Team members' ability matters for career concerns*

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Abstract

This paper studies career concerns in teams when the support a worker receives depends on the quality of the team she belongs to - the effort *and* ability of her fellow team members. It argues that implicit incentives to work *and* help arise. By exerting effort and providing support, a worker influences her own and colleague's performances and thus, can effectively bias the learning process in her favor. Each agent enjoys a reputational bonus equal to the total rents generated by her activity. Intensified dependence among team members also increases the returns of supplying labor and thus, implicit incentives. This paper also argues that, if explicit contracts are provided, reputation and sabotage-like incentives arise.

Keywords: career concerns, team incentives, incentives to help, sabotage-like incentives

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1 Introduction

Modern corporations launch innovative employment practices in workplace including teamwork, profit-sharing, employee involvement in decision-making so as to raise productivity and profits.[1] Managing team workers though and designing incentive schemes turn into a challenge. Workers are usually subject to various incentive mechanisms, including explicit incentives due to compensation contracts and implicit incentives due to career concerns; i.e. concerns about the effect of reputation on external labor market and thus, on future remuneration. Holmstrom (1982), Gibbons and Murphy (1992) demonstrate that career concerns can be used as an incentive device in the intra-firm relationships which may substitute explicit incentives.[2] Auriol, Friebel, and Pechlivanos (2002) study career concerns in teams where each worker undertakes effort to support her colleagues. However, it is reasonable to suppose that team members' ability also matters for the support a worker provides since high-qualified workers are more capable to influence colleague's performance. This paper extends the existing literature by studying explicit incentives and career concerns in teams when the support depends on both colleagues' effort *and* ability.

Empirical literature provides evidence that knowledge is transmitted within a team and skills diversity affects labor supply and productivity (i.e. Lazear (1999)). The benefits of team interactions depend on whether the workers have distinct or identical knowledge and skills indicating the degree of heterogeneity among the teammates. The 2004 Workplace Employee Relations Survey about British workplaces provides evidence that the effect of knowledge transmission from workplace education and training (measures of ability) on a worker's earnings is considerable and independent from the effect of her own education and training. The findings also reveal that interactions between colleagues affect the hourly pay positively and significantly.

This paper assumes Holmstrom's (1982, 1999) career concerns framework where neither the agents nor the principal have knowledge about agents' innate abilities and they both learn from past performance. It addresses the question of how the learning process about

[1] The fourth European Working Conditions Survey (2007) about workplaces in 31 European countries reports that around 50% of employees in the EU27 rotate tasks with their colleagues and 60% do part or all their work in teams. The findings also show that, across sectors, teamwork is most prevalent in health, electricity, gas and water, education and construction. The opposite is observed in transport, communications and in a number of service sectors. The 2004 Workplace Employee Relations Survey about British workplaces documents that almost 72% of them have at least some core employees informally-designated teams. For instance, work groups are pretty common in manufacturers of cars (Land Rover, Jaguar) and of electric equipments (British electric, Siemens). Teams in Japanese firms such as Toyota and Hitachi, among others, differ substantially in hierarchy, the degree of autonomy, communication from the European firms but 'groupish' organization of production is the common practice. For the US workplaces, the Bureau of Labor Statistics is one of the sources that provide relevant information.

[2] The use of career concerns as an incentive device that may substitute explicit incentives is first discussed by Fama (1980) and elaborated by Holmström (1982). Gibbons and Murphy (1992) consider linear contracts and formalize this argument. Harris and Holmstrom (1982) also study the long-term implicit incentives.

a worker's ability is shaped and career concerns arise in the presence of teamwork and incentives to help. It also examines how effectively explicit contracts can be used in this dynamic setting where cooperation is an issue and support depends on colleague's effort and ability. This paper argues that implicit incentives arise due to work *and* support provision. Given that colleague's ability enters a worker's production function, each teammates' project output conveys information about a worker's ability. Thus, by exerting effort and providing support, an agent can influence all performance measures used in the learning process so as to manipulate the market's assessments in her favor. Implicit incentives to work *and* help arise. This paper also finds that, higher degrees of collaboration intensify career concerns. The amount of available information may increases, though there are more tools available to bias market's assessments implying greater returns to supplying labor. If explicit contracts are used with respect to team workers' assessments, the incentives to sabotage team members are also present. A worker has implicit incentives to make the principal believe that she is teamed with a lower productivity teammate. This paper also demonstrates the desirability of the principal to use disaggregate performance measures in the learning process and in incentive contracting.

The analysis is performed in a set-up where a risk-neutral employer (the principal) appoints two risk-averse employees (the agents) to produce a homogeneous good. Thus, there is a division between ownership and control over the outputs and moral hazard over the agents' actions. Following Itoh (1991, 1992), this paper also assumes that individual outputs are observable and contractible allowing the principal to treat agents separately through individual-based schemes. The agent's production is a linear stochastic function of own effort and ability as well as of the teammate's support. The support an agent receives depends on both her colleague's effort and ability; colleague's ability is an input in an agent's production function. This feature makes this production function to differ from that of Auriol, Friebel, and Pechlivanos (2002). In their model, each agent considers work and help as two separate tasks and only help effort enters teammate's production function.

In this dynamic setting, the dependence of future reward on past performance plays a key role in agents' decisions. Career concerns present the incentive of an agent to work harder in the current period as a mean to shape market's perceptions about her ability and enhance future remuneration.[3] In particular, as long as there is uncertainty about ability and moral hazard over the agent's action, the market extracts information from

[3]Empirical studies confirm career concerns for professionals such as lawyers, journalists, doctors, managers and employees in civil service (Glanter and Palay (1991), Gibbons and Murphy (1992). Coupe, Smeets, and Warzynski (2006), for instance, find that young researchers exert more effort at the beginning of their career when dynamic incentives are present. The probability of promotion and past performance are also positively related and the sensitively of promotion to performance declines with experience, indicating the presence of a learning process. See also Borland (1992) for a survey on career concerns.

current production and attributes some part of good performance to agent's ability. Thus, an agent has incentives to influence learning of her ability by distorting her effort upward. Higher implicit incentives apply the less information the market has. In this setting, both teammates' abilities are inputs in an agent's production function making performance to be subject to higher uncertainty. Each agent's project output as a signal of her own ability becomes more vague, however, teamwork interactions make the colleague's project output to convey information. By devoting effort to work and help, an agent can influence all performance measures used in the process of inference and enjoys greater returns of her activity. Thus, this paper finds that implicit incentives arise due to work *and* support provision. We argue that what matters for career concerns is how many components of the production and learning processes an agent can affect so as to bias the market's assessments in her favor and how many elements of future remuneration depend on current effort. The agent cashes in a reputational bonus. That is the expected rents of work and help. Thus, current effort has a greater impact on future remuneration. This paper also argues that career concerns are strengthened even if intensified teamwork interactions entail gain in information. In this setting, as the degree of collaboration increases, the amount of available information might increase, though the agent becomes better able to manipulate market's inference and enjoys higher rents of supporting the team. Career concerns are strengthened as a result.

This paper also examines career concerns when explicit contracts are also provided. Principal uses explicit short-term contracts in a framework where the bargaining power is allocated to the agents. By making a 'take-it-or-leave-it' offer to the principal as in Gibbons and Murphy (1992) (GM model, hereafter) and Auriol, Friebel, and Pechlivanos (2002) (AFP model, hereafter), agents can exploit contract negotiations.[4] The incentive packages are derived in a linear principal-agent model (Holmstrom and Milgrom (1987)) and are based on explicit comparisons of team members' outputs (Auriol, Friebel, and Pechlivanos (2002), Meyer and Vickers (1997)).[5] Team-incentive contracts are the consequence of the efficient use of information conveyed by individual outputs about each agent's effort and ability. The existing literature uses such contracts when the market shocks that hit agents' production are correlated. In this setting, individual outputs are correlated only due to teamwork interactions. Provided that the principal can better infer the level of an agent's ability and effort by looking at her colleague's performance, incentive contracts are contingent on both

[4]In the principal-agent models, the distribution of the bargaining power is an issue. Some studies consider both parties to hold some bargaining power (i.e. Pitchford (1998)) while some other examine the extreme cases whether either party can make a 'take-it-or-leave-it' offer (i.e. Mookherjee and Ray (2002)). The career concerns models also allocate the bargaining power either to the principal (i.e. Chen and Jiang (2005)) or to the agent (i.e. Gibbons and Murphy (1992)). Bilanakos (2009) argues that the provision of general training increases the worker's bargaining power vis-à-vis the employer.

[5]For a discussion on unobservable contracts, see Andersson (2002).

performance measures (Holmstrom (1979)). Such contracts can effectively internalize the positive effects of team members' help.

This paper examines the reputation-like effect and confirms the substitutability between explicit and implicit incentives in line with the prior literature.[6] In the presence of risk-aversion, a lower pay-performance relationship is imposed for higher-power incentives to built up reputation as in GM model. In particular, each agent has implicit reputation incentives to exert effort and provide support so as to induce an upward revision of the market's estimates of her ability. Sabotage incentives also arise due to an increasing willingness of each agent to persuade the principal that she is teamed with a lower productivity teammate. There are implicit incentives for each agent to induce a downward readjustment of market's priors of her colleague's ability. It is so because the enhanced reputation of her colleague cannot benefit the agent, since she is unable to capitalize such bonus, and it actually hurts her. If the teammate is perceived as being highly productive, the principal expects to pay a large part of the compensation through the contractual incentive components. Given that individual remuneration is pinned down by the outside option, the fixed part of the salary decreases making an agent worse-off. The reputation and sabotage effects differ from those in AFP model where only the teammate's 'support' effort enters an agent's production function. In AFP setting where work and help are two separate tasks, there are reputation incentives to work and sabotage incentives to help. We find that, in this one-task model, reputation incentives to help and sabotage incentives to work also arise. An agent devotes such level of effort that influences both performance measures and signals that she is high productive in absolute and relative terms. The total explicit incentives also reveal that each agent requires insurance against a low realization of all teammates' ability. Thus, in this setting, the principal faces a considerable decrease in his ability to insure each agent against these risks.

The implicit and explicit incentive systems when total output is observable and individual contracts are contingent on this aggregate measure are also discussed.[7] The results confirm Holmstrom (1999) argument that two independent measures of team performance are jointly more informative than a single measure of total production. Lower effort levels are exerted throughout the agents' working life time. It is so because total output is a less reliable signal

[6] Dewatripont, Jewitt, and Tirole (1999) argue that the implicit and explicit incentives are substitutes in a production function where the inputs are additive while they might be complements if the agent's ability is multiplicative to her effort.

[7] There are few papers that study differences in visibility. Ortega (2003) considers a model of power in the firm, where power confers visibility. In this model, visibility is in limited supply and thus, in a sense, externalities are present. As an agent becomes more visible, the visibility of her colleague must decline. Jeon (1996) and Bar-Isaac (2007) examine how visibility may be distorted through team production. By assuming information asymmetries between current and potential employers, Milgrom and Oster (1987) study discrimination in labor markets in a setting where jobs offer different levels of visibility (jobs either fully reveal ability, or convey no information).

of agents' ability and team-incentives schemes fail to effectively control each teammate's behavior.[8]

The rest of the paper is organized as follows. Section 2 presents the model. Section 3 points out the process of updating expectations and the effect of agents' interactions on the 'amount' of available information. It also derives an agent's career concerns when 'implicit contracts' are used and examines the effect of the degree of collaboration on the intensity of implicit incentives. Section 4 solves the dynamic principal-agents problem when explicit contracts are provided. The optimal contractual parameters in each period are calculated and discussed. In section 5, we provide an interpretation of the results. We also comparatively evaluate the intensity of incentives when total or individual outputs are observable and examine the informativeness of aggregate and disaggregate performance measures about agents' ability. Section 6 contains the concluding remarks.

2 The model

A risk-neutral and profit-seeking principal hires two agents i and j to carry out a risky project; $i, j = \{1, 2\}$, $i \neq j$. Employment lasts for two periods indexed by $t = \{1, 2\}$ as the working life of the agents and at each time t, a clear task is assigned to each agent. Agents are risk- and effort- averse and they do not discount the future. In this model, the individual output is observable and contractible allowing the principal to deal with each agent separately as in Itoh (1991, 1992). We examine the contracting game where agents behave non-cooperatively while there are interactions between them. Principal and agents play the two-period game described in Figure 1.

Period 1 *Contracting stage:*	→	*Production stage:*	→	Period 2 *Contracting stage:*	→	*Production stage:*
Each agent i makes a take-it-or-leave-it offer to the principal. If the contracts are accepted, they are signed.		Agent i chooses the effort level $\left(e_1^i\right)$. Events beyond the agents' control occur, the outputs are determined and the rewards are received.		All parties observe 1st-period outputs and update their beliefs. New contract offers are made. If agent i stays in the firm, the contracts are signed. Otherwise, the game ends.		Agent i makes the effort choice $\left(e_2^i\right)$. The outputs are realized and the contracts are executed.

Figure 1. Timing of the game

[8] Arya and Mittendorf (2008) is a recent work on the trade-off between the incentive benefits of aggregation and the incentive cost due to information loss. They find that aggregation can increase incentives when individual performance measures exhibit differences in terms of their sensitivities to effort and talent. In this setting, the use of an aggregate measure leads an employee to undertake effort so as to influence market perceptions of ability; on the other hand, separate measures diminish such an incentive due to the fact that the market puts primary emphasis on skill-intensive measures and disregards those influenced by effort in making assessments. This impetus for effort generated by aggregation is weighed against the dampened incentives that come from the inherent information loss.

2.1 Production technology

At time t, each agent i is engaged in a stochastic production process that yields the output z_t^i; individual outputs are homogeneous and their price is normalized to unity. Agent i's 'project' output depends on her own innate ability (or talent) θ^i and her effort e_t^i (choice variable) as well as her teammate's support, $h\left(\theta^j + e_t^j\right)$, and a noise term, ε_t^i:[9]

$$z_t^i = \theta^i + e_t^i + h\left(\theta^j + e_t^j\right) + \varepsilon_t^i, \;\; h \in [0,1] \tag{1}$$

All parties have imperfect information about agents' invariant ability. However, they share the common prior that θs follow a normal distribution with zero mean and finite variance, $N\left(0, \sigma_\theta^2\right)$, and are independently and identically distributed across agents, $cov\left(\theta^i, \theta^j\right) = 0$. Prendergast and Topel (1996) consider θ^i as the fit between the agent and her job that is contingent on some systemic variation, (symmetrically) unknown to all players in the pre-contracting stage.[10]

The term $h\left(\theta^j + e_t^j\right)$ indicates the total effect of j's effort and ability on i's project output. This is the 'support' (or help) an agent receives from her teammate. The parameter h stands for the degree of cross-agents interaction; i.e. the fraction of agent j's 'production' output (say $\theta^j + e_t^j$) that enters i's project production function.[11] It indicates the degree of linear dependence between an agent's help and her colleague's project output. For the rest of the study, we mention h as the degree of collaboration or teamwork interactions between the team members. h is assumed to be identical for both agents and independent of the actions undertaken; i.e. symmetric and exogenous. Supportive interactions are reasonable to occur when agents use similar technologies, mainly due to the causality between their actions. Such teamwork interactions are 'value-creating'.

Being j's ability an input in i's production function makes i's project output to be subject to higher uncertainty. Individual project output as a performance measure also becomes more vague since team interactions weaken the link between an agent's project performance and her ability. The relationship between θ^i and z_1^i is less accountable and autonomous and z_1^i as a signal of θ^i is less pronounced. If θ^j does not enter into i's production function and an agent considers work and help as two separate tasks, we are in similar framework as in Auriol, Friebel, and Pechlivanos (2002) where an agent receives 'support' that depends exclusively on her colleague's 'help' effort. The Holmstrom's model for career concerns applies, if no interactions occur.

[9] The scale of production is identical in all t periods and thus, there is no growth potential for the firm.

[10] See, for instance, Laffont and Tirole (1988) and Lewis and Sappington (1997) for a discussion on the optimal incentives when an agent has private information about her ability before she goes to the market.

[11] The degree of team interactions depends on the information control over the production outcomes, the amount of knowledge embodied in the outputs, the degree of tacit knowledge required, the ease of imitation, the characteristics of the technologies, etc.

