta_1\beta_2 r_{12})/2\end{aligned}$$

where $p_j = a_j^2/k_j$ is an indicator of the ability of the professor to fulfill task j relative to the marginal cost of effort k_j, $r_j = \varphi\sigma_j^2$ is an index of the rate of risk premium in task j, and $r_{12} = \varphi\sigma_{12} = \varphi\rho\sigma_1\sigma_2$ is a measure of the relatedness of the two tasks.

The later term in (10) represents a professor-specific risk premium, which is reduced when the two tasks are complements and increases when they are substitutes. Conditional on

β_1 and β_2, the size of guarantee is inversely related to the professor's reservation utility $(\bar{u})$ and ability for the assigned tasks (a_1 and a_2), and positively related to the marginal cost of his effort (k_1 and k_2), the variance of the payoff in each task (σ_j^2), and the correlation between payoffs for the two tasks (σ_{12}).

Substituting (9) and (10) into (6), the concentrated maximization problem is

$$\max_{\beta_1,\beta_2}\ (1-\beta_1)\beta_1 p_1 + (1-\beta_2)\beta_2 p_2 - \bar{u} + (\beta_1^2 p_1 + \beta_2^2 p_2)/2 - (\beta_1^2 r_1 + \beta_2^2 r_2 + 2\beta_1\beta_2 r_{12})/2$$

for which first-order conditions for maximization with respect to β_1 and β_2 reveal the optimal professor performance incentives,

$$(11)\qquad \beta_j = \frac{p_j(p_i + r_i) - r_{12}p_i}{(p_1 + r_1)(p_2 + r_2) - r_{12}^2},\ i \neq j,$$

where $i \neq j$ is understood to mean either $i = 1$ and $j = 2$ or $i = 2$ and $j = 1$. Second-order conditions, $p_j + r_j > 0,\ j = 1,2,$ and $(p_1 + r_1)(p_2 + r_2) - r_{12}^2 > 0,$ hold assuming $k_j > 0, j = 1,2,$ and $\varphi > 0$, upon noting that correlation cannot exceed 1 in absolute value (a squared covariance cannot exceed the product of respective variances). This solution also assumes that the optimal payoff to the administrator is positive, which is equivalent to assuming that the professor's reservation utility is low enough to permit a contract agreeable to both parties.

Further, this solution is appropriate only if both incentive terms are positive assuming a professor cannot produce negative quality in response to a negative incentive. The denominator of (11) is positive under the latter second-order condition. Thus, the incentive terms defined in (11) are both positive if the covariance is non-negative. If the covariance is negative, then $\beta_j > 0$ if $r_{12} > -(p_i + r_i)(p_j/p_i)$. If this condition fails for one of the incentive terms, then the problem is solved by imposing nonnegativity on the β's, which under Kuhn-Tucker conditions would convert the problem into a single task problem as analyzed by Huffman and Just (2000). Thus, if the correlation of outputs is sufficiently negative, then administrators prefer giving professors specialized tasks. Accordingly, we assume henceforth that both incentive terms are positive to consider the interesting multitask problem. We also note that if the two tasks are uncorrelated then equation (11) implies $\beta_j = p_j/(p_j + r_j)$, j = 1,2. This is the same expression derived and discussed by Huffman and Just (2000) for the single task problem, implying that the administrator can manage the tasks independently if and only if the task outputs are uncorrelated.

Assuming the optimal pay scheme in (11) produces positive incentives for both tasks, three results characteristic of optimal incentive models follow. First, the administrator chooses an incentive scheme for the professor to maximize the joint payoff of the administrator and professor so that both have an incentive to fulfill the contract. Second, the administrator compensates the professor for effort in both tasks at a rate that provides partial insurance against income risk. With asymmetric information on the professor's effort, the administrator does not provide full-income insurance because that would provide weaker incentives for effort allocated to the two tasks. Third, the attention of the professor to the two tasks is directed by the optimal incentive rates.

Examining the derivatives of the optimal incentives in (11) generates the interesting qualitative results of the model. First, to consider what happens to the incentive for one task when a second task is assigned, compare (11) to the optimal incentive in the single-task problem, $\beta_j^* = p_j / (p_j + r_j)$, which yields $\beta_j - \beta_j^* = -\beta_i r_{12}/(p_j + r_j) < (=)(>) \ 0$ as $r_{12} > (=)(<) \ 0$. Thus, if the added task is a stochastic complement (substitute) then the incentive for the existing task increases (decreases) when a second task is added. Intuitively, this adjustment takes account of the increased (decreased) return to both parties that tends to occur from multitasking when the tasks are stochastic complements (substitutes).

