Pay to Quit and Team Incentives*

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March 2016

Abstract

This paper examines the optimal compensation scheme, job design, and severance policy for a team using a model of repeated moral hazard. In the optimal contract, the agent may be paid to quit after a poor performance. We show that a generous severance policy facilitates the adoption of team incentives and team-based production by making it cost-effective to implement peer monitoring and sanction among the agents.

Keywords Team incentives, Teamwork, Severance policy, Peer Monitoring

JEL Codes D86, J65

1 Introduction

In the company's annual letter to shareholders published in April 2014, Amazon's founder and CEO Jeff Bezos revealed the human resource program "Pay to Quit," which works as follows: "Once a year, we offer to pay our associates to quit. The first year the offer is made, it's for $2,000. Then it goes up one thousand dollars a year until it reaches $5,000." He stated that the goal of the program is to "encourage folks to take a moment and think about what they really want. In the long-run, an employee staying somewhere they don't want to be isn't healthy for the employee or the company." The innovative human resource practice of paying employee to quit was first introduced in Zappos in 2008.[1] Its CEO, Tony Hsieh, explained one

*I am grateful to Yeon-Koo Che, Yuk-fai Fong, Fuhai Hong, Chiu Yu Ko, Anton Kolotolin, Jin Li, Jingfeng Lu, and Hodaka Morita for their helpful discussion and comments. I would also like to thank seminar participants at Nanyang Technological University, National University of Singapore, University of New South Wales, the 6th Shanghai Microeconomics Workshop, the 5th Singapore Economic Review Conference, and the 2015 World Congress of Econometric Society. All errors are my own.

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[1] The initial exit pay was $2000. Today, it has increased to one month's salary.

of the rationale is to foster a strong corporate culture and core values, including building a positive team and being passionate and determined (Hsieh (2010)). Since its introduction, this HR practice has caught widespread attention and discussion. Besides Amazon, Netflix followed the footstep in adopting a similar program "Adequate performance gets a generous severance package". In a set of well-circulated slides on Netflix's corporate culture and management philosophy,[2] its founder and CEO Reed Hastings explained the rationale for its policy, "[T]he other people should get a generous severance now, so we can open a slot to try to find a star for that role." The slides also go on to discuss the importance of teamwork and peer influence by underlining that a "Great workplace is stunning colleagues." More recently, Riot Games, a large American-based video game publisher, offers its employees 10% of their annual salary, up to $25,000, if they quit voluntarily. The company explains the purpose is to "reinforce Riot's culture", which "operates on a foundation of shared mission, values, passion, trust, and mutual respect". Uri Gneezy commented that Riot's strategy is "incentive compatible for [employees] to say that they really want to stay with you." Moreover, he expected these programs are good way to weed out potentially disengaged workers in an industry reliant on creativity instead of measurable output.[3]

These companies adopting a "Pay to Quit" program emphasize the need to establish a strong corporate culture of teamwork and cooperation. However, at first glance, generous exit pay seems to be at odds with teamwork in a standard model of repeated interaction: increasing workers' turnover would reduce the expected duration of the team members' relationship and make cooperation more difficult to sustain. On the other hand, the literature in management, organizational behavior, and psychology have pointed out that misbehavior of members can hurt team morale and performance. A large-scale survey conducted by Porath and Pearson (2009) find that having "toxic colleagues" cause a reduction in reported work effort, work quality and overall employee performance. In fact, a senior vice president of a Fortune 50 firm told them, "They [toxic employees] can and do sit in the boat without pulling the oars...and that may be worse than leaving." In a similar spirit, empirical studies by Duffy, Ganster, and Pagon (2002) and Chiaburu and Harrison (2002) find that behaviors that undermine coworker relationship have a negative impact on team effectiveness and productivity. Therefore, it may be a good idea to induce these toxic employees to quit for the sake of preserving team morale and performance. In this paper, we use a model of dynamic moral hazard to investigate the interaction of "Pay to Quit" and teamwork.

[2] The slides can be downloaded at http://www.businessinsider.com/netflix-management-presentation-2011?IR=T&#-1. According to McCord (2014), the slides have been viewed 5 million times on the Web. Sheryl Sandberg, Chief Operating Officer of Facebook, desribed the slides as "one of the most important documents ever to come out of Silicon Valley."

[3] Sipek, B. (2014, July 9). "Why One Company Pays $25,000 to Quit." at the Talent Management Magazine. Retrieved from http://www.talentmgt.com/articles/6617-why-one-company-pays-25000-to-quit

The model formally illustrates why paying employees to quit can facilitate the adoption of teamwork, and more generally a team-based incentive scheme. We identify conditions under which these human resources practices are optimal, and we outline the mechanism at work.

In our basic model, in each of the infinitely many periods, a principal has two technologically independent tasks, each of which requires the effort of an individual agent. The agency relationship is characterized by moral hazard with limited liability: each agent makes his effort decision privately and must receive a nonnegative wage, while the principal is able to observe and contract only on a noisy objective performance measure. As the agents interact closely with each other, they are able to better observe each others' effort than the principal. We model this by assuming that each agent's effort generates a stochastic signal, which is (i) publicly observed only between the agents, and (ii) a sufficient statistics of the objective performance measure observed by the principal. The principal may fire an agent for poor performance, in which case an identical replacement can be found at no cost. The employment contract stipulates wage, firing decision, and severance payment conditional on the objective performance measures. We focus on stationary contracts that motivate both agents' effort, and solve for the one that minimizes the principal's expected agency cost.

Consider two types of severance policies: harsh or generous. A harsh severance policy fires the agent with no severance payment if his performance measure is poor. A generous severance policy never fires an agent regardless of his performance, and may even offer him a severance payment when he quits voluntarily. On the other hand, consider two kinds of wage schemes: independent performance evaluation (IPE) and joint performance evaluation (JPE). With IPE, each agent receives a wage that depends only on his own performance, while with JPE, each agent is rewarded more if his partner performs well. Stock options, division and team bonuses are examples of JPE scheme.

Two combinations of severance policies and wage schemes are particularly relevant: (i) a harsh severance policy and IPE scheme; and (ii) a generous severance policy and JPE scheme. The first combination resembles a classical efficiency wage contract (Shapiro and Stiglitz (1984)), and it is well known that the termination threat can lower the agency cost. We show that the second combination can make effective use of peer monitoring and sanction, and may often outperform the optimal efficiency wage contract.

Below we explain how peer monitoring and sanction work under the shadow of a generous severance policy and JPE. Each stationary contract defines a repeated game of imperfect public monitoring between the agents. A JPE wage scheme can make the stage game between them a prisoners' dilemma: while shirking is a dominant strategy, both agents are better off if they both exert effort. As a result, it is a perfect public equilibrium (PPE) for each agent to shirk permanently, so there is a credible punishment for a poor signal. Since monitoring is imperfect, even if both agents put in effort in every period, there is a positive probability that an agent gives a bad signal in some period. In this case, he must be punished, for otherwise, the ex-ante incentive for exerting effort is insufficient. A problem of the punishment is that not only does the agent with a bad signal suffer, but so does the principal who loses valuable effort from the agents. To make an agent with a poor signal receive an equilibrium punishment without forgoing valuable effort, the principal can pay the agent to quit: compensate the quitting agent with the difference between his inside option and outside option. The quitter is then replaced by an identical agent, and a fresh relationship starts between the new hire and the remaining agent.

The benefit of the contract (and the associated PPE) outlined above is that the punishment of losing the job is based on a more precise signal of the agents' effort. The downside is that severance payment is costly to the principal, and the threat of losing the job is a less severe punishment compared to the efficiency wage contract. Which contract prevails depends on this trade-off of benefit and cost. It is natural that the efficiency wage contract is more appealing if the principal has access to a precise performance measure relative to the agents' signals. Perhaps more surprising is the finding that a higher outside option of the agents tilts the balance toward JPE: a high outside option implies that a smaller severance payment is needed. Furthermore, this analysis allows us to identify conditions under which a generous severance policy and a team-based incentive scheme are complementary human resource practices.

Our main model assumes exogenous and independent production technology. In Section 4, we allow the principal to choose between an individual-based and a team-based production technology. To highlight the effect of peer monitoring, we assume away any synergy in team production. It is found that because of a free-riding problem inherent in team-based production, individual-based production is always preferred in a static setting. Team production is optimal only in a dynamic setting, when adopted in conjunction with a generous severance policy. Precise sufficient conditions for the optimality of team production with a generous severance policy are identified. This extension thus illustrates that the insight of the complementary nature of teamwork (and team incentives) and generous severance policy are robust to endogenous job design.

