How to Reward Co-authorship?

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Title of   Project   *How To Reward Co-authorship?*

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Abstract

Consider an academic department using a merit-based payment scheme to induce faculty to undertake the efficient allocation of research effort across solitary and joint projects. A common practice in the award of merit is to give a coauthor of a N-author work the fraction 1/N of the credit for the work in calculating merit. In this paper we show that if the departments objective is to maximize its total research output, agents are risk neutral, and the joint work is within the department then even when effort is unobservable solo authored and joint work should be equally weighted. Only if the department gets 1/N of the credit for the joint work (i.e. the joint work is with N-1 coauthors outside the department) should the joint work be discounted by 1/N.

Dedicated to ba-ba and ma-ma

Acknowledgements

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1 Introduction

In academic economics, we have observed a dramatic increase in collaboration in the past few decades. The average number of authors per article in economics was near one in the 1950s, and had risen to 1.5 by the mid–1990s. Presently, over fifty percent of articles published in leading journals are not solitary work (Laband and Tollison, 2000). Building on McDowell and Melvin (1983), Barnett, Ault and Kaserman (1988) find evidence in support of the following reasons for the increase of coauthorship in economics: increasing opportunity cost of time, risk spreading due to the uncertainty of editorial process, and an explosion of knowledge in economics making specialization and the division of labor more desirable. Clearly, providing researchers with the right incentives in allocating their effort between solo–authored and co–authored work is important.

Many departments receive a pool of merit money from their universities. The merit money is then awarded to individual professors by the department based on their research performance.[1] Their performance is usually evaluated in terms of quality, length and quantity of research output. In determining an aggregate measure of a professor's productivity, the department must aggregate solo authored papers with co–authored papers. In that aggregation, papers are often discounted by the number of co-authors. That is, the reward for solo publications receive a weight of one, but the reward for a coauthored paper with N coauthors, would

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[1] We are ignoring teaching and administrative merit for simplicity.

be discounted by receiving a weight of $1/N$. In terms of coauthorship within and across departments, there is no standard practise. Departments weight a paper with N-1 coauthors outside the department strictly between 1 and $1/N$ because of bias in assuming that the author within the department is the most valuable member of the team, and thus more deserving. This paper investgates whether this commonly used reward structure is in fact sensible.

From work such as Baker (1992), we learn that if the agent's payoff is not based on principal's objective, the first best actions cannot be induced even when the agent is risk neutral. Thus we can speculate at this point that the only incentive system that would work is one that makes each professor a residual claimant so that each professor shares the same objective with the department.

Sauer (1988) uses a linear equation to regress academic salary on articles published, experience, and other variables, and finds that the reward for a N coauthored paper is approximately 1/N relative to 1 for a solo paper. His study only analyzes the existing system in economic academia. Sauer does not provide normative analysis which would support the existing system as one which would stimulate the efficient outcome.

Eaton and Hollis (2003) show that if the reward for solo work is 1, the optimal reward for teamwork is between 1 and 1/N. Their model is based on the value of different projects. The department's objective is to maximize the total value created by professors, and individual professor wishes to maximize his/her

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payoff which is a fraction of the value created by this individual. Each period, each professor generates one solo work idea and one team work idea, and each professor can decide on wether to share his/her idea and decide on to work in a team or not. Both exponential and uniform distributions of value (value of their ideas) are examined, and both cases yield the same answer: the optimal reward for teamwork is between 1 and $1/N$. In their model, the welfare of the department is based on the value of opportunity realized by the professors not on the total research output. They deal with asymmetric information on the value of agents' ideas not on effort. Also, they completely ignore production and cost functions. It is a one-period model and each agent can only work on one solo paper or work jointly with other agents, the allocation of effort among different activities is not discussed. In our model, we adapt a two-part tax scheme with both lump-sum payments and per unit payments, while Eaton and Hollis employ a model with only a per unit payment scheme.

In this paper, I want to find the incentive contract which weights the reward between solo work and teamwork properly to achieve efficiency. The department's (principle's) objective is to maximize total research output of the department subject to budget constraint and I assume that any work which is co-authored with N-1 co-authors external to the department gets the department $1/N$ credit for the work. Professors (agents) devote effort to solitary and joint work to produce research output. The production functions for solo and joint work, and the cost

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functions for effort are general and standard, which allows professors of different quality and energy. I assume the principal and agents are risk neutral throughout this paper.