First, as the riskiness of a task or difficulty of measurement increases, the optimal incentive rate is reduced, i.e., $\partial\beta_j/\partial\sigma_j^2 < 0$. This is the same qualitative result found by

Huffman and Just (2000) for the single task problem. Here, however, the result applies to each task in a multitask problem, e.g., research, teaching, and outreach.

A second qualitative result is that increasing the riskiness of either task reduces the optimal incentive rate for all tasks when the outputs are negatively correlated. However, the optimal incentive of the other task is increased if the outputs are positively correlated. To see this, note that

$$\frac{\partial \beta_i}{\partial \sigma_j^2} = \frac{\varphi \beta_j r_{12}}{(p_1 + r_1)(p_2 + r_2) - r_{12}^2} > (=)(<)\ 0 \text{ as } r_{12} > (=)(<)\ 0,\ i \neq j.$$

Thus, for example, if the riskiness of teaching or research increases, then the optimal incentive rates for both teaching and research decline if the payoffs are negatively correlated, which is explained by the accompanying relaxation of the professor's reservation utility constraint. Moreover, it is immediately apparent from (11) that as a task becomes highly risky, e.g., as $\sigma_j^2 \to \infty,$ the incentive associated with it will go to zero, i.e., $\beta_j \to 0,$ while the incentive of the other task will approach the optimal single task incentive, i.e., $\beta_i \to p_i/(p_i + r_i),\ i \neq j.$

These results are altered somewhat if the correlation of outputs is held constant as the riskiness of a task is changed. For example, if $\sigma = \rho\sigma_1\sigma_2$ where ρ is fixed as σ_1 or σ_2 is changed, then as a task becomes highly risky, e.g., as $\sigma_j \to \infty,$ the incentive associated with it will go to zero, i.e., $\beta_j \to 0,$ but the incentive of the other task will approach a positive value, $\beta_i \to p_i/[p_i + r_i(1-\rho^2)],\ i \neq j,$ which is larger than when the covariance is unaffected. This result suggests, for example, that high riskiness in measuring research output can lead to higher incentives for teaching and reduced incentives for research.

Third, if the professor's ability for a task improves (i.e., p_j or, more basically, a_j increases or k_j decreases), then the incentive rate for that task will increase, as in the single task framework of Huffman and Just (2000), i.e., $\partial \beta_j / \partial p_j > 0,$ as long as the covariance of outputs between tasks is not larger negatively than the variance of output for the specific task. More generally,

$$\frac{\partial \beta_j}{\partial p_j} = (p_i + r_i)\frac{(r_i + r_{12})p_i + (r_1 r_2 + r_{12}^2)}{[(p_1 + r_1)(p_2 + r_2) - r_{12}^2]^2} > 0 \text{ if } r_i > r_{12}.$$

If the covariance of outputs is negative and absolutely larger than, say, the teaching output variance, and the problem is not highly concave, then the administrator may prefer to cut back the incentive for teaching to obtain relatively less teaching output than the increased productivity would allow with the same effort, because this reduces the variance of research output and the risk premium the administrator must pay the professor to meet the reservation utility.

Fourth, if the professor's ability for a task improves, then the effect on the incentive for the other task can either increase or decrease depending on the correlation of random variation in outputs of the tasks. That is,

$$\frac{\partial \beta_j}{\partial p_i} = -r_{12}\frac{(r_i + r_{12})p_j + (r_1 r_2 - r_{12}^2)}{[(p_1 + r_1)(p_2 + r_2) - r_{12}^2]^2} < (=)(>)\ 0 \text{ as } r_{12} > (=)(<)\ 0 \text{ if } r_i \geq r_{12}.$$

This expression has a sign oppositve of the sign of the correlation of outputs except possibly in the peculiar case where $r_i < r_{12}$, and in particular, $\partial \beta_j / \partial p_i$ has the same sign as $\partial \beta_j / \partial p_j$ if the correlation of outputs is negative and the opposite sign if the correlation of outputs is positive. If the payoff to high quality research tends to be larger than for high quality teaching, then $r_i > r_{12}$ is likely for research but may not hold for teaching. Thus, if unanticipated variations in research and teaching output are complementary, then improved research is likely to lead to improved incentives for both, but improved teaching may lead only to improved incentives for research.