Our model builds on the work of Che and Yoo (2001). They assume perfect monitoring between the agents and show that a properly designed JPE scheme enables the mechanism of peer sanction to reduce the agency cost. We adapt their model to allow for (i) imperfect public monitoring between the agents, as well as (ii) costless agent replacement. The assumption of imperfect monitoring among workers is quite realistic: agents may be better informed about each others' work than the principal, but their observation is likely to be partial. In fact, imperfect observation of team members' activity is often a source of workplace conflict and misunderstanding (Robbins and Judge (2013)). The assumption of costless agent replacement helps simplify our analysis. All results reported are qualitatively valid if the firing and recruiting costs are relatively mild. Whereas agent replacement is typically costly in reality, the cost may be insignificant compared to that of a loss in team morale, as pointed out by Porath and Pearson (2009).[4] Below we discuss how each modification on its own alters the results of Che and Yoo (2001).

First, Che and Yoo (2001) show that an optimal contract is a JPE scheme[5] and is supported by a grim-trigger equilibrium: the agents exert effort provided that they have done so in all previous periods; if any agent shirked, the punishment phase begins in which both agents shirk for the rest of the game. The equilibrium punishment between the agents imposes a negative externality on the principal, who loses valuable effort. However, the principal does not need to worry about this because, as the authors point out, the punishment phase is off the equilibrium path: it happens with zero probability under the assumption of perfect monitoring. Relaxing the perfect monitoring assumption to allow for imperfect public monitoring results in the punishment phase occurring with a positive probability. In this case, the original contract in Che and Yoo (2001) may become very costly, especially if the principal highly values the agents' effort. Second, Che and Yoo (2001) assume that replacing an agent is prohibitively costly, so that the principal cannot terminate an agent with poor performance. Therefore, an efficiency wage contract is irrelevant in their setting. On the other hand, if an agent can be easily replaced, an efficiency wage contract may outperform the JPE wage scheme they consider, especially if the agents have a low outside option.[6] We show that, with imperfect public monitoring between the agents and costless agent replacement, the principal can mitigate the negative externality of punishment by offering a generous severance package that encourages the poorly performing agent to quit voluntarily and hiring an replacement agent. In our analysis, since agent replacement is possible, the principal has to compare

[4] According to a report published by a consulting firm CPP in 2008, workers in the United States spend an average of 2.8 hours per week on dealing with workplace conflict. The figures are 3.3 hours in Germany and Ireland. They also report that about 10% of their survey respondents would take relatively extreme measures such as failing to attend meetings and taking multiple days off when dealing with workplace conflict.

[5] In our setting, there is no common shock of production, so Proposition 2 of Che and Yoo (2001) implies that the JPE scheme is optimal.

[6] After all, both the JPE scheme of Che and Yoo (2001) and the efficiency wage contract make use of dynanmic incentive to lower the agency cost. In the former, shirking is punished by a permanent mutual shirking equilibrium; in the latter, shirking is punished by being fired.

the performance of this contract against an efficiency wage contract.

By incorporating the realistic features of agent relationship and agent replacement in an otherwise standard dynamic moral hazard model, we contribute to the literature by pointing out that the severance policy can play a key role in shaping team-incentive provision. Interestingly, encouraging voluntary quitting can benefit the adoption of teamwork and the maintenance of high team performance. By taking agent replacement into account, we are able to identify novel conditions on severance policy and workplace design that favor the adoption of team incentives.

The paper proceeds as follows. A literature review is given below. We set up the model in Section 2. Section 3 solves for the optimal contracts in different parameter cases, and identifies conditions under which a generous severance package and a JPE wage scheme are complementary practices. Section 4 analyzes an extension of the model which endogenizes the choice of production technology. Section 5 discusses alternative model specifications and theories. The appendix contains omitted proofs, and an extension of the model that allows for a more general contract space.

Related Literature

Our analysis relies on the techniques developed in the literature of repeated games with imperfect public monitoring. The seminal article of Green and Porter (1984) shows that colluding oligopolists may engage in a price war if their observations of the market demand is imperfect. The destruction of producers' surplus by a price war, while costly to the oligopolists, is necessary to provide incentives for sustaining collusion. It is clear that the price war is not renegotiation-proof: the colluding firms are better off ex-post if they forgive each other and return to collusion. Therefore, the equilibrium is inefficient, in the sense that Pareto improvement exists if their actions were fully contractible. Fong and Li (2008) point out that allowing player turnover in a repeated game can mitigate this inefficiency problem. The equilibrium we focus on also has a flavor of player turnover: by replacing the agent with a poor signal, the agents on the job always play the action profile that maximizes their joint payoffs in equilibrium.

There are three major differences between Fong and Li (2008) and this paper. First, the contracting problem considered in Fong and Li (2008) is one of single-agent relational contracting (over observable but unverifiable outcomes), whereas we study multi-agent contracting in which the principal can commit to a long-term contract over verifiable outcomes. *Importantly, severance payment never arises in their equilibrium, but is an integral part of the optimal contract in our setting.* Second, whereas Fong and Li (2008) focus on the total equilibrium payoffs of all players, we focus on the profit of the principal, who *cannot* be modelled as a player in the repeated game, as she commits to a contract in the initial stage.[7] In fact, the benefit of our optimal contract arises from mitigating not only the impact of the punishment phase on the agents, but also the negative externality it imposes on the principal (who is not a player in the repeated game). Finally, in the contracting problem considered in Fong and Li (2008), the benefit of player turnover arises only if the public history of the game is fully observable to all players (including those who are currently idle, but may potentially enter the game in the future), we show that the optimality of inducing voluntary quitting remains valid in a more realistic setting in which the history of the signal and outcome profile is observable *only* to agents on the job.

Team incentives have been extensively studied (see Fleckinger and Roux (2012) for an excellent survey). The literature focuses on identifying circumstances under which IPE, JPE or relative performance evaluation (RPE) are optimal. The results typically depend on the nature of interdependencies in production technology and/or information structure. The idea that complementarity in production technology favors JPE dates back to Alchian and Demsetz (1972), and Marschak and Radner (1972). A recent contribution by Gershkov and Winter (2005) show that with complementary technology, informal peer monitoring can substitute formal monitoring. In contrast, our results do not rely on any interdependency in technology. With independent production technology, Holmstrom (1979)'s Informativeness Principle implies that JPE (RPE) can be optimal if agents performance measures are positively (negatively) correlated. Lazear and Rosen (1981) show that tournament, a particular form of RPE, can achieve the first-best outcome for the principal. Green and Stokey (1983) show that if the agents' outputs contain a common shock component, tournament helps filter out the shock, thus saving the agency cost. Our model features neither types of interdependencies. Moreover, we emphasize the importance of severance policy in managing team incentives.

A number of articles consider relational contracts in a team. Levin (2002) considers the tradeoff between establishing relational contracts to the whole workplace, and to individual workers. Kvaloy and Olsen (2006, 2012) show that as team bonus is relatively large in JPE compared with the necessary bonus in IPE and RPE, the use of JPE is less appealing because the principal faces strong temptation to renege on the large bonus. Deb, Li, and Mukherjee (2016) allow for subjective peer evaluations and show that the interaction of incentive compatibilities in effort exertion and truth-telling of peers' performance complicates the use of peer reporting in compensation. They show that peer evaluations are used sparingly in the optimal contract: either they are completely ignored, or relevant only in the extreme case of the worst possible public outcome and the worst possible report. Baldenius, Glover, and

[7] This is in contrast to the relational contracting approach in which the principal offers a short-term contract every period.

Xue (forthcoming) show that the threat of collusion among agents forces the principal to adopt a wage scheme with the flavor of IPE. In contrast, we focus on contracting over verifiable performance measures, and the principal does not have commitment problem. Moreover, none of the studies discussed above investigate the role of severance policy.

Peer pressure has been modelled by Kandel and Lazear (1992) as a direct imposition of disutility on shirkers (e.g., mental harassment). They investigate how job and pay scheme should be designed to make optimal use of peer pressure. We abstract from direct social sanction and focus only on punishment by mutual shirking on the job. Allowing these social sanction lowers the quitting agent's inside option, and a lower severance payment is needed to induce exit. Empirical studies have provided evidence for the effectiveness of peer pressure. Mas and Moretti (2009) document evidence on peer pressure among supermarket clerks. Ichino and Maggi (2000) show that absenteeism and misconduct have an effect on peers in an Italian bank. Knez and Simester (2001) find that mutual monitoring makes firmwide bonus successful.

Our finding that a generous severance package and teamwork/team incentives should be adopted together echoes the theme that human resource practices are often complementary of each other (Milgrom and Roberts (1990, 1995)). The classic study of Ichniowski, Shaw, and Prennushi (1997) on steel mills finds strong complementarities among innovative human resources practices, such as teamwork, information sharing, and job security. Hamilton, Nickerson, and Owan (2003) find evidence on complementarity of team-based production technology and group incentives in a garment plant.