Agent i's performance is also subjected to a transitory shock ε_t^i. It is normally distributed, $N(0, \sigma_\varepsilon^2)$, and independent of j's noise, ε_t^j, and abilities θ^i, θ^j. There are also no intertemporal correlations.

2.2 Players' objectives and contracts

The principal is residual claimant on firm's net profits which are given by the sum of outputs net the agents' compensation - i.e. the cost of production incurred by the firm:

$$U^P = \sum_{t=1}^{2}\sum_{i=1}^{2}\left(z_t^i - w_t^i\right)$$

Agents have constant absolute risk-averse (CARA) preferences. Thus, by receiving the payment w_t^i at time t, agent i is endowed with the utility function[12]

$$U^i = -\exp\left\{-r\sum_{t=1}^{2}\left[w_t^i - \psi\left(e_t^i\right)\right]\right\}$$

where r is the Arrow-Pratt measure of risk aversion, $r > 0$, and $\psi\left(e_t^i\right)$ is the cost-of-effort function.[13] $\psi\left(e_t^i\right)$ is convex implying that there are diminishing returns to scale in the production process and satisfies $\psi'(0) = 0$, $\psi'(\infty) = \infty$ and $\psi''' \geq 0$.[14] The cost of effort can be considered as the opportunity cost, since undertaking a project limits the earnings that could be generated from other activities. Moreover, the compensation schemes considered in this model, either implicit or explicit, are linear. Thus, given normally distributed random terms and linear contracts, the certaint equivalent of agent i's utility can be written in a mean-variance form (Holmstrom and Milgrom (1987)) :[15]

$$CE^i \equiv \sum_{t=1}^{2}\left[E\left\{w_t^i \mid z_{t-1}^i, z_{t-1}^j\right\} - \psi\left(e_t^i\right)\right] - \frac{r}{2}var\left\{\sum_{t=1}^{2} w_t^i \mid z_{t-1}^i, z_{t-1}^j\right\}$$

where $z_0^i = \emptyset$. If an agent rejects to stay in the firm at period t, she picks the outside option which is denoted by $\widetilde{\theta_t^i}$ and depends on the reputational bonus an agent can claim given her

[12] Being the utility function (and the production) multiplicative separable across periods implies that agents do not engage in income smoothing and make choices as if they act in a setting with perfect capital markets. This feature allows the contract at t to be written only on current outcomes and eliminates the (potential) benefits from intertemporal risk sharing.

[13] Risk-aversion of the part of the agents guarantees that career concerns are not completely eliminated by the optimal explicit contracts.

[14] The condition $\psi''' \geq 0$ is sufficient to guarantee that some maximization problems are concave.

[15] Effort alters only the first two moments of the distribution of output; higher moments remain unaffected.

past performance:

$$\widetilde{\theta}_t^i = E\left\{(1+h)\,\theta^i \mid z_{t-1}^i, z_{t-1}^j\right\} + (1+h)\,\widehat{e}_t^i$$

Thus, agent i enjoys the total rent which is expected to be generated by her work and help. That is the expected increase in both her own and teammate's performance due to her effort and ability given the history of outputs. Thus, the reputational bonus is the bonus an agent can require due to an upward revision of the market's estimate of her ability. None of the competing employers can make a better offer than $\widetilde{\theta}_t^i$. The principal also seems to be equally well-off either appointing a high reputation agent at a high wage or a low reputation agent at a low wage. First-period reputational bonus $\widetilde{\theta}_1^i$ is zero since $E\left\{\theta^i\right\} = \widehat{e}_1^i = 0$. Thus, the market anticipates that, if the agent does not enter into the market, she will undertake no effort.

One can interpret this allocation of the bargaining power as the equilibrium outcome of an extensive-form game (Auriol, Friebel, and Pechlivanos (2002)). In such a game, each agent is randomly addressed to a prospective principal and waits in the queue with the other applicants. The principal makes a contract offer to the agent first in line, having first received her report. It the agent accepts the offer, she is appointed by this principal. Otherwise, the agent applies and queues for another job, and the principal makes an offer to the next agent in line.

3 Implicit incentives

This section gives an insight into the effect of teamwork interactions on the learning process and career concerns. To make the first step towards an understanding of agents' reputation concerns and the effect of the intensity of teamwork interactions, this analysis is performed under the assumption that only 'implicit' contracts are provided.

3.1 Learning process

As performance observations accumulate, the market updates its assessments about ability. Following DeGroot (1970), the distribution of each agent's ability given the observed first-period outputs z_1^i, z_1^j is normal with mean[16,17]

$$\begin{aligned} E\left\{\theta^i \mid z_1^i, z_1^j\right\} &= \rho_{ii}\left(z_1^i - \widehat{e}_1^i - h\widehat{e}_1^j\right) + \rho_{ij}\left(z_1^j - \widehat{e}_1^j - h\widehat{e}_1^i\right) \\ E\left\{\theta^j \mid z_1^i, z_1^j\right\} &= \rho_{ij}\left(z_1^i - \widehat{e}_1^i - h\widehat{e}_1^j\right) + \rho_{ii}\left(z_1^j - \widehat{e}_1^j - h\widehat{e}_1^i\right) \end{aligned} \tag{2}$$

and variance

$$var\left\{\theta^i \mid z_1^i, z_1^j\right\} = var\left\{\theta^j \mid z_1^i, z_1^j\right\} = \sigma_\theta^2\left(1 - \rho_{ii} - h\rho_{ij}\right) \tag{3}$$

where $\rho_{ii} = \rho_{jj}$, $\rho_{ij} = \rho_{ji}$. $\widehat{e}_1^i$ is the market conjecture about the first-period effort e_1^i which contributed to both z_1^i and z_1^j. Provided that all players have rational expectations, the equilibrium conjecture must be correct, $e_1^i = \widehat{e}_1^i$.[18] Thus, agents cannot fool the market. ρ_{ii}, ρ_{ij} are the 'regression' coefficients of own and teammate's performance respectively:

$$\rho_{ii} = \frac{\sigma_\theta^2\left[\sigma_\varepsilon^2 + \left(1 - h^2\right)\sigma_\theta^2\right]}{\left[\sigma_\varepsilon^2 + (1+h)^2\sigma_\theta^2\right]\left[\sigma_\varepsilon^2 + (1-h)^2\sigma_\theta^2\right]} \tag{4}$$

$$\rho_{ij} = \frac{h\sigma_\theta^2\left[\sigma_\varepsilon^2 - \left(1 - h^2\right)\sigma_\theta^2\right]}{\left[\sigma_\varepsilon^2 + (1+h)^2\sigma_\theta^2\right]\left[\sigma_\varepsilon^2 + (1-h)^2\sigma_\theta^2\right]} \tag{5}$$

ρ_{ii}, ρ_{ij} lie between $[-1, 1]$ and $1 > \rho_{ii} + h\rho_{ij} > 0$.

The regression coefficient ρ_{ii} represents the linear dependence of i's ability θ^i in the first-period i's output z_1^i given z_1^j. This correlation coefficient is positive in the entire parameter space implying that, given the other agent's output, high own performance signals high own ability and vise versa; i.e. $\rho_{ii} > 0$ since $\frac{cov\left(\theta^i, z_1^i\right)}{cov\left(\theta^i, z_1^j\right)} > \frac{cov\left(z_1^i, z_1^j\right)}{var\left(z_1^j\right)}$ for all $h \in (0, 1)$.

The market also values the information revealed by z_1^j for θ^i. To get a better insight, we first examine the unconditional correlation between z_1^j and θ^i; i.e. $corr\left\{\theta^i, z_1^j\right\} > 0$.[19] Given the i's positive contribution in z_1^j, the market attributes some part of j's high output to high i's ability. However, the observation of z_1^i makes the interdependence of θ^i and z_1^j less straightforward. For being ρ_{ij} positive requires $\frac{cov\left(\theta^i, z_1^j\right)}{cov\left(\theta^i, z_1^i\right)} > \frac{cov\left(z_1^i, z_1^j\right)}{var\left(z_1^i\right)}$.[20] It is so if the degree of interactions h, which denotes the degree of covariance between ability and teammate's output, exceeds the ratio $\frac{cov\left(z_1^i, z_1^j\right)}{var\left(z_1^i\right)}$; this ratio is sensitive to changes in the transitory shock.

[16] If $h = 0$, we are back to the Holmström's (1999) model, where the conditional mean and variance of agent i's ability have respectively as $\frac{\sigma_\theta^2}{\sigma_\varepsilon^2 + \sigma_\theta^2}\left(z_1^i - \widehat{e}_1^i\right)$ and $\sigma_\varepsilon^2 \frac{2\sigma_\theta^2 + \sigma_\varepsilon^2}{\sigma_\varepsilon^2 + \sigma_\theta^2}$.

[17] In appendix 5.7.1, see how the conditional distributions of θs are obtained given different learning processes.

[18] In this model as in the career concerns framework, there are no out-of-equilibrium realizations of observables because of the presence of noise. Thus, given rational expectations and forward-looking players, market's conjectures are correct (and the equilibrium of the model is unique).

[19] The unconditional correlations are $corr\left(\theta^i, z_t^i\right) = \left[\sigma_\theta^2 / \left(\sigma_\varepsilon^2 + \left(1 + h^2\right)\sigma_\theta^2\right)\right]^{\frac{1}{2}}$, $corr\left(\theta^i, z_t^j\right) = h$ $corr\left(\theta^i, z_t^i\right)$. Higher h decrease $corr\left(\theta^i, z_t^i\right)$ and increase $corr\left(\theta^i, z_t^j\right)$.

[20] This inequality requires $1 > \frac{2\sigma_\theta^2}{\left(1+h^2\right)\sigma_\theta^2 + \sigma_\varepsilon^2}$ which is reduced to $\sigma_\varepsilon^2 > \left(1 - h^2\right)\sigma_\theta^2$.

We consider asymmetries in the variance of the random terms and conclude that this ratio depends on the variances of θ^j and ε_1^i; both inputs are apart from i's characteristics and beyond her control.[21] If h is higher than $\frac{cov\left(z_1^i,z_1^j\right)}{var\left(z_1^i\right)}$, ρ_{ij} is positive; higher j's performance is good news for i's ability. The market anticipates that, given a relatively high h, increases in z_1^j might be driven by θ^i. Otherwise, higher z_1^j is attributed to θ^j and the assessments of θ^i are revised downwards.

In this world, where individual outputs are correlated due to agents' interactions and thus, both outputs convey information about individual abilities, the variance of the posterior estimates of θs decreases as new information arrives resulting in better market's assessments; i.e. $\rho_{ii} + h\rho_{ij} > 0$ for all $h \in [0,1]$. A cumulated stock of information leads the market to learn. At this point, it might be illustrating to discuss learning processes about θ^i when the performance measures used for market's perceptions differ. Consider, for instance, the case where expectations are based only on z_1^i;

$$\begin{aligned} E\left\{\theta^i \mid z_1^i\right\} &= \lambda\left(z_1^i - \widehat{e}_1^i - h\widehat{e}_1^j\right) \ , \ E\left\{\theta^i \mid z_1^j\right\} = h\lambda\left(z_1^j - \widehat{e}_1^j - h\widehat{e}_1^i\right) \\ & var\left\{\theta^i \mid z_1^i\right\} = (1-\lambda)\,\sigma_\theta^2 \\ \text{where } \lambda &= \frac{\sigma_\theta^2}{\sigma_\varepsilon^2 + (1+h^2)\,\sigma_\theta^2} \end{aligned}$$

If $\rho_{ij} > 0$, λ exceeds ρ_{ii}, $\lambda \geq \rho_{ii}$, implying that the market puts a lower weight on own performance to perceive the level of own ability as more signals are used in the learning process. z_1^i turns out to be a more vague signal. However, the market can better infer the level of i's ability by looking also at her teammate's production. Two (or more) independent measures of performance are *jointly* more informative about θ^i than a single measure of output. If $h > 0$ and $\frac{\sigma_\varepsilon^2}{\sigma_\theta^2} \neq 1 - h^2$, the inequality $\rho_{ii} + h\rho_{ij} \geq \lambda$ holds implying that $var\left\{\theta^i \mid z_1^i, z_1^j\right\} \leq var\left\{\theta^i \mid z_1^i\right\}$. Learning is enhanced allowing for better assessment of θ^i. Thus, both available signals must be used in the process of inference.

Figure 2b shows the effect of the degree of collaboration on the informativeness of the signals in estimating abilities. If agents do not interact, $h = 0$, no inference is being drawn from z_1^j concerning θ^i and $\rho_{ii} = \lambda$. If support is provided, $h > 0$, condition $(A1)$ holds;

$$\frac{\sigma_\varepsilon^2}{\sigma_\theta^2} > \frac{1}{3}\left[2\left[1 - h^2\left(1-h^2\right)\right]^{\frac{1}{2}} - \left(1+h^2\right)\right] \tag{A1}$$

$(A1)$ guarantees that the market puts a lower weight on i's signal in estimating i's ability as the degree of collaboration increases, $\frac{\partial\rho_{ii}}{\partial h} < 0$. In turn, z_1^i becomes more dim. Higher

[21] See appendix 5.7.1 for more details on the correlation coefficients when there are asymmetries in the variance of abilities and market shocks.

h though makes the teammate's signal more informative; i.e. $\frac{\partial|\rho_{ij}|}{\partial h} > 0$ for all $h \in (0,1]$. Whether the market gains in information as h increases depends on the variability of the inputs in production function.

Lemma 1 *Intensified degrees of collaboration diminish the conditional variance of each agent i's ability,* $\frac{\partial\left(\rho_{ii}+h\rho_{ij}\right)}{\partial h} > 0$, *if, and only if,* $\frac{\sigma_\varepsilon^2}{\sigma_\theta^2} > (1-h^2)^{\frac{1}{2}}\left[2+(1-h^2)^{\frac{1}{2}}\right]$.

[Figure 2 is about here]

For low σ_θ^2 such that this inequality holds, higher degrees of collaboration make both signals to 'speak' more about ability and thus, the market updates its beliefs by having more available information. However, if θs vary a lot (high σ_θ^2), the intensity of collaboration plays a key role. For low or even negligible interactions, the market finds it harder to disentangle the contribution of each input to the final output and the information extracted by z_1^i and z_1^j about ability is less pronounced. The conditional variance of θ^i decreases with h as a result. Though, if h exceeds a threshold, the derivative of $var\left\{\theta^i \mid z_1^i, z_1^j\right\}$ with respect to h turns out to be positive. i's help matters more for j's performance implying that both individual outputs become better estimates of i's ability as h increases. Figure 2 displays the effect of h on learning.

3.2 Teamwork interactions & career concerns

This analysis discusses effort choices in a setting where only 'implicit contracts' are used. Agent i is compensated with a fixed payment equal to the expected rents of her activity given the history of outputs:

$$w_t^i = E\left\{(1+h)\,\theta^i \mid z_{t-1}^i, z_{t-1}^j\right\} + (1+h)\,\widehat{e}_t^i$$

These rents are expected to be generated due to i's work and help. The two-period game is solved by using backwards induction.

In period 2, no effort is exerted, $e_2^{i*} = 0$, since there are no career concerns. Current action leaves w_2^i unaffected; the learning process depends on past efforts and performances. In equilibrium, the market knows what effort level to expect and adjusts the output measure accordingly. In a sense, each agent is trapped in supplying the equilibrium level that is expected of her, because lower effort will bias the evaluation procedure against her.

The first-period payment is $w_1^i = E\left\{(1+h)\,\theta^i \mid priors\right\}+(1+h)\,\widehat{e}_1^i$. The lifetime certain equivalent of i's utility at period 1 has as

$$CE^i = E\left\{w_1^i\right\} - \psi\left(e_1^i\right) + E\left\{w_2^i\left(e_2^{i*}\right) \mid z_1^i, z_1^j\right\} - \psi\left(e_2^{i*}\right) - \frac{r}{2}Var\left\{w_1^i + w_2^i\right\}$$

Note that the variance of θs is independent of effort implying that the first-period actions can only affect the mean of the distribution of abilities. Thus, omitting terms that are independent of e_1^i, each agent i maximizes the form $-\psi\left(e_1^i\right) + E\left\{(1+h)\,\theta^i \mid z_1^i, z_1^j\right\}$.