I show that efficiency requires equal marginal products of effort across solo and co–authored work.[2] Next, with full information when effort is observable, agents choose the allocation and level of effort. The linear payment scheme which induces first–best effort pays researchers the marginal product of their effort. In the final section effort is assumed unobservable and so contracts are written on research output. I show that the efficient weighting scheme is to weight all work internal to the department equally at one. Only work with external co–authors should be discounted. The logic is that it is this scheme which makes each agent the residual claimant.

One might have expected that there would be free rider problems (shirking) associated with the team production. This turns out to not be the case. The logic is that the reward scheme gives each agent full credit for each internal coauthored paper so that they work according to their full marginal product. There is also no problem with one hard-working high productivity worker not wanting to work with a lazy low productivity worker because each gets full credit for the others effort. You would always want people to help you on a paper even if you had to share credit. A department with this payment scheme is a very cooperative place where

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[2] Recall that from the department's perspective the marginal product in joint work with N coauthors outside the department is 1/N of the full marginal product.

ideas and efforts are shared freely.

The conclusion will discuss limitations of the model.

2 The Model and Results

There is a department with only two professors, i=A and B. Each professor can allocate their effort among the following four options: take leisure; write solo papers; work with another professor from the same department to co-author papers; or work with individuals from another institute to co-author papers. The department (principal) wants to set up a payment scheme for merit which induces the optimal total research output produced by professors A and B (agents) while the agents wish to maximize their own utility. I assume that the principal and agents are risk neutral.

2.1 The First-Best Efforts

I start with the simple full information case where both agents' costs and actions (efforts) are observable and the reward offered by department is not restricted in any form. I characterize the particular allocation which maximizes the objective of the principle subject to the agents' participation.[3] This will lead to a contract that maximizes total surplus. I assume that the department cares about the total research output of the department.

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[3] This allocation is best not thought of as a Pareto efficient allocation because it ignores the well being of individuals outside of the department and the department (principle) is not an individual.

Let X denote the total papers produced by A and B.[4]

$$X = X_A^s(E_A^s) + X_B^s(E_B^s) + X^J\left(E_A^J, E_B^J\right)$$
$$+ \frac{1}{N_A}X_A^O\left(E_A^O, E^O\right) + \frac{1}{N_B}X_B^O\left(E_B^O, E^O\right)$$

where X_i^s is the solo work done by i, X^J is the joint work completed together by A and B, X_i^O is the joint work done by i with people outside the department and N_i is the total number of coauthors. Note that when i coauthors with individuals from another institute, the department only receives $\frac{1}{N_i}$ of the credit. X_i^s is a stochastic function of E_i^s, i's solo effort. X^J is a stochastic function of E_A^J and E_B^J. E_i^J is i's effort towards teamwork with j who belongs to the same department. X^O is a stochastic function of E_i^O and E^O. E_i^O is the effort devoted by i to joint work with outsiders and E^O denotes the efforts of outsiders. Any arbitrary stochastic fuction is acceptable.

Let S be the reward scheme offered by the department, since efforts are observable, $S = S_A(E_A^s, E_A^J, E_A^O, E_B^J, E^O) + S_B(E_B^s, E_B^J, E_B^O, E_A^J, E^O)$

The principal's problem is to maximize total output minus the reward payment, X-S or,

$$X_A^s(E_A^s) + X_B^s(E_B^s) + X^J\left(E_A^J, E_B^J\right) + \frac{1}{N_A}X_A^O\left(E_A^O, E^O\right) + \frac{1}{N_B}X_B^O\left(E_B^O, E^O\right)$$

$$- S_A(E_A^s, E_A^J, E_A^O, E_B^J, E^O) - S_B(E_B^s, E_B^J, E_B^O, E_A^J, E^O)$$

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[4] Generating an aggregate measure of research output would require adjusting papers for quality and length. Departments use such procedures.

The agents may choose not to participate, therefore the payment scheme must satisfy the following participation constraint:

$$S_i(E_i^s, E_i^J, E_i^O, E_j^J, E^O) - C_i(E_i^s + E_i^J + E_i^O) \geq \bar{U}_i \qquad \forall i$$

where $\bar{U}_i$ is the reservation utility for i and C_i is the total cost function for i. Denote $C_i'(E_i)$ as the marginal cost of effort for i.

Since the department is a maximizer, it wants to pay the minimum payment to the agents or the amount which binds the participation constraint, that is $S_i(E_i^s, E_i^J, E_i^O, E_j^J, E^O) - C_i(E_i^s + E_i^J + E_i^O) = \bar{U}_i$ for $i = A, B$. Thus $S_i(E_i^s, E_i^J, E_i^O)$ can be replaced by $\bar{U}_i + C_i(E_i^s + E_i^J + E_i^O)$ in the objective X-S. Hence the optimal or first-best actions from the principal's perspective maximize

$$
\begin{aligned}
\pounds \;=\; & X_A^s\left(E_A^s\right) + X^J\left(E_A^J, E_B^J\right) + \frac{1}{N_A} X_A^O\left(E_A^O, E^O\right) - C_A(E_A^s + E_A^J + E_A^O) \\
& -\bar{U}_A + X_B^s\left(E_B^s\right) + \frac{1}{N_B} X_B^O\left(E_B^O, E^O\right) - C_B(E_B^s + E_B^J + E_B^O) - \bar{U}_B
\end{aligned}
$$

with respect to E_i^s, E_i^J and E_i^O. The first order conditions are:

$$\frac{\partial \pounds}{\partial E_i^s} = \frac{\partial X_i^s}{\partial E_i^s} - C_i'\left(E_i^*\right) = 0 \qquad \forall i \tag{1}$$

$$\frac{\partial \pounds}{\partial E_i^J} = \frac{\partial X^J}{\partial E_i^J} - C_i'\left(E_i^*\right) = 0 \qquad \forall i \tag{2}$$

$$\frac{\partial \pounds}{\partial E_i^O} = \frac{1}{N_i}\frac{\partial X_i^O}{\partial E_i^O} - C_i'\left(E_i^*\right) = 0 \qquad \forall i \tag{3}$$

The optimal efforts E_i^{s*}, E_i^{J*} and E_i^{O*} must satisfy

$$\frac{\partial X_i^s\left(E_i^{s*}\right)}{\partial E_i^s} = \frac{\partial X^J\left(E_i^{J*}\right)}{\partial E_i^J} = \frac{1}{N_i}\frac{\partial X^O\left(E_i^{O*}\right)}{\partial E_i^O} = C_i'\left(E_i^*\right) \qquad \forall i$$

Note that action $E_A^{s*}, E_A^{J*}, E_A^{O*} E_B^{s*}, E_B^{J*}$ and E_B^{O*} can be called first best actions because they maximize the principal's objective function subject to the agents receiving their reservation level of utility with perfect information.

The reason why the marginal products among activities for an individual must be equalized is that if they were not, effort devoted to a low marginal product activity could be reallocated to a higher marginal product activity and total output could be increased. Note that although the marginal product of E_i^{O*} is $\frac{\partial X^O\left(E_i^{O*}\right)}{\partial E_i^O}$, since the department only gets $\frac{1}{N_i}$ credit for X^O, the marginal product of E_i^{O*} for the principal is $\frac{1}{N_i}\frac{\partial X^O\left(E_i^{O*}\right)}{\partial E_i^O}$. The reason why each marginal product must equal the marginal cost of effort is that if the marginal cost is smaller (larger) than the marginal product, the cost for the principle of inducing additional effort by the agent through the participation constraint is less (more) than the value to the principle created by the additional effort so the principle should induce more (less) effort.

2.2 Full information: A linear payment scheme

The focus of this section will be to see what form of linear payment scheme would induce the agents to choose the first–best levels of effort, when effort is observable. Since effort is observable, we will consider linear payment scheme with lump-sum

transfor that is written on the efforts of i or

$$S_i = S_i(E_i^s, E_i^J, E_i^O) = \alpha_i E_i^s + \beta_i E^J + \gamma_i E_i^O - T_i \qquad \forall i$$

where T_i is an individual specific lump sum payment.

For the optimal efforts $E_A^{s*}, E_A^{J*}, E_A^{O*}, E_B^{s*}, E_B^{J*}$ and E_B^{O*} to be induced, the optimal reward scheme must satisfy another constraint: the incentive constraint. The incentive constraint is

$$S_i \left(E_i^{s*}, E_i^{J*}, E_i^{O*} \right) - C_i \left(E_i^{s*} + E_i^{J*} + E_i^{O*} \right)$$

$$\geq \quad S_i \left(E_i^s, E_i^J, E_i^O \right) - C_i \left(E_i^s + E_i^J + E_i^O \right) \qquad \forall i$$

and where E_i^s, E_i^J, E_i^{OJ} represent all the possible levels of efforts devoted to solo work, teamwork within the department, teamwork with outsiders. The incentive constraint makes sure that by taking action E_i^{s*}, E_i^{J*} and E_i^{O*}, agent i cannot be made worse off than by taking any other actions. Each agent faces the problem of maximizing his or her own utility: $U_i = S_i - C_i$, since $S_i = \alpha_i E_i^s + \beta_i E^J + \gamma_i E_i^J$ the problem for agent i is to maximize

$$U_i = \alpha_i E_i^s + \beta_i E^J + \gamma_i E_i^{OJ} - C_i(E_i^s + E_i^J + E_i^O)$$

with the effort choices.

The first order conditions are:

$$\frac{\partial U_i}{\partial E_i^s} = \alpha_i^* - C_i^{'}\left(E_i^*\right) = 0 \qquad \forall i \qquad (4)$$

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$$\frac{\partial U_i}{\partial E_i^J} = \beta_i^* - C_i'\left(E_i^*\right) = 0 \qquad \forall i \tag{5}$$

$$\frac{\partial U_i}{\partial E} = \gamma_i^* - C_i'\left(E_i^*\right) = 0 \qquad \forall i \tag{6}$$

Comparing equations (1)-(3) with (4)-(6), the α_i^*, β_i^* and γ_i^* which induce the agents to choose the first best actions from the principal's perspective are those which pay the agents the marginal product of each of their efforts.

$$\alpha_i^* = \frac{\partial X_i^s\left(E_i^{s*}\right)}{\partial E_i^s}, \qquad \beta_i^* = \frac{\partial X_i^J\left(E_i^{J*}\right)}{\partial E_i^J}, \qquad \gamma_i^* = \frac{1}{N_i}\frac{\partial X^O\left(E_i^{O*}\right)}{\partial E_i^O}$$

The T_i can then be chosen to bind the participation constraint.[5]

2.3 Asymmetric information

In reality, effort is not observable and a payment scheme that is based on effort is not possible. In this section, I adapt a more realistic approach, one where effort is not observable. I will assume that the cost function $C_i\left(\cdot\right)$ and all production functions $X_i^s\left(\cdot\right)$, $X^J\left(\cdot\right)$ and $X_i^O\left(\cdot\right)$ are some known stochastic process and again we assume risk neutrality. The department will use a payment schedule that is based on research output. $S_i = S_i(X_i^s, X^J, X_i^O)$ for $i = A, B$. To ensure participation of professors, the participation constraint

$$S_i(X_i^s, X^J, X_i^O) - C_i\left(E_i^s + E_i^J + E\right) \geq \bar{U}_i \quad \forall i$$

[5] This will be more fully explained in the next section.

must be satisfied for $i = A, B$.

In order to ensure professors will devote optimal efforts if they participate, the following incentive constraint must be satisfied for both agents.

$$S_i \left(X_i^s \left(E_i^{s*} \right), X_i^J \left(E_i^{J*} \right), X^O \left(E_i^{O*} \right) \right) - C_i \left(E_i^{s*}, E_i^{J*}, E_i^{O*} \right)$$

$$\geq \quad S_i \left(X_i^s \left(E_i^s \right), X_i^J \left(E_i^J \right), X^O \left(E_i^O \right) \right) - C_i \left(E_i^s + E_i^J + E_i^O \right) \qquad \forall i$$

Let the linear payment scheme with lump-sum transfor be

$$S_i \left(X_i^s, X_i^J, X_i^O \right) = \alpha_i X_i^s + \beta_i X^J + \gamma_i X_i^O - T_i$$

The agent now maximizes

$$U_i = \alpha_i X_i^s \left(E_i^s \right) + \beta_i X^J \left(E_j^s \right) + \gamma_i X_i^O \left(E_j^O \right) - T_i - C_i \left(E_i^s + E_i^J + E_i^O \right)$$

The first–order conditions are:

$$\frac{\partial U_i}{\partial E_i^s} = \alpha_i^* \frac{\partial X_i^s}{\partial E_i^s} - C_i' \left(E_i^* \right) = 0 \qquad \forall i \tag{7}$$

$$\frac{\partial U_i}{\partial E_i^J} = \beta_i^* \frac{\partial X_i^J}{\partial E_i^J} - C_i' \left(E_i^* \right) = 0 \qquad \forall i \tag{8}$$

$$\frac{\partial U_i}{\partial E_i^O} = \gamma_i^* \frac{\partial X_i^O}{\partial E_i^O} - C_i' \left(E_i^* \right) = 0 \qquad \forall i \tag{9}$$

Comparing equations (1)-(3) with (7)-(9) the set $\alpha_i^*, \beta_i^*, \gamma_i^*$ which induce the agents to choose the first best actions from the principal's perspective are

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$$\alpha_i^* = \beta_i^* = \gamma_i^* N_i = 1 \qquad \forall i$$

That is, the reward of solo authored papers and coauthored papers within the department should be equally weighted by one and papers which are coauthored with those outside the department should be discounted by the weight $1/N_i$ where $N_i - 1$ is the number of coauthors outside the department. This is surprising for a number of reasons.

First, the initial reaction of most people would be to question the idea that this payment scheme leads to too much teamwork within the department. Agent i receives a weight of one for both solo authored papers and coauthored paper within the department and obviously it takes less effort for i to complete a coauthored paper than a solo paper, thus, any agent will choose to produce only teamwork. This is not the case. These results are completely independent of the particular production or cost functions for research output. Regardless of agent i's productivity or laziness(high or low C) , the agent produces at the point which marginal product equalizes marginal cost. When the marginal cost of producing teamwork is more than the marginal cost, agent i stops producing teamwork; therefore, the result is always efficient.

Second, even with unobservable effort, first-best effort levels can be implemented. Free rider problem associated with team production is overcome by the

reward scheme $\beta_i^* = 1$ which gives each agent full credit for each within–department coauthored paper so that they work according to their full marginal product. Also, hard-working high productivity workers are willing to work with a lazy low productivity worker because each gets full credit for the others effort. This reward scheme provide strong incentive for cooperative work because ideas and efforts are shared freely.

Third, $\alpha_i^* = \beta_i^* = 1$ and $\gamma_i^* = 1/N_i$ are very inconsistent with observations about the actual workings of merit in departments. The discussion at the beginning of this section would correspond to $1 = \alpha_i^* > \gamma_i^* > \beta_i^* = 1/N_i$. Under this structure individuals would place too much effort on solo authored papers and papers with outsiders but free ride and have an incentive to exclude people form coauthorship on papers within a department.

Fourth, under the structure of $\alpha_i^* = \beta_i^* = 1$ and $\gamma_i^* = 1/N_i$, teamwork within the department should be more popular than teamwork with outsiders. Only if the degree of complimentary with outsiders is a lot greater than with j, agent i will choose to work on coauthored paper with outsiders.

Last, although efforts are no longer observable, $\alpha_i^* = \beta_i^* = 1$ and $\gamma_i^* = 1/N_i$, this payment scheme can lead to efficient outcome. The fundamental reason is that the principal made each agent the residual claimant, making each professor face the department's problem, that is to maximize $X_i^s \left(E_i^s \right) + X^J \left(E_i^J \right) + \frac{1}{N_i} X_i^O \left(E_i^{OJ} \right) - C_i \left(E_i^s + E_i^J + E_i^{OJ} \right)$. Under the optimal scheme, $X_i^s \left(E_i^s \right) + X^J \left(E_i^J \right) + \frac{1}{N_i} X_i^O \left(E_i^{OJ} \right)$

is the total output produced by i and it is also the reward received by i.

The reward scheme is $X_i^s\left(E_i^s\right) + X^J\left(E_A^J, E_B^J\right) + \frac{1}{N_i}X_i^O\left(E_i^O\right) - T_i^*$ for $i = A, B$.

For the participation constraint to bind

$$X_i^s\left(E_i^{s*}\right) + X^J\left(E_i^{J*}\right) + \frac{1}{N_i}X_i^O\left(E_i^{O*}, E^O\right) - T_i^* - C_i(E_i^{s*} + E_i^{J*} + E_i^{O*}) = \bar{U}_i \qquad \forall i$$

or

$$T_i^* = X_i^s\left(E_i^{s*}\right) + X^J\left(E_i^{J*}\right) + \frac{1}{N_i}X_i^O\left(E_i^{O*}, E^O\right) - C_i(E_i^{s*} + E_i^{J*} + E_i^{O*}) - \bar{U}_i \qquad \forall i$$

The minimum budget required to achieve efficiency is $X_A^s\left(E_A^{s*}\right) + X^J\left(E_A^{J*}\right) +$

$\frac{1}{N_i}X_A^O\left(E_A^{O*}\right) - T_A + X_B^s\left(E_B^{s*}\right) + X^J\left(E_B^{J*}\right) + \frac{1}{N_j}X_B^O\left(E_B^{O*}\right) - T_B$ or unsurprisingly

with substitution, the sum of the total costs of efforts and reservation utility levels.

Considering the overall payment received by i from the department, (S_i) is also

interesting. It will in the end be equal to $C_i(E_i^{s*} + E_i^{J*} + E_i^{O*}) + \bar{U}_i$. The idea that the

compensation will be higher for individuals with higher outside options is obvious

and consistent with common practise. In regard to the costs of efforts, imagine

that both agents were equally lazy; in particular they had the same C_i function.

Then the agent who works more would receive higher compensation. This would

typically be the worker who is more productive. But it would also be possible to

construct examples where a less able and lazier worker $(C_i(E) > C_j(E)\ \forall E)$ would

receive a higher payment.

3 Conclusion

This paper finds the optimal reward scheme for solo work and teamwork. First, in section 2.1, I find that marginal products of effort must be the same across all activities to produce an efficient outcome. In section 2.2, where we have full information and observable effort, I assign a linear payment scheme written on effort to examine the payment structure that induces the first best actions. We find the optimal payment scheme is to pay an agent's effort at the marginal product of his/her effort. In section 2.3 where effort is not observable, the payment contract is written on research output. I find that the optimal reward structure that induces the first best actions is to reward solo work and internal teamwork equally at one, and to discount external teamwork by the total number of coauthors.

The above finding has several features. It is independent of any particular production or cost function; agents simply produce at the point which marginal cost equals marginal product among all activities. It motivates cooperation in the department, the more productive or less lazy agent is willing to work with someone even if the other agent is less productive or lazier. Also it is able to eliminate free rider problems. This particular payment scheme can reach an optimum because it makes the goal of the department coincide with the goal of each agent i. Also, it is not consistent with the actual working of merit in most departments. It shows that the common practice of rewarding solo work at one, rewarding internal coauthored

papers at one over total number of coauthors, and rewarding external coauthored papers between one and one over total number of authors can lead to too many solo authored papers, and too many papers with outsiders, but too little coauthorship on papers within a department.

In addition, in my model, the principal does play a budget breaking role as mentioned in Holmstrom (1982). At optimum, the department is left with the total lump-sum payment minus the internal joint work on hand and we have no good reason to believe it equals to zero other than by accident.

Finally, the crucial point for a payoff scheme to be optimal is that the weight of the reward has to coincide the weight of credit generated by the department for the research work. For example, if the reward for a coauthored paper is 2/n, as long as the department receives 2/n credit for this coauthored paper, the payment of 2/n can induce efficiency. The reason is that if the weight of the reward equals to the weight of credit generated by the department, the principal made each agent the residual claimant, making each professor face the department's problem.

I was able to find the reward scheme that induced the first best allocation of efforts in both a full information and asymmetric information case, because we assumed risk neutrality. If agents are risk averse, and face uncertainty (this is the case since X_i^s , X^J and X^O are stochastic functions of E_i^s, E_i^J ,E_j^J, E_i^O and E^O), the first best allocation is feasible only if rewards are based on efforts. If the payment is based on output, the first best allocation is not likely to be reached.

For the participation constraint to bind, a higher level of reward is required. The total payment is then higher than in the risk neutrality case so that I know that only the second best allocation is feasible. I can speculate that the optimal reward structure in this case should involve risk sharing between principal and agents. Risk neutral agents are willing to bear all risks because they only care about the expected payoffs. When agents are risk averse, the principal has to insure the agents' payoff to some extent. T_i^* in this case should be smaller than T_i^* in risk neutrality case, α_i^*, β_i^*, and $\gamma_i^* N_i$ in this case should be less than one.

Also, knowledge of the cost and production functions is a strong assumption. If we relax this assumption, the optimal T_i cannot be determined, and the optimal reward scheme does not exist.

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