Compensation contracts and career concerns*

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Abstract

This paper studies compensation contracts and career concerns of team workers when an agent’s individual production depends on her teammate’s effort and ability. We show that a principal who commits herself to a life-time salary path and induces a low-risk averse agent to help her colleague, she may encourage her to sabotage, as her employment is extended to many periods. If commitment is not feasible, sabotage incentives emerge because of career concerns. Such incentives arise for both long-term and temporary workers. Negative contractual incentives now are used to diminish workers’ appetite to sabotage.

Keywords: career concerns, compensation contracts, team incentives, sabotage incentives, relative performance

Jel codes: D83, J24, M54

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1 Introduction

In recent years, the re-engineering of R&D process in large corporations has shifted the organization of work towards various forms of teamworking. The cross-functional and multi-disciplinary nature of research teams often entails that team members have different abilities that bring in the innovation process. The degree to which each team member contributes to a specific project and the number of years each researcher is involved in a project also vary. The U.S. Bureau of Labor Statistics show that for 1991, the median tenure of engineers was 6.7 years, and that of mathematical and computer scientists was 4.2 years. Innovative firms also differ in their employment policies: they sign either long-term or short-term contracts with their workers, whose research outcome also depends on the abilities of the fellow members of their team. Auriol, Friebel & Pechlivanos (2002) assume that a worker’s production depends on her colleagues’ help effort and examine how cooperation among workers is affected by managerial commitment. This paper extends the existing literature by investigating how compensation contracts are shaped by managerial commitment and career concerns when team members’ effort and ability influence a worker’s performance.

This paper employs Holmström’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. We analyze how the managerial commitment and the duration of employment affect a worker’s incentives to help her teammate when her individual performance and thus the learning process about her own ability depend on the quality of her team. We show that the principal who fully commits to a life-time income path may induce a high risk-averse agent, whose contribution in her teammate’s project output is insignificant, even to sabotage her colleague, due to the trade-off between insurance and incentives. We also argue that while for a short work life-span the principal can induce an agent to help her colleague, for a long life-span, the same agent may be induced to sabotage. As the duration of employment is extended and thus the uncertainty associated to a teammate’s ability increases the variance of a worker’s wage, sabotage incentives prevail. Note that when a worker’s performance is independent of her teammate’s ability as in Auriol et al. (2002), workers behave altruistically and always help their colleagues. Assuming now that only short-term contracts are provided which are renegotiated in each period, career concerns also arise. A worker now has implicit incentives to sabotage her colleague because she wants to bias the learning process about her ability in her favor. A negative explicit incentive now will be used by the principal as a mean

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1Empirical literature provides evidence that knowledge is transmitted within a team and skills diversity affects labor supply and productivity (Lazear (1999)). The benefits of team interactions depend on whether the workers have distinct or identical knowledge and skills, which indicate the degree of heterogeneity among the teammates.

2The use of career concerns as an incentive device in the intra-firm relationships which may substitute explicit incentives due to compensation contracts is first discussed by Fama (1980) and elaborated by Holmström (1982). Gibbons & Murphy (1992) consider linear contracts and formalize this argument.
of diminishing the worker's eagerness to sabotage. When a worker's ability affect her teammate's performance, help or sabotage incentives arise even for temporary workers who will be matched with another worker in the next period, in their attempt to manipulate market perceptions about their own ability through their current teammates' production.

We consider a risk-neutral principal who appoints two risk-averse agents whose individual "project" outputs are observable and contractible, allowing the principal to treat agents separately through individual-based schemes (Itoh (1991), Itoh (1992), Auriol et al. (2002)). The incentive packages are derived in a linear principal-agent model (Holmström & Milgrom (1987), Gibbons & Murphy (1992)) and are based on explicit comparisons of team members' outputs. Agents consider work and help as two separate tasks and their cost-of-effort functions are task-specific. A worker's production function is linear in her "work" effort and her own innate ability, her teammate's "help" effort and ability, and a transitory shock. Thus, a teammate's ability influences a worker's performance. Workers' abilities and the shocks in production are independent and normally distributed. We also consider different degrees of incoming and outgoing skills benefit to and from an agent: these degrees indicate how sensitive an agent's output is to her teammate's characteristics. The degrees of teamwork interactions that measure the contribution of an agent's help effort to her teammate's production can also be different. All these degrees are exogenous.

We first assume that multiperiod contracts are feasible, implying that the principal can commit herself to a life-time income path before the realization of outputs. Each agent is exposed to the risk associated with her own and her teammate's innate ability, which are inputs in both workers' production functions. The optimal contractual parameter based on an agent's own project output is always positive, indicating that higher agent performance is rewarded with a higher payment. However, we argue that the optimal contractual parameter based on a teammate's output can be negative for a highly risk-averse agent whose contribution in the other's production is negligible. This happens because both performance measures are sensitive to both teammates' unknown abilities, increasing the variance of the rewards. Due to risk-sharing, the principal provides insurance that

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3 The existing literature uses such contracts when the market shocks that hit agents' production are correlated. In our setting, market shocks are independent, however, as in Chalioti (2015), individual outputs are correlated due to teamwork interactions. Team-incentive contracts are the consequence of the efficient use of information conveyed by both performance measures about an agent's effort and ability.

4 Some principal-agent models allow both parties to hold some bargaining power (e.g., Pitchford (1998)) while other models assume that either party can make a 'take-it-or-leave-it' offer (e.g., Mookherjee & Ray (2002)). Bernhardt (1995) studies how the composition of an agent's skills and the non-observability of her ability affect wage and promotion paths. Ferrer (2010) studies the effects of lawyers' career concerns on litigation when the outcome of a trial depends on the opposing lawyers' effort and abilities. Bilanakos (2013) argues that the provision of general training increases the worker's bargaining power vis-à-vis the employer.

5 Because of task-specific cost functions, there are benefits of influencing the teammate's project output. Such incentives will not arise with a total-effort-cost function as in Holmström & Milgrom (1991a), where there are negative externalities between the tasks: providing support crowds out effort allocated to an agent's own task.
involves underprovision of effort to fulfill both tasks. It is striking that instead of shutting down the effect of a teammate’s production on a worker’s compensation by setting the pay-for-teammate performance parameter zero, the principal sets it negative. In turn, she induces this worker to sabotage, decreasing her teammate production and thus her teammate’s payment as well as the variance of her wage. This is in sharp contrast to Auriol et al. (2002) where the principal, who provides long-term contracts, always induces both agents to help their colleagues, regardless of their degree of tolerance against risk.

We also establish that under full commitment, while a principal can induce an agent to help her colleague for a short work life-span, she may induce the same agent to sabotage if her work life-span is long. Notice that the covariance of wages provided in different periods depends only on the variance of teammates’ abilities. As employment extends to many periods, the risk associated with the teammates’ abilities increases and influences significantly the principal’s inference about agents’ effort levels. Thus, a principal who installs cooperation when employment is short, she may induce competition as the duration of long-term contracts increases.

Without commitment for income paths, the principal renegotiates the contracts with the agents in each period and reputation incentives also arise. The market draws inferences about abilities via both agents’ current project outputs. By exerting effort, an agent can influence her own and her teammate’s performance measures in order to bias the learning process in her favor. In our model, if an agent’s contribution in her teammate’s production is insignificant, the market attributes higher other’s performance to her teammate’s ability. This is a bad signal for the agent. Her help will increase the teammate’s performance further, which biases the learning process against her. Thus, an agent will now sabotage in her attempt to induce an upward revision of her own ability and thus increase her future remuneration. If explicit contracts are also provided, which are short-term, each agent wants to look as productive as possible in absolute and relative terms. In order to undo agent’s implicit incentives to sabotage, by setting a negative pay-for-teammate contractual parameter, the principal intends to weaken agents’ desire to sabotage.

We also analyze the optimal contracts and career concerns of workers whose tenure in a specific firm is short. Temporary workers will be hired by a different firm in the next period and be paired up with another worker. They know that they are unable to capitalize any change in market beliefs about her current colleague’s ability. However, in our framework, implicit incentives to help or sabotage also arise for a temporary worker. Although she does not care to influence the process of inference of her current teammate’s ability, her own reputation depends on her current colleague’s output and thus she wants to influence this performance measure. We also show the conditions under which weaker explicit incentives are provided to temporary workers than to long-term workers. In Auriol
et al. (2002), any implicit incentives to influence a teammate’s production disappears in the case of temporary workers.

This paper is tied to the literature on career concerns based on Holmström (1982a). In his single-agent model, career concerns induce an agent who has bargaining power vis-à-vis the market to work harder in the current period in order to build up her reputation, seeking for higher future rewards. Harris & Holmstrom (1982) study long-term implicit incentives. In a two-agent model, Meyer & Vickers (1997) show that an agent with no bargaining power still wants to increase her reputational bonus but a ratchet effect arises: in the attempt to convince the market that she is of higher ability, the agent increases the expectations with respect to her production, allowing the principal to become more demanding. Assuming that agents’ abilities are positively correlated, each agent free-rides on the effort of the other to enhance reputation. Auriol et al. (2002) use relative performance evaluations, and consider work and help as two separate tasks, while an agent’s output depends only on her own ability: the process of inference of each teammate’s ability is independent. They examine passive sabotage of colleagues’ work: higher performance of a colleague hurts the agent because it will convince the market that the team consists of productive workers, resulting in a smaller fixed payment. Lazear (1989) considers sabotage incentives in tournaments. In our setting, the teammates’ innate characteristics are independent but they enter in both teammates’ production functions. We show that under certain conditions, incentives to help or sabotage can be provided through explicit contracts to both long-term and temporary workers. Nevertheless, the channels through which explicit incentives are determined in these two contractual environments are different.6,7

We also contribute to the existing literature on moral hazard in teams. In a multiagent environment where individual outputs are observable and correlated, an agent’s compensation contract is made contingent on other agents’ production. Holmström (1982b) and Mookherjee (1984) show that relative performance evaluation (RPE) schemes can filter out the common shock from an agent’s reward, assuming that there are no technological interactions among agents. Since the agents are exposed to lower risk, the trade-off between insurance and incentives is shifted, facilitating stronger explicit incentive schemes. Itoh (1991, 1992) shows that a principal who uses RPE can install cooperation among agents only if the correlation between the workers’ performances is low. We use a

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7Recent works on reputation give additional insights. Ely & Välimäki (2003) develop a model in which a long-lived agent’s concern for his reputation undermines commitment power. Iossa & Rey (2014) study reputation building for contract renewal and show that incentives are stronger when the contract approaches its expiry date. Deb & Ishii (2016) construct a model to study reputation building under uncertain monitoring.
similar framework as the latter works and assume that individual production depends on both agents’ innate abilities which are unknown as in Chalioti (2016). We investigate how effectively a principal can induce cooperation or competition between agents through RPE when principal’s commitment power changes.

This paper also complements the literature on the substitutive relationship between explicit and implicit incentives based on Gibbons & Murphy (1992), due to the additive production technology. Dewatripont et al. (1999) show that explicit and implicit incentives may become complements, assuming that ability and effort enter the production function in a multiplicative fashion. Meyer, Olsen & Torsvik (1996) state that the ratchet effect can be weakened by inducing teamwork. This relationship is less straightforward in our setting where RPE are provided and an agent’s ability influences both teammates’ performance measures, since an agent’s implicit incentives to help or sabotage depend on both contractual parameters of her future explicit compensation.

Career concerns literature also examines whether Fama (1980)’s conclusion is correct: explicit contracts are unnecessary to solve the principal-agent conflicts, since the market induces the "right" effort levels. Holmström (1999) shows that risk-aversion and discounting place limitations on the market’s ability to engender adequate incentives.\textsuperscript{8} Our model with explicit contracts supports Holmström’s argument: with no discounting, the stationary level of explicit incentives is zero, and the effort levels are efficient.

The paper is organized as follows. Section 2 describes the model. It discusses the production technologies and the workers’ objectives. Section 3 analyzes the contracts when the principal can fully commit herself to a life-time income path. It derives and intuitively discusses the optimal explicit incentives in a two-period and a multi-period setting. Section 4 studies short-term contracts when the team members work together as long as employment lasts. It discusses the process of inference of workers’ abilities and the trade-off between explicit and implicit incentives for these long-term workers. Then, the explicit and implicit motivation for temporary workers is analyzed. Section 5 concludes.

2 The model

There are two risk and effort averse agents, denoted by $i$ and $j$ where $i \neq j$. They are also rational and forward-looking. They live for two periods indexed by $t = \{1, 2\}$, and discount the future with some factor $\delta$, where $\delta \in [0, 1]$. We also assume that they are appointed by a risk neutral and profit seeking principal, who compensates them with explicit contracts. At each period $t$, individuals work

\textsuperscript{8}Bar-Isaac & Hörner (2014) and Bonatti & Hörner (2015) also discuss the role of discounting in stationary models.
to fulfill their own task, while interacting with their fellow team member. Each project output is observable and contractible, allowing the principal to deal with each agent separately as in Itoh (1991, 1992).

2.1 Production technology

In period \( t \), each agent \( i \) controls a stochastic production process in which her "project" output, \( z_i^t \), is the sum of the agent’s own innate ability, \( \theta^i \), her nonnegative work effort, \( e_i^t \), her teammate’s support and a transitory shock, \( \varepsilon_i^t \). Agent \( j \)’s support depends on her own ability, \( \theta^j \), weighted by a parameter \( h_j \in [0,1] \), and her help effort, \( a_j^t \), weighted by \( k_j \in [0,1] \). Thus, agent \( i \)’s production function is\(^9\)

\[
    z_i^t = \theta^i + e_i^t + \varepsilon_i^t + h_j \theta^j + k_j a_j^t.
\]

Before production takes place, all parties have symmetric but imperfect information about the agents’ abilities as in Holmström (1982). However, the agents and all prospective employers believe that \( \theta^i \) is drawn from a normal distribution with mean \( m_1^i \) and variance \( \sigma^2 \). The abilities are also independent of each other and of the noise terms. Agent \( i \)’s characteristic \( \theta^i \) can manifest the agent’s ability to successfully accomplish a project which is symmetrically unknown to the agents and the market at each stage.\(^{10}\) We also assume that each agent uses the same set of skills to improve her own and her teammate’s project output. The random terms \( \varepsilon_i^t, \varepsilon_j^t \) follow a normal distribution with zero mean and variance \( \sigma^2 \). They are also independently distributed across agents and periods.

In this model, an agent’s ability and "help" effort enter her teammate’s production process additively. Note that although an agent always exerts (positive) work effort to improve her own project outcome, her career concerns and the principal-agent problems may induce her either to help or even sabotage her colleague. Thus, agents’ help efforts \( a_i^t \) and \( a_j^t \) can even be negative. The parameter \( h_j \) measures the degree of incoming skills benefit to agent \( i \) that is generated by being teamed with an agent of ability \( \theta^j \). It indicates how sensitive agent \( i \)’s output is to her teammate’s characteristics. Similarly, \( h_i \) denotes the degree of outgoing skills benefit from agent \( i \) to agent \( j \). These parameters are exogenous and less than one, so are \( k_i \) and \( k_j \). The parameter \( k_j \) captures the degree of incoming teamwork interactions which is the fraction of agent \( j \)’s help effort that increases agent \( i \)’s project output, while \( k_i \) represents the degree of outgoing teamwork interactions. It shows the contribution of agent \( i \)’s help effort to agent \( j \)’s production. The nature of such interactions is imperfect, implying

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\(^9\)We normalize the price of the agents’ output to one and in all periods, we assume that the scale of production remains the same.

\(^{10}\)Some papers study the optimal explicit incentives when the agent is better informed about her own characteristics than the market (Laffont & Tirole (1988)).
that putting effort into an agent’s own task is more productive than providing help to a fellow member of the team. The level of all these parameters affects each agent’s capacity to influence individual production as well as manipulate market perceptions about abilities.

2.2 Agents’ preferences and objectives

Agent $i$ receives the reward $w^i_t$ and has constant absolute risk-averse (CARA) preferences. She is endowed with the utility function

$$U^i = -\exp \left( -r \sum_{t=1}^{2} \delta^{t-1} \left[ w^i_t - \psi \left( e^i_t \right) - \psi \left( a^i_t \right) \right] \right),$$

where $r$ is the Arrow-Pratt measure of risk aversion, $r > 0$. Risk-aversion on the part of the agents is essential when explicit contracts are provided in order the incentive parameters to be less than one. Otherwise, the optimal contract will impose substantial human capital risk on the agents. Gibbons & Murphy (1992) consider explicit payments and state that risk-aversion is necessary so that optimal contracts do not completely eliminate career concerns. In particular, a risk-averse agent wishes to be insured against low realizations of her project output and thus, weaker explicit incentives are provided. Given that explicit payments will decrease, reputation incentives increase. Due to the additive separability of the utility function, agents also do not consider income smoothing across periods. They make their decisions as if they enjoy access to perfect capital markets in each period. They also consider discounting, implying that a payment is worth more today than it would be worth in the subsequent periods. In the absence of discounting where $\delta = 1$, agents value equally all payments that are to be received in the future, strengthening their career concerns.

We assume that agents’ disutilities are task specific, as in the multi-agent models of Auriol et al. (2002), and Itoh (1992). The cost functions of work effort and help effort, $\psi \left( e^i_t \right)$ and $\psi \left( a^i_t \right)$ respectively, are twice continuously differentiable and convex, implying that there are diminishing returns to scale in the production process. We also assume that $\psi' \left( 0 \right) = 0$, $\lim_{e^i_t \to \infty} \psi' \left( e^i_t \right) = \infty$ and $\lim_{a^i_t \to \infty} \psi' \left( a^i_t \right) = \infty$. These cost functions are in stark contrast to other models of multitasking based on Holmström & Milgrom (1991b) that assume total-effort-cost functions $\psi \left( e^i_t + a^i_t \right)$. In the latter models, the cross-partial derivatives with respect to two tasks are positive. As an agent increases the effort devoted to one task, the marginal cost of effort to the other task will also increase. Thus, exerting help effort would be costly to an agent and it crowds out effort directed to her own project, decreasing her own production. In equilibrium, each agent equates the marginal return to effort in both tasks. These models focus on the allocation of an agent’s "attention" between the tasks.

In our model with task-specific-cost functions, allocating a given total effort to both tasks entails
lower disutility. The cross-partial of the cost function is zero: the cost of exerting effort to perform a given task is independent of the cost of the other task. An agent can focus on eliciting effort to affect her teammate’s project output without having to consider simultaneously technologically founded externalities. Putting effort in a task does not require effort away from the other task. Multitasking in the absence of crowding out effects between the tasks keep worker highly motivated to elicit effort in environments where sabotage incentives may emerge.