More Implications from the Multi-Task Principal-Agent Model

Scientists who are professors in American universities are employed under a promotion and tenure system, where they are on probationary appointments for up to seven years. They are not civil servants, as in Europe, where lifetime jobs are awarded after a short (generally two-year) probationary period. New doctorates differ in their ability and risk preferences, and those who are quite risk averse (or of low ability) are likely to select civil service as an employment option, provided they can obtain a job offer. On average, those who choose to become academics can be expected to be both more able and/or less risk averse. However, new assistant professors can be expected to have relatively noisy technology for producing both research and teaching, as evidenced by the frequency of complaints received by department chairs about them.

After a few years of teaching, both a professor's ability for and variance of teaching quality is expected to decrease, but it is generally more difficult to improve ability for research and reduce the variance of research quality. Under the model of this paper, these changes in key parameters of the principal-agent model imply that optimal incentives for both teaching and research would be adjusted. In the promotion and tenure system, an assistant professor is typically reviewed for promotion and tenure in the fourth or fifth year of a contract. If the review is favorable, the professor is awarded tenure and promoted to associate professor. As a result of this probationary period, individuals who lack ability likely do not receive renewed contracts and highly risk averse individuals are more likely to seek other employment, leaving the more able and less risk averse. Also, universities, especially public ones, are not known as high paying institutions relative to the private sector, so individuals who have high reservation utilities for outside activities may also obtain other employment.

In addition to the guarantee and the incentive rates for assigned tasks, administrators have additional tools to strengthen their hand as managers of professors. Administrators can change the effort allocated to tasks directly by altering the incentive rates and guarantee. However, they may also be able to reduce reservation utilities of professors by restricting outside activities, which reduces their marginal opportunity cost of effort allocated to research and teaching.[3] Recall that as an additional task is assigned to a professor, the optimal incentive rate of the existing task increases (decreases) if the new task is a stochastic complement (substitute). Hence, for professors who are assigned research, campus instruction and extension/outreach, the incentive rate for these tasks may be quite weak. The administrator can strengthen incentives for performance by limiting the number of tasks assigned to the professor, for example, assign him research and on-campus instruction, research and outreach/extension, but not all three. And in fact, we observe in land-grant universities that professors are seldom assigned three major tasks, and assistant professors are never assigned them (Huffman and Evenson 2006).

The principle of affecting the opportunity cost of a professor's effort by restricting his activities has broader implications. Constraints or prohibitions on outside activities are a substitute for performance incentives on inside activities/tasks and are extremely useful when an administrator finds it difficult to assess the performance of a professor on his inside activities/tasks (Holmstrom and Milgrom 1987). For example, a faculty member who has been delegated the task of local extension work may be prohibited from undertaking local private consulting work. The problem is not with the attribute of the outside job (private consulting) but with the hard-to-measure nature of the inside task (local extension). Most critically, an administrator cannot set incentives optimally for a professor's effort on inside tasks unless she knows the complete list of all inside and outside activities/tasks for which the agent is likely to engage. This seems to be weakly enforced by the fact that public universities require professors to file annual reports of their consulting activities. However, principals find it optimal to allow agents, who are delegated highly responsible tasks/activities, more freedom of outside work relative to lesser skilled support staff. Given that U.S. universities since at

[3] If the agent is also dealing with an incentive setting principal for "outside" activities, the two principals will compete for the agent's attention, leading to higher incentive rates for their work/tasks. This becomes especially problematic if the professor is operating as an independent contractor in his field of expertise because independent contractors normally face very high incentive rates (Holmstrom and Milgrom 1991). Dewatripont et al. (2000) suggest that this competition leads to incentive rates that are too high-powered, and the administrator may justifiably demand exclusive dealings with the agent.

least the 1960s have hired individuals who hold doctorates of science (Ph.D's), which are very specialized degrees, to fill professorial positions (see Huffman and Evenson 2006, pp. 79), this is consistent with them obtaining faculty who have high expected ability for research and teaching in their specialty, but also relatively low productivity and opportunity cost on many potential outside activities.