Proposition 2 (Career concerns) *Under (A1), agent i's implicit reputation incentives arise due to work* ***and*** *support provision;*

$$\psi'\left(e_1^{i*}\right) = (1+h)\left(\rho_{ii} + h\rho_{ij}\right)$$

Proof. See appendix. ■

The optimal effort is a weighted sum of the measures the market uses to draw inference about ability. Thus, effort depends on how much weight the market puts on outputs in estimating ability. Though, given that $h < 1$, the learning process of θ^i is based more on ρ_{ii} implying that the own-signal effect dominates the cross-signal effect.

If support depends only on effort, the optimal implicit incentives are equal to $\frac{\sigma_\theta^2}{\sigma_\varepsilon^2+\sigma_\theta^2}$ implying that the processes of inference of teammates' abilities is completely separable and independent of the degree of collaboration. However, if θ^j is an input in i's production function, the equilibrium sequence of labor inputs changes and additional reputation incentives arise due to support provision. Agent i undertakes effort to increase future remuneration through her work $(1+h)\,\rho_{ii}$ and help $(1+h)\,h\rho_{ij}$.[22] This paper argues that what matters for career concerns is how many components of the production process and the learning process an agent can affect in order to bias market's inference in her favor and how many (say) elements of future remuneration depend on current action. By exerting higher effort, the agent affects both performance measures and induces an upward revision of θ^i whose contribution to i's future remuneration increases by $E\left\{h\theta^i \mid z_1^i, z_1^j\right\}$ due to support. There are two tools available an agent can use to shape market's assessments and current effort has a greater impact on future wage. Therefore, each team member is subject to additional implicit incentives. To sum up, agents have stronger incentives to exert higher effort at the early stage of their career as more elements of learning process depend on current effort and as the contribution of those on total remuneration increases.

[22] Let us assume that an agent chooses her 'work' effort, a_t^i, which is devoted to the task she is responsible for and the 'help' effort, b_t^i, that improves her colleague's output; i.e. $z_t^i = \theta^i + a_t^i + h\left(\theta^j + b_t^j\right) + \varepsilon_t^i$. Each agent incurs disutility that is (say) task-specific, $\psi\left(a_t^i\right) + \psi\left(b_t^i\right)$. Then, agent i's implicit incentives to work have as $\psi'\left(a_1^i\right) = (1+h)\,\rho_{ii}$ and her implicit incentives to help as $\psi'\left(b_1^i\right) = (1+h)\,h\rho_{ij}$.

The effect of collaboration on the 'amount' of available information and thus, on the intensity of career concerns is not clear cut. In line with the literature, it seems that as long as the market knows more about θs, it puts a lower weight on output observations when revising its beliefs. An increase in available information is represented by decreasing conditional variances of θs over time. Thus, career concerns are stronger the more there is uncertainty about ability since agent's action will be more effective in manipulating market's perceptions. However, in this model, it is likely higher degrees of collaboration to entail gain in information and implicit incentives to increase. This represents a decrease in the conditional variance of θs in period t due to h.

Proposition 3 (Information & career concerns) *Under* $(A1)$*, if implicit contracts are provided, intensified degrees of teamwork interactions increase career concerns,* $\frac{\partial e_1^{i*}}{\partial h} > 0$*, only if,* $\frac{\partial\left(\rho_{ii}+h\rho_{ij}\right)}{\partial h} > 0$ *or* $\frac{\partial\left(\rho_{ii}+h\rho_{ij}\right)}{\partial h} < 0$ *and* $\frac{\rho_{ii}+h\rho_{ij}}{1+h} > \frac{\partial\left|\rho_{ii}+h\rho_{ij}\right|}{\partial h}$.

Proof. See appendix. ■

In the parameter space where intensified interactions increase learning according to lemma 1, individual implicit incentives to influence the evaluation process are strengthened. Agent j's output as signal of i's ability becomes more valuable as h increases, and in total, agent i is more capable to induce an upward revision of her ability. Thus, even though the market can draw inference by two performance measure that convey more information, agents become better able to manipulate market's perceptions. The gains from reputation increase and thus, there are greater returns to supplying labor and providing support. Notably, if h diminishes the market's ability to learn and thus, makes the parties to act in a more dim environment, $\frac{\partial\left(\rho_{ii}+h\rho_{ij}\right)}{\partial h} < 0$, career concerns increase with h only if $\frac{\rho_{ii}+h\rho_{ij}}{1+h} > \frac{\partial\left|\rho_{ii}+h\rho_{ij}\right|}{\partial h}$. The negative effect of h on the learning process must be relatively small.

Information asymmetries over the agent's actions also give rise to inefficiency in the intra-firm incentives. Under full information about each agent's actions, efficient incentives can (normally) be achieved and full insurance is entailed at the optimum. i's remuneration is a fixed payment equal to the disutility of effort, $w_t^{i,FI} = \psi\left(e_t^i\right)$, so as the individual rationality constraint to be binding. The full information contract induces the efficient effort level $\psi'\left(e_t^{i,FI}\right) = 1 + h$.[23] Given the agent's preferences, the contract offered under full information at each period of the dynamic model is the contract that is optimal in the one-shot game.

Under asymmetric information, optimal effort falls short of its efficient level; i.e. $e_1^{i*} < e_1^{i,FI}$ for all $h \in [0,1]$. e_1^{i*} is less responsive to changes in h due to the monitoring problem.

[23] Under full information, the optimal effort maximizes $U^P = z_t^i + z_t^j - \psi\left(e_t^i\right) - \psi\left(e_t^j\right)$.

In turn, teammates' interactions produce an increase in the intensity of the moral hazard problem; i.e. $\frac{\partial\left(e_1^{i,FI}-e_1^{i*}\right)}{\partial h} > 0$ for all $h \in (0,1]$. The efficiency of control the agent's actions progressively diminishes implying that there is far more distortion in incentives as the interactions are intensified. In a sense, under asymmetric information, each agent free-rides to some extent on her colleague's effort to enhance reputation yielding to weaker incentives compared to the full information case. Some productive opportunities remain unexploited due to inadequate 'motivation'.

4 Explicit incentives

We examine the dynamic game where, at each period, explicit output-contingent contracts are provided and, if they are accepted, each agent undertakes the utility-maximizing effort level. Given the expectations about her teammates' action, each agent makes her (single-shot) decisions, anticipating though the effect of her reputation on her future remuneration. The optimal contractual choices are extensively discussed.

4.1 Explicit contracts and principal's problem

Each agent separately makes an offer to the principal at each contracting stage, provided that none of the players can commit to long-term contracts. Given that effort is private information to the agent and the subsequent realizations of θ^i, ε_t^i are unknown to everybody, enforceable contracts are contingent on project outputs. In particular, they are restricted to be linear to both agents' project outputs since the latter are correlated due to teamwork interactions (Holmstrom and Milgrom (1987)).[24] The principal can better infer agent i's effort and ability by also looking at z_t^j. It is so because z_t^i is not a sufficient statistic of e_t^i (Holmstrom (1979), Mookherjee (1984)). Such 'team-incentive schemes' introduce 'cooperation' between agents and promote efficiency in designing incentives for a risk-averse agent. In a sense, cooperation provides a richer information base on which to write contracts (Holmstrom and Tirole (1989)). At time t, i's compensation generates a payment[25]

$$w_t^i = \alpha_t^i + \beta_t^i z_t^i + \gamma_t^i z_t^j \tag{6}$$

[24] Based on Holmstrom and Milgrom (1987), such contracts are optimal in this setting.

[25] Linear contracts (may) describe the form of the wages of executive officers in modern corporations. The wages comprise a base payment related to health insurance, family benefits, housing that (mainly) remain fixed throughout the duration of the contract and bonus factors related to the performance. In this analysis, such contracts are useful because they shed light on the trade-off between the implicit and explicit incentives in a simple manner: weak career concern incentives are compensated with strong explicit incentives. The pay-for-performance parameters demonstrate the intensity of the contractual incentives.

α_t^i denotes the fixed salary component and β_t^i, γ_t^i are the incentive parameters.[26]

At each time t, principal and agents sign the two-piece rate contracts C_t^i where $C_t^i \equiv \left(\alpha_t^i, \beta_t^i, \gamma_t^i\right)$. In this model, the bargaining outcome we consider (described in subsection 2.2) results in effectively making each agent the residual claimant only to her total rent of her work and help. Thus, given the history of project outputs, the principal's problem becomes:[27]

$$\max_{C_t^i, e_t^i, C_t^j, e_t^j} \; E\left\{U^P\right\} = E\left\{\sum_{t=1}^{2}\sum_{i=1}^{2}\left(z_t^i - w_t^i\right) \mid z_{t-1}^i, z_{t-1}^j\right\}$$

$$\text{subject to} \quad e_t^{i*} = \arg\max_{e_t^i} E\left\{U^i\left(w_t^i, e_t^i\right) \mid z_{t-1}^i, z_{t-1}^j\right\}, \;\; \forall i,t \quad \left(IC_t^i\right)$$
$$E\left\{U^i\left(w_t^i, e_t^i\right) \mid z_{t-1}^i, z_{t-1}^j\right\} \geq \widetilde{\theta}_t^i, \;\; \forall i,t \quad \left(IR_t^j\right)$$

The incentive compatibility constraint (IC_t^i) guarantees that, in period t, agent i will choose the effort level that maximizes her expected utility given the information gathered in period $t-1$. The individual rationality constraint (IR_t^i) demonstrates that the agent will participate in the production process only if her expected utility of doing so exceeds her outside option. That is the reputational bonus she can require due to good past performance.[28]. The principal signs the most appealing contracts.

4.2 Second-period contracts

In period 2, given the subsequent realizations of z_1^i, z_1^j, the form of contracts and the market's inference about θs (equations (2), (6)), each agent i maximizes her certain equivalent of her utility $CE_2^i \equiv E\left\{w_2^i \mid z_1^i, z_1^j\right\} - \psi\left(e_t^i\right) - \frac{r}{2}Var\left\{w_2^i \mid z_1^i, z_1^j\right\}$ and chooses the effort level that satisfies the first-order condition

$$\psi'\left(e_2^{i*}\right) = \beta_2^i + h\gamma_2^i \tag{7}$$

Given that the agent's problem is strictly concave in e_2^i, we can use the first-order approach and replace the incentive compatibility constraint IC_2^i in the principals' problem with equa-

[26] This model also assumes rational expectations and forward-looking players.

[27] The random terms do not appear since their expected values are zero. The market also uses the information revealed in $t-1$ since the play lasts only for two periods. In a multi-period model, learning is based on outputs realized in all previous periods.

[28] In this model, the bargaining power allocated to the agents vis-à-vis the market has as in Auriol, Friebel, and Pechlivanos (2002).

tion (7).[29,30]

Each agent exercises her bargaining power and signs the contract that allows her to earn her reputational bonus. The base payment satisfies the individual rationality constraint IR_2^i with equality:

$$\alpha_2^i\left(\beta_2^i,\gamma_2^i\right)=\widetilde{\theta}_2^i-E\left\{\beta_2^i z_2^i+\gamma_2^i z_2^j \mid z_1^i,z_1^j\right\}+\psi\left(e_2^{i*}\right)+\frac{r}{2}var\left\{w_2^i \mid z_1^i,z_1^j\right\} \tag{8}$$

Using the equations (7) and (8), the optimal second-period contractual choices are obtained and summarized in proposition 11.

Proposition 4 (Second-period explicit incentives) *There exists a symmetric equilibrium in the second-period performance-based parameters in which:*

$$\beta_2^{i*}=\frac{1+h}{1+h^2\Delta_2+r\Sigma_2\psi''\left(e_2^{i*}\right)} \text{ and } \gamma_2^{i*}=h\Delta_2\beta_2^{i*},$$

where $\Delta_2\equiv\frac{\sigma_\varepsilon^2-(1+2\delta)\left(1-h^2\right)\left(1-\rho_{ii}-h\rho_{ij}\right)\sigma_\theta^2}{\sigma_\varepsilon^2+(1+2h^2\delta)(1-h^2)\left(1-\rho_{ii}-h\rho_{ij}\right)\sigma_\theta^2}$, $\delta\equiv\frac{corr\left(\theta^i,\theta^j|z_1^i,z_1^j\right)}{h}$ *and*

$\Sigma_2\equiv\sigma_\varepsilon^2+\left[1+h^2\left(1+2\Delta_2\right)+2h\delta\left[2+\Delta_2\left(1+h^2\right)\right]\right]\left(1-\rho_{ii}-h\rho_{ij}\right)\sigma_\theta^2$.[31]

Proof. See appendix. ■

Therefore, at the optimum, each agent receives the payment that induces her to undertake the effort level e_2^{i*} such that

$$\psi'\left(e_2^{i*}\right)=\left(1+h^2\Delta_2\right)\beta_2^{i*} \tag{9}$$

The positive sign of β_2^{i*} implies that higher own performance is compensated with higher wage. Given that the weight Δ_2 lies in the range $[0,1]$, supportive teamwork interactions also make the pay-for-other project performance parameter positive. That is, the principal induces each agent to be given a long position in teammate's project output. He anticipates the support an agent provides to her colleague and rewards her when her teammate does better. By doing so, he motivates the agents to exert higher effort in order to increase total production. This analysis demonstrates that there are two equivalent incentive tools available in 'team' performance appraisals that can affect the agents' behavior. Such evaluation schemes can effectively be used as means of internalizing the team members' help.

[29] In this multi-agent framework, the monotone likelihood ratio property (MLRP) and the convexity of the distribution function condition (CDFC) are not sufficient for the first-order approach to be valid as in a singe-agent setting. Itoh (1991) argues that, in a model with cross-agents interactions, a generalized CDFC for the joint probability distribution of the outputs is needed and the wage schemes must be nondecreasing. The coefficient of absolute risk aversion must also not decline too fast. In our model with linear contracts and technology, and CARA preferences, all these assumptions are satisfied and the first-order approach applies.

[30] The second-order conditions of the principal's problem are also satisfied.

[31] It is $\delta\equiv\frac{h\sigma_\theta^2\left[\sigma_\varepsilon^2-\left(1-h^2\right)\sigma_\theta^2\right]}{(2+h^4-3h^2)\sigma_\theta^4+(3+2h^2)\sigma_\theta^2\sigma_\varepsilon^2+\sigma_\varepsilon^4}$, $|\delta|\leq 1$.

The 'compensation ratio' $\frac{\gamma_2^{i*}}{\beta_2^{i*}}$ is less than unity indicating that a higher weight is put on own project output in compensating own effort, $\beta_2^{i*} > \gamma_2^{i*}$.[32] Own- and other- project performance matter equally to an agent's reward only if $h = 1$. In such a case, each agent is compensated for higher total output, $w_2^{i*} = \alpha_2^{i*} + \beta_2^{i*}\left(z_2^i + z_2^j\right)$, regardless of whose agent's ability or effort is enhanced. In particular, an increase in the slope of the optimal contract β_2^{i*} raises the effort level twice, $\psi'\left(e_2^{i*}\right) = 2\beta_2^{i*}$, since each agent contributes equally to both individual outputs and is rewarded for the 'team' production. Thus, she is eager to double her effort and improve the total performance.

By compensating the agents with team-incentive schemes, optimal effort increases as the teamwork interactions are intensified. However, e_2^{i*} is lower than its first-best level, $e_2^{i,FB}$, implying that moral hazard distorts the second-period efforts downwards. Given the information structure, higher h intensify effort as well as the conflicts in the principal-agents relationship increasing the agency cost.