The offer of severance payment upon voluntary quitting of CEO, known as the golden handshake, is quite common. Bebchuk and Fried (2003) attribute this practice to the CEO exerting influence over the board of directors. In Almazan and Suarez (2003), the board may use a severance payment to help commit to a contract, or to replace the current CEO with a superior candidate. In Inderst and Mueller (2010), the CEO has private information on his productivity if he stays in the firm, and the board may use severance payment, in conjunction with a steep incentive scheme, to encourage the exit of a CEO with bad information. In contrast, the principal in our model has full bargaining and commitment power. Moreover, the agents in our model has no private information on their productivity; in fact, they are all identical. Furthermore, we consider multiagents/team production, whereas CEO contracting is typically a single-agent contracting problem. In Section 5, we provide a detailed discussion on the predictions that distinguish our theory of severance pay from this line of literature.

The importance of coworker relationship in the workplace has long been recognized in management, psychology and organizational behavior.[8] Coworker support and good interpersonal relationship at work are positively associated with employee performance and firm profit (Koys (2001), Chiaburu and Harrison (2002), and Podsakoff, Whiting, Podsakoff and Blume (2009)). On the other hand, workplace conflict is costly to the firm as it has a negative impact on individual and team performance (Cortina and Magley (2003), de Jong, Curseu and Leenders (2014), Robinson, Wang and Kiewitz (2014)). Particularly related to this paper are studies on the effect of coworker relationship on employees' intention and actual decision to quit. Mossholder, Settoon and Henagan (2005) find that employees who are well connected with other employees and engage in interpersonal citizenship behavior[9] are less likely to quit. Humphrey, Nahrgang, and Morgeson (2007) find that greater support and interaction with coworkers significantly reduces employees' intention to quit, whereas job characteristics do not have a significant impact.[10] These studies provide supportive evidence for the relevance of our model in the real workplace: good coworker relationship is key to the success of a team and consequently an organization; whereas poor relationship is costly to the team and the organization, and is likely to trigger employee turnover.

2 Model

Time is discrete and infinite, $t = 1, 2, ...$ Every player shares a common discount $\delta \in (0, 1)$, and is risk-neutral. In each period t, a (female) principal hires two identical (male) agents, $i = 1, 2$, to perform an independent and identical task. The outcome of the task performed by agent i, denoted by y_i^t, is either good ($y_i^t = 1$) or bad ($y_i^t = 0$). In each period, each agent i makes a binary effort decision $e_i^t \in \{0, 1\}$, i.e., he either works ($e_i^t = 1$) or shirks ($e_i^t = 0$). The cost of effort to the agent is $c > 0$. Work effort increases the probability that the task is a success. There is no serial correlation in production across periods.

The monitoring technology is as follows. In each period, a signal about the agent's effort is realized and observed ONLY by himself and his partner. Agent i's signal $x_i \in \{0, 1\}$ is either good ($x_i = 1$) or bad ($x_i = 0$). The signal distribution depends on the agent's effort choice. Specifically,

$$\Pr(x_i = 1|e_i = 1) \equiv p > q \equiv \Pr(x_i = 1|e_i = 0)$$

[8]For related contribution in behavioral economics, see among others, Itoh (2004), Chillemi (2008) ,and Dur and Sol (2010).

[9]They define interpersonal citizenship behavior as "citizenship behavior directed toward coworkers and immediate others and focuses on cooperative assistance for individuals in need".

[10]Mueller, Charles, and Price (1990), Alexander, Lichtenstein, Oh and Ullman (1998), Morrison (2004) and Borzaga and Depedri (2005) find that poor relationship with coworkers is a major factor in shaping employees' intention and/or actual decision of voluntary quitting.

Each individual agent's signal and outcome is independent of each other. The signal realizations are not observable to the principal, so they are NOT contractible. On the other hand, the agent's outcome is contractible. We assume agent i's period outcome y_i is a garbling of his signal. Specifically,

$$\Pr(y_i = 1 | x_i = 1) = r > 0 = \Pr(y_i = 1 | x_i = 0)$$

The value of a successful outcome to the principal is $Y > 0$. The agents are subject to limited liability. Specifically, the principal cannot impose negative wages on the agents. It is apparent that there is interdependency in neither agents' production technology nor their signal structure.

We further assume that it is **infeasible** for the agents to (i) send reports to the principal, and (ii) make transfers between them. The first assumption rules out the possibility that the principal can learn the signal profile by designing a proper report solicitation mechanism. The second assumption prohibits the agents from engaging in side-contracting.[11]

Every agent has the right to resign from the firm at the end of each period without any penalty. Denote the outside option to each agent by $\bar{U}$: this is the per-period payoff the agent can get by leaving the firm. The employment contract may also give the principal the right to terminate the employment relationship. When there is a vacancy, the principal can costlessly hire a new identical agent to fill it.

The principal can commit to the employment contract offered. We focus on the class of stationary, deterministic and symmetric contracts.[12] Stationarity requires that the contract terms are invariant over time. Symmetry requires that the contract for each agent is identical. A deterministic contract does not have any stochastic clause. Moreover, we focus on contracts in which the decision of forced termination depends only on the agent's own outcome, but not the partner's. The last restriction can be rationalized on the ground of empirical observations: employment contracts often contain termination clauses that are conditional on the agent's poor performance, but rarely do they refer to his colleagues' performance. In the appendix, we relax this assumption to allow the termination clauses to be conditional on both agents' outcomes.

[11] The same assumptions are made by Che and Yoo (2001). They point out communication to the principal can be (i) costly and/or impractical in many environments, (ii) subject to collusion among agents in a repeated setting. Relatedly, Deb, Li, and Mukherjee (2016) show that even if peer report is feasible, it is often optimal to ignore it. Peiperl (1999) and May and Gueldenzoph (2006) observe that peer evaluation is subject to various forms of rater bias. Peiperl (1999) point out that peer evaluation is typically used only for development and training purposes.

[12] Che and Yoo (2001) restricts to the same class of contracts. We discuss the effect of these contractual restrictions in Section 6.

Formally, a contract stipulates (i) the wage payment based on contractible outcomes $\{w_{y_i,y_j}\}$; (ii) the decision of termination $\{f_{y_i}\}$; and (iii) severance payments in case of voluntary resignation $\{s_{y_i,y_j}\}$ and forced termination $\{\sigma_{y_i}\}$ respectively. Here, $f_{y_i} = 1$ stands for firing and $f_{y_i} = 0$ stands for not firing.

In each period, events happen in the following order:

1. Each agent on the job makes his effort decision independently and simultaneously.

2. Signals x_1 and x_2 are realized and observed by both agents (but not the principal).

3. Outcomes y_1 and y_2 are realized. Agents get paid according to the wage scheme $\{w_{y_i,y_j}\}$.

4. If $f_{y_i} = 1$, agent i is fired and paid severance payment σ_{y_i}.

5. If $f_{y_i} = 0$, agent i can still exit the firm. If he does so, he collects severance payment s_{y_i,y_j}.

6. If any agent exits, a new identical agent is hired to replace him.

An agent observes only the history of signals in periods during which he is working for the principal. Each contract defines a repeated game between the hired agents. In the repeated game, the relevant public history contains all signals and outcomes realized in all periods in which the pair of agents have worked for the principal. A public strategy for an agent is a mapping from the public history to the effort decision and the voluntary exit decision. We say a contract induces full effort if under the contract, there exists a perfect public equilibrium (PPE) such that on the equilibrium path, both agents exert effort in every period.[13],[14]

A note on terminology. We say a wage scheme features independent performance evaluation (IPE) if the wage agent i receives depends only on his own outcome and not on that of his partner, i.e., $w_{y_i,1} = w_{y_i,0}$ for $y_i \in \{0,1\}$. A wage scheme features joint performance evaluation (JPE) if the wage agent i receives weakly increases with the outcome of his partner, i.e., $w_{y_i,1} \geq w_{y_i,0}$ for all $y_i \in \{0,1\}$ and $w_{y_i,1} > w_{y_i,0}$ for some $y_i \in \{0,1\}$.[15]

[13] The restriction to public strategies is without loss of generality, as the game has a product structure (Fudenberg and Levine (1994)).

[14] In the main analysis, we assume the agents do NOT have access to any public randomization device. The existence of such device weakly expands the set of PPE, thus weakly improving the performance of a contract that makes use of repeated-game incentives.

[15] Note that as there is no common shock in the agents' production technology (in contrast to Che and Yoo (2001)), there is no role for relative performance evaluation (RPE).