A Role for Selective Audits

Selective audits may be useful as an added administrative tool to complement optimal incentive pay where principals' decision making becomes difficult. With the assignment of additional tasks, the incentive rate for each task of an agent may be reduced relative to a unitask situation and the incentive rates may become quite low, even zero, then optimal compensation is a guarantee or fixed salary. Even in these situations, it may be clear than the primary task of professors is research and teaching is secondary. More generally, research and teaching quality are difficult to assess. Finally, both an agent's effort and ability may be unknown to the administrator.

When ability and effort are uncertain and some tasks are difficult for the principal to evaluate, selective audits of the hard-to-measure tasks are a potentially effective management tool (Sinclair-Desgagner 1999). They are useful when the agent has a long-term employment objective. For example, assistant professors who accept jobs with a university generally have an objective of obtaining tenure and ultimately being promoted to full professor. If the administrator finds that optimal incentives are too weak, she can strengthen incentives for hard to measure tasks by a scheme of *selective audits*, in which the evaluation of an agent's (assistant professor's) hard-to-measure task(s) is (are) triggered by his high performance on easier measured task(s).

The key features of the selective audit(s) are as follows. First, an easy to measure task is used to establish a threshold that will trigger an intensive audit of a hard to measure task, e.g., quality of research and/or teaching. Second, the administrator sets the assistant professor's expected compensation in subsequent periods so that it is significantly higher with a successful audit of the hard-to-measure task(s) and being definitely lowered if the audit report(s) is (are) bad. Thus, the assistant professor gains in the second period only with successful audit(s) of the hard-to-measure task(s).

For example, an assistant professor, who undertakes research and teaching, can easily document the number of his publications and courses and students taught, but the quality of these activities is hard to measure, meaning that at best some useful information about quality can be obtained only at considerable expense to his administrator. After the faculty member has published six or eight articles and taught 12-16 semester classes, his "high volume" of output triggers a detailed audit by the administrator of the quality dimensions of his research and teaching. Research assessments are normally heavily based on reports obtained from independent outside evaluators (i.e., professors in the same field in similar quality institutions) and teaching assessments are obtained by a careful inside evaluation of teaching quality (i.e., evaluations of students during the period in which they took his courses and of past students, peer review of teaching materials, and peer observation of in-classroom teaching). If the quality evaluations of research and teaching are favorable, then the assistant professor will be given tenure and promoted. If one or both of the quality assessments is negative, he will be temporarily turned down for promotion, unless the evaluation comes in his last year of tenure eligibility, in which case a one-year terminal contract is typical.

With contingent auditing, the agent has an incentive to choose total effort and to allocate it among tasks so as to raise the probability of obtaining a favorable audit of research and teaching quality relative to other outcomes. The principal has an incentive to offer the agent compensation such that his expected wage under an audit scheme is higher than under a no-audit scheme. The key point is that the audit of quality is triggered by high performance on the easy-to-measure tasks—quantity of research and teaching output—even when audits provide noisy information. Thus, the assistant professor will not want to allocate all of his effort to the easy-to-measure tasks and will increase his effort allocated to the hard-to-measure tasks (quality). Hence, when ability and effort are unobservable to the principal and multiple tasks with hard-to-measure quality dimensions are assigned to the agent, incentives for effort can be strengthened by the use of selective audits. The agent works hard(er) in the first period to raise the probability of getting a good job in the second and subsequent periods—i.e., tenure and the academic rank of associate professor with the option for promotion to full professor in the future.

Moreover this line of reasoning can be extended to other secondary or "soft tasks" that are frequently assigned to professors. These include his or her involvement with the internal working of the university such as departmental, college, and university committee work and development and implementation of long term departmental, college, and university objectives and strategic planning. After sufficient quantity of research and teaching output has been attained, a selective audit can also be triggered on these secondary or soft tasks to judge worthiness for tenure and promotion. These are some of the reasons why new faculty members are seldom hired with tenure, and why assistant professors who achieve a high quantity of research output in a short period of time are generally not promoted until their fourth or fifth year of the probationary period. However, giving the noisiness of the production process for major activities undertaken by assistant professors (equation (1)), administrators may choose to limit the assignment of soft tasks to them so as to strengthen incentives for and keep them focused upon research and teaching!

A university is one example of a non-profit agency that has multiple goals that are frequently difficult to measure accurately, and for which it is difficult to identify the contribution of each individual professor. If a professor has unknown effort and ability but has a long term employment goal, he will expend effort in order to convince his administrator (and senior professors) and the outside labor market that he has high ability (see Dewatripont et al. 1999). Moreover, a high performance evaluation raises the perception of his ability and translates into future job opportunities within and outside the university. However, given that ability and effort are complementary and both are unobservable, the market may experience some difficulty in identifying the source of his observed payoff, for example, low payoff could be due to low ability and low effort, but also high ability and low effort, or low ability and high effort.[4] This reasoning implies that a good candidate for a professor position is someone who has all of the traditional indicators of high ability (e.g., Ph.D. from a prestigious department, high grades, excellent dissertation, excellent written and communication skills, and creativity) and has a low opportunity utility or cost of outside activities.

In a new twist on incentives for multitask agents, Acemoglu et al. (2007) have argued that it is optimal for some institutions to commit to low-powered incentives and others to high-powered incentives. In particular, a university, which is a non-profit institution, may have advantages in undertaking a combination of education, discovery, and outreach because it can credibly commit to low-powered incentives. With the agent's ability and effort being unobservable, his ability and effort being complementary, and him being interested in long term employment as reflected in promotion and tenure, high powered incentives can distort the composition of effort between current and future effort, leading to excessive signaling in the first period—the probationary period. Given the multitask nature of professors, low powered incentives might be generally optimal and can be adventitiously provided by non-profit institutions such as universities but not by a for-profit institution. This may be an explanation for why education and outreach activities are provided almost exclusively by universities and not by for-profit institutions. The provision of discoveries with public good attributes by universities is less surprising, and private entities face difficult incentive problems. Moreover, in U.S. public universities, the discovery, education, and outreach activities have been

[4] Dewatripont et al. (1999) emphasize that in a multitask career concerns model where ability and effort are complementary, multiple equilibria can arise, and the market's expectation of high and low effort can be self fulfilling.

organized such that they are largely complementary activities (Huffman and Evenson 2006, pp. 39-49; 50-52, 55-65).

Conclusions

Principal-agent theory as developed in this paper provides a rich framework for viewing optimal contracting between university administrators and professors or scientists. This paper is the first to apply these models to setting optimal incentives for multitask scientists or professors. Optimal incentives not only reward effort and allocate risk but also allocate professors' effort among tasks. In addition, administrators may find that limiting the number of different tasks assigned to professors, or restricting their participation in competitive outside subcontracting as a mechanism for lowering their reservation utility and refocusing their effort on major university tasks. In our model, research and teaching each have two dimensions, quantity and quality. These two dimensions differ in difficulty with which they can be measured—quality assessments being more difficult than quantity. The results in our paper imply that departments and universities that implement simple counting schemes for measuring research and teaching output will be dysfunctional. Moreover, we have shown that contingent quality audits, triggered by high volume, are one mechanism for strengthening incentives for research and teaching quality.

After hiring new scientists or professors, administrators can fine-tune incentives in a way that is consistent with the incentive contracting model presented here. While one-shot ex post incentive payments have not been typical in universities, permanent salary increments (merit increments) based on annual and periodic (promotion) reviews of past performance have been a fundamental part of compensation schemes. In effect, offering incentives in the form of permanent salary increments rather than one-shot payments has provided administrators a method of paying large implicit incentive payments with limited short-term budget flexibility and may be viewed as consistent with the implications of our paper.

Three decades ago, universities received relatively large amounts of programmatic funding for research, and university professors were frequently guaranteed support for research and creative works and required to teach classes. However, over the past decade, public universities have faced declining real state support (Just and Huffman 2009), and they have increasing turned to outside funding. Some universities and administrators have also chosen to implement new research policies that affect the size of institutional research risk facing professors. Such policies have been characterized by abrupt termination of some research projects, fostering more competition for the use of federal and state programmatic funds thereby reducing the amount and length of expected funding for each professor and project, eliminating funds for research assistants and more directly managing current expenditure of funds. In our multitask principal-agent model, these policy changes imply immediate increases in the riskiness of university research to professors and lower optimal incentive rates for research but also teaching, and less total effort.

Under a long-term employment goal, the incentive for good performance in the last period of employment wanes. However, retired university professors frequently pursue later employment in their field of expertise, for example in consulting and expert witness work, and this elevates the importance of a good performance record as they leave their tenured university jobs.

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