The contracts depend linearly on both agents’ project outputs since the performance measures are correlated due to teamwork interactions. Holmström & Milgrom (1987) establish that in a model much like the single-period version of this model (but lacking the uncertainty about an agent’s ability), the optimal contract is linear.11 Gibbons & Murphy (1992), in a single-agent model, and Auriol et al. (2002), in their multi-agent framework, also consider contracts that are linear in outputs. At each period $t$, the principal offers contracts of the form $C_i^t \equiv (\omega_i^t, \beta_i^t, \gamma_i^t)$ and agent $i$ receives $w_i^t = \omega_i^t + \beta_i^t z_i^t + \gamma_i^t z_j^t$, (3) where $\omega_i^t$ denotes the fixed salary component and $\beta_i^t, \gamma_i^t$ are the incentive parameters. Such "team-incentive" schemes introduce either cooperation or competition between the teammates, depending on the sign of $\gamma_i^t$. If an agent rejects the contract offer, she receives her outside option that equals her reputational bonus

$$\Theta_i^t \equiv (1 + h_i) E \{\theta^i | z_{i-1}^i, z_{j-1}^j \} + \tilde{c}_i^t + h_i \tilde{a}_i^t.$$ That is a fixed payment equals the total rents each agent can claim for her contribution to both teammates’ project outputs. Given the available information, her payment increases with an upward revision of the market’s estimate of her own ability.12

Under full information, the principal observes the agents’ effort levels, allowing her to make contract offers that achieve specific effort assignments. In particular, agent $i$’s payment is fixed and equal to the sum of the cost of both efforts, $\psi (e_i^t) + \psi (a_i^t)$. The agents receive the same contract in each period which is the repetition of the optimal contract in a one-shot game. The first best contracts also provide perfect insurance to the agents against low realizations of production. The first-best levels of work and help efforts, $e_i^{t, fb}$ and $a_i^{t, fb}$, satisfy the conditions $\psi' (e_i^{t, fb}) = 1$ and $\psi' (a_i^{t, fb}) = k_i$, respectively.

11Holmström & Milgrom (1987) show that in a static version of their dynamic model, the optimal compensation scheme that is offered to an agent with CARA preferences is a linear function of the performance measures.

12Gibbons & Murphy (1992), Holmström (1999), among others, assume that the agent has all the bargaining power, and thus the principal maximizes subject to a zero-profit condition. In a multi-agent setting, this assumption would be problematic. Following Auriol et al. (2002), we consider a bargaining process that effectively makes each teammate the residual claimant only to her reputational bonus.
3 Full commitment to life-time income

We assume that long-term contracts are feasible. In a two-period model, the principal can commit herself to a second-period salary before the observation of the first-period outputs. Thus, the principal succeeds in insulating an agent’s expected life-time compensation from the uncertainty she faces with respect to true abilities - actual $\theta^i$ and $\theta^j$ - which significantly affects each period’s explicit incentives when short term contracts are provided and career concerns arise. Instead, if the principal commits herself to a life-time salary path, an agent’s problem is identical in each period. Note that a long-term contract is not identical with two one-period contracts.

3.1 Two-period model

The principal is the residual claimant on firm’s net profits which equal the sum of the project outputs net of agents’ compensations. In a two-period model, the principal’s problem is

$$\max_{C^t_i, e^t_i, a^t_i} E \{ U^P \} = E \left\{ \sum_{t=1}^{2} \sum_{i=1}^{2} \delta^{t-1} (z^i_t - w^i_t) \right\}$$

subject to $CE^i_t \equiv \sum_{t=1}^{2} \delta^{t-1} [E \{ w^i_t \} - \psi (e^i_t) - \psi (a^i_t)] - \frac{\bar{\sigma}}{2} \text{Var} \{ w^i_1 + w^i_2 \} \geq \Theta^i_t, \forall i$ (IR$^i$)

$$e^*_t = \arg \max_{e^i_t} CE^i_t, \forall i, t \quad (IC^i_{e,t})$$

$$a^*_t = \arg \max_{a^i_t} CE^i_t, \forall i, t \quad (IC^i_{a,t})$$

where $\text{Var} \{ w^i_1 + w^i_2 \} = \left[ \sum_{t=1}^{2} (\beta^i_t + h^i_t \gamma^i_t) \right]^2 \sigma_i^2 + \left[ \sum_{t=1}^{2} (h_j \beta^i_t + \gamma^i_t) \right]^2 \sigma_j^2 + \sum_{t=1}^{2} \left[ (\beta^i_t)^2 + (\gamma^i_t)^2 \right] \sigma_z^2$.

The individual rationality constraint (IR$^i$) shows that the agent will participate in the production process only if the certainty equivalence of her utility, $CE^i_t$, exceeds her outside option. Since the principal specifies the long-term incentive schemes before the realization of the first period outputs, the outside option is equal to her expected innate ability, $\Theta^i_1 = (1 + h^i_t) m^i_1 + \tilde{c}^i_1 + h^i \tilde{a}^i_1$. In this framework where agents’ utility is additively separable across time, and current production is independent of the agents’ actions and the exogenous shocks in previous periods, the principal cannot exploit any gains from intertemporal risk sharing. Instead, the certainty equivalence specifies compensation contracts that are contingent only on the contemporaneous outcomes: the second-period rewards

\[\text{Var} \{ w^i_1 + w^i_2 \} = \left[ \sum_{t=1}^{2} (\beta^i_t + h^i_t \gamma^i_t) \right]^2 \sigma_i^2 + \left[ \sum_{t=1}^{2} (h_j \beta^i_t + \gamma^i_t) \right]^2 \sigma_j^2 + \sum_{t=1}^{2} \left[ (\beta^i_t)^2 + (\gamma^i_t)^2 \right] \sigma_z^2.\]

\[\text{Var} \{ w^i_1 + w^i_2 \} = \left[ \sum_{t=1}^{2} (\beta^i_t + h^i_t \gamma^i_t) \right]^2 \sigma_i^2 + \left[ \sum_{t=1}^{2} (h_j \beta^i_t + \gamma^i_t) \right]^2 \sigma_j^2 + \sum_{t=1}^{2} \left[ \left( \beta^i_t \right)^2 + \left( \gamma^i_t \right)^2 \right] \sigma_z^2.\]

\[\text{Var} \{ w^i_1 + w^i_2 \} = \left[ \sum_{t=1}^{2} (\beta^i_t + h^i_t \gamma^i_t) \right]^2 \sigma_i^2 + \left[ \sum_{t=1}^{2} (h_j \beta^i_t + \gamma^i_t) \right]^2 \sigma_j^2 + \sum_{t=1}^{2} \left[ \left( \beta^i_t \right)^2 + \left( \gamma^i_t \right)^2 \right] \sigma_z^2.\]
depend only on the second-period outcomes, ignoring the realization of the first-period production. Thus, the same payment schemes are provided in both periods, implying that the agents’ problem is identical across time. The incentive compatibility constraints, \((IC^i_{e,t})\) and \((IC^i_{a,t})\), guarantee that an agent chooses the (expected) utility maximizing efforts.

The optimal work and help effort satisfy, respectively,

\[
\beta^i_t = \psi^i(e^i_t) \quad \text{and} \quad k;\gamma^i_t = \psi^i(a^i_t), \quad \forall i.
\]

Each agent also accepts the contract that allows her to earn (at least) her reputational bonus: in equilibrium, the \((IR^i)\) constraint is binding. The principal signs the most appealing contracts. Her problem is solved in appendix (A.1). Let \(\Phi^i = k^2 \frac{1 + r \Sigma^i \psi''_{e,fe} - 2 - 2 \Sigma^i \psi''_{a,fe}}{k^2 \frac{1 - 2 r \Sigma^i \psi''_{e,fe} + r \Sigma^i \psi''_{a,fe}}{1 + r \Sigma^i + r \Sigma^i + r \Sigma^j}}\), where \(\Sigma^i \equiv \sigma^2 + 2 \left( \sigma_i^2 + h_j^2 \sigma_j^2 \right)\) and \(\Sigma^j \equiv h_i \sigma_i^2 + h_j \sigma_j^2\). Convex cost-of-effort functions imply that their second derivatives \(\psi''_{e,fe}\) and \(\psi''_{a,fe}\) are negative. The long-term explicit incentives are

\[
\beta^i_{fe} = \frac{1}{1 + r (\Sigma^i + \Phi \Sigma^j) \psi''_{e,fe}} \quad \text{and} \quad \gamma^i_{fe} = \Phi^i \beta^i_{fe}.
\]

In case of perfect teamwork interactions and identical skills benefit, \(h_i = h_j = k_i = k_j = 1\), where there are no frictions in interacting with other team members, both incentive parameters in (5) are identical. Agents’ remuneration is contingent on the total team output and no additional information is required about agents’ individual performance: only the observation of the aggregate measure \(z^i_t + z^j_t\) is needed. Disaggregate information is required only when there are technological differences between working on one’s own task and helping others, as well as when the effect of agents’ abilities on both production processes is not identical. In this case, the agents’ task assignment problem necessitates the observation of each teammate’s project output.

Proposition 1 establishes that the principal who provides long-term contracts may find it optimal to induce an agent to sabotage her colleague during the entire employment period. This is in sharp contrast to Auriol et al. (2002) where the long-term explicit incentives based on both agents’ performance measures are always positive, inducing the agents to help their colleague.

**Proposition 1 (Long-term explicit incentives)** Given that the principal fully commits to a lifetime income path, the equilibrium pay-for-own-performance parameter is always positive, \(\beta^i_{fe} > 0\), while the pay-for-teammate-performance parameter is negative, \(\gamma^i_{fe} < 0\), inducing the agent to sabotage, if and only if the degree of risk aversion is large enough so that

\[
\frac{k_i^2}{\Sigma^i \psi''_{a,fe} - k_i^2 \Sigma^i \psi''_{e,fe}} < r.
\]
Proof. In Appendix (A.1).

The positive sign of $\beta_{fc}^i$ indicates that an agent’s higher own project output is compensated with a higher wage. The sign of $\gamma_{fc}^i$ is less straightforward. The principal sets $\gamma_{fc}^i$ positive for low degrees of risk aversion and large outgoing teamwork interactions (high $k_i$) so that $\Phi^i > 0$, giving the agent a long position in her teammate’s performance. The principal anticipates the support an agent provides to her colleague and rewards her when the teammate does better. The "compensation ratio" $\frac{\gamma_{fc}^i}{\beta_{fc}^i}$ is also higher in compensation packages that are rewritten to accommodate increasing $k_i$. The higher $k_i$ is, the more sensitive is agent $j$’s project output to agent $i$’s help effort, and thus the use of relative performance evaluations becomes more essential. For agents with high tolerance for risk, implying that the cost of exerting effort is small, such evaluation schemes can effectively be used as means of internalizing the positive effects of providing support. In contrast, for a high risk averse agent, if the outgoing teamwork interactions are small (low $k_i$), $\Phi^i$ becomes negative: due to risk-sharing and the fact that agent $i$’s contribution in her teammate’s project output is insignificant, the principal infers that agent $j$ is the high productivity worker in the team and penalizes agent $i$ as agent $j$’s project output increases. By setting $\gamma_{fc}^i$ negative, the principal filters out the outgoing teamwork interactions from agent $i$’s compensation. Thus, if the principal decides to commits herself to a life-time compensation at a pre-production stage, she may induce an agent to work in order to fulfill her own task, improving her production, but also to sabotage her colleague as long as employment lasts.

Under full commitment to a life-time salary, negative explicit incentives are in contrast to the existing literature with career concerns and teams as in Auriol et al. (2002). In their model, the pay-for-teammate-performance parameter is lower than the optimal pay-for-own-performance parameter, but always positive. However, in our framework where an agent’s ability is an input in her teammate’s production function, such incentives can be reversed. This happens because the sensitivity of both performance measures on both team members’ abilities, which are unknown, increases the variance of the rewards. In particular, under moral hazard, agents seek insurance against the risk they face. Due to risk-sharing, the principal provides insurance that involves underprovision of effort in respect to the accomplishment of both tasks. The higher the agents’ tolerance against risk, the lower powered is the incentive scheme. Indeed, both $\beta_{fc}^i$ and $\gamma_{fc}^i$ fall short from their efficient levels, but $\gamma_{fc}^i$ can even be negative. It is striking that the principal induces an agent to exert costly effort in order to decrease her teammate’s output. Sabotage can be achieved by putting effort into stealing, destroying or hiding some part of a colleague’s production.

Suppose that agent $i$ is highly risk averse and her outgoing teamwork interactions are small enough (low $k_i$) so that the condition in Proposition 1 is satisfied. Given that the principal’s benefit equals
the sum of both projects’ outputs, \( z^i_t + z^j_t \) at each period \( t \), one could consider that the principal would prefer to shut down any incentives of agent \( i \) to affect her teammates’ output by setting \( \gamma^i_{fc} \) zero. However, in this case, \( \beta^i_{fc} \) is smaller, so is the total production \( z^i_t + z^j_t \). It is optimal for a profit-seeking principal to set a negative \( \gamma^i_{fc} \). To shed additional insights, let us assume that the cost-of-effort functions are \( \psi(e^i_t) = \frac{1}{2}(e^i_t)^2 \) and \( \psi(a^i_t) = \frac{1}{2}(a^i_t)^2 \). Suppose also that agent \( j \) does not contribute to her teammate’s production, \( h_j = k_j = 0 \), while the contribution of agent \( i \) to her teammate performance is significant so that \( h_i = k_i = 1 \). For any degree of risk-aversion, the principal encourages agent \( i \) to help her teammate and compensates her by setting \( \gamma^i_{fc} \) positive - i.e., \( \gamma^i_{fc} = \frac{1+2r\sigma^2}{1+2r(\sigma^2 + 2\sigma^2_j)}\beta^i_{fc} \) - while the principal decreases her teammate’s (agent \( j \)) payment for an increase in \( z^i_t \) by setting \( \gamma^j_{fc} \) negative - i.e., \( \gamma^j_{fc} = -\frac{2a^2}{2\sigma^2_i + \sigma^2_j} \beta^j_{fc} \). The principal provides opposing incentives to team members.

The intensity of teamwork interactions and the contribution of abilities in agents’ performance measures play a key role in specifying the optimal long term explicit incentives. As the degree of outgoing teamwork interactions increases (higher \( k_i \)), implying that agent \( i \)’s help effort weights more in her colleague’s project output, the principal sets a lower \( \beta^i_{fc} \) and a higher \( \gamma^i_{fc} \). Agent \( i \)’s support to her teammate becomes increasingly more important and the principal is benefited by shifting agent \( i \)’s focus on improving agent \( j \)’s production. Any change in \( k_j \) leaves agent \( i \)’s incentives unaffected since the channel through which her efforts influence the total production and the risk to which she is exposed only depend on \( h_i, h_j \) and \( k_i \). Besides, as the degree of the incoming skills benefit from agent \( j \) to agent \( i \), measured by \( h_j \), increases, \( \beta^i_{fc} \) will decrease. Agent \( i \)’s output as a performance measure becomes noisier and thus conveys less information about agent \( i \)’s work effort. The principal relies less on \( z^i_t \) to anticipate agent’s effort. Given also that the variance of her compensation increases due to higher risk which is introduced by a factor incorporated in \( z^i_t \), a lower \( \beta^i_{fc} \) will mitigate this effect. Similarly, for a higher \( h_i \), stronger incentives are provided through \( \beta^i_{fc} \).

### 3.2 Multiperiod model

We now examine the effects of fully committing to a life-time salary when the quality of a fellow team member affects both agents’ compensation but employment extends to many periods. Tenure is long. Suppose that the workers are appointed for \( \tau \) periods, where \( \tau > 2 \). In this framework, the variance of the life-time payments is

\[
Var \left\{ \sum_{t=1}^{\tau} w^i_t \right\} = \left[ \sum_{t=1}^{\tau} (\beta^i_t + h_i \gamma^i_t) \right]^2 \sigma^2_i + \left[ \sum_{t=1}^{\tau} (h_j \beta^i_t + \gamma^i_t) \right]^2 \sigma^2_j + \sum_{t=1}^{\tau} \left[ (\beta^j_t)^2 + (\gamma^i_t)^2 \right] \sigma^2_j.
\]
In equilibrium, the contractual parameters become

$$\beta^i_{\tau, fc} = \frac{1}{1 + r (\Sigma^{ii} + \Phi^i_{\tau} \Sigma^{ij}) \psi^{i,j}_{er,fc}}$$

and

$$\gamma^i_{\tau, fc} = \Phi^i_{\tau} \beta^i_{\tau, fc},$$

where

$$\Phi^i_{\tau} = \frac{k^2_i \left[ 1 + r \Sigma^{ii} \psi^{i,j}_{er,fc} \right] - \tau r \Sigma^{ij} \psi^{i,j}_{er,fc}}{k^2_i \left[ 1 - \tau r \Sigma^{j} \psi^{i,j}_{er,fc} \right] + \tau r \Sigma^{ij} \psi^{i,j}_{er,fc}}$$

and

$$\Sigma^{ii} = \sigma^2_\varepsilon + \tau \left( \sigma^2_i + h^2_j \sigma^2_\varepsilon \right).$$

Proposition 2 highlights that the span of agents’ work life affects the equilibrium explicit incentives provided through a multi-period contract when the principal commits herself at the beginning of agents’ employment. For a short work life-span, an agent can be induced to help her colleague, while for a long life-span, such incentives can be negative. Thus, sabotage incentives can be induced when the agents are committed to interact for many periods.

**Proposition 2 (Incentives & multiperiod employment)** Given that the principal fully commits to a life-time income path, the equilibrium pay-for-teammate-performance parameter is negative, $\gamma^i_{\tau, fc} < 0$, if and only if agents’ work life-span is long enough so that

$$\frac{k^2_i \left( 1 + r \sigma^2_\varepsilon \psi^{i,j}_{er,fc} \right)}{r \Sigma^{j} \psi^{i,j}_{er,fc} - k^2_i \left( \sigma^2_i + h^2_j \sigma^2_\varepsilon \right) \psi^{i,j}_{er,fc}} < \tau.$$

Note that although the variance of an agent’s one-period wage depends on the variance of the transitory shock, the covariance of wages realized in different periods depends only on the variance of teammates’ abilities. In particular, under the assumption of independently distributed random terms, such covariances depend solely on $\sigma^2_i$ and $\sigma^2_j$ (not $\sigma^2_\varepsilon$), since we have $\text{cov} \left( w^i_t, w^j_{t+1} \right) = 2 \left[ (\beta^i_t + h_i \gamma^i_t) (\beta^i_{t+1} + h_i \gamma^i_{t+1}) \sigma^2_i + (h_j \beta^i_t + \gamma^i_t) (h_j \beta^i_{t+1} + \gamma^i_{t+1}) \sigma^2_j \right]$, for any $t$. Thus, for a longer life-span, the noise in the production processes introduced by teammates’ abilities matters more in shaping principal’s perceptions about agents’ effort levels. As employment extends to many period, a teammate’s ability which is subject to some systemic variation affects an agent’s production of many periods, increasing the risk to which the agent is exposed. Higher risk in longer life-span contracts is compensated with weaker pay-for-own-performance incentives, $\frac{\partial \beta^i_{\tau, fc}}{\partial \tau} < 0$ for all $\tau$. Besides, although for a short life-span, the principal would incentivize an agent to help her fellow member of team (positive $\gamma^i_{\tau, fc}$), for a longer life-span, the principal will induce the same agent to sabotage. Under full commitment, contracts with different duration will provide reversed incentives to the same agent on how to influence a teammate’s production.
4 Short-term contracts

We now examine the explicit incentives in a $T$-period setting where the principal cannot commit herself to a life-time compensation scheme. Instead, she renegotiates a contract offer in each period. The timing of the game has as follows. In the beginning of period 1, the principal simultaneously makes a contract offer to each agent. If agent $i$ accepts the offer, she makes the effort choices. Events beyond the agents’ control occur, both project outputs are realized and the contracts are executed. In period 2, all parties observe the realization of $z_i^1$ and $z_j^1$, and update their assessments about abilities. Thus, past production affects future remuneration and incentives. New contract offer is made to each fellow member of the team and if an agent stays in the firm, she chooses the new effort levels. After the observation of the current production, the rewards are paid. This sequence of decisions is repeated till the end of workers’ employment.

4.1 Learning process and career concerns

Suppose that employment lasts for two periods, $t = 1, 2$. All parties observe past production in order to infer the level of agents’ abilities. When output shocks are uncorrelated and an agent’s ability does not enter her teammate’s production function as in Auriol et al. (2002), the process of inference of each teammate’s ability is independent. However, in this model where agent $i$’s ability affects agent $j$’s performance, $z_j^1$ also conveys information about $\theta^i$. As in Chalioti (2016), there are two performance measures that can be used in the updating process about $\theta^i$. One can compute the conditional distribution of $\theta^i$ in period 2, which is normal with mean

$$m_2^i \equiv \mu_1^i m_1^i + \rho_{1ii} (z_1^i - \hat{\epsilon}_1^i - k_j \hat{a}_1^j - h_j m_1^j) + \rho_{1ij} (z_1^j - \hat{\epsilon}_1^j - m_1^j - k_i \hat{a}_1^i),$$

and variance $\sigma_{1,2}^2 \equiv \sigma_{1i}^2 \mu_1^i$, where $\mu_1^i \equiv 1 - \rho_{1ii} - h_i \rho_{1ij}^j$, and $\hat{\epsilon}_1^i, \hat{\epsilon}_1^j$ are the conjectures of agent $i$’s current efforts. The conditional correlation coefficients are, respectively,

$$\rho_{1ii} \equiv \text{corr} (\theta^i, z_1^i | z_1^i) = \frac{\sigma_2^2_1}{\lambda_1} \left[ \sigma_2^2 + (1 - h_i h_j) \sigma_2^2_j \right],$$

$$\rho_{1ij} \equiv \text{corr} (\theta^i, z_1^j | z_1^i) = \frac{\sigma_2^2_1}{\lambda_1} \left[ h_i \sigma_2^2 - (1 - h_i h_j) h_j \sigma_2^2_j \right],$$

where $\lambda_1 = \sigma_2^4 + (\tau - 1)^2 (1 - h_i h_j)^2 \sigma_2^2 \sigma_2^2_j + (\tau - 1) \sigma_2^2 \left[ (1 + h_i^2) \sigma_2^2_i + (1 + h_j^2) \sigma_2^2_j \right]$.

The signal $\rho_{1ii}$ is always positive, $\rho_{1ii} > 0$, implying that given the realization of agent $j$’s production, agent $i$’s high own performance signals high own ability and vice versa. However, the sign of $\rho_{1ij}$ is less straightforward. It is positive as long as the outgoing skills benefit to agent $j$ is substantial.
(high \(h_i\)), while the incoming skills benefit is small (low \(h_j\)) so that agent \(i\)'s performance is not very sensitive to \(\theta^i\). In this case, higher \(z^j_1\) is good "news" for agent \(i\)'s ability. Given \(z^i_1\), a higher \(z^j_1\) is attributed to higher agent \(i\)'s ability, resulting in an upward revision of the market estimate of \(\theta^i\). Effort is a substitute for ability, implying that an agent can manipulate market perceptions about her ability by distorting effort levels. Thus, in the absence of explicit motivation where an agent’s reward equals her reputational bonus, agent \(i\) has implicit incentives to help her colleague. Agent \(i\)'s help will increase \(z^j_1\), inducing the market to update its assessments about \(\theta^i\) upwards, increasing agent’s future remuneration.

The opposite occurs in a setting with a small outgoing skills benefit but high \(h_j\). If \(h_i\) is small and the variance of \(\theta^j\) is large enough, it is more likely that both performance measures reflect the level of \(\theta^j\). Thus, if both agents perform well, the market attributes these outcomes to high \(\theta^j\), causing the estimate of \(\theta^j\) to be revised downwards. A higher \(z^j_1\) is now a bad signal of agent \(i\)'s ability. By helping a teammate to further increase her project output, agent \(i\) will induce market inferences to be revised against her. Instead, bad performance by her teammate will be a good signal of her own ability. A decrease in \(z^j_1\) will increase agent \(i\)'s reputation so that she now has incentives to sabotage her colleague, even when explicit contracts are not provided.

Assuming also that all parties have rational expectations, we have \(\hat{\epsilon}^i_1 = e^{i*}_1\) and \(\hat{a}^i_1 = a^{i*}_1\). The equilibrium conjectures must be correct. The presence of noise insures that there are no off-equilibrium realizations of observables, and in equilibrium, each agent is restricted to exert the levels of effort that are expected of her. Underprovision of effort will influence the updating process against her.

### 4.2 Explicit and implicit incentives

In each period \(t\), the individual rationality constraint \((IR^i_t)\) of agent \(i\)'s utility becomes

\[
CE^i_t = \sum_{t=1}^{2} \delta^{t-1} \left[ E \{ w^i_t \mid z^i_{t-1}, z^j_{t-1} \} - \psi (e^i_t) - \psi (a^i_t) \right] - \frac{r}{2} \text{Var} \left\{ \sum_{t=1}^{2} w^i_t \mid z^i_{t-1}, z^j_{t-1} \right\} \geq \Theta^i_t.
\]

The constraint \((IR^i_t)\) is binding at the optimum, implying that competing employers cannot make a better offer than \(\Theta^i_t\).\(^{14}\) Note that \(\Theta^2_i = (1 + h_i) E \{ \theta^i \mid z^i_1, z^j_1 \} + \hat{\epsilon}^i_2 + h_i \hat{a}^i_2\). The principal is equally well-off by hiring either a high reputation agent at a high wage or a low reputation agent at a low wage. This bargaining outcome can arise as the equilibrium of an extensive-form game. In this game, an agent is randomly assigned to a prospective principal and queues with the other job applicants.

\(^{14}\)Gibbons & Murphy (1992), Holmström (1999), among others, assume that the agent has all the bargaining power, and thus the principal maximizes subject to a zero-profit condition. In a multi-agent setting, this assumption would be problematic. Following Auriol et al. (2002), we consider a bargaining process that effectively makes each teammate the residual claimant only to her reputational bonus.
The principal makes a contract offer to the first agent in line. If the agent accepts the offer, she works for this principal. Otherwise, the agent queues for another job and the principal makes an offer to the next agent in line. Therefore, each agent receives only her reputational bonus that arises due to work and support provision.

The second period of the short-term contracting framework is isomorphic to the incentives raised in the first period in the full-commitment case, analyzed in Section 3. In particular, the optimal work and help efforts, \(e_1^i\) and \(a_1^i\), satisfy equations (4). We also compute the base payment by solving the \((IR_2^i)\) constraint when binding:

\[
\omega_2^i = \Theta_2^i - E \left\{ \beta_2^i z_2^i + \gamma_2^i z_2^j z_1^i z_1^j \right\} + \psi (e_2^i) + \psi (a_2^i) + \frac{r}{2} Var \left\{ w_2^i \mid z_1^i, z_1^j \right\}.
\]

The optimal contractual parameters \(\beta_2^i\) and \(\gamma_2^i\) can be obtained by replacing \(\Sigma^{ii}\) with \(V_2^{ii} \equiv \sigma_2^2 + h_i \sigma_{i,2}^2 + \sigma_{j,2}^2\) and \(\Sigma^{ij}\) with \(V_2^{ij} \equiv h_i \sigma_{i,2}^2 + h_j \sigma_{j,2}^2\).

In period 1, agents have explicit incentives from the current compensation contract and implicit incentives from career concerns. There is an implicit dependence of the future wage on the current project outputs. However, current efforts only affect the intercept of future wage because there are no wealth effects in agent utility and the production functions are additive. Both agents have the same marginal product of effort regardless of their true ability. The contractual parameters of future wages are independent of current and past production and thus of agents’ reputation. As a result, agent \(i\) chooses the effort levels that satisfy the conditions

\[
\beta_1^i + \delta M_1^{ii} = \psi' (e_1^i) \quad \text{and} \quad k_i (\gamma_1^i + \delta M_1^{ij}) = \psi' (a_1^i),
\]

where \(\frac{\partial \omega_2^{ii}}{\partial e_1^i} \equiv M_1^{ii}\) and \(\frac{\partial \omega_2^{ij}}{\partial a_1^i} \equiv k_i M_1^{ij}\). The implicit incentives that arise through work and help efforts are, respectively,

\[
M_1^{ii} = (1 + h_i - \beta_2^i - h_i \gamma_2^i) \rho_1^{ii} - (h_j \beta_2^i + \gamma_2^i) \rho_1^{ji}, \tag{7}
\]

\[
M_1^{ij} = (1 + h_i - \beta_2^i - h_i \gamma_2^i) \rho_1^{ij} - (h_j \beta_2^i + \gamma_2^i) \rho_1^{ji}. \tag{8}
\]

Notice that the explicit terms \((\beta_2^i + h_i \gamma_2^i) \rho_1^{ii}\) and \((h_j \beta_2^i + \gamma_2^i) \rho_1^{ji}\) in equation (7) arise due to the effect of \(e_1^i\) on \(E \{ \theta_2^i \mid z_1^i, z_1^j \}\) and \(E \{ \theta_2^i \mid z_1^i, z_1^j \}\) through \(z_1^i\). Similarly, the terms \((\beta_2^i + h_i \gamma_2^i) \rho_1^{ij}\) and \((h_j \beta_2^i + \gamma_2^i) \rho_1^{ji}\) in equation (8) arise due to the effect of \(a_1^i\) on the conditional expectations of \(\theta_2^i\) and \(\theta_2^j\) through \(z_1^i\).

By exerting more work effort in the current period, as in the absence of explicit contracts, an agent gains by the subsequent increase in her reputational bonus by \((1 + h_i) \rho_1^{ij}\). However, because of the ‘explicit incentive component’, this bonus is diminished by \(\beta_2^i (\rho_1^{ii} + h_j \rho_1^{ji}) + \gamma_2^i (h_i \rho_1^{ii} + \rho_1^{ji})\).
If the outgoing teamwork interactions are strong (high $k_i$) so that $\gamma_2^{is} > 0$, the principal anticipates that agent $i$ will be assessed as being of higher ability and the explicit incentive component of her future remuneration will be large. Thus, the principal offers a contract whose base payment increases by less than the increase in the agent’s reputational bonus. However, if $k_i$ is small enough so that $\gamma_2^{is} < 0$, the principal now anticipates that the explicit incentive component in the second period will also be small and does not lower the fixed part of the salary as much.

Implicit incentives also arise due to the provision of help effort, captured by $M_1^{ij}$. As long as agent $i$’s support contributes significantly in her teammate’s project output (high $k_i$) so that $\rho_1^{ij} > 0$, by undertaking more help effort in the first period and increasing $z_1$, agent $i$ induces the principal to infer that she is a high productivity agent. The increase $(1 + h_i) \rho_1^{ij}$ in her reputation bonus though decreases by the explicit incentive component $\beta_2^{is} \left( \rho_1^{ij} + h_j \rho_1^{ij} \right) + \gamma_2^{is} \left( h_i \rho_1^{ij} + \rho_1^{ij} \right)$, where $\rho_1^{ij} + h_j \rho_1^{ij} > 0$ and $h_i \rho_1^{ij} + \rho_1^{ij} > 0$. In the regime where $\rho_1^{ij} < 0$, remark 1 highlights that a negative second-period pay-for-teammate performance parameter can decrease an agent’s implicit incentives to sabotage her colleague, which arise due to career concerns.

**Remark 1 (Trade-off between explicit and implicit incentives)** In the parameter space in which $(1 + h_i) \rho_1^{ij} - \beta_2^{is} \left( \rho_1^{ij} + h_j \rho_1^{ij} \right) < 0$, a negative $\gamma_2^{is}$ diminishes agent $i$’s incentives to sabotage her colleague’s production that arise due to career concerns.

With weak outgoing teamwork interactions (low $k_i$), negative implicit incentive to help arise, $M_1^{ij} < 0$. It is in agent $i$’s interest to convince the principal that she is teamed with a lower productivity agent and thus she has implicit incentives to sabotage. However, by setting $\gamma_2^{is}$ negative, the principal makes agent $i$ less eager to destroy part of her teammate’s output in order to build up her own reputation. Thus, a negative $\gamma_2^{is}$ encourages agent $i$’s to focus more on her own project in the first-period rather than sabotaging her teammate in her attempt to shape market assessments about her ability.

To derive the first period explicit incentives, we denote $B_1^i \equiv \beta_1^i + \delta M_1^{ij}$ and $\Gamma_1^i \equiv \gamma_1^i + \delta M_1^{ij}$. The equilibrium incentive parameters in the first period are

\[
\beta_1^{is} = \frac{1}{\Omega_1} - \delta M_1^{ij} - \frac{r \delta \psi_{a_1}}{\zeta_1 \Omega_1} \left\{ \left[ \left( k_i^2 + r \Sigma_1^{ij} \psi_{a_1}^{in} \right) \left( \sigma_i^2 + h_j^2 \sigma_j^2 \right) - r \left( \Sigma_1^{ij} \psi_{a_1}^{in} \right) \right] \beta_2^{is} - \Sigma_1 \left( k_i^2 + r \sigma_j^2 \psi_{a_1}^{in} \right) \gamma_2^{is} \right\},
\]

\[
\gamma_1^{is} = \Phi_1 B_1^i - \delta M_1^{ij} - \frac{r \delta}{\zeta_1} \left\{ \left[ \Sigma_1^{ij} \psi_{a_1}^{in} - k_i^2 \left( \sigma_i^2 + h_j^2 \sigma_j^2 \right) \psi_{a_1}^{in} \right] \beta_2^{is} + \left[ \left( \sigma_j^2 + h_j^2 \sigma_j^2 \right) \psi_{a_1}^{in} - k_i^2 \Sigma_1 \psi_{a_1}^{in} \right] \gamma_2^{is} \right\},
\]

where $\Omega_1^i \equiv 1 + r \left( \Sigma_1^{ii} + \Phi_1 \Sigma_1^{ij} \right) \psi_{a_1}^{in}$ and $\zeta_1^i \equiv k_i^2 \left( 1 - r \Sigma_1^{ij} \psi_{a_1}^{in} \right) + r \Sigma_1^{ij} \psi_{a_1}^{in}$ (see appendix (A.2)).

To shed insights, we decompose the optimal explicit incentives and examine the underlying effects.
The first term in (9) reflects the noise reduction effect that arises due to changes in the "amount" of available information about ability. In the next period, as the market learns more about abilities and their conditional variance decreases, we have $\Omega_1 > \Omega_2$. Therefore, the optimal trade-off between provision of work effort and insurance is improved for the principal (over time), in the sense that lower risks are incurred and a higher-power explicit incentive, $\beta_2^i$, can be provided, $\beta_2^i > \frac{1}{\Omega_1}$. Higher $k_i$ shifts the incentive-insurance trade-off towards the former even more.

The principal also adjusts the optimal explicit incentives to account for agents’ reputation incentives. Given that $M_1^{ii} > 0$, the principal imposes a lower pay-for-own performance relation when the optimal implicit incentives to work are stronger. Similarly, for high $k_i$ so that $M_1^{ij} > 0$, $\gamma_1^i$ is adjusted downwards. The opposite occurs and thus the optimal $\gamma_1^i$ increases when outgoing teamwork interactions are weak so that $M_1^{ij} < 0$. The negative reputation incentives need to be undone by a higher $\gamma_1^{is}$.

Risk-aversion and uncertainty about abilities also induce each agent to require insurance against low realizations of both $\theta_i$ and $\theta_j$: the own-performance and teammate-performance (human capital) insurance effects arise. In particular, the principal offers a contract that insures the agents against the intertemporal risk they face. For strong outgoing interactions so that both $\beta_2^{is}$ and $\gamma_2^{is}$ are positive, agents incur higher risk in the second period. Thus, the principal reduces the power of the first-period incentive scheme in order to share the risk. Both human capital insurance effects are negative, implying that lower $\beta_1^{is}$ and $\gamma_1^{is}$ can provide insurance against low realizations of both agents’ abilities. In our model, the principal provides additional insurance to agent $i$ due to $\theta_i$ taking the form of a further reduction in explicit incentives. However, a negative $\gamma_2^{is}$ increases $\gamma_1^{is}$. In Gibbons & Murphy (1992) and Auriol et al. (2002), the teammate-performance human capital insurance effect does not hold.

The compensation ratio effect reflects the relationship between the "effective" incentives - i.e., the sum of the explicit and implicit incentives - agent $i$ is influenced by. We have $\frac{\gamma_1^{is} + M_1^{ij}}{\beta_1^{is} + M_1^{ij}} = \Phi_i^i$ that is positive when the outgoing teamwork interactions are strong enough so that the principal finds it optimal to induce cooperation between the teammates. For low $k_i$ so that $\Delta_i^i$ becomes negative, the principal induces competition between them.

Agents’ incentives also differ from those in Lazear (1989) where sabotage incentives arise in tournaments because an agent’s compensation is conditioned negatively to her colleagues’ performances. Using such schemes, agents may desire to destroy other workers’ output rather than to work harder on their own project. In our model, as long as $\rho_1^{ij}$ is negative, agent $i$ has implicit incentives to

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The own-performance and teammate-performance human capital insurance effects can be separated because agents’ project outputs are observable and relative performance evaluation schemes are used. If learning is based on an aggregate measure and wages are contingent on the team production, these two effects are merged.
sabotage and a negative $\gamma_{2i}^i$ weakens such incentives. This result is also different from Meyer & Vickers (1997) where the agents’ abilities are correlated and implicit incentives are weakened due to the ratchet effect.\textsuperscript{16}

4.3 Temporary workers

In the preceding analysis, we assume that agents differ with respect to their innate ability as well as their contribution to their colleague’s project output, but they are assigned in a specific team as long as employment lasts. Tenure is long and agents anticipate their employment in a specific firm as a life-time career. However, there may be agents whose tenure in a specific firm is short. To examine the reputation incentives and explicit contracting when employment is temporary, we assume that agents are hired by a different employer in any subsequent period. Thus, in each period, each agent is paired to work with different workers of different ability. In this framework, agents do not intent to shape the market’s assessments about her current teammate’s ability since there are no benefits of convincing the market that she is teamed with a low productivity agent. Market perceptions about her teammate’s ability play no role in her future remuneration. However, she still exerts help effort in order to affect the other’s output, because this performance measure is used in the updating process about her own ability.

Suppose that a principal appoints two temporary workers. Each agent knows that in each period, she will work for another firm and be teamed with another worker. Given that the current period’s teammate will be different than the next period’s one, in Auriol et al. (2002), any implicit incentives to exert help effort disappear. Each agent knows that she is unable to capitalize any change in market beliefs about her current colleague’s ability while she has to bear the cost of taking an action to influence these beliefs. Her own reputation is also independent from her current colleague’s output. This performance measure does not reveal any information about her own ability. Thus, a temporary worker focuses on influencing the learning process about her own ability which depends only on her own production. Her focus is shifted on improving only her own performance.

\textsuperscript{16}Our model with explicit contracts supports Fama’s argument that the market forces alone can eliminate moral hazard problems. Assuming $T \to \infty$, as in Holmström (1999), abilities fluctuate over time and remain unknown to the parties: $\theta_{t+1}^i = \theta_t^i + \eta_t^i$, where $\eta_t^i \sim N(0, \sigma^2)$ is independently distributed. In the stationary case where $\rho_{t+1}^{ij} = \rho_t^{ij} = \tilde{\rho}^{ij}_t$ and $\rho_{t+1}^{ji} = \rho_t^{ji} = \tilde{\rho}^{ji}_t$, the work and help effort satisfy

\begin{align*}
\psi' (\tilde{\theta}_t^i) &= \tilde{\beta}_s^i + \frac{4}{1 - 4\delta^2_i} \left[ (1 + h_i - \tilde{\beta}_s^i - h_i \gamma_s^i) \tilde{\rho}_s^i - (h_j \beta_s^i + \gamma_s^i) \tilde{\rho}_s^i \right], \\
\psi' (\tilde{\gamma}_t^i) &= \tilde{\gamma}_s^i + \frac{\delta}{1 - 8\delta^2_i} \left[ (1 + h_i - \tilde{\beta}_s^i - h_i \gamma_s^i) \tilde{\rho}_s^i - (h_j \beta_s^i + \gamma_s^i) \tilde{\rho}_s^i \right],
\end{align*}

respectively. In the supplementary material, we show that if there is no discounting, $\delta = 1$, and $r > 0$, the stationary explicit incentives are zero, $\tilde{\beta}_s^i = \tilde{\gamma}_s^i = 0$, and efforts are efficient for any $h_i, h_j, k_i$ and $k_j$.\textsuperscript{16}
In our setting, implicit incentives to work and help or sabotage still arise for temporary workers:

\[ \tilde{M}^{ii}_1 = (1 + h_i - \beta^{i*}_2 - h_i \gamma^{i*}_2) \rho^{ii}_1, \]  
\[ \tilde{M}^{ij}_1 = (1 + h_i - \beta^{i*}_2 - h_i \gamma^{i*}_2) \rho^{ij}_1. \]

The optimal explicit incentives \( \tilde{\beta}^{i*}_1 \) and \( \tilde{\gamma}^{i*}_1 \) are given by (9) and (10) replacing \( M^{ii}_1 \) and \( M^{ij}_1 \) with \( \tilde{M}^{ii}_1 \) and \( \tilde{M}^{ij}_1 \), respectively. The comparison of equations (7) and (11) reveals that a temporary worker does not bother to influence the expected ability of this worker, since she will not be teamed with her in the subsequent period. Thus, the last term in (7) which reflects the incentives of a long-term worker to manipulate market perceptions about her teammate’s ability is missing. A worker who is appointed in a temporary basis disregards the effect of her actions on the market estimate about \( \theta^j \), while she intends to exert \( \alpha^i_1 \) in order to affect her current teammate’s output so as to induce an upward revision of the estimate of \( \theta^j \). Her own ability is an input in agent \( j \)'s production process, and by influencing \( z^j_1 \), agent \( i \) can bias the learning process in her favor, regardless the fact that indirectly the estimate of \( \theta^j \) is also affected. The intertemporal risk associated with a teammate’s human capital matters for an agent’s reputation incentives only when teams stay together for many periods.

**Proposition 3 (Implicit incentives to help or sabotage for temporary workers)** Suppose \( h_j \) is high enough so that \( h_j \beta^{i*}_2 + \gamma^{i*}_2 > 0 \). Agent \( i \)'s implicit incentives to help or sabotage also arise for temporary workers, and are stronger than the ones arise for long-term workers, \( \tilde{M}^{ij}_1 - M^{ij}_1 = \left( h_j \beta^{i*}_2 + \gamma^{i*}_2 \right) \rho^{ij}_1 > 0 \).

Implicit incentives to help or sabotage do arise for a temporary worker \( i \), although she does not bother to affect the process of inference of \( \theta^j \). In contrast, the long-term workers consider the effect of their actions on the expectation about \( \theta^j \) and given that \( h_j \) is high enough, the explicit components based on the incentives in the next period decrease \( M^{ii}_1 \) and \( M^{ij}_1 \). Instead, the principal compensates them by providing stronger explicit incentives in the current period. Therefore, the substitution relationship between explicit and implicit incentives implies that the principal offers contracts with lower incentive parameters to temporary workers. In a \( T \)-period model where \( T > 2 \), lower explicit incentives imply that the own-human capital effects will also be smaller. The teammate-human capital effects will be eliminated, since a temporary worker does not incur any intertemporal risk with respect to her current colleague’s human capital.
5 Conclusion

This paper analyzes compensation contracts and reputation incentives of team workers when individual performances depend on the quality of fellow members and the degree of managerial commitment changes. We assume that the support an agent receives depends on both her colleague’s effort and innate ability, as it is likely to happen in innovative firms with several research groups. We show that due to the incentives-insurance trade-off, the principal who fully commits to a life-time income path may provide long-term contracts that induce a high risk-averse agent even to sabotage her colleague. Under full commitment, career concerns do not arise since long-term contracts are offered and signed at the beginning of workers’ employment. Thus, sabotage is induced solely by the explicit contracts. We also argue that the duration of employment is a key determinant of teammates’ contracts, in contrast to Auriol et al. (2002). While for a short-term employment, the principal can motivate an agent to support a fellow member of the team, as employment is extended to many periods, the same agent may be induced to sabotage.

This paper also examines short-term contracts which are renegotiated in each period. Career concerns now arise and shape explicit contracts. A worker now has implicit incentives to sabotage her teammate because she wants to manipulate market assessments about her own ability. The principal now can set a negative explicit incentive in her attempt to decrease worker’s desire to sabotage. We show that reputation incentives also arise for temporary workers who will be matched with another worker in the next period. This happens because a worker can shape market assessment about her ability by influencing her current teammate’s production.

The present model can be used as a reference point for future works and extensions. Indicatively, one can consider production functions in which a worker’s help effort is multiplied with her teammate’s ability. The substitutive relationship between implicit and explicit incentives formulated by Gibbons & Murphy (1992) may be challenged. Dewatripont et al. (1999) examine this relationship in a single-agent model in which an agent’s effort and her own ability enter the production function in a multiplicative fashion. This paper can also be used as a reference point to develop a model in which a worker contributes to multiple projects and her commitment to be involved in each project varies. Given that she is teamed with workers of different abilities in each project, one can examine if she has incentives to work in projects where teammates’ ability are of lower productivity or in projects of longer duration. The size of the team and the degree of heterogeneity between the teammates’ skills are other key determinants of compensation contracts in the presence of career concerns. For instance, in software and microelectronics-based industry, research groups are small and the research time span is short, while in pharmaceutical and biotechnology, teams are large, lacking the ability to break them up into small independent modules. The research time span is also long, since it
involves experimentation. One can also enrich this framework by considering different allocations of the bargaining power or allowing for side payments between the agents.

References


A. APPENDIX

A.1 Long-term explicit incentives

In the beginning of period 1, given (4), the principal maximizes

\[ L = \sum_{t=1}^{2} \sum_{i=1}^{2} \delta^{t-1} E \left\{ z_i^t - \omega_i^t - \beta_i^t z_i^t - \gamma_i^t z_i^t \right\} + \sum_{i=1}^{2} \lambda_i \left[ \beta_i^t - \psi' (e_i^t) \right] + \sum_{i=1}^{2} \mu_i \left[ k_i \gamma_i^t - \psi' (a_i^t) \right] \]

\[ + \sum_{t=1}^{2} \sum_{i=1}^{2} \delta^{t-1} \xi_i \left[ E \left\{ \omega_i^t + \beta_i^t z_i^t + \gamma_i^t z_i^t \right\} - \psi (e_i^t) - \psi (a_i^t) \right] - \frac{r}{2} \text{Var} \left\{ w_1^t + w_2^t \right\} - \Theta_i. \]

Omitting details, the Kuhn-Tucker condition with respect to \( \omega_i^t \) gives \(-1 + \xi_i = 0 \iff \xi_i = 1\), implying that the \( IR_i \) constraint binds at the optimum. Then, the Kuhn-Tucker conditions become

\[ \frac{\partial L}{\partial \lambda_i^t} = \beta_i^t - \psi' (e_i^t) \geq 0 \text{ or } \lambda_i^t \geq 0, \quad \lambda_i^t \left[ \beta_i^t - \psi' (e_i^t) \right] = 0, \forall i, t \]

\[ \frac{\partial L}{\partial \mu_i^t} = k_i \gamma_i^t - \psi' (a_i^t) \geq 0 \text{ or } \mu_i^t \geq 0, \quad \mu_i^t \left[ k_i \gamma_i^t - \psi' (a_i^t) \right] = 0, \forall i, t \]

\[ \frac{\partial L}{\partial \beta_i^t} = -r \left\{ (\beta_1^t + \beta_2^t) (\sigma_i^2 + h_i^2 \sigma_j^2) + (\gamma_1^t + \gamma_2^t) \Sigma_i^j + \beta_i^t \sigma_i^2 \right\} + \lambda_i^t \leq 0 \text{ or } \beta_i^t \geq 0, \quad \frac{\partial L}{\partial \beta_i^t} = 0, \forall i, t \]

\[ \frac{\partial L}{\partial \gamma_i^t} = -r \left\{ (\beta_1^t + \beta_2^t) \Sigma_i^j + (\gamma_1^t + \gamma_2^t) (\sigma_j^2 + h_i^2 \sigma_j^2) + \gamma_i^t \sigma_i^2 \right\} + \mu_i^t \leq 0 \text{ or } \gamma_i^t \geq 0, \quad \frac{\partial L}{\partial \gamma_i^t} = 0, \forall i, t \]

\[ \frac{\partial L}{\partial e_i^t} = 1 - \lambda_i^t \psi^{in}_i - \psi' (e_i^t) \leq 0 \text{ or } e_i^t \geq 0, \quad \frac{\partial L}{\partial e_i^t} = 0, \forall i, t \]

\[ \frac{\partial L}{\partial a_i^t} = \lambda_i^t - \mu_i^t \psi^{in}_i - \psi' (a_i^t) \leq 0 \text{ or } a_i^t \geq 0, \quad \frac{\partial L}{\partial a_i^t} = 0, \forall i, t \]

We have \( \lambda_i^t = \frac{1 - \psi' (e_i^t)}{\psi^{in}_i} \) and \( \mu_i^t = k_i \frac{1 - \psi' (a_i^t)}{\psi^{in}_i} \). Given that \( \lambda_i^t > 0 \) and \( \mu_i^t > 0 \), equations (4) hold. Thus, we solve the conditions with respect to \( \beta_i^t \) and \( \gamma_i^t \), and obtain equations (5). Note that substituting \( \gamma_i^{j_{fc}} = \Phi^i \beta_i^{j_{fc}} \) into the condition with respect to \( \beta_i^t \) gives

\[ \lambda_i^t = r \left( \Sigma_i^j + \Phi^i \Sigma_i^j \right) \beta_i^{j_{fc}}. \]

A long-term contract provides the same explicit incentives \( \beta_i^{j_{fc}} \) and \( \gamma_i^{j_{fc}} \) in each period. A positive \( \gamma_i^{j_{fc}} \) requires a positive \( \Phi^i \), whose denominator is positive for all \( h_i, h_j, k_i \) and \( k_j \). Thus, its sign depends on the sign of the numerator. It is positive when the condition in proposition 1 holds.

A.2 Short-term explicit incentives

To find the optimal incentives in period 1, we first need to derive the form of

\[ \text{Var} \left\{ \hat{w}_1^i + w_2^i \right\} = \text{Var} \left\{ \hat{w}_1^i \right\} + \text{Var} \left\{ w_2^i \right\} + 2 \text{Cov} \left\{ \hat{w}_1^i, w_2^i \right\}, \quad (13) \]
where
\[
    \text{Var} \left\{ \hat{w}_1^i \right\} = \text{Var} \left\{ w_1^i \right\} + \text{Var} \left\{ \omega_2^i \right\} + 2 \text{Cov} \left\{ w_1^i, \omega_2^i \right\}.
\]  
(14)

The variance of the first-period wage is given by
\[
    \text{Var} \left\{ w_1^i \right\} = (\beta_1^i + h_i \gamma_1^i)^2 \sigma_i^2 + (h_j \beta_1^i + \gamma_1^i)^2 \sigma_j^2 + \left[ (\beta_1^i)^2 + (\gamma_1^i)^2 \right] \sigma_x^2.
\]  
(15)

Note that
\[
    \Theta_1^i - E \left\{ \beta_2^i z_2^i + \gamma_2^i z_2^i | z_1^i, z_1^i \right\} =
\]
\[
    = E \left\{ (1 + h_i - \beta_2^i - h_i \gamma_2^i) \theta^i - (h_j \beta_2^i + \gamma_2^i) \theta^i + (1 - \beta_2^i) e_2^i + k_i (1 - \gamma_2^i) a_2^i - k_j \beta_2^i a_2^i - \gamma_2^i e_2^i | z_1^i, z_1^i \right\}
\]
\[
    = M_1^{ii} (z_1^i - e_1^i - h_j \hat{a}_1^i) + M_1^{ij} (z_1^i - e_1^i - h_i \hat{a}_1^i) + (1 - \beta_2^i) e_2^i + k_i (1 - \gamma_2^i) \hat{a}_2^i - k_j \beta_2^i \hat{a}_2^i - \gamma_2^i e_2^i,
\]
where $M_1^{ii}$ and $M_1^{ij}$ are given by (7) and (8). Thus, the variance of $\omega_2^i (\beta_2^i, \gamma_2^i)$ is
\[
    \text{Var} \left\{ \omega_2^i \right\} = (M_1^{ii} + h_i M_1^{ij})^2 \sigma_i^2 + (h_j M_1^{ii} + M_1^{ij})^2 \sigma_j^2 + \left[ (M_1^{ii})^2 + (M_1^{ij})^2 \right] \sigma_x^2.
\]  
(16)

By (15) and (16), we also have
\[
    \text{Cov} \left\{ w_1^i, \omega_2^i \right\} = (\beta_1^i + h_i \gamma_1^i) (M_1^{ii} + h_i M_1^{ij}) \sigma_i^2 + (h_j \beta_1^i + \gamma_1^i) (h_j M_1^{ii} + M_1^{ij}) \sigma_j^2
\]
\[
    + \left[ \beta_1^i M_1^{ii} + \gamma_1^i M_1^{ij} \right] \sigma_x^2.
\]  
(17)

To obtain the variance of $\hat{w}_1^i$, let $B_1^i \equiv \beta_1^i + M_1^{ii}$ and $\Gamma_1^i \equiv \gamma_1^i + M_1^{ij}$. Then, by (15), (16) and (17), the variance in (14) becomes
\[
    \text{Var} \left\{ \hat{w}_1^i \right\} = (B_1^i + h_i \Gamma_1^i)^2 \sigma_i^2 + (h_j B_1^i + \Gamma_1^i)^2 \sigma_j^2 + \left[ (B_1^i)^2 + (\Gamma_1^i)^2 \right] \sigma_x^2,
\]
and the covariance of $\hat{w}_1^i$ and $w_2^i$ can be written as
\[
    \text{Cov} \left\{ \hat{w}_1^i, w_2^i \right\} = (\beta_2^i + h_i \gamma_2^i) (B_1^i + h_i \Gamma_1^i) \sigma_i^2 + (h_j \beta_2^i + \gamma_2^i) (h_j B_1^i + \Gamma_1^i) \sigma_j^2.
\]

Therefore, equation (13) takes the form
\[
    \text{Var} \left\{ \hat{w}_1^i + w_2^i \right\} = \left[ B_1^i + \beta_2^i + h_i (\Gamma_1^i + \gamma_2^i) \right] \sigma_i^2 + \left[ h_j (B_1^i + \beta_2^i) + \Gamma_1^i + \gamma_2^i \right] \sigma_j^2
\]
\[
    + \left[ (B_1^i)^2 + (\Gamma_1^i)^2 + (\beta_2^i)^2 + (\gamma_2^i)^2 \right] \sigma_x^2.
\]
Provided that the $IR_1^i$ constraint binds and $\Theta_1^i$ is zero, the first-period base payment is
\[
    \omega_1^i = -E \left\{ \beta_1^i z_1^i + \gamma_1^i z_1^i \right\} + \psi (e_1^i) + \psi (a_1^i) - E \left\{ w_2^i \right\} + \psi (e_2^i) + \psi (a_2^i) + \frac{r}{2} \text{Var} \left\{ \hat{w}_1^i + w_2^i \right\}.
\]
We take the Kuhn-Tucker conditions as in appendix (A.1) and solve the equations:

\[
\begin{align*}
[B_i^i + \beta_2^i + h_i (\Gamma_1^i + \gamma_2^i)] \sigma_i^2 + [h_j (B_1^i + \beta_2^i) + \Gamma_1^i + \gamma_2^i] h_j \sigma_j^2 + B_1^i \sigma_s^2 &= \frac{\lambda_i}{r} \\
[B_i^i + \beta_2^i + h_i (\Gamma_1^i + \gamma_2^i)] h_i \sigma_i^2 + [(h_j (B_1^i + \beta_2^i) + \Gamma_1^i + \gamma_2^i)] \sigma_j^2 + \Gamma_1^i \sigma_s^2 &= \frac{h_i \mu_i}{r}
\end{align*}
\]

\[
1 - B_1^i - \lambda_i \psi_{\varepsilon t} = 0 \\
k_i (1 - \Gamma_1^i) - \mu_i \psi_{\alpha t} = 0
\]

We derive the optimal \(\beta_1^*\) and \(\gamma_1^*\), given by the equations (9) and (10).