Suppose temporarily that the production occurs only once, and that the agents have a zero outside option. It is clearly without loss that the principal adopts an IPE wage scheme and sets the wage for $y_i = 0$ at zero. Denote the wage for $y_i = 1$ by w. Then the following incentive compatibility constraint must be satisfied for effort to be exerted:

$$prw - c \geq qrw \Leftrightarrow w \geq \frac{c}{r(p-q)} \equiv w^I.$$

Thus, the minimum agency cost is $prw^I = \frac{pc}{p-q}$, and the agency rent is $prw^I - c = \frac{qc}{p-q}$. We call this contract a *simple IPE contract*.[16]

Now return to the repeated setting. The threat of losing the job is useful in motivating effort only if the agents' outside option $\bar{U}$ is lower than the agency rent on the job. Specifically, we make the following assumption:

Assumption $\bar{U} < \frac{qc}{p-q}$.

The objective of our analysis is to solve for the cost-minimizing stationary contract that induces full effort. We will call this the optimal contract. The focus on contracts that induce full effort can be justified by assuming that Y is very large, so that the agents' effort is very valuable to the principal.

Che and Yoo (2001) consider a model similar to ours. A major difference is that they assume the agent pair can perfectly observe each other's effort: i.e., $p = 1$ and $q = 0$. Moreover, in their model, the contract does not contain termination clauses and severance packages. They show that a JPE scheme allows the principal to save on agency cost by making use of peer monitoring and sanction (reverting to the permanent shirking equilibrium). As pointed out in the introduction, if the monitoring between the agents is imperfect, i.e., $p < 1$ and $q > 0$, punishment is now a positive probability event, and whenever it happens, the principal suffers from lost effort in production. In particular, if p is small and Y is large, this negative externality of punishment can be so severe that the principal would rather use a simple IPE contract.[17] In the analysis below, we show that if replacement agents are available, a JPE scheme becomes less costly when used in conjunction with a properly designed severance package. Such a contract can be optimal even if Y is large and p is small.

[16] It is useful to note that in a static setting, the principal does NOT lose anything from the unobservability and uncontractibility of the signal x_i. This is because all parties are risk neutral and the signal x_i and the outcome y_i share the same likelihood ratio for effort:

$$\frac{\Pr(x_i = 1|k_i = 1)}{\Pr(x_i = 1|k_i = 0)} = \frac{p}{q} = \frac{pr}{qr} = \frac{\Pr(y_i = 1|k_i = 1)}{\Pr(y_i = 1|k_i = 0)}.$$

[17] To see this, suppose the wage scheme takes the form found in Che and Yoo (2001): $w_{11} \equiv w > 0 = w_{01} = w_{10} = w_{00}$. For this JPE scheme to incur a lower cost than the simple IPE contract, it is necessary that $w \leq \frac{c}{p^2r^2 - pqr^2}$. Under this wage

3 Optimal Severance Policy and Wage Scheme

In this section, we solve for the cost-minimizing contracts. A couple of simple and useful observations are made below. First, since the termination threat is used to punish agents with a poor outcome, it is immediate that in the optimal contract, the agent is always retained after producing a good outcome, i.e., $f_1 = 0$. Moreover, when the agent is fired for a poor outcome, he does not receive any severance payment, i.e., $\sigma_{y_i} = 0$, as any positive σ_{y_i} only weakens the strength of the punishment.

Using the first observation above, contracts can be classified according to whether the agent is fired following $y_i = 0$. If the contract states that the agent is fired after $y_i = 0$, then we say it has a *harsh severance policy*. Otherwise, the agent is never fired and we say the contract has a *generous severance policy*. In the case of a harsh severance policy, the severance payment is necessarily zero. On the other hand, with a generous severance policy, an agent may receive positive severance payment upon voluntary resignation.

We analyze each class of contracts in turn. We then compare their cost performance to identify the optimal contract. The last subsection identifies conditions under which a generous severance policy and team-based incentives are complementary human resources practices.

3.1 Harsh Severance Policy

Suppose the agent is fired if and only if $y_i = 0$. This means that if the agent is retained, he must have both $y_i = 1$ and $x_i = 1$. Therefore, there is no need for the agents to engage in any form of punishment

scheme, the stage game of effort decision between the agents is one of a prisoners' dilemma. Since the highest feasible payoff and the minmax payoff are respectively pqr^2w and $(qr)^2 w$, an upper bound on the maximum difference in equilibrium continuation payoff is $pqr^2w - (qr)^2 w \leq c$. The least costly punishment (not necessarily sufficient to deter shirking) is to have the partner shirk for one period (with some probability) following a bad signal. For simplicity, suppose a public randomization device exists and a bad signal triggers punishment with probability $\rho > 0$. Then a necessary condition for effort to be exerted is

$$(1-\delta)\left((pr)^2 w - c\right) \geq (1-\delta)(prqrw) - \delta\rho(p-q)c \Leftrightarrow (pr)^2 w \geq \frac{pc}{p-q} - \frac{\delta p}{1-\delta}\rho c.$$

Thus the saving in the (per-period) expected wage by making use of this punishment is no more than $\frac{\delta p}{1-\delta}\rho c$. On the other hand, the loss in effort costs the principal no less than $\delta\rho(1-p)\left(p\left(Y - \frac{c}{p-q}\right) - qY\right)$. Thus, whenever

$$Y > \left(\frac{p}{(1-\delta)(1-p)} + \frac{1}{p-q}\right)\frac{c}{p-q},$$

the JPE scheme found in Che and Yoo (2001) is less profitable than the simple IPE contract.

between themselves because of poor signals. In other words, repeated-games incentives play no role in this class of contracts.

Denote by V the agent's payoff on the job. While on the job, he exerts effort. Whenever $y_i = 1$, he gets paid an expected wage w and keeps the job. If $y_i = 0$, he is fired and paid nothing. Therefore, V is given by

$$V = (1-\delta)(prw - c) + \delta\left(prV + (1-pr)\bar{U}\right).$$

Shirking saves the effort cost but increases the chance of bad outcome. The incentive compatibility constraint for exerting effort is given by:

$$V \geq (1-\delta)\, qrw + \delta\left(qrV + (1-qr)\bar{U}\right).$$

Combining the two conditions above, the expected wage w has to satisfy

$$w \geq \frac{c}{r(p-q)}(1-\delta pr) + \delta\left(c + \bar{U}\right) \equiv w^{EW}.$$

Clearly, at optimum, the condition above holds at equality. Moreover, such a contract can be implemented using IPE by setting $w_{11} = w_{10} = w^{EW}$ and $w_{01} = w_{00} = 0$. We call this the optimal *efficiency wage contract.* The principal's unit agency cost (per agent per period) is given by

$$\Psi^{EW} \equiv \frac{pc}{p-q} - \delta pr\left(\frac{qc}{p-q} - \bar{U}\right).$$

Recall that in the absence of the termination threat, the simple IPE contract is optimal, with the resulting agency cost being $\Psi^{SI} \equiv \frac{pc}{p-q}$. Because of the assumption $\bar{U} < \frac{qc}{p-q}$, we have $\Psi^{EW} < \Psi^{SI}$. The threat of employment termination following poor performance saves the necessary agency cost.

3.2 Generous Severance Policy

In this subsection, we consider contracts in which the agent is never fired, i.e., $f_{y_i} = 0$ for all $y_i \in \{0, 1\}$, although he may choose to quit voluntarily. In some real-world situations, the inability of the principal to unilaterally terminate employment may be due to legal restrictions. Therefore, studying the optimal contracts within this class is interesting in its own right.

In the class of contracts such that the associated PPE does not require the agents to quit voluntarily, the least costly contract is clearly the simple IPE contract. The majority of this subsection considers contracts in which the agent is induced to resign voluntarily with positive probability on the equilibrium path. Moreover, since the contract to each agent is identical, it is without loss to focus on symmetric PPEs.

We first characterize the structure of the PPE corresponding to the optimal contract. To make use of the dynamic incentive to save the agency cost, an agent who produces a bad signal must suffer punishment in subsequent periods. Since on the equilibrium path, every agent on the job must exert effort, an agent can only be punished by losing his job. To induce voluntary resignation, the agent must be prescribed a weakly lower continuation payoff were he deviated to stay on the job. These considerations imply that the symmetric PPE of the optimal contract necessarily has the following structure. There are three phases: (i) employment phase, (ii) punishment phase on the equilibrium path, and (iii) punishment phase off the equilibrium path. Every new pair of agents begins the relationship in the employment phase, which is characterized by both agents exerting effort and a high continuation payoff. In the on-path punishment phase, one (and only one) agent is prescribed to voluntarily resign. An identical replacement agent fills the vacancy, and the game switches back to the employment phase. Since the continuation payoff of the employment phase exceeds that of the on-path punishment phase, there is no PPE in which both agents resign simultaneously. Otherwise, each agent can profitably deviate by staying and starting a fresh relationship with a new partner.[18] Therefore, in the symmetric PPE, the on-path punishment phase is triggered if and only if a single bad signal realizes; if both agents generate a bad signal, the game stays in the employment phase. Finally, the off-path punishment phase is triggered whenever the only agent with a bad signal deviates from resigning. Clearly, the associated continuation payoff must be low enough so that the agent finds it profitable to resign voluntarily. The exact continuation strategies in this phase are to be computed later. Our objective is to solve for the cost-minimizing stationary contract such that its associated PPE has each agent willing to (i) exert effort in the employment phase; and (ii) voluntarily resign in the punishment phase on the equilibrium path.