4.3 First-period contracts

Agent i anticipates the implicit dependence of the second-period wage on the first-period performance and chooses the effort level that maximizes:

$$CE_1^i \equiv E\left\{w_1^i\right\} - \psi\left(e_1^i\right) + E\left\{w_2^i\left(\beta_2^{i*}, \gamma_2^{i*}\right)\right\} - \psi\left(e_2^{i*}\right) - \frac{r}{2}Var\left\{w_1^i + w_2^i\right\} \tag{10}$$

The optimal effort solves the first-order condition and has as

$$\psi'\left(e_1^{i*}\right) = \beta_1^i + h\gamma_1^i + \frac{\partial\alpha_2^i\left(\beta_2^{i*}, \gamma_2^{i*}\right)}{\partial e_1^i} \tag{11}$$

Thus, an agent is motivated by the total explicit incentives $\beta_1^i + h\gamma_1^i$ generated from the first-period contract and the implicit incentives from career concerns. Given that there are no wealth effects in agent's utility and the production function is additive, the second-period explicit incentives β_2^{i*}, γ_2^{i*} are independent of z_1^i, z_1^j and thus of agents' reputation. It is so because both agents have the same marginal product of effort regardless of agents' true ability. Reputation affects only the fixed component of w_2^i and the implicit incentives can be represented simply by the term $\frac{\partial\alpha_2^i\left(\beta_2^{i*}, \gamma_2^{i*}\right)}{\partial e_1^i}$; how current effort can affect the intercept of future wage (equation (8)). Substituting (2) into (8) and differentiating with respect to the

[32] The compensation ratio $\left|\gamma_2^{i*}/\beta_2^{i*}\right|$ is decreasing in σ_θ^2 and increasing in σ_ε^2. It also increases with h implying that a higher weight is put on other's performance for higher degrees of teamwork interactions.

first-period action, implicit incentives have as follows:[33]

$$\frac{\partial \alpha_2^i\left(\beta_2^{i*},\gamma_2^{i*}\right)}{\partial e_1^i}=\frac{\partial \alpha_2^i\left(\beta_2^{i*},\gamma_2^{i*}\right)}{\partial z_1^i}\frac{\partial z_1^i}{\partial e_1^i}+\frac{\partial \alpha_2^i\left(\beta_2^{i*},\gamma_2^{i*}\right)}{\partial z_1^j}\frac{\partial z_1^j}{\partial e_1^i}=M_1^{ii}+hM_1^{ij} \tag{12}$$

$$\text{where}\qquad \begin{aligned} M_1^{ii} &= \left(1+h-\beta_2^{i*}-h\gamma_2^{i*}\right)\rho_{ii}-\left(h\beta_2^{i*}+\gamma_2^{i*}\right)\rho_{ij} \\ M_1^{ij} &= \left(1+h-\beta_2^{i*}-h\gamma_2^{i*}\right)\rho_{ij}-\left(h\beta_2^{i*}+\gamma_2^{i*}\right)\rho_{ii} \end{aligned} \tag{13}$$

M_1^{ii} is the incentive an agent has to work harder in order to improve her own current project performance and thus, increase her future remuneration. M_1^{ij} represents the additional incentive that arises due to support: higher i's current effort also affects j's project performance, z_1^j, due to teamwork interactions and thus, i's second-period wage. Agent's implicit incentives are accumulated and reinforced.

Given equations (7), (11), (12) and (13), we solve the agents' problems and conclude proposition 12.

Proposition 5 (First-period explicit incentives) *There exists a symmetric equilibrium in first-period performance-based parameters in which:*

$$\begin{aligned} \beta_1^{i*} \;=\; & \frac{1+h}{1+h^2\Delta_1+r\Sigma_1\psi''\left(e_1^{i*}\right)}-M_1^{ii}-\frac{\left[\left(1+h^2\right)\beta_2^{i*}+2h\gamma_2^{i*}\right]r\sigma_\theta^2\psi''\left(e_1^{i*}\right)}{1+h^2\Delta_1+r\Sigma_1\psi''\left(e_1^{i*}\right)} \\ & +h\frac{\left(1-h^2\right)\left(h\beta_2^{i*}+\gamma_2^{i*}\right)\sigma_\theta^2\left[1+2r\sigma_\theta^2\psi''\left(e_1^{i*}\right)\right]}{\left[1+h^2\Delta_1+r\Sigma_1\psi''\left(e_1^{i*}\right)\right]\left[\sigma_\varepsilon^2+\left(1-h^2\right)\sigma_\theta^2\right]} \end{aligned}$$

$$\textit{and }\gamma_1^{i*}=h\Delta_1\left(\beta_1^{i*}+M_1^{ii}\right)-M_1^{ij}-\frac{\left(1-h^2\right)\sigma_\theta^2\left(h\beta_2^{i*}+\gamma_2^{i*}\right)}{\sigma_\varepsilon^2+\left(1-h^2\right)\sigma_\theta^2}$$

where $\Delta_1\equiv\frac{\sigma_\varepsilon^2-\left(1-h^2\right)\sigma_\theta^2}{\sigma_\varepsilon^2+\left(1-h^2\right)\sigma_\theta^2}$ *and* $\Sigma_1\equiv\sigma_\varepsilon^2+\left(1+2h^2\Delta_1+h^2\right)\sigma_\theta^2$.

Proof. See appendix. ■

One can verify that explicit incentives are increasing over time, $\beta_1^{i*}+h\gamma_1^{i*}<\beta_2^{i*}+h\gamma_2^{i*}$.

5 Discussion

To intuitively interpret the first-period choices, we decompose the total explicit incentives, $\beta_1^{i*}+h\gamma_1^{i*}$, and examine the underlying effects. We compare our results with those of Gibbons and Murphy (1992) and realize that new effects are coming up and those effects that hold in both frameworks change with the degree of teamwork interactions considerably. We also discuss the contractual choices when individual contracts are unobservable and when aggregate performance measures are used for market's inference and incentive provision.

[33] Appendix 5.7.5 derives the form of $\alpha_2^i\left(\beta_2^{i*},\gamma_2^{i*}\right)$.

5.1 Decomposition of optimal explicit incentives

The optimal explicit incentives are decomposed into four effects;

$$\beta_1^{i*} + h\gamma_1^{i*} = \underbrace{\frac{(1+h)\left(1+h^2\Delta_1\right)}{1+h^2\Delta_1 + r\Sigma_1\psi''\left(e_1^{i*}\right)}}_{\text{noise reduction effect}} - \underbrace{\frac{\left(1+h^2\Delta_1\right)\left(\beta_2^{i*}+h\gamma_2^{i*}\right) r\sigma_\theta^2\psi''\left(e_1^{i*}\right)}{1+h^2\Delta_1 + r\Sigma_1\psi''\left(e_1^{i*}\right)}}_{\text{own-task human capital insurance effect}}$$
$$- \underbrace{h\frac{\left(1+\Delta_1\right)\left(h\beta_2^{i*}+\gamma_2^{i*}\right) r\sigma_\theta^2\psi''\left(e_1^{i*}\right)}{1+h^2\Delta_1 + r\Sigma_1\psi''\left(e_1^{i*}\right)}}_{\text{other's-task human capital insurance effect}} - \underbrace{\left(M_1^{ii} + hM_1^{ij}\right)}_{\text{career concerns}}$$

First, it is the so called *noise reduction effect* that arises due to changes in the 'amount' of available information about ability. Accumulating information by past performance causes the uncertainty about an agent's output to decline over time; it is $\Sigma_1 > \Sigma_2$. In an individual compensation package, given h, the compensation ratio is also higher every next period, $\Delta_1 < \Delta_2$. Thus, given that the noise reduction effect is increasing in Δ_t and decreasing in Σ_t, the optimal trade-off between incentive provision and insurance is (say) 'improving' for the principal since lower risks are incurred and higher-power incentives can be provided; i.e. for positive r and σ_θ^2, it is $\beta_2^{i*} + h\gamma_2^{i*} > \frac{(1+h)\left(1+h^2\Delta_1\right)}{1+h^2\Delta_1+r\Sigma_1}$. The difference between $\beta_2^{i*} + h\gamma_2^{i*}$ and the noise reduction effect also increases with h. Intensified teamwork interactions induce the market to learn more between the first and second period and thus, the insurance-incentive trade-off is shifted towards the latter even more.

The second term captures the *human capital insurance effect* on agent i's explicit incentives due to θ^i: risk-aversion of the part of the agent and uncertainty about her own ability induce agent i to require insurance against low realizations of θ^i. Weaker total explicit incentives provide such insurance. Note that technological interaction and team-incentive schemes make θ^i to matter more for i's compensation increasing the severity of this effect and yielding to further reductions in explicit incentives.[34] Thus, as h increases the contribution of θ^i in i's wage, the agent seeks additional insurance.

Third, it is the human capital insurance effect that arises due to changes in the variance of i's wages caused by θ^j. It represents the insurance a risk-averse agent i requires against low realizations of j's ability. Introducing θ^j into i's technology makes i's production and thus, i's compensation to be subject to higher risk. The insurance takes the form of a decrease in the total explicit incentives in the current period. Less motivation is provided explicitly. Note that we can distinguish the own- and other's- task human capital insurance effects because individual projects outputs are observable and team-incentive schemes are

[34] Remember that the optimal effort might be negative if the insurance an agent requires against low realizations of both teammates' ability is relatively high. For instance, if the number of agents increases, the severity of the human capital insurance effect will also be greater and the total explicit incentives will be more likely to be negative.

used. The subsection 5.2 sheds more light in these effects and shows that they are merged in a setting where aggregate information is provided and the wages are contingent on the team production.

The last term captures the effect of *career concerns* which depicts the substitutability between the explicit and implicit incentives as is pretty common in the literature (Gibbons and Murphy (1992), Dewatripont, Jewitt, and Tirole (1999)). If $h = 0$, this model generates the standard result that the slope of the current linear compensation scheme is reduced for higher-power implicit incentives; it is $\frac{\partial \beta_1^{i*}}{\partial M_1^{ii}} \mid_{h=0} < 0$ and $M_1^{ii} \mid_{h=0} > 0$.[35] In other words, a lower pay-performance relation is imposed when the incentive to build up reputation is high.

If support is provided and depends on ability, an agent's action can shape market's beliefs through the expectations of both teammates' project outputs and impact her future remuneration through the expectations of both teammates' abilities:

$$M_1^{ii} + hM_1^{ij} = \left[1 + h - \left(\beta_2^{i*} + h\gamma_2^{i*}\right)\right] \frac{\partial E\left\{\theta^i \mid z_1^i, z_1^j\right\}}{\partial e_1^i} - \left(h\beta_2^{i*} + \gamma_2^{i*}\right) \frac{\partial E\left\{\theta^j \mid z_1^i, z_1^j\right\}}{\partial e_1^i}$$

The first term exposes the implicit incentives each agent i has to built up reputation and enjoy higher future compensation by inducing the market to update its assessments about her own ability upwards. In particular, an upward revision of $E\left\{\theta^i \mid z_1^i, z_1^j\right\}$ entails gains by the subsequent increase in i's reputational bonus; i.e. $(1+h)\left(\rho_{ii} + h\rho_{ij}\right)$. However, the reputational bonus is diminished by the 'incentive component' $\left(\beta_2^{i*} + h\gamma_2^{i*}\right)\left(\rho_{ii} + h\rho_{ij}\right)$. The principal anticipates that the agent will be assessed as being of higher ability and the explicit incentive component of future compensation will be large. Thus, the agent signs a contract whose base payment increases by less than the increase in her reputational bonus. For this to be the case, the agents are required to be risk-averse. Due to the trade-off between effort provision and insurance, the incentive component will be less than unity; i.e. given that $\Delta_2 \leq 1$ and $\beta_2^{i*} < 1$ for $r > 0$, it is $1 + h > \beta_2^{i*} + h\gamma_2^{i*}$.

The second term represents the implicit sabotage incentives; i.e. $\left(h\beta_2^{i*} + \gamma_2^{i*}\right)\left(h\rho_{ii} + \rho_{ij}\right)$. Such incentives manifest that an implicit ratchet effect arises. By undertaking higher effort, agent i improves both performance measures but she gains nothing from the subsequent increase in her colleague's reputational bonus. An increase in the conditional expectation of θ^j makes j better-off while harms agent i. Given that agent i does not internalize j's reputational gains, negative implicit incentives to induce an upward readjustment of market's priors of θ^j arise. Therefore, it is at i's interest to persuade the principal that she is teamed with a lower productivity agent.[36] The principal will anticipate that the contractual components

[35] In standard career concern models, the implicit incentives are $M_1^{ii}(h=0) = \sigma_\theta^2\left(\frac{1}{\sigma_\varepsilon^2+\sigma_\theta^2} - \frac{1}{\sigma_\varepsilon^2+\sigma_\theta^2+r\sigma_\varepsilon^2\left(2\sigma_\varepsilon^2+\sigma_\theta^2\right)}\right)$.

[36] One could open a discussion about the intensity of the optimal explicit incentives provided by short-

of the compensation will be large and, given that each agent's remuneration is set according to her outside option, he will diminish the base payment of the salary respectively. Thus, in this setting, career motives are beneficial or detrimental from the principal's perspective since reputation and sabotage effects are at work.[37]

Unlike Auriol, Friebel, and Pechlivanos (2002) where career concerns and sabotage incentives could be completely separated, here, this is not possible. In their model, two tasks are assigned to each teammate. Agent i undertakes effort to work and support her colleague, though only i's 'help' effort enters additively j's project production function. Thus, agent i has reputation incentives to work in order to improve her own performance and shape the beliefs about her own ability as well as sabotage incentives to help her colleague. Reputation and sabotage incentives are completely separable since high i's 'work' effort increases only i's output and the conditional priors of her own ability, while her 'help' effort is chosen such that will decrease the expectations about j's ability. In our framework, each agent has one choice variable and additional reputation and sabotage incentives arise since teammates' ability affect their support. Agent i requires a reputational bonus due to her good task-performance. Thus, her bonus increases by $h\left(\rho_{ii}+h\rho_{ij}\right)$ due to the support she provides. However, the principal anticipates the teamwork interactions and decreases i's bonus by $\gamma_2^{i*}\left(\rho_{ii}+h\rho_{ij}\right)$ additional to $\beta_2^{i*}\left(\rho_{ii}+h\rho_{ij}\right)$. Thus, due to support provision, agent i enjoys $h\left(1-\gamma_2^{i*}\right)$ by an increase in $E\left\{\theta^i \mid z_1^i, z_1^j\right\}$. The substitution between the implicit and explicit incentives also induces agent i to gain by a further decrease in $E\left\{\theta^j \mid z_1^i, z_1^j\right\}$ by $h\beta_2^{i*}\left(h\rho_{ii}+\rho_{ij}\right)$ additional to $\gamma_2^{i*}\left(h\rho_{ii}+\rho_{ij}\right)$. In a sense, agent i's effort choice is affected by countervailing incentives.

One could also contrast the results with those of Lazear (1989). In Lazear's framework, the sabotage incentives arise because an agent is given a short position in her colleague's performance. The pay-for-other performance parameter is negative implying that agent i is paid less the higher j's project output. In a sense, an agent is penalized when her teammate does better. The principal anticipates that each agent acts in a favorable environment with teamwork interaction which should be discounted from her reward. Such contract induces competition between agents. This paper shows that sabotage arises even in a setting where

and long- term contracts. Gibbons and Murphy (1992) prove that if long-term contracts are feasible, they must also be Pareto efficient at each date. They show that the sequence of (optimal) short-term contracts provide exactly the same incentives as those of the optimal renegotiation-proof long-term contracts (denoted by $\beta_1^{rf,i*}$, $\gamma_1^{rf,i*}$). It is also the case in this model since $\beta_1^{i*}+h\gamma_1^{i*}+M_1^{ii}+hM_1^{ij}=\beta_1^{rf,i*}+h\gamma_1^{rf,i*}$. However, it is not always $\beta_1^{i*}+h\gamma_1^{i*}>\beta_1^{rf,i*}+h\gamma_1^{rf,i*}$ as in Gibbons and Murphy (1992)'s single-agent setting where there are no sabotage incentives. In this model, the optimal short-term explicit incentives are lower than those of a renegotiation-proof contract in the regime where the ratchet effect holds. See also Auriol, Friebel, and Pechlivanos (2002) for further discussion on this topic.

[37] If agents receive individual wage payments and are negotiating as a team, the individual rationality constraint becomes: $\sum_{i=1}^{2}\left[E\left\{w_2^i \mid z_1^i, z_1^j\right\}-\psi\left(e_2^i\right)\right]-\frac{r}{2}\sum_{i=1}^{2}\left[Var\left\{w_2^i \mid z_1^i, z_1^j\right\}\right]\geq\widetilde{\theta}_2^i+\widetilde{\theta}_2^j$. In this case, providing support benefits both agents since both gain by an increase in either reputational bonus. There is no sabotage effect and career concerns are higher-powered than those arise when agents are negotiating individually.

an agent is compensated for her colleague's good performance.

5.2 Aggregate vs disaggregate information

We examine the market responses to aggregate information. Consider that an aggregate performance measure is observed by the market and used in incentive contracting. This is the total output $z_t^i + z_t^j$ whose unconditional distribution is normal with mean $(1+h)\left(\widehat{e}_t^i + \widehat{e}_t^j\right)$ and variance $2\left[\sigma_\varepsilon^2 + (1+h)^2 \sigma_\theta^2\right]$.[38] Being the principal unable to identify the individual contribution to the total output is what determines the learning process and the effectiveness of controlling team incentives. If the single measure of performance used for market's perceptions is the total output $z_1^i + z_1^j$, less information is available in the entire parameter space.

$$\begin{aligned} E\left\{\theta^i \mid z_1^i + z_1^j\right\} &= \rho_{i+j}\left[z_1^i + z_1^j - (1+h)\left(\widehat{e}_1^i + \widehat{e}_1^j\right)\right] \\ var\left\{\theta^i \mid z_1^i + z_1^j\right\} &= \left[1 - (1+h)\,\rho_{i+j}\right]\sigma_\theta^2 \qquad (14) \\ \text{where } \rho_{i+j} &= \frac{(1+h)\,\sigma_\theta^2}{2\left[\sigma_\varepsilon^2 + (1+h)^2 \sigma_\theta^2\right]} \qquad (15) \end{aligned}$$

ρ_{i+j} stands for the correlation coefficient between θ^i and $z_1^i + z_1^j$, and indicates a positive dependence of ability and total output. It seems that the market wishes to draw inference from disaggregate performance measures than from the sum of such measures; i.e. $\rho_{ii} + h\rho_{ij} \geq (1+h)\,\rho_{i+j}$.

Using the total output as the single performance measure, the market finds it harder to distinguish whose input increase brought about an enhancement in team production, given also that such measure is subject to higher market uncertainty. Two market shocks hit the production process that affect the overall performance and the reliability of this measure as a signal of agents' ability. In turn, being the posterior belief about θs updated based on aggregate information implies a worse estimate and higher conditional variance; i.e. $Var\left\{\theta^i \mid z_1^i + z_1^j\right\} > Var\left\{\theta^i \mid z_1^i, z_1^j\right\}$ for all $h \in [0,1]$. Thus, aggregation entails a more dim environment.

Implicit incentives drive an agent to exert the first-period effort level

$$\psi'\left(e_1^{i,ag}\right) = (1+h)^2\,\rho_{i+j}$$

As in the disaggregate information case, each agent has implicit incentives to work and help

[38] Appendix 5.7.1 describes the conditional distributions of θs given aggregate information and appendices 5.7.6 and 5.7.7 show the detailed solution of the dynamic principal's problem.

her teammate in order to induce an upward revision of the market's estimate of her ability. However, lower effort is exerted under aggregation, $\psi'\left(e_2^{i,ag}\right) < \psi'\left(e_2^{i*}\right)$, for all $h \in [0,1)$ and thus, lower total output is produced. The market relies less on an aggregate measure to form its beliefs and agent i's current effort as a mean of shaping market's assessments becomes less effective. Higher h thought increases such incentives.

Corollary 6 (Career concerns & aggregate information) *If an aggregate performance measure is used, career concerns increase as the teamwork interactions are intensified,* $\frac{\partial e_1^{i,ag}}{\partial h} > 0$*, for all* $h \in (0,1]$*.*

Proof. See appendix. ■

Note that own and other agent's ability matter equally in total production and thus, in team members' compensation. Thus, agent i benefits from an increase in the estimate of either teammate's ability. Her incentives to work and help are equally-powered. Such incentives also become stronger for higher degrees of teamwork interactions. In particular, higher h increases the weight the market puts on this aggregate measure to infer the level of each θ^i when h increases the covariance of θ^i with $z_i + z_j$ more than it does to the variance of this measure; i.e. $\frac{\partial \rho_{i+j}}{\partial h} > 0$ if, and only if, $\frac{\partial cov\left(\theta^i, z_i+z_j\right)/\partial h}{\partial var(z_i+z_j)/\partial h} > \rho_{i+j}$. The effect of h on ρ_{i+j} is not clear cut. Given though that agent i's reputational bonus depends on her task performance, $(1+h)\,E\left\{\theta^i \mid z_1^i + z_1^j\right\}$, and learning increases with h - i.e. $\frac{\partial Var\left(\theta^i | z_1^i+z_1^j\right)}{\partial h} < h$ for all $h \in (0,1]$ - agent i's implicit incentives to work and help are strengthened.

If explicit incentives are provided, each agent receives $w_t^i = \alpha_t^i + \beta_t^{i,ag}\left(z_t^i + z_t^j\right)$. In a sense, the incentive parameters are such that $\beta_t^i = \gamma_t^i$ implying that "delegated cooperation" is attained. This analysis is based on Itoh (1992) discussion about managing team members by using induced or delegated cooperation. Solving the game backwards, we derive the optimal second-period effort level, $\psi'\left(e_2^{i,ag}\right) = (1+h)\,\beta_2^i$, and substitute it into the principal's problem. Given that each base payment α_2^i will be adjusted to provide i's reputational bonus (each IR_2^i constraint is binding), the optimal slope of the second-period contract is obtained:

$$\beta_2^{i,ag} = \frac{(1+h)^2}{(1+h)^2 + r\Sigma_2^{i+j}\psi''\left(e_2^{i,ag}\right)}$$

where $\Sigma_2^{i+j} \equiv 2\left[\sigma_\varepsilon^2 + (1+h)^2\left[1-(1+h)\,\rho_{i+j}\right]\sigma_\theta^2\right]$. Lower effort is exerted under aggregation, $\psi'\left(e_2^{i,ag}\right) < \psi'\left(e_2^{i*}\right)$, for all $h \in [0,1)$ and thus, lower total output is produced. The market relies less on an aggregate measure to form its beliefs and explicit contracts, as tools to handle team members, become less efficient. Under disaggregation, there are two statistics to be used for market's inference which also convey information about agents' state uncertainty. Tying an agent's reward to each agent's performance is an attempt to exploit such information. Team-incentive contracts contingent on individual performances serve as devices that increase the efficiency of monitoring and control the agents' actions. The principal can better manipulate agents' choices and thus, their incentives to shirk mute. Disaggregation makes it possible for the players to sign a less distorted contract. Thus, less observability is associated with weaker explicit incentives and intensified principal-agents conflicts.

It is $\psi'\left(e_2^{i,ag}\right) = \psi'\left(e_2^{i*}\right) = 2\beta_2^{i*}$ and $\beta_2^{i*} = \gamma_2^{i*} = \beta_2^{i,ag}$ only for $h = 1$ where the learning processes that use z_1^i, z_1^j or z_1^i+ z_1^j as performance measures are equally informative. Both z_1^i, z_1^j weight equally for individual wage. The wage is enhanced with an increase in total production regardless of whose agent's input caused it. In such cases, observing individual performances is of no value to the principal. The "hidden gaming" problem is eliminated.

Aggregation also affects career concerns. In the first period, i's effort choice is given by $\psi'\left(e_1^{i,ag}\right) = (1+h)\,\beta_1^{i,ag} + \frac{\partial\alpha_2^i\left(\beta_2^{i,ag}\right)}{\partial e_1^i}$ where

$$\frac{\partial\alpha_2^i\left(\beta_2^{i,ag}\right)}{\partial e_1^i} = \left(1 - 2\beta_2^{i,ag}\right)(1+h)^2\,\rho_{i+j} \tag{16}$$

Implicit incentives are stronger under disaggregate information since, by working harder, an agent is better able to signal her ability through both her own and her teammate's performance. Substituting the optimal effort levels $e_1^{i,ag}$ and $e_2^{i,ag}$ in the principal's problem and taking the first-order condition, the optimal explicit incentive has as:

$$\beta_1^{i,ag} = \frac{(1+h)^2}{(1+h)^2 + r\Sigma_1^{i+j}\psi''\left(e_1^{i,ag}\right)} - \left(1 - 2\beta_2^{i,ag}\right)(1+h)\,\rho_{i+j} - \frac{2\,(1+h)^2\,r\sigma_\theta^2\psi''\left(e_1^{i,ag}\right)}{(1+h)^2 + r\Sigma_1^{i+j}\psi''\left(e_1^{i,ag}\right)}\beta_2^{i,ag}$$

where $\Sigma_1^{i+j} \equiv 2\left[\sigma_\varepsilon^2 + (1+h)^2\sigma_\theta^2\right]$. Note that the noise reduction effect is greater under aggregation and the human capital insurance effects are merged since the insurance required for low realizations of each agent's ability cannot be distinguished. Having more information and a greater number of performance measures available seem to be always desirable from the principal's perspective when the moral hazard problem is present.

For a more complete discussion, one could compare the team production models with this model where disaggregate performance measures are used and $h = 1$; let the team production production function take the form $z_t = \theta^i + e_t^i + \theta^j + e_t^j + \epsilon_t$ where ϵ_t follows the same distribution as ε_t^i, and each agent i's wage be $w_t^i = \alpha_t^i + \beta_t^i z_t$.[39] Solving the

[39] It is $var\,(z_t) = \sigma_\varepsilon^2 + 2\sigma_\theta^2$, $cov\left(\theta^i, z_t\right) = \sigma_\theta^2$, $E\left\{\theta^i \mid z_t\right\} = \frac{\sigma_\theta^2}{\sigma_\varepsilon^2 + 2\sigma_\theta^2}\left(z_t - \widehat{e}_1^i - \widehat{e}_1^j\right)$ and $var\left\{\theta^i \mid z_t\right\} = \sigma_\varepsilon^2 + 2\sigma_\theta^2\left(1 - \frac{\sigma_\theta^2}{\sigma_\varepsilon^2 + 2\sigma_\theta^2}\right)$. We solve the second-period principal's problem and conclude that the optimal individual effort of a team worker is equal to the slope of the linear contract which is $1/\left(1 + r\left[\sigma_\varepsilon^2 + 2\sigma_\theta^2\left(1 - \frac{\sigma_\theta^2}{\sigma_\varepsilon^2 + 2\sigma_\theta^2}\right)\right]\psi''\right)$. The signal-to-noise ratio (say ζ) is the ratio of the variance of uncertain ability of an agent) to the variance of the 'effective noise' (the sum of the other agent's uncertain

two-period team production model, it seems that lower explicit and implicit incentives are generated compared to those in our model. Under disaggregation, it is as if the market sees the realization of the sum of team members' effort and ability when two market shocks hit the production, one at a time. There are two draws that can be used in the learning process. Thus, two signals of the same level of production convey more information and can be exploited in designing individual-based instead of team-based compensation schemes.

6 Conclusion

Dynamic incentives to work and help are examined in a multi-agent framework where teamwork interactions occur among the team members (Auriol, Friebel, and Pechlivanos (2002)) and the amount of help an agent receives depends on both her colleagues' effort *and* innate ability. Teamwork interactions affect the learning process and are at the heart of this analysis. An agent's ability is an input in her colleague's production function. We argue that intensified teamwork interactions stimulate career concerns. Each agent can signal her own ability through all teammates' individual performances and thus, she is better able to induce the market to revise its assessment about ability upwards. She has more tools available to bias the learning process in her favor. Such tools become more valuable as the teamwork interactions are intensified.

This paper also considers explicit incentive devices. Provided that individual outputs are observable and contractible, each (risk-averse) agent is treated separately (Itoh (1991), (1992)) and makes a take-it-or-leave-it offer to the principal. The compensation schemes are based on 'team' incentives that can effectively internalize the positive effects of supportive interactions. In line with the literature, this paper finds that career concerns are positive and substitute the explicit incentives since a lower pay-performance relation is imposed for intensified implicit incentives, and vise versa. This paper argues that reputation and implicit sabotage incentives arise. Allowing for side payments between the agents and different allocations of the bargaining power may boost this analysis further.

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ability and the exogenous shock ϵ) and has as $\frac{\sigma_\theta^2}{\sigma_\varepsilon^2+\sigma_\theta^2}$. Thus, the reputation coefficient that captures the individual career incentives in teams is given by $\frac{\zeta}{1+\zeta}=\frac{\sigma_\theta^2}{\sigma_\varepsilon^2+2\sigma_\theta^2}$.

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A APPENDIX

A.1 Distribution of θ^i

Unconditional distribution: Let us consider asymmetries in the variance of θs and εs; i.e. $\theta^i \sim N\left(0, \sigma^2_{\theta^i}\right)$ and $\varepsilon^i_t \sim N\left(0, \sigma^2_{\varepsilon^i_t}\right)$. The asymmetries will allow the reader to specify what causes the variation in each agent's performance. Then, the variance-covariance matrix of the unconditional multivariate normal distribution of the variables θ^i, z^i_t and z^j_t has as

$$\begin{pmatrix} \sigma^2_{\theta^i} & \sigma^2_{\theta^i} & h\sigma^2_{\theta^i} \\ \sigma^2_{\theta^i} & \sigma^2_{\theta^i} + h^2\sigma^2_{\theta^j} + \sigma^2_{\varepsilon^i_t} & h\sigma^2_{\theta^i} + h\sigma^2_{\theta^j} \\ h\sigma^2_{\theta^i} & h\sigma^2_{\theta^i} + h\sigma^2_{\theta^j} & \sigma^2_{\theta^j} + h^2\sigma^2_{\theta^i} + \sigma^2_{\varepsilon^j_t} \end{pmatrix}$$

Their correlations are given by the forms

$$corr\left(\theta^i, z^i_t\right) = \frac{cov\left(\theta^i, z^i_t\right)}{\sqrt{var\left(\theta^i\right) var\left(z^i_t\right)}} = \left(\frac{\sigma^2_{\theta^i}}{\sigma^2_{\theta^i} + h^2\sigma^2_{\theta^j} + \sigma^2_{\varepsilon^i_t}}\right)^{\frac{1}{2}}, \quad corr\left(\theta^i, z^j_t\right) = h\ corr\left(\theta^i, z^i_t\right)$$

Spillovers decrease the correlation of θ^i and z^i_t,

$$\frac{\partial corr\left(\theta^i, z^i_t\right)}{\partial h} = -h\sigma_{\theta^i}\sigma^2_{\theta^j}\left(\sigma^2_{\theta^i} + h^2\sigma^2_{\theta^j} + \sigma^2_{\varepsilon^i_t}\right)^{-\frac{3}{2}} < 0$$

and increase the correlation of θ^i and z^j_t,

$$\frac{\partial corr\left(\theta^i, z^j_t\right)}{\partial h} = \left(\frac{\sigma^2_{\theta^i}}{\sigma^2_{\theta^i} + h^2\sigma^2_{\theta^j} + \sigma^2_{\varepsilon^i_t}}\right)^{\frac{1}{2}} \frac{\sigma^2_{\theta^i} + \sigma^2_{\varepsilon^i_t}}{\sigma^2_{\theta^i} + h^2\sigma^2_{\theta^j} + \sigma^2_{\varepsilon^i_t}} > 0$$

Both correlation coefficients also increase with $\sigma^2_{\theta^i}$ and decrease with $\sigma^2_{\theta^j}$, $\sigma^2_{\varepsilon^i}$, $\sigma^2_{\varepsilon^j}$.

Theoretical background to conditional distributions: If a random vector $x = (x_1, x_2)$ follows a normal distribution with mean $\mu = \begin{bmatrix} \mu_1 \\ \mu_2 \end{bmatrix}$ with sizes $\begin{bmatrix} \kappa \times 1 \\ (N - \kappa) \times 1 \end{bmatrix}$

and variance $\Sigma = \begin{bmatrix} \Sigma_{11} & \Sigma_{12} \\ \Sigma_{21} & \Sigma_{22} \end{bmatrix}$ with sizes $\begin{bmatrix} \kappa \times \kappa & \kappa \times (N-\kappa) \\ (N-\kappa) \times \kappa & (N-\kappa) \times (N-\kappa) \end{bmatrix}$, the distribution of x_1 conditional on x_2 is also normal; i.e. $(x_1 \mid x_2 = \chi) \sim N\left(\overline{\mu}, \overline{\Sigma}\right)$ where $\overline{\mu} = \mu_1 + \Sigma_{12}\Sigma_{22}^{-1}(\chi - \mu_2)$ and $\overline{\Sigma} = \Sigma_{11} - \Sigma_{12}\Sigma_{22}^{-1}\Sigma_{21}$. The matrix $\Sigma_{12}\Sigma_{22}^{-1}$ represents the matrix of regression coefficients. The terms $\Sigma_{12}\Sigma_{22}^{-1}(\chi - \mu_2)$ and $\Sigma_{12}\Sigma_{22}^{-1}\Sigma_{21}$ show how much the unconditional mean and variance of x_1 are shifted compared to the situation of not knowing χ. In the bivariate case, the distribution of y conditional on x has as $(y \mid x = \chi) \sim N\left(\mu_y + corr(y,x)\frac{\sigma_y}{\sigma_x}(\chi - \mu_x), \left(1 - corr(y,x)^2\right)\sigma_x^2\right)$. Note that $corr(y,x)\frac{\sigma_y}{\sigma_x} = \frac{cov(y,x)}{\sigma_x^2}$.

Conditional priors based on both individual outputs (two disaggregate signals):

Conditional mean: Following DeGroot (1970), the expectation of θ^i at period 2 conditional on z_1^i, z_1^j is

$$E\left\{\theta^i \mid z_1^i, z_1^j\right\} = E\left\{\theta^i\right\} + \sigma'\Sigma^{-1}\begin{pmatrix} z_1^i - \widehat{e}_1^i - h\widehat{e}_1^j \\ z_1^j - \widehat{e}_1^j - h\widehat{e}_1^i \end{pmatrix}$$

where $\sigma' = \begin{pmatrix} cov\left(\theta^i, z_1^i\right) & cov\left(\theta^i, z_1^j\right) \end{pmatrix}$ and $\Sigma = \begin{pmatrix} var\left(z_1^i\right) & cov\left(z_1^i, z_1^j\right) \\ cov\left(z_1^i, z_1^j\right) & var\left(z_1^j\right) \end{pmatrix}$ and $\widehat{e}_1^i$ is the market conjecture for the effort level e_1^i. We have

$$\Sigma^{-1} = \frac{1}{var\left(z_1^i\right)var\left(z_1^j\right) - \left[cov\left(z_1^i, z_1^j\right)\right]^2}\begin{pmatrix} var\left(z_1^j\right) & -cov\left(z_1^i, z_1^j\right) \\ -cov\left(z_1^i, z_1^j\right) & var\left(z_1^i\right) \end{pmatrix} \tag{17}$$

In this model, it is

$$\sigma'\Sigma^{-1} = \Omega\begin{pmatrix} \sigma_{\theta^i}^2 & h\sigma_{\theta^i}^2 \end{pmatrix}\begin{pmatrix} \sigma_{\theta^j}^2 + h^2\sigma_{\theta^i}^2 + \sigma_{\varepsilon_t^j}^2 & -\left(h\sigma_{\theta^i}^2 + h\sigma_{\theta^j}^2\right) \\ -\left(h\sigma_{\theta^i}^2 + h\sigma_{\theta^j}^2\right) & \sigma_{\theta^i}^2 + h^2\sigma_{\theta^j}^2 + \sigma_{\varepsilon_t^i}^2 \end{pmatrix}$$

where $\Omega \equiv \frac{1}{var\left(z_1^i\right)var\left(z_1^j\right) - \left[cov\left(z_1^i, z_1^j\right)\right]^2} = \frac{1}{\left(\sigma_{\theta^i}^2 + h^2\sigma_{\theta^j}^2 + \sigma_{\varepsilon_t^i}^2\right)\left(\sigma_{\theta^j}^2 + h^2\sigma_{\theta^i}^2 + \sigma_{\varepsilon_t^j}^2\right) - \left(h\sigma_{\theta^i}^2 + h\sigma_{\theta^j}^2\right)^2}$.

Note that

$$\sigma'\Sigma^{-1} = \begin{pmatrix} \rho_{ii} & \rho_{ij} \end{pmatrix}$$

where

$$\rho_{ii} = \sigma_{\theta^i}^2\left[\sigma_{\varepsilon_t^j}^2 + \left(1 - h^2\right)\sigma_{\theta^j}^2\right]\Omega \quad , \rho_{ij} = h\sigma_{\theta^i}^2\left[\sigma_{\varepsilon_t^i}^2 - \left(1 - h^2\right)\sigma_{\theta^j}^2\right]\Omega$$

ρ_{ii} and ρ_{ij} are the regression coefficients of z_t^i and z_t^j and represent the correlation between the agent i's ability and the t-period output produced by i and j.[40] Imposing symmetry, it

[40] Let us derive the expectation of z_2^i given z_1^i and z_1^j, $E\left\{z_2^i \mid z_1^i, z_1^j\right\}$, where $\sigma' = \begin{pmatrix} cov\left(z_2^i, z_1^i\right) & cov\left(z_2^i, z_1^j\right) \end{pmatrix}$ and Σ^{-1} is given by (17). Note that $\sigma'\Sigma^{-1}$ is also the matrix of the

is $\sigma^2_{\theta^i} = \sigma^2_{\theta^j} = \sigma^2_\theta$, $\sigma^2_{\varepsilon^i_t} = \sigma^2_{\varepsilon^j_t} = \sigma^2_\varepsilon$ and the coefficients become

$$\rho_{ii} = \frac{\sigma^2_\theta \left[\sigma^2_\varepsilon + \left(1-h^2\right)\sigma^2_\theta\right]}{\left[\sigma^2_\varepsilon + (1+h)^2 \sigma^2_\theta\right]\left[\sigma^2_\varepsilon + (1-h)^2 \sigma^2_\theta\right]} \quad , \quad \rho_{ij} = \frac{h\sigma^2_\theta \left[\sigma^2_\varepsilon - \left(1-h^2\right)\sigma^2_\theta\right]}{\left[\sigma^2_\varepsilon + (1+h)^2 \sigma^2_\theta\right]\left[\sigma^2_\varepsilon + (1-h)^2 \sigma^2_\theta\right]}$$

We conclude that

$$E\left\{\theta^i \mid z^i_1, z^j_1\right\} = \rho_{ii}\left(z^i_1 - \widehat{e}^i_1 - h\widehat{e}^j_1\right) + \rho_{ij}\left(z^j_1 - \widehat{e}^j_1 - h\widehat{e}^i_1\right)$$

$$E\left\{\theta^j \mid z^i_1, z^j_1\right\} = \rho_{ij}\left(z^i_1 - \widehat{e}^i_1 - h\widehat{e}^j_1\right) + \rho_{ii}\left(z^j_1 - \widehat{e}^j_1 - h\widehat{e}^i_1\right)$$

since $\rho_{ii} = \rho_{jj}$ and $\rho_{ij} = \rho_{ji}$.

Correlation coefficients: The own-performance correlation coefficient is given by

$$\rho_{ii} = \left[cov\left(\theta^i, z^i_1\right) var\left(z^j_1\right) - cov\left(\theta^i, z^j_1\right) cov\left(z^i_1, z^j_1\right)\right]\Omega$$

It is $\frac{cov\left(\theta^i, z^i_1\right)}{cov\left(\theta^i, z^j_1\right)} > \frac{cov\left(z^i_1, z^j_1\right)}{var\left(z^j_1\right)}$ or $\frac{1}{h} > \frac{2h\sigma^2_\theta}{(1+h^2)\sigma^2_\theta + \sigma^2_\varepsilon}$ or $\sigma^2_\varepsilon + \left(1-h^2\right)\sigma^2_\theta > 0$ in the entire parameter space. Given also that $\Omega > 0$, ρ_{ii} is positive.

The cross-performance correlation coefficient is given by

$$\rho_{ij} = \left[cov\left(\theta^i, z^j_1\right) var\left(z^i_1\right) - cov\left(\theta^i, z^i_1\right) cov\left(z^i_1, z^j_1\right)\right]\Omega$$

It is $\rho_{ij} > 0$ if, and only if, $\frac{cov\left(\theta^i, z^j_1\right)}{cov\left(\theta^i, z^i_1\right)} > \frac{cov\left(z^i_1, z^j_1\right)}{var\left(z^i_1\right)}$ or $h > \frac{2h\sigma^2_\theta}{(1+h^2)\sigma^2_\theta + \sigma^2_\varepsilon}$ or $\sigma^2_\varepsilon - \left(1-h^2\right)\sigma^2_\theta > 0$.

Conditional variance: The conditional variance of θ^i at period 2 is

$$var\left\{\theta^i \mid z^i_1, z^j_1\right\} = var\left(\theta^i\right) - \sigma'\Sigma^{-1}\begin{pmatrix} cov\left(\theta^i, z^i_1\right) \\ cov\left(\theta^i, z^j_1\right)\end{pmatrix} = \sigma^2_\theta\left(1 - \rho_{ii} - h\rho_{ij}\right)$$

This is also the conditional variance of θ^j. Note that $0 < 1 - \rho_{ii} - h\rho_{ij} < 1$ since

$$1 - \rho_{ii} - h\rho_{ij} = \frac{\sigma^2_\varepsilon\left[\sigma^2_\varepsilon + \left(1+h^2\right)\sigma^2_\theta\right]}{\left[\sigma^2_\varepsilon + (1+h)^2 \sigma^2_\theta\right]\left[\sigma^2_\varepsilon + (1-h)^2 \sigma^2_\theta\right]}$$

Its derivative with respect to spillovers is given by

$$\frac{\partial\left(1 - \rho_{ii} - h\rho_{ij}\right)}{\partial h} = 2h\sigma^2_\theta\sigma^2_\varepsilon \frac{\left[\left(3 - 2h^2 - h^4\right)\sigma^2_\theta + 2\left(1-h^2\right)\sigma^2_\varepsilon\right]\sigma^2_\theta - \sigma^4_\varepsilon}{\left[\sigma^2_\varepsilon + (1+h)^2 \sigma^2_\theta\right]^2\left[\sigma^2_\varepsilon + (1-h)^2 \sigma^2_\theta\right]^2}$$

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conditional correlations $corr\left(z^i_2, z^i_1 \mid z^j_1\right)$ and $corr\left(z^i_2, z^j_1 \mid z^i_1\right)$; the partial correlation between z^i_2 and z^i_1 given z^j_1 is the correlation between the residuals resulting from the linear regression of z^i_2 with z^j_1 and z^i_1 with z^j_1 and takes the form $corr\left(z^i_2, z^i_1 \mid z^j_1\right) = \frac{corr\left(z^i_2, z^i_1\right) - corr\left(z^i_2, z^j_1\right) corr\left(z^i_1, z^j_1\right)}{\sqrt{1 - corr\left(z^i_2, z^j_1\right)^2}\sqrt{1 - corr\left(z^i_1, z^j_1\right)^2}}$. This equivalence requires the variables to be elements of the same random vector, $z = \left(z^i_1, z^i_2, ..., z^i_T, z^i_T\right)$. Thus, ρ_{ii} of the matrix $\sigma'\Sigma^{-1}$ in $E\left\{\theta^i \mid z^i_1, z^j_1\right\}$ does not satisfy the above form of conditional correlation, though it shows the linear dependence of θ^i and z^i_1 given z^j_1.

whose sign is ambiguous.

Conditional priors based only on an agent's output (one disaggregate signal):[41] The expectation of θ^i at period 2 conditional on z_t^i is

$$E\left\{\theta^i \mid z_1^i\right\} = E\left\{\theta^i\right\} + \frac{cov\left(\theta^i, z_1^i\right)}{var\left(z_1^i\right)}\left(z_1^i - \widehat{e}_1^i - h\widehat{e}_1^j\right)$$

where $\frac{cov\left(\theta^i, z_1^i\right)}{var\left(z_1^i\right)} = corr\left(\theta^i, z_1^i\right)\frac{var\left(\theta^i\right)}{var\left(z_1^i\right)} = \frac{\sigma_{\theta^i}^2}{\sigma_{\theta^i}^2 + h^2\sigma_{\theta^j}^2 + \sigma_{\varepsilon_t^i}^2}$. In the symmetric case, it is

$$E\left\{\theta^i \mid z_1^i\right\} = \lambda\left(z_1^i - \widehat{e}_1^i - h\widehat{e}_1^j\right) \quad , E\left\{\theta^i \mid z_1^j\right\} = h\lambda\left(z_1^j - \widehat{e}_1^j - h\widehat{e}_1^i\right)$$

where

$$\lambda = \frac{\sigma_\theta^2}{\sigma_\varepsilon^2 + (1 + h^2)\,\sigma_\theta^2}$$

and $0 < \lambda < 1$. The variance of θ^i given z_1^i has as

$$var\left\{\theta^i \mid z_1^i\right\} = \left[1 - corr\left(\theta^i, z_1^i\right)^2\right] var\left(\theta^i\right)$$

Thus, the conditional variances of θ^i on each of the available signals take the form

$$var\left\{\theta^i \mid z_1^i\right\} = (1 - \lambda)\,\sigma_\theta^2 \quad , var\left\{\theta^i \mid z_1^j\right\} = \left(1 - h^2\lambda\right)\sigma_\theta^2$$

Comparison: The effect of z_t^i on market's inference about θ^i is greater when it is the only performance measure. It is

$$\rho_{ii} - \lambda = \frac{-2h^2\sigma_\theta^4\left[\sigma_\varepsilon^2 - (1 - h^2)\,\sigma_\theta^2\right]}{\left[\sigma_\varepsilon^2 + (1 + h)^2\sigma_\theta^2\right]\left[\sigma_\varepsilon^2 + (1 - h)^2\sigma_\theta^2\right]\left[\sigma_\varepsilon^2 + (1 + h^2)\,\sigma_\theta^2\right]} \leq 0$$

However, z_t^i and z_t^j jointly are more informative about θ^i:

$$\frac{\partial E\left\{\theta^i \mid z_1^i, z_1^j\right\}}{\partial\theta^i} \geq \frac{\partial E\left\{\theta^i \mid z_1^i\right\}}{\partial\theta^i}$$

[41] Define $y_t^i \equiv z_t^i - e_t^i - he_t^j = \theta^i + h\theta^j + \varepsilon_t^i$ to be the part of i's output at period t that is random and not behavioral. Note also that $y_t^i \sim N\left(0, \sigma_\varepsilon^2 + \left(1 + h^2\right)\sigma_\theta^2\right)$ and $y_t^i \mid \theta^i \sim N\left(\theta^i, \sigma_\varepsilon^2 + h^2\sigma_\theta^2\right)$ since $E\left(y_t^i \mid \theta^i\right) = E\left(\theta^i \mid \theta^i\right) + hE\left(\theta^j \mid \theta^i\right) + E\left(\varepsilon_1^i \mid \theta^i\right) = \theta^i + hE\left(\theta^j\right) + E\left(\varepsilon_1^i\right) = \theta^i$ and $var\left(y_t^i \mid \theta^i\right) = E\left\{\left[y_t^i - E\left(y_t^i \mid \theta^i\right)\right]^2 \mid \theta^i\right\} = E\left\{\left[h\theta^j + \varepsilon_1^i\right]^2 \mid \theta^i\right\} = \sigma_\varepsilon^2 + h^2\sigma_\theta^2$.

By Bayes rule, it is: $f\left(\theta^i \mid y_t^i\right) = \frac{f\left(y_t^i, \theta^i\right)}{f\left(y_t^i\right)} = \frac{f\left(y_t^i \mid \theta^i\right) f\left(\theta^i\right)}{f\left(y_t^i\right)} = \frac{\frac{1}{\sqrt{2\pi\left(\sigma_\varepsilon^2 + h^2\sigma_\theta^2\right)}}\frac{1}{\sqrt{2\pi\sigma_\theta^2}}}{\frac{1}{\sqrt{2\pi\left[\sigma_\varepsilon^2 + (1+h^2)\sigma_\theta^2\right]}}}\frac{e^{-\frac{1}{2}\frac{\left(y_t^i - \theta^i\right)^2}{\sigma_\varepsilon^2 + h^2\sigma_\theta^2}} e^{-\frac{1}{2}\frac{\left(\theta^i\right)^2}{\sigma_\theta^2}}}{e^{-\frac{1}{2}\frac{\left(y_t^i\right)^2}{\sigma_\varepsilon^2 + (1+h^2)\sigma_\theta^2}}}$ where the exponential function becomes $e^{-\frac{1}{2}\left(\sigma_\theta^2\frac{\sigma_\varepsilon^2 + h^2\sigma_\theta^2}{\sigma_\varepsilon^2 + (1+h^2)\sigma_\theta^2}\right)^{-1}\left[\theta^i - \frac{\sigma_\theta^2}{\sigma_\varepsilon^2 + (1+h^2)\sigma_\theta^2}\left(z_t^i - \widehat{e}_t^i - h\widehat{e}_t^j\right)\right]^2}$ implying that $\theta^i \mid y_t^i \sim N\left(\frac{\sigma_\theta^2\left(z_t^i - \widehat{e}_t^i - h\widehat{e}_t^j\right)}{\sigma_\varepsilon^2 + (1+h^2)\sigma_\theta^2}, \sigma_\theta^2\frac{\sigma_\varepsilon^2 + h^2\sigma_\theta^2}{\sigma_\varepsilon^2 + (1+h^2)\sigma_\theta^2}\right)$ where $\sigma_\theta^2\frac{\sigma_\varepsilon^2 + h^2\sigma_\theta^2}{\sigma_\varepsilon^2 + (1+h^2)\sigma_\theta^2} = \left(1 - \frac{\sigma_\theta^2}{\sigma_\varepsilon^2 + (1+h^2)\sigma_\theta^2}\right)\sigma_\theta^2$.

since

$$\rho_{ii} + h\rho_{ij} - \lambda = \frac{h^2\sigma_\theta^2 \left[\sigma_\varepsilon^2 - \left(1-h^2\right)\sigma_\theta^2\right]^2}{\left[\sigma_\varepsilon^2 + (1+h)^2\sigma_\theta^2\right]\left[\sigma_\varepsilon^2 + (1-h)^2\sigma_\theta^2\right]\left[\sigma_\varepsilon^2 + \left(1+h^2\right)\sigma_\theta^2\right]} \geq 0$$

and, in particular, it is $\frac{\partial\left(\rho_{ii}+h\rho_{ij}-\lambda\right)}{\partial h} > 0$.

A.2 Proof of lemma 1

Past performance allows the market to learn more about θ^i as it is manifested by a decrease in the unconditional variance of θ^i; i.e. $var\left(\theta^i\right) - var\left\{\theta^i \mid z_1^i, z_1^j\right\} = \rho_{ii} + h\rho_{ij}$ where

$$\rho_{ii} + h\rho_{ij} = \frac{\sigma_\theta^2\left[\left(1-h^2\right)^2\sigma_\theta^2 + \left(1+h^2\right)\sigma_\varepsilon^2\right]}{\left[\sigma_\varepsilon^2 + (1+h)^2\sigma_\theta^2\right]\left[\sigma_\varepsilon^2 + (1-h)^2\sigma_\theta^2\right]}$$

The derivative with respect to spillovers is given by

$$\frac{\partial\left(\rho_{ii}+h\rho_{ij}\right)}{\partial h} = -2h\sigma_\theta^2\sigma_\varepsilon^2\frac{\left[\left(3-2h^2-h^4\right)\sigma_\theta^2 + 2\left(1-h^2\right)\sigma_\varepsilon^2\right]\sigma_\theta^2 - \sigma_\varepsilon^4}{\left[\sigma_\varepsilon^2 + (1+h)^2\sigma_\theta^2\right]^2\left[\sigma_\varepsilon^2 + (1-h)^2\sigma_\theta^2\right]^2}$$

Thus, $\frac{\partial\left(\rho_{ii}+h\rho_{ij}\right)}{\partial h} > 0$ if, and only if, the nominator is negative; i.e. $\frac{\sigma_\varepsilon^2}{\sigma_\theta^2} > \left(1-h^2\right)^{\frac{1}{2}}\left[2 + \left(1-h^2\right)^{\frac{1}{2}}\right]$.

A.3 Proof of proposition 2

Omitting terms that are independent of e_1^i and having $w_t^i = E\left\{(1+h)\theta^i \mid z_{t-1}^i, z_{t-1}^j\right\} + (1+h)\widehat{e}_t^i$, each agent i maximizes the form

$$-\psi\left(e_1^i\right) + E\left\{(1+h)\ \theta^i \mid z_1^i, z_1^j\right\}$$

Given the conditional mean of θ^i by (2), agent i's implicit reputation incentives arise;

$$\psi'\left(e_1^{i*}\right) = (1+h)\left(\rho_{ii} + h\rho_{ij}\right)$$

A.4 Proof of proposition 3

The derivative of the implicit incentives with respect to h has as

$$\frac{\partial\psi'\left(e_1^{i*}\right)}{\partial h} = \rho_{ii} + h\rho_{ij} + (1+h)\frac{\partial\left(\rho_{ii}+h\rho_{ij}\right)}{\partial h}$$

Under assumption $(O1)$ and according to lemma 3, we have:

- if $\frac{\sigma_\varepsilon^2}{\sigma_\theta^2} > \left(1-h^2\right)^{\frac{1}{2}}\left[2 + \left(1-h^2\right)^{\frac{1}{2}}\right]$, it is $\frac{\partial\left(\rho_{ii}+h\rho_{ij}\right)}{\partial h} > 0$ and $\frac{\partial e_1^{i*}}{\partial h} > 0$.

- if $\frac{\sigma_\varepsilon^2}{\sigma_\theta^2} < (1-h^2)^{\frac{1}{2}}\left[2+(1-h^2)^{\frac{1}{2}}\right]$, it is $\frac{\partial\left(\rho_{ii}+h\rho_{ij}\right)}{\partial h} < 0$. Then, career concerns increase with the degrees of teamwork interactions only if, $\frac{\rho_{ii}+h\rho_{ij}}{1+h} < \frac{\partial\left|\rho_{ii}+h\rho_{ij}\right|}{\partial h}$. That is only if, $\frac{2h\sigma_\theta^2\sigma_\varepsilon^2}{1+h}\frac{\sigma_\theta^2\left[\left(1-h^2\right)^2\sigma_\theta^2+\left(1+h^2\right)\sigma_\varepsilon^2\right]}{\sigma_\varepsilon^2+\left[(1-h^2)^2\sigma_\theta^2+2(1+h^2)\sigma_\varepsilon^2\right]\sigma_\theta^2} < \frac{\sigma_\varepsilon^2-\left[\left(3-2h^2-h^4\right)\sigma_\theta^2+2\left(1-h^2\right)\sigma_\varepsilon^2\right]\sigma_\theta^2}{\left[\sigma_\varepsilon^2+(1+h)^2\sigma_\theta^2\right]^2\left[\sigma_\varepsilon^2+(1-h)^2\sigma_\theta^2\right]^2}$

A.5 Proof of proposition 4

Each agent exercises her bargaining power and sings the contract that allows her to earn her reputational bonus. The base payment satisfies the individual rationality constraint (IR_2^i) with equality:

$$\alpha_2^i\left(\beta_2^i,\gamma_2^i\right)=\widetilde{\theta}_2^i-E\left\{\beta_2^i z_2^i+\gamma_2^i z_2^j \mid z_1^i,z_1^j\right\}+\psi\left(e_2^i\right)+\frac{r}{2}var\left\{w_2^i \mid z_1^i,z_1^j\right\} \tag{18}$$

Substituting (7) and (8) into the principal's utility, it becomes

$$E\left\{U_t^P\right\}=\sum_{i=1}^{2}\left\{E\left\{\theta^i+h\theta^j \mid z_1^i,z_1^j\right\}+e_2^{i*}+he_2^{j*}-\widetilde{\theta}_2^i-\psi\left(e_2^{i*}\right)\right\}-\frac{r}{2}\sum_{i=1}^{2}Var\left\{w_2^i \mid z_1^i,z_1^j\right\}$$

The conditional variance of the second-period wage is

$$\begin{aligned}Var\left\{w_2^i \mid z_1^i,z_1^j\right\} \;=\; & \left[\left(\beta_2^i+h\gamma_2^i\right)^2+\left(h\beta_2^i+\gamma_2^i\right)^2+2h\delta\left(\beta_2^i+h\gamma_2^i\right)\left(h\beta_2^i+\gamma_2^i\right)\right]\left(1-\rho_{ii}-h\rho_{ij}\right)\sigma_\theta^2\\ & +\left[\left(\beta_2^i\right)^2+\left(\gamma_2^i\right)^2\right]\sigma_\varepsilon^2\end{aligned}$$

where $corr\left(\theta^i,\theta^j \mid z_1^i,z_1^j\right)=h\delta$, $|\delta|\leq 1$.[42] In this multi-agent framework, the principal chooses the incentive parameters that satisfy the first-order conditions of his problem with respect to β_2^i and γ_2^i. The optimal pay-for-other performance parameter is obtained by the equation:

$$\frac{\partial Var\left(w_2^i\right)/\partial\beta_2^i}{\partial\psi'\left(e_2^{i*}\right)/\partial\beta_2^i}=\frac{\partial Var\left(w_2^i\right)/\partial\gamma_2^i}{\partial\psi'\left(e_2^{i*}\right)/\partial\gamma_2^i}$$

Given equation (7), we get

$$\left[\left(1+2h^2\delta\right)\left(\beta_2^i+h\gamma_2^i\right)+h\left(1+2\delta\right)\left(h\beta_2^i+\gamma_2^i\right)\right]\left(1-\rho_{ii}-h\rho_{ij}\right)\sigma_\theta^2+\beta_2^i\sigma_\varepsilon^2=$$

$$\frac{1}{h}\left\{\left[h\left(1+2\delta\right)\left(\beta_2^i+h\gamma_2^i\right)+\left(1+2h^2\delta\right)\left(h\beta_2^i+\gamma_2^i\right)\right]\left(1-\rho_{ii}-h\rho_{ij}\right)\sigma_\theta^2+\gamma_2^i\sigma_\varepsilon^2\right\}$$

resulting to $\gamma_2^{i*}=h\Delta_2\beta_2^{i*}$ where $\Delta_2\equiv\frac{\sigma_\varepsilon^2-(1+2\delta)\left(1-h^2\right)\left(1-\rho_{ii}-h\rho_{ij}\right)\sigma_\theta^2}{\sigma_\varepsilon^2+(1+2h^2\delta)(1-h^2)\left(1-\rho_{ii}-h\rho_{ij}\right)\sigma_\theta^2}$. Letting also $\Sigma_2\equiv\sigma_\varepsilon^2+\left[1+h^2\left(1+2\Delta_2\right)+2h\delta\left[2+\Delta_2\left(1+h^2\right)\right]\right]\left(1-\rho_{ii}-h\rho_{ij}\right)\sigma_\theta^2$, the first-order-condition with re-

[42] It is $\delta\equiv\frac{\sigma_\theta^2\left[\sigma_\varepsilon^2-\left(1-h^2\right)\sigma_\theta^2\right]}{\left[\sigma_\varepsilon^2+(1+h)^2\sigma_\theta^2\right]\left[\sigma_\varepsilon^2+(1-h)^2\sigma_\theta^2\right]+\sigma_\theta^2\left[\sigma_\varepsilon^2+(1-h^2)\sigma_\theta^2\right]}$.

spect to β_2^i can be reduced to

$$1+h-\psi'\left(e_2^{i*}\right)-r\Sigma_2\frac{\psi'\left(e_2^{i*}\right)}{1+h^2\Delta_2}\psi''\left(e_2^{i*}\right)=0$$

or, by equation (7),

$$1+h-\left(1+h^2\Delta_2\right)\beta_2^{i*}-r\Sigma_2\beta_2^{i*}\psi''\left(e_2^{i*}\right)=0$$

$$\beta_2^{i*}=\frac{1+h}{1+h^2\Delta_2+r\Sigma_2\psi''\left(e_2^{i*}\right)}$$

A.6 Proof of proposition 5

Second-period base payment. The second-period base payment is such that satisfied the second-period individual rationality constraint (IR_2^i) with equality:

$$\alpha_2^i\left(\beta_2^i,\gamma_2^i\right)=\widetilde{\theta}_2^i-E\left\{\beta_2^i z_2^i+\gamma_2^i z_2^j\mid z_1^i,z_1^j\right\}+\psi\left(e_2^i\right)+\frac{r}{2}var\left\{w_2^i\mid z_1^i,z_1^j\right\}$$

where

$$\widetilde{\theta}_2^i-E\left\{\beta_2^i z_2^i+\gamma_2^i z_2^j\mid z_1^i,z_1^j\right\}=$$

$$\begin{aligned}
&= E\left\{(1+h)\,\theta^i\mid z_1^i,z_1^j\right\}-E\left\{\beta_2^i z_2^i+\gamma_2^i z_2^j\mid z_1^i,z_1^j\right\}\\
&= E\left\{\left(1+h-\beta_2^i-h\gamma_2^i\right)\theta^i-\left(h\beta_2^i+\gamma_2^i\right)\theta^j-\left(\beta_2^i+h\gamma_2^i\right)e_2^i-\left(h\beta_2^i+\gamma_2^i\right)e_2^j-\beta_2^i\varepsilon_2^i-\gamma_2^i\varepsilon_2^j\mid z_1^i,z_1^j\right\}\\
&= \left[\left(1+h-\beta_2^i-h\gamma_2^i\right)\rho_{ii}-\left(h\beta_2^i+\gamma_2^i\right)\rho_{ij}\right]\left(z_1^i-\widehat{e}_1^i-h\widehat{e}_1^j\right)\\
&\quad+\left[\left(1+h-\beta_2^i-h\gamma_2^i\right)\rho_{ij}-\left(h\beta_2^i+\gamma_2^i\right)\rho_{ii}\right]\left(z_1^j-\widehat{e}_1^j-h\widehat{e}_1^i\right)-\left(\beta_2^i+h\gamma_2^i\right)\widehat{e}_2^i-\left(h\beta_2^i+\gamma_2^i\right)\widehat{e}_2^j\\
&= M_1^{ii}\left(z_1^i-\widehat{e}_1^i-h\widehat{e}_1^j\right)+M_1^{ij}\left(z_1^j-\widehat{e}_1^j-h\widehat{e}_1^i\right)-\left(\beta_2^i+h\gamma_2^i\right)\widehat{e}_2^i-\left(h\beta_2^i+\gamma_2^i\right)\widehat{e}_2^j
\end{aligned}$$

Derivation of $Var\left\{w_1^i+w_2^i\right\}$. Let the first-period wage be $\widetilde{w}_1^i=\alpha_1^i+\beta_1^i z_1^i+\gamma_1^i z_1^i$. It is

$$Var\left\{w_1^i\right\}=Var\left\{\widetilde{w}_1^i\right\}+Var\left\{\alpha_2^i\left(\beta_2^{i*},\gamma_2^{i*}\right)\right\}+2Cov\left\{\widetilde{w}_1^i,\alpha_2^i\left(\beta_2^{i*},\gamma_2^{i*}\right)\right\}$$

where

$$Var\left\{\widetilde{w}_1^i\right\}=\left[\left(\beta_1^i+h\gamma_1^i\right)^2+\left(h\beta_1^i+\gamma_1^i\right)^2\right]\sigma_\theta^2+\left[\left(\beta_1^i\right)^2+\left(\gamma_1^i\right)^2\right]\sigma_\varepsilon^2 \tag{19}$$

Omitting non-stochastic variables, the second term is derived by equations (1), (2), (8) and (13);

$$\begin{aligned}
Var\left\{\alpha_2^i\left(\beta_2^{i*},\gamma_2^{i*}\right)\right\} &= Var\left\{\left(1+h-\beta_2^{i*}-\Delta h^2\beta_2^{i*}\right)\left[\rho_{ii}z_1^i+\rho_{ij}z_1^j\right]-\left(\beta_2^{i*}+\Delta\beta_2^{i*}\right)\left[\rho_{ij}z_1^i+\rho_{ii}z_1^j\right]\right\}\\
&= \left[\left(M_1^{ii}+hM_1^{ij}\right)^2+\left(hM_1^{ii}+M_1^{ij}\right)^2\right]\sigma_\theta^2+\left[\left(M_1^{ii}\right)^2+\left(M_1^{ij}\right)^2\right]\sigma_\varepsilon^2
\end{aligned}$$

The third term takes the form

$$\begin{aligned} Cov\left\{\widetilde{w}_1^i, \alpha_2^i\left(\beta_2^{i*}, \gamma_2^{i*}\right)\right\} &= \left[\left(\beta_1^i + h\gamma_1^i\right)\left(M_1^{ii} + hM_1^{ij}\right) + \left(h\beta_1^i + \gamma_1^i\right)\left(hM_1^{ii} + M_1^{ij}\right)\right]\sigma_\theta^2 \\ &\quad + \left[\beta_1^i M_1^{ii} + \gamma_1^i M_1^{ij}\right]\sigma_\varepsilon^2 \end{aligned}$$

Thus, letting $B_1^i \equiv \beta_1^i + M_1^{ii}$ and $\Gamma_1^i \equiv \gamma_1^i + M_1^{ij}$ be (say) *total* 'own-performance' and 'other-performance' incentives, the variance of the first-period wage is

$$Var\left\{w_1^i\right\} = \left\{\left[B_1^i + h\Gamma_1^i\right]^2 + \left[hB_1^i + \Gamma_1^i\right]^2\right\}\sigma_\theta^2 + \left[\left(B_1^i\right)^2 + \left(\Gamma_1^i\right)^2\right]\sigma_\varepsilon^2$$

Given equation (**??**), we also have

$$Cov\left\{w_1^i, w_2^i\right\} = \left\{\left(\beta_2^i + h\gamma_2^i\right)\left[B_1^i + h\Gamma_1^i\right] + \left(h\beta_2^i + \gamma_2^i\right)\left[hB_1^i + \Gamma_1^i\right]\right\}\sigma_\theta^2$$

Therefore, the variance of agent i's compensation is

$$Var\left\{w_1^i + w_2^i\right\} = Var\left\{w_1^i\right\} + Var\left\{w_2^i\right\} + 2Cov\left\{w_1^i, w_2^i\right\}$$

$$= \left\{\left[B_1^i + \beta_2^i + h\left(\Gamma_1^i + \gamma_2^i\right)\right]^2 + \left[h\left(B_1^i + \beta_2^i\right) + \Gamma_1^i + \gamma_2^i\right]^2\right\}\sigma_\theta^2 + \left[\left(B_1^i\right)^2 + \left(\Gamma_1^i\right)^2 + \left(\beta_2^i\right)^2 + \left(\gamma_2^i\right)^2\right]\sigma_\varepsilon^2$$

Optimal first-period incentive parameters. Given that the individual rationality constraint is binding at the optimum and $\widetilde{\theta}_1^i$ is zero, the first-period base payment takes the form

$$\alpha_1^i = -E\left\{\beta_1^i z_1^i + \gamma_1^i z_1^j\right\} + \psi\left(e_1^{i*}\right) - E\left\{w_2^{i*}\right\} + \psi\left(e_2^{i*}\right) + \frac{r}{2}var\left\{w_1^i + w_2^i\right\} \tag{20}$$

Thus, the market perceives that the optimal first-period contractual choices are obtained by the principal's problem given that the certain equivalent of each agent i's utility takes the form (equations (8), (10))

$$CE_1^i\left(\beta_1^i, \gamma_1^i\right) = E\left\{z_1^i\right\} - \psi\left(e_1^{i*}\right) + E\left\{z_2^{i*}\right\} - \psi\left(e_2^{i*}\right) - \frac{r}{2}Var\left\{w_1^i + w_2^i\right\}$$

The optimal efforts in each period are given by equations (7), (11), (12) and (13). Setting $B_1^i \equiv \beta_1^i + M_1^{ii}$ and $\Gamma_1^i \equiv \gamma_1^i + M_1^{ij}$ as (say) *total* 'own-performance' and 'other-performance' incentives, the optimal γ_1^i is derived by:

$$\frac{\partial Var\left(w_1^i + w_2^i\right)/\partial\beta_1^i}{\partial\psi'\left(e_1^{i*}\right)/\partial\beta_1^i} = \frac{\partial Var\left(w_1^i + w_2^i\right)/\partial\gamma_1^i}{\partial\psi'\left(e_1^{i*}\right)/\partial 1 + h\gamma_1^i}$$

or

$$\begin{aligned} &\left[\left(1 + h^2\right)\left(B_1^i + \beta_2^i\right) + 2h\left(\Gamma_1^i + \gamma_2^i\right)\right]\sigma_\theta^2 + \left(B_1^i + \beta_2^i\right)\sigma_\varepsilon^2 \\ = &\frac{1}{h}\left\{\left[2h\left(B_1^i + \beta_2^i\right) + \left(1 + h^2\right)\left(\Gamma_1^i + \gamma_2^i\right)\right]\sigma_\theta^2 + \left(\Gamma_1^i + \gamma_2^i\right)\sigma_\varepsilon^2\right\} \end{aligned}$$

or

$$\gamma_1^{i*} = h\Delta_1 B_1^{i*} - M_1^{ij} - \frac{\left(1-h^2\right)\sigma_\theta^2\left(h\beta_2^{i*}+\gamma_2^{i*}\right)}{\sigma_\varepsilon^2+\left(1-h^2\right)\sigma_\theta^2}$$

where $\Delta_1 \equiv \frac{\sigma_\varepsilon^2-\left(1-h^2\right)\sigma_\theta^2}{\sigma_\varepsilon^2+\left(1-h^2\right)\sigma_\theta^2}$. Substituting γ_1^{i*} in the first-order condition with respect to β_1^i, we get

$$\begin{aligned}\beta_1^{i*} \;=\; & \frac{1+h}{1+h^2\Delta_1+r\Sigma_1\psi''\left(e_1^{i*}\right)} - M_1^{ii} - \frac{\left[\left(1+h^2\right)\beta_2^{i*}+2h\gamma_2^{i*}\right]r\sigma_\theta^2\psi''\left(e_1^{i*}\right)}{1+h^2\Delta_1+r\Sigma_1\psi''\left(e_1^{i*}\right)} \\ & +h\frac{\left(1-h^2\right)\left(h\beta_2^{i*}+\gamma_2^{i*}\right)\sigma_\theta^2\left[1+2r\sigma_\theta^2\psi''\left(e_1^{i*}\right)\right]}{\left[1+h^2\Delta_1+r\Sigma_1\psi''\left(e_1^{i*}\right)\right]\left[\sigma_\varepsilon^2+\left(1-h^2\right)\sigma_\theta^2\right]}\end{aligned}$$

where $\Sigma_1 \equiv \sigma_\varepsilon^2 + \left(1+2h^2\Delta_1+h^2\right)\sigma_\theta^2$.

A.7 Aggregate measure of performance

The aggregate measure observed is the total output:

$$z_t^i + z_t^j = (1+h)\left(\theta^i+\theta^j+e_t^i+e_t^j\right)+\varepsilon_t^i+\varepsilon_t^j$$

where $Var\left(z_t^i+z_t^j\right) = 2\left[\sigma_\varepsilon^2+(1+h)^2\sigma_\theta^2\right]$ and $Cov\left(\theta^i, z_t^i+z_t^j\right) = (1+h)\sigma_\theta^2$. The conditional distribution of θs has as based on this signal has as

$$\begin{aligned}E\left\{\theta^i \mid z_1^i+z_1^j\right\} &= E\left\{\theta^j \mid z_1^i+z_1^j\right\} = \rho_{i+j}\left[z_1^i+z_1^j-(1+h)\left(\widehat{e}_1^i+\widehat{e}_1^j\right)\right] \\ Var\left(\theta^i \mid z_t^i+z_t^j\right) &= Var\left(\theta^j \mid z_t^i+z_t^j\right) = \left[1-Corr\left(\theta^i, z_t^i+z_t^j\right)^2\right]Var\left(\theta^i\right) = \left[1-(1+h)\rho_{i+j}\right]\sigma_\theta^2\end{aligned}$$

where

$$\rho_{i+j} = \frac{(1+h)\sigma_\theta^2}{2\left[\sigma_\varepsilon^2+(1+h)^2\sigma_\theta^2\right]}$$

ρ_{i+j} increases with h if, and only if,

$$\begin{aligned}\frac{\partial\rho_{i+j}}{\partial h} > 0 &\Leftrightarrow \frac{\partial\left[Cov\left(\theta^i, z_t^i+z_t^j\right)/Var\left(z_t^i+z_t^j\right)\right]}{\partial h} > 0 \Leftrightarrow \frac{\partial Cov\left(\theta^i, z_t^i+z_t^j\right)/\partial h}{Cov\left(\theta^i, z_t^i+z_t^j\right)} > \frac{\partial Var\left(z_t^i+z_t^j\right)/\partial h}{Var\left(z_t^i+z_t^j\right)} \\ &\Leftrightarrow \sigma_\theta^2\frac{\sigma_\varepsilon^2-(1+h)^2\sigma_\theta^2}{2\left[\sigma_\varepsilon^2+(1+h)^2\sigma_\theta^2\right]^2} > 0 \Leftrightarrow \frac{\sigma_\varepsilon^2}{\sigma_\theta^2} > (1+h)^2\end{aligned}$$

$$\frac{\partial\rho_{i+j}}{\partial h} = \sigma_\theta^2\frac{\sigma_\varepsilon^2-(1+h)^2\sigma_\theta^2}{2\left[\sigma_\varepsilon^2+(1+h)^2\sigma_\theta^2\right]^2}$$

However, implicit incentives increase for all $h \in (0,1]$;

$$\frac{\partial e_{i+j}^*}{\partial h} > 0 \Leftrightarrow 2(1+h)\rho_{i+j} + (1+h)^2\frac{\partial\rho_{i+j}}{\partial h} > 0$$

A.8 Explicit incentives & aggregate measure of performance

Agent i maximizes

$$CE_2^i = E\left\{\alpha_2^i + \beta_2^i\left(z_2^i + z_2^j\right) \mid z_1^i + z_1^j\right\} - \psi\left(e_2^i\right) - \frac{r}{2}Var\left\{w_2^i \mid z_1^i + z_1^j\right\}$$

where

$$Var\left\{w_2^i \mid z_1^i + z_1^j\right\} = 2\beta_{2i}^2\left\{\sigma_\varepsilon^2 + (1+h)^2\left[1-(1+h)\rho_{i+j}\right]\sigma_\theta^2\right\}$$

We derive the optimal second period effort, $\psi'\left(e_2^{i,ag}\right) = \beta_2^i(1+h)$, and substitute it in the principal's problem. Given also the second-period individual rationality constraints are binding, the first-order condition implies the optimal slope:

$$\beta_2^{i,ag} = \frac{(1+h)^2}{(1+h)^2 + r\Sigma_2^{i+j}\psi''\left(e_2^{i,ag}\right)}$$

where $\Sigma_2^{i+j} = 2\left[\sigma_\varepsilon^2 + (1+h)^2\left[1-(1+h)\rho_{i+j}\right]\sigma_\theta^2\right]$. In the first-period, agent i's objective function is

$$CE_1^i = E\left\{w_1^i\right\} - \psi\left(e_1^i\right) + E\left\{w_2^i\left(\beta_2^{i,ag}\right)\right\} - \psi\left(e_2^{i,ag}\right) + \frac{r}{2}Var\left\{w_1^i + w_2^i\right\}$$

By the (IR_2^i) constraint, the base payment becomes

$$\alpha_2^i\left(\beta_2^{i,ag}\right) = \widetilde{\theta}_2^i - E\left\{\beta_2^i\left(z_2^i + z_2^j\right) \mid z_1^i + z_1^j\right\} + \psi\left(e_2^{i,ag}\right) + \frac{r}{2}var\left\{w_2^i \mid z_1^i + z_1^j\right\}$$

It is

$$\widetilde{\theta}_2^i - E\left\{\beta_2^i\left(z_2^i + z_2^j\right) \mid z_1^i + z_1^j\right\} =$$

$$\begin{aligned}
&= E\left\{\theta^i \mid z_1^i, z_1^j\right\} - E\left\{\beta_2^i z_2^i + \beta_2^i z_2^j \mid z_1^i, z_1^j\right\} \\
&= E\left\{\left(1-\beta_2^i\right)\theta^i - \beta_2^i\theta^j \mid z_1^i, z_1^j\right\} \\
&= E\left\{\left(1+h-2\left(\beta_2^i + h\beta_2^i\right)\right)\theta^i - \left(\beta_2^i + h\beta_2^i\right)e_2^i - \left(h\beta_2^i + \beta_2^i\right)e_2^j - \beta_2^i\varepsilon_2^i - \beta_2^i\varepsilon_2^j \mid z_1^i, z_1^j\right\} \\
&= \left(1+h-2\left(\beta_2^i + h\beta_2^i\right)\right)E\left\{\theta^i \mid z_1^i, z_1^j\right\} - \left(\beta_2^i + h\beta_2^i\right)e_2^i - \left(h\beta_2^i + \beta_2^i\right)e_2^j \\
&= (1+h)\left(1-2\beta_2^i\right)\rho_{i+j}\left[z_t^i + z_t^j - (1+h)\left(\widehat{e}_t^i + \widehat{e}_t^j\right)\right] - (1+h)\beta_2^i e_2^i - (1+h)\beta_2^i e_2^j
\end{aligned}$$

To derive the form of $Var\left\{w_1^i + w_2^i\right\}$, we first calculate the following statistics:

$$\begin{aligned}
Var\left\{\alpha_t^i + \beta_t^i z_t^i + \gamma_t^i z_t^j\right\} &= 2\left(\beta_t^i\right)^2\left[\sigma_\varepsilon^2 + (1+h)^2\sigma_\theta^2\right] \\
Var\left\{\alpha_2^i\right\} &= 2(1+h)^2\left(1-2\beta_2^i\right)^2\rho_{i+j}^2\left[\sigma_\varepsilon^2 + (1+h)^2\sigma_\theta^2\right] \\
Cov\left\{\alpha_1^i + \beta_1^i z_1^i + \gamma_1^i z_1^j, \alpha_{2i}\right\} &= 2(1+h)\left(1-2\beta_2^i\right)\rho_{i+j}\beta_1^i\left[\sigma_\varepsilon^2 + (1+h)^2\sigma_\theta^2\right] \\
Var\left\{w_1^i(\alpha_1^i, \alpha_2^i)\right\} &= 2\left[\sigma_\varepsilon^2 + (1+h)^2\sigma_\theta^2\right]\left[\beta_1^i + (1+h)\left(1-2\beta_2^i\right)\rho_{i+j}\right]^2
\end{aligned}$$

implying that

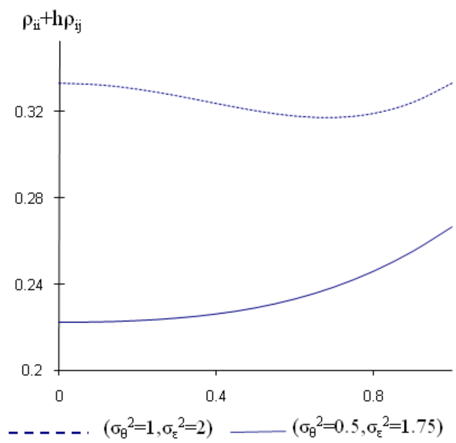
$$Var\left\{w_1^i + w_2^i\right\} = 2\left[\beta_1^i + (1+h)\left(1-2\beta_2^i\right)\rho_{i+j} + \beta_2^i\right]^2\left\{\sigma_\varepsilon^2 + (1+h)^2\sigma_\theta^2\right\}$$

Given that the optimal effort is $\psi'\left(e_1^{i,ag}\right) = (1+h)\left[\beta_1^i + \left(1-2\beta_2^{i,ag}\right)(1+h)\rho_{i+j}\right]$, we take the first-order condition and derive the optimal slope of the first-period contract:

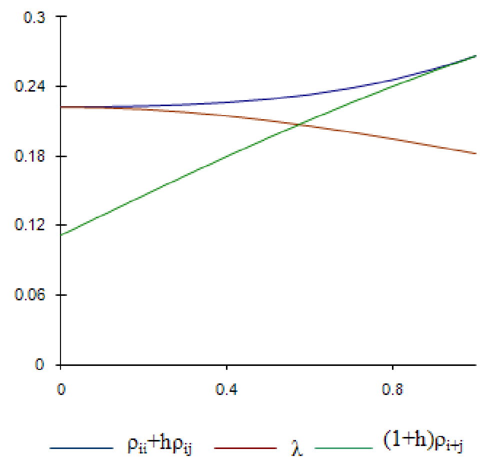
$$\beta_1^{i,ag} = \frac{(1+h)^2}{(1+h)^2 + r\Sigma_1^{i+j}\psi''\left(e_1^{i,ag}\right)} - \left(1-2\beta_2^{i,ag}\right)(1+h)\rho_{i+j} - \frac{2(1+h)^2 r\sigma_\theta^2\psi''\left(e_2^{i,ag}\right)}{(1+h)^2 + r\Sigma_1^{i+j}\psi''\left(e_1^{i,ag}\right)}\beta_2^{i,ag}$$

where $\Sigma_1^{i+j} = 2\left[\sigma_\varepsilon^2 + (1+h)^2\sigma_\theta^2\right]$.

Figure 2. Learning process and spillovers



2a



2b