We proceed by first solving a relaxed problem, and then showing that the solution of the relaxed problem solves the full problem. The relaxed problem is formulated below. Let's first write down the incentive compatibility constraint for effort exertion in the relaxed problem. Denote by $\pi(e_i, e_j)$ the agent's expected period payoff provided that the effort decisions of him and his partner are e_i and e_j respectively. Denote by V the continuation payoff of the employment phase. Denote by W the resignation payoff: this is the continuation payoff in the on-path punishment phase for the agent with a poor signal.

[18] If the agents have access to a public randomization device, there is a symmetric PPE in which one and only one agent is asked to leave voluntarily. This PPE involves a more severe punishment for bad signals, thus further lowering the agency cost.

In the employment phase, the agent exerts effort and remains on the job provided that (x_i, x_j) is different from $(0,1)$. If $(x_i, x_j) = (0,1)$, then the agent resigns voluntarily and collects δW. Therefore, V can be expressed recursively as

$$V = (1-\delta)(\pi(1,1) - c) + \delta\left[\left(p + (1-p)^2\right)V + \left(1 - \left(p + (1-p)^2\right)\right)W\right]. \tag{1}$$

Shirking saves effort cost but increases the chance of bad outcome. The incentive compatibility constraint for effort is thus

$$V \geq (1-\delta)\pi(0,1) + \delta\left[(q + (1-p)(1-q))V + (1 - (q + (1-p)(1-q)))W\right]. \tag{2}$$

Combining (1) with (2) and rearranging, we get

$$(1-\delta+\delta p(1-q))\pi(1,1) - \left(1 - \delta\left(p + (1-p)^2\right)\right)\pi(0,1) \geq c(1-\delta+\delta p(1-q)) + \delta p(p-q)W. \tag{3}$$

Next, we consider the incentive compatibility constraint for voluntary resignation. Payoff W consists of a severance payment s_{y_i,y_j} at the end of the current period, and $\bar{U}$ for the rest of the agent's life. Thus, the severance payment is independent of outcomes and is set at

$$s = \frac{\delta}{1-\delta}\max\left\{W - \bar{U}, 0\right\}. \tag{4}$$

Clearly, the agent is willing to quit voluntarily if and only if W is no lower than the continuation payoff in the off-path punishment phase. A lower bound on the latter payoff is given by

$$W \geq \max\left\{\min\left\{\max\left\{\pi(1,0) - c, \pi(0,0)\right\}, \max\left\{\pi(1,1) - c, \pi(0,1)\right\}\right\}, \bar{U}\right\}. \tag{5}$$

To understand the lower bound, note first that the agent can always quit and guarantee himself $\bar{U}$. Second, the partner's punishment on the agent cannot be made more severe by resigning himself, as this leads to a restart of the employment phase, which has a higher continuation payoff. Third, the term $\min\left\{\max\left\{\pi(1,0) - c, \pi(0,0)\right\}, \max\left\{\pi(1,1) - c, \pi(0,1)\right\}\right\}$ is the minmax payoff of the stage game were the agents stay on the job forever. In the relaxed problem, we replace the right-hand side of inequality (5) with an even smaller number:

$$W \geq \max\left\{\min\left\{\pi(0,0), \pi(0,1)\right\}, \bar{U}\right\}. \tag{6}$$

We relax the principal's problem by assuming that for any contract, there is a continuation PPE that achieves the payoff $\max\left\{\min\left\{\pi(0,0), \pi(0,1)\right\}, \bar{U}\right\}$. This assumption weakly relaxes the principal's problem because (i) it weakly lowers the severance payment needed to induce voluntary resignation (see

(4)), and (ii) it weakly relaxes the incentive compatibility constraint (3). Moreover, dropping a condition on the equilibrium perfection requirement weakly expands the set of feasible contracts.

Formally, the relaxed problem for the principal is to choose nonnegative wages $\{w_{11}, w_{10}, w_{01}, w_{00}\}$ and W in order to minimize

$$(pr)^2 w_{11} + pr(1-pr)(w_{10}+w_{01}) + (1-pr)^2 w_{00} + \frac{\delta}{1-\delta}(1-p)p\left(W-\bar{U}\right),$$

subject to constraints (3) and (6). The solution to the relaxed problem is given by the lemma below.

Lemma 1 *Denote* $\bar{U}^* \equiv \frac{q^2 c}{p(p-q)}\frac{1-\delta(1-p+pq)}{1-\delta(1-p+q^2)} \in \left(0, \frac{qc}{p-q}\right)$*. The solution to the relaxed problem is as follows.*

(i) If $\bar{U} < \bar{U}^*$*, then* $w_{11} = \frac{c}{pr^2(p-q)}\frac{1-\delta(1-p+pq)}{1-\delta(1-p+q^2)}$*,* $w_{10} = w_{01} = w_{00} = 0$*, and* $s = \frac{\delta}{1-\delta}\left(\bar{U}^* - \bar{U}\right)$*.*

(ii) If $\bar{U} > \bar{U}^*$*, then* $w_{01} = w_{00} = 0$*, and* $s = 0$*. Moreover,* w_{11} *and* w_{10} *satisfy*

$$prw_{11} + (1-pr)w_{10} = \frac{\frac{c}{p-q}(1-\delta+\delta p-\delta pq)+\delta p\bar{U}}{r(1-\delta+\delta p)}, \text{ and}$$

$$w_{11} \in \left[\frac{1-qr}{r^2(p-q)}\left(\frac{1}{q} - \frac{\delta p}{1-\delta+\delta p}\right)\left(\frac{qc}{p-q}-\bar{U}\right)+\frac{\bar{U}}{qr}, \frac{1}{pr^2}\left(\frac{c}{p-q}-\frac{\delta p}{1-\delta+\delta p}\left(\frac{qc}{p-q}-\bar{U}\right)\right)\right].$$

It can be directly computed that $w_{11} > w_{10}$ holds in the contracts of case (ii) of Lemma 1. Thus, it features JPE, though not necessarily as extreme as the contracts in case (i).

It remains to show that the minmax payoff corresponding to the solution in Lemma 1 can indeed be achieved as a continuation PPE payoff. Moreover, the relaxed problem only considers the class of contracts that induce voluntary resignation. Recall that the simple IPE contract elicits effort in every period without the need of voluntary resignation. This contract is particularly appealing if the severance payment required to induce voluntary resignation is large. Solving the full problem therefore requires comparison of the simple IPE contract and those contracts identified in Lemma 1. These are done in the proof of the proposition below.

Proposition 1 *Define* $\bar{U}_0 \equiv \max\left\{0, \frac{qc}{p-q}\left(1-\frac{(p-q)\left(1-\delta\left(1-p+p^2\right)\right)}{p(1-p)\left(1-\delta\left(1-p+q^2\right)\right)}\right)\right\} < \bar{U}^*$*. Suppose forced termination is infeasible.*

(i) If $\bar{U} \in \left(\bar{U}_0, \frac{qc}{p-q}\right)$*, then the optimal contract is the JPE wage contract identified in Lemma 1.*

(ii) If $\bar{U} < \bar{U}_0$*, then the optimal contract is the simple IPE contract.*

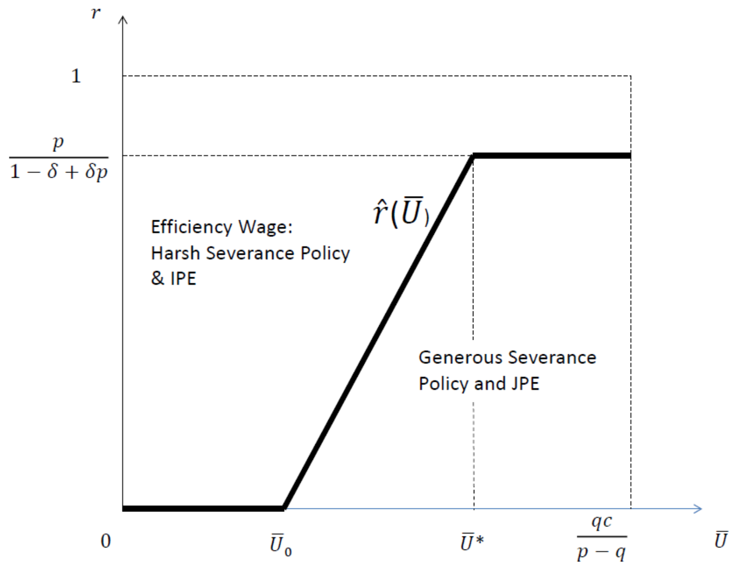
3.3 Comparison

Using the results from the previous two subsections, we can obtain the overall optimal contract by comparing the cost performance of generous and harsh severance policies. Define a boundary on the $\bar{U}$-r

space by

$$\hat{r}\left(\bar{U}\right) \equiv \begin{cases} 0 & \text{if } 0 \leq \bar{U} \leq \bar{U}_0 \\ \frac{1-p}{1-\delta}\left(\frac{\bar{U}-\bar{U}_0}{\frac{qc}{p-q}-\bar{U}}\right) & \text{if } \bar{U}_0 \leq \bar{U} \leq \bar{U}^* \\ \frac{p}{1-\delta+\delta p} & \text{if } \bar{U}^* \leq \bar{U} < \frac{qc}{p-q} \end{cases}.$$

The boundary is depicted in the figure below:



Proposition 2 *If* $r \leq \hat{r}\left(\bar{U}\right)$*, the optimal contract has a generous severance policy and a JPE wage scheme. If* $r \geq \hat{r}\left(\bar{U}\right)$*, the optimal contract is the optimal efficiency wage contract.*

The proposition points to the key tradeoff concerning the adoption of team incentives: it allows incentives to be based on more accurate signals, at the cost of a weaker and more expensive punishment (in the form of voluntary exit with severance pay). In light of this observation, it is natural that an inaccurate performance measure (i.e., a smaller value of r), as well as a low outside option (i.e., a high value of $\bar{U}$) favor the adoption of team incentives and the generous severance policy.

Below we provide a detailed discussion for each region of $\bar{U}$ in turn. First, if $\bar{U} \in [0, \bar{U}_0]$, then a contract with a generous severance policy and a JPE wage scheme is outperformed by a simple IPE contract (recall Proposition 1), which in turn is dominated by the optimal efficiency wage contract. A generous severance policy with JPE is costly when $\bar{U}$ is small because a large severance payment is needed to induce voluntary exit. Next, if $\bar{U} \in \left[\bar{U}_0, \bar{U}^*\right]$, then a generous severance policy with JPE is least costly, provided that r is relatively small. A small value of r means that outcome y_i is a poor indicator of signal x_i. Therefore, the agents observe a much more accurate performance measure than the principal, and the agency cost can be saved by making use of the agents' signals. While the principal does not have direct access to the signal realizations, she can design a contract such that the agent with a poor signal voluntarily resigns (with a high probability), thus suffering an equilibrium punishment. The key for this scheme to work is that voluntary resignation can be supported as an equilibrium outcome. Proposition 1 shows that the principal can achieve this by using a JPE scheme, which makes the threat of permanent mutual shirking an equilibrium. If $\bar{U} \in \left[\bar{U}_0, \bar{U}^*\right]$, this scheme is costly to the principal since a severance payment is needed to induce voluntary resignation. As a result, the trade-off is the improved accuracy of the performance measure against a costly severance payment. Since the necessary severance payment goes down as $\bar{U}$ increases, the principal finds it optimal to offer a generous severance policy for a wider range of r. Finally, if $\bar{U} \in [\bar{U}^*, \frac{qc}{p-q})$, a severance payment is not needed to induce voluntary resignation. The comparison between the optimal efficiency wage contract versus the optimal contract with generous severance policy and JPE then hinges only on how well each contract targets punishment at the agent with a poor signal. Therefore, the comparison depends only on r but not on $\bar{U}$. Naturally, a large value of r means that the objective measure is accurate and hence favors the efficiency wage contract.

An implication of Proposition 2 is that whenever $r < \frac{p}{1-\delta+\delta p}$, a high outside option $\bar{U}$ favors the adoption of a JPE scheme relative to an IPE scheme. This finding runs counter to the intuition that high outside options make cooperation harder to sustain in a repeated game, which in turn raises the cost of the JPE scheme. The result here arises because a high outside option allows the principal to save on severance payments needed to induce voluntary resignation, thus lowering the cost of punishment borne by the principal in making use of agents' peer monitoring.

Proposition 2 is obtained under the assumption of no replacement cost. Assuming a positive replacement cost[19] would favor the combination of JPE scheme and generous severance policy relative to efficiency wage. The reason is that efficiency wage is associated with a higher expected probability of agent replacement every period. Specifically, the optimal efficiency wage contract gives rise to a per-period probability of agent replacement $1 - pr$, whereas the optimal contract with JPE and a generous severance policy gives a lower probability of $1 - \left(p + (1-p)^2\right)$. Of course, if the replacement cost is sufficiently high, a simple IPE contract becomes optimal.

The appendix contains an analysis that removes the restriction that each agent's termination depends only on his outcome (but not on his partner's outcome). Specifically, the termination clauses can be

[19] Replacement cost may arise from difficulties in finding and training a replacement worker, or the legal cost of terminating an employment contract.

conditioned on the outcomes of both the agent and his partner, i.e., the firing decision f_{y_i,y_j} is now a function of the outcome profile $(y_i, y_j) \in \{0,1\}^2$, and we allow $f_{y_i,0} \neq f_{y_i,1}$ for any $y_i \in \{0,1\}$. This expands the set of feasible contracts, but the insight that a generous severance policy makes JPE more appealing is shown to remain valid. The main novel result is that if r and $\bar{U}$ are both large enough, then the optimal contract is a JPE scheme, and it fires the team if and only if they both produce bad outcomes.[20] The intuition is as follows. Recall in the PPE constructed in Section 3.2, the agents forgo punishment if both of them have bad signals. If the outcome is an accurate performance measure, i.e., r is close to one, then in the event that both agents have bad outcomes, it is very likely that they both also have bad signals; firing the team is a "correct" punishment with a high probability.

3.4 Interaction of Human Resources Practices

This subsection investigates the interaction of various human resources practices. First, we consider the interaction of the severance policy and team incentives. It is clear from Proposition 2 that whenever a generous severance policy is adopted, it is used in conjunction with a JPE scheme. Here, we make precise the complementary nature of these two HR practices. Second, we consider practices that facilitate the mechanism of peer monitoring and sanction outlined in the previous subsection.

First consider the harsh severance policy, and compare the IPE with JPE wage schemes. Under the IPE scheme, the optimal efficiency wage contract is cost-minimizing. Using the JPE scheme here does not lower the agency cost, as repeated-game incentives are infeasible: the agent is fired whenever the outcome is $y_i = 0$ regardless of his signal x_i. Moreover, because of the risk-neutrality assumption, the expected cost of the optimal JPE scheme with a harsh severance policy is equal to that of the optimal efficiency wage contract. As a result, with a harsh severance policy, there is no effect of group incentives on the agency cost.

Next, suppose the principal offers a generous severance policy. If the IPE scheme is used, it is clear that the cost-minimizing contract is the simple IPE contract. Under a JPE scheme, if repeated-game incentives are used, the cost-minimizing contract is given in Lemma 1. Thus, whenever the contract in Lemma 1 outperforms the simple IPE scheme, there is complementarity of a generous severance policy and team incentives. Using Proposition 1, we have the following corollary:

Corollary 1 *If $\bar{U} \in \left(\bar{U}_0, \frac{qc}{p-q}\right)$, then a generous severance policy and team incentives are complementary practices.*

[20] Severance payment is offered in case of voluntary resignation for some parameter region.

The corollary above is consistent with the empirical finding in Ichniowski, Shaw, and Prennushi (1997) that HR practices of teamwork, line incentives and employment security are complementary. To the best of our knowledge, we are the first to provide a formal theory on the value of employment security in the adoption of teamwork and/or team incentives. Che and Yoo (2001) hint at this connection by highlighting the role of the discount factor in supporting cooperation in a team. However, as they explicitly rule out the possibility of firing the agents throughout, their analysis is silent on the value of promising job security in supporting teamwork and team incentives.

In the remainder of this section, we consider the effect of HR practices that facilitate peer monitoring. Improving the technology of peer monitoring, while holding fixed that of the principal can be modelled as an increase in p with a compensating decrease in r such that their product pr remains constant. The following corollary shows that an improvement in peer monitoring necessarily favors the adoption of team incentives.

Corollary 2 *Take a pair of monitoring technologies (p, r) and (p', r') such that $p' > p$, $pr = p'r'$, and assumption 2 hold for both p and p'. If the generous severance policy and JPE scheme is optimal under technology (p, r), then it necessarily remains optimal under technology (p', r'). Moreover, the principal's agency cost is lower under technology (p', r').*

The corollary is very intuitive. An improvement in the peer monitoring technology lowers the probability that a bad signal is observed, thus the expected cost involved in punishing a non-performing agent. Note that the comparison in peer monitoring technology conducted in this corollary is possible only in a model with imperfect monitoring. The empirical study of Knez and Simester (2001) illustrates that peer monitoring can be improved by having small workgroups, appropriately-designed workplace, and rotating workers with standardized tasks.

Proposition 2 and Corollary 2 point to the complementary nature of peer monitoring and team incentives. Specifically, if the peer monitoring technology becomes more accurate relative to the principal's monitoring technology, the benefit of linking agents' payment scheme increases. Gershkov and Winter (2015) obtain a related result in which the causality is somewhat reversed: if the production technology satisfies complementarity, peer's informal monitoring substitutes principal's formal monitoring. Their result is obtained under a (non-repeated) setting in which agents exert effort sequentially, and choosing formal monitoring is costly. Incorporating these features in our model would therefore strengthen our result.

4 Optimal Job Design

The analysis so far assumes that each agent's production technology is exogenous and independent. This assumption highlights that the benefit of JPE can arise even in the absence of technological advantage of team production. In this section, we investigate the problem of optimal job design by allowing the principal to choose between *individual-based* and *team-based production.* The key tradeoff involved in team-based production is the cost of free-riding among members against the benefit of sharper incentive provision (by making use of more precise signals). Besides showing that the insight obtained in the previous section remains robust, we are also interested in conditions on the production technology that favors team-based production.

The principal has a task which requires the efforts of two agents, each endowed with one unit of effort. If the individual production technology is adopted, the task is broken down into two identical and independent subtasks, each of which is assigned to a separate agent. The production technology of each subtask is identical to the benchmark model in Section 2, which is briefly recapped below. The outcome of each subtask i is either good ($y_i = 1$) or bad ($y_i = 0$); its realization depends stochastically on the assigned agent's effort. If the assigned agent exerts effort, then a good signal ($x_i = 1$) is generated with probability p, and a bad signal ($x_i = 0$) is generated with the complementary probability. Otherwise, a good signal is generated with probability $q < p$. Given a good signal, the probability of a good outcome is $r \in (0, 1)$; given a bad signal, the probability of a good outcome is 0.

If the team production technology is adopted, the task is performed jointly. The effort of each agent independently generates an individual signal, with the signal generation process identical to the case of individual production. The outcome of the joint task is either good ($y = 1$) or bad ($y = 0$), depending stochastically on the total number of good signals. If both agents produce good signals, then the probability that the joint task has a good outcome is l_2. If there is only one good signal (and one bad signal), then the probability of a good outcome is $l_1 \in [0, l_2)$. Finally, if both agents produce bad signals, the outcome of the joint task is bad for sure.

We make two assumptions on the production technologies. First, the team production technology is weakly convex in the total number of good signals:

$$l_2 - l_1 \geq l_1. \tag{7}$$

This assumption guarantees that each agent benefits from his partner's work effort. Second, to focus on the effect of peer monitoring on job design, we assume that if both agents exert effort, then the two production technologies give the principal identical expected outcome value. Specifically, the principal's value for a bad outcome is zero. She values a good outcome of the joint task in the team production setting twice as much as that of a subtask in the individual production setting. Moreover, conditionally on effort being exerted by both agents, the two technologies have equal expected value of outcome, i.e.,

$$2pr = 2\left(p^2 l_2 + 2p(1-p) l_1\right) \Leftrightarrow r = pl_2 + 2(1-p) l_1. \tag{8}$$

In the terminology of Che and Yoo (2001), this condition rules out any synergy in team production. It is clear that the existence of synergy would favor team production relative to individual production. Production technology is chosen at the initial stage; once chosen, it is fixed for the rest of the game.

The monitoring technologies is as follows. Similar to the benchmark model, the effort decision is privately known to the agent, and signals are not observable to the principal. Only the outcomes of the tasks (or subtasks) are contractible. In the case of individual production, the signal realization of each agent is NOT observable to the other agent; in the case of team production, the profile of signal realizations is observed by both agents.

We continue to focus on stationary and deterministic contracts. If individual production is adopted, the contract stipulates wage contingent on outcome $\{w_{y_i}\}$, firing decision $\{f_{y_i}\}$, and severance payment in case of voluntary exit $\{s_{y_i}\}$ and forced termination $\{\sigma_{y_i}\}$. If team production is adopted, the contract stipulates individual wage contingent on team outcome $\{w_y\}$, firing decision $\{f_y\}$, and severance payment in case of voluntary exit $\{s_y\}$ and forced termination $\{\sigma_y\}$.

Like the benchmark model, the value of a good outcome to the principal is so large that she prefers effort to be always exerted by both agents on the job. Moreover, agent replacement is feasible and costless. The objective of the principal is to choose the production technology and contract that minimize the agency cost, subject to the incentive compatibility constraint that both agents on the job are willing to exert effort, and voluntarily quit when they are supposed to.

4.1 Static Setting

As a benchmark, we first consider a static setting in which production takes place only once. Suppose individual production is adopted. It is clear that $w_0 = 0$. The agent is willing to put in effort if and only if

$$prw_1 - c \geq qr \Leftrightarrow w_1 \geq \frac{c}{r(p-q)}.$$

Therefore, the expected agency cost for each agent is $\frac{pc}{p-q}$. Next suppose team production is adopted. It is an equilibrium for both agents to put in effort if and only if

$$\begin{aligned} & \left(p^2 l_2 + 2p\left(1-p\right) l_1\right) w_1 - c \geq \left(pql_2 + \left(p\left(1-q\right) + q\left(1-p\right)\right) l_1\right) w_1 \\ \Leftrightarrow \quad & w_1 \geq \frac{c}{\left(p-q\right)\left(pl_2 + \left(1-2p\right) l_1\right)}. \end{aligned}$$

Thus, the expected agency cost for each agent is $\frac{pc}{p-q}\frac{pl_2+2(1-p)l_1}{pl_2+(1-2p)l_1}$. Compared with that of individual production, team production entails a higher agency cost whenever $l_1 > 0$. Intuitively, the agent benefits from a positive externality generated by his partner's effort, as his expected wage goes up even if he shirks himself. This positive externality raises the agency cost. This effect is smaller if l_1 goes down, since the benefit of free-riding decreases.

4.2 Repeated Setting

Now suppose the production setting is infinitely repeated, and the principal can fill up a vacancy immediately at no cost. Similar to the analysis in Section 3, it is immediate that regardless of production technology, agents are not fired for good outcomes (i.e., $f_1 = 0$), and no severance pay is offered following forced termination ($\sigma_{y_i} = \sigma_y = 0$). Severance policy can therefore be classified according to whether an agent (or a team of agents) is fired following bad individual (team) outcomes or not. If so, we call the severance policy harsh; otherwise, it is generous. Below, we consider these severance policies in turn.

4.2.1 Harsh Severance Policy

Suppose individual production is adopted. It is clear that the setting is identical to the one considered in Section 3.1, with r given by (8). Thus, the minimum expected agency cost, achieved by an efficiency wage contract, is given by

$$\Psi^{HI} \equiv \frac{pc}{p-q} - \delta p\left(2l_1\left(1-p\right) + pl_2\right)\left(\frac{qc}{p-q} - \bar{U}\right).$$

Next, suppose team production is adopted. It is clear that $w_0 = 0$ and $w_1 > 0$. The strongest termination threat is to fire the team whenever the team outcome is bad. Denote by V the value of the job to each agent. We have

$$V = (1-\delta)\left(\left(p^2 l_2 + 2p\left(1-p\right) l_1\right) w_1 - c\right) + \delta\left(\left(p^2 l_2 + 2p\left(1-p\right) l_1\right) V + \left(1 - \left(p^2 l_2 + 2p\left(1-p\right) l_1\right)\right) \bar{U}\right).$$

Each agent is willing to put in effort if and only if

$$\begin{aligned} V \quad \geq \quad & (1-\delta)\left(pql_2 + \left(p\left(1-q\right) + q\left(1-p\right)\right) l_1\right) w_1 \\ & +\delta\left(\left(pql_2 + \left(p\left(1-q\right) + q\left(1-p\right)\right) l_1\right) V + \left(1 - \left(pql_2 + \left(p\left(1-q\right) + q\left(1-p\right)\right) l_1\right)\right) \bar{U}\right). \end{aligned}$$

Combining the two conditions above,

$$w_1 \geq \frac{1-p\delta l_1}{l_1-2pl_1+pl_2}\frac{c}{p-q}-\delta\left(\frac{qc}{p-q}-\bar{U}\right).$$

The expected agency cost is thus

$$\Psi^{HT} \equiv \frac{(pl_2+2(1-p)l_1)(1-p\delta l_1)}{(l_1-2pl_1+pl_2)}\frac{pc}{p-q}-\delta\left(p^2l_2+2p(1-p)l_1\right)\left(\frac{qc}{p-q}-\bar{U}\right).$$

By direct comparison, we have $\Psi^{HT} > \Psi^{HI}$, i.e., team production entails a higher agency cost whenever a harsh severance policy is used. The intuition of this finding is similar to that in the static setting above.

4.2.2 Generous Severance Policy

In this subsection, we suppose the principal withdraws her ability to fire the agent and look for the optimal contract with a generous severance policy. Suppose individual production is adopted. It is easy to see that agent turnover is not induced, and the cost-minimizing contract in this case is a simple IPE contract: $w_1 = \frac{c}{r(p-q)}$ and $w_0 = s = 0$. The corresponding agency cost is $\frac{pc}{p-q}$.

Next, suppose team production is adopted. Consider a candidate PPE in which an agent resigns voluntarily if his signal is a bad while his partner's signal is good. Denote by W the resignation payoff. The value of the job V is given by

$$V = (1-\delta)\left(\left(p^2l_2+2p(1-p)l_1\right)w_1-c\right)+\delta\left[\left(p+(1-p)^2\right)V+\left(1-\left(p+(1-p)^2\right)\right)W\right].$$

The agent is willing to put in effort provided that

$$V \geq (1-\delta)\left[\left(pql_2+\left(q(1-p)+p(1-q)\right)l_1\right)w_1-c\right]+\delta\left\{\left[q+(1-p)(1-q)\right]V+\left(1-\left[q+(1-p)(1-q)\right]\right)W\right\}.$$

Combining the two conditions:

$$\left[(l_1-2pl_1+pl_2)\left(1-\delta\left(p+(1-p)^2\right)\right)+\delta p^2\left(pl_2+2(1-p)l_1\right)\right]w_1 \geq \frac{c}{p-q}\left(1-\delta+\delta p(1-q)\right)+\delta pW. \tag{9}$$

Since the agent always benefits from the partner's effort (by (7)), a lower bound for W is given by

$$W \geq \max\left\{\bar{U}, \left(q^2l_2+2q(1-q)l_1\right)w_1\right\}. \tag{10}$$

The relaxed problem is to minimize w_1 subject to constraints (9) and (10). It is straightforward to see that the two constraints hold with equality at the optimum. This also implies that at the optimum, both agents shirking is indeed a Nash equilibrium in the stage game. To see this, note that the incentive for effort exertion is binding even if the partner is exerting effort. Shirking therefore is strictly optimal knowing that the partner is shirking. The following lemma states the cost-minimizing contract with a generous severance policy.

Lemma 2 *Suppose team production is adopted. If the contract does not induce voluntary resignation in any circumstance, the optimal contract has* $w_1 = \frac{c}{(p-q)(pl_2+(1-2p)l_1)}$.

On the other hand, consider contracts that induce voluntary resignation whenever the agent produces a bad signal while his partner has a good signal. Define

$$\bar{U}_T \equiv \frac{(ql_2 + 2(1-q)l_1)(1-\delta+\delta p(1-q))}{((1-2p)l_1 + pl_2)\left(1-\delta\left(p+(1-p)^2\right)\right) + \delta p(p-q)(2(1-p-q)l_1 + (p+q)l_2)} \frac{qc}{p-q} \geq 0.$$

If $\bar{U} \in [0, \bar{U}_T)$*, then the optimal contract within this class is*

$$\begin{aligned} w_1 &= \frac{1-\delta+\delta p(1-q)}{((1-2p)l_1 + pl_2)\left(1-\delta\left(p+(1-p)^2\right)\right) + \delta p(p-q)(2l_1(1-p-q) + (p+q)l_2)} \frac{c}{p-q}; \\ s &= \frac{\delta}{1-\delta}\left(\left(q^2 l_2 + 2q(1-q)l_1\right)w - \bar{U}\right). \end{aligned}$$

If $\bar{U} \in [\bar{U}_T, \frac{qc}{p-q})$*, then the optimal contract within this class is*

$$\begin{aligned} w_1 &= \frac{\frac{c}{p-q}(1-\delta+\delta p(1-q)) + \delta p\bar{U}}{((1-2p)l_1 + pl_2)\left(1-\delta\left(p+(1-p)^2\right)\right) + \delta p^2(pl_2 + 2(1-p)l_1)}; \\ s &= 0. \end{aligned}$$

The lemma allows us to compute the expected agency cost if team production and a generous severance policy are adopted. The exact expression can be found in the proof of Proposition 3 below. It is useful to note that the expected cost is a nonmonotone function of the agents' outside option. If $\bar{U} \in [0, \bar{U}_T)$, an increase in $\bar{U}$ lowers the necessary severance payment; if $\bar{U} \in [\bar{U}_T, \frac{qc}{p-q})$, an increase in $\bar{U}$ makes the punishment of voluntary exit less effective. Thus, the expected agency cost has a single trough at $\bar{U} = \bar{U}_T$.

4.2.3 Comparison

From the analysis above, if team production is ever adopted, the principal always finds it optimal to offer a generous severance policy.[21] Moreover, if individual production is ever adopted, the principal always finds it optimal to offer an efficiency wage contract. As a result, it suffices to compare only these two combinations of production technology and severance policy: (i) individual production with a harsh policy; and (ii) team production with a generous policy.

[21] Note that this finding is obtained under the no-synergy condition (8). If team production gives synergy, then it may be adopted with a termination contract.

Recall in the static setting, individual production gives a lower expected agency cost, and the result is carried over to a repeated setting when a harsh severance policy is used. The intuition is that the payoff of shirking goes up as a result of the partner's effort exertion. This cost of team production is still present in the repeated setting with a generous severance policy. On the other hand, team production with a generous severance policy allows the principal to make use of a more accurate signal on effort in incentivizing the agents, thus potentially lowering the agency cost. This trade-off determines the optimal combination of production technology and contract. The following proposition identifies the sufficient condition that favors team production and a generous severance policy.

Proposition 3 *Suppose $r < \frac{p}{1-\delta+\delta p}$ and l_1 is sufficiently small. Then there exists a pair of values $\bar{U}_{T,0}$ and $\bar{U}_{T,1}$ with $0 \leq \bar{U}_{T,0} < \bar{U}_T < \bar{U}_{T,1} < \frac{qc}{p-q}$ such that for all $\bar{U} \in \left(\bar{U}_{T,0}, \bar{U}_{T,1}\right)$, the cost-minimizing arrangement is team production and a generous severance policy. Whenever this is the case, they are complementary practices.*

The intuition for the sufficient condition is simple. As noted in Section 4.1, the agency cost of team production is small if l_1 is low. Moreover, a small value of r means that the individual outcome is an imprecise measure of effort, and thus makes the use of peer monitoring more appealing. Furthermore, the cost of a generous severance policy is lowest if $\bar{U}$ is close to $\bar{U}_T$. Finally, since team production raises the agency cost when a harsh severance policy is used, it is clear that, whenever team production and a generous severance policy is the optimal combination, they are complementary to each other.

Recall that, in the analysis of independent production in Section 3, the optimal contract features a JPE wage scheme and a generous severance policy whenever the outside option is high enough. Here, in contrast, the optimality of team production and a generous severance policy may not hold if $\bar{U}$ is too large. The difference arises because individual production inherently incurs a lower agency cost, as shown in the static setting in Section 4.1. If $\bar{U}$ is large, the dynamic incentive is necessarily weak, and the benefit of individual production prevails.

Che and Yoo (2001) find that a necessary condition for the optimality of team production is the presence of team synergy. In contrast, Proposition 3 shows that even if team synergy is absent, team production may still be the optimal job design. In fact, the proposition suggests that a new necessary condition for the optimality of team production: it must be used in conjunction with a generous severance policy. Our result therefore strengthens and enriches the message of Che and Yoo (2001): the benefit arising from peer monitoring can be large enough to overcome the inherent limitation of team production, provided that an appropriate severance policy is in place.

5 Discussion and Concluding Remarks

Work team is an integral part of modern organizations. In fact, even if joint performance evaluation is not explicitly used, members in a team often inherently face a common stake in the team performance. For instance, a well-performing division in a company is allocated more budget. A successful university department is better respected, and all members benefit from the established reputation. The general message of our analysis is that the design of severance policy is an important dimension in team management. We show that, contrary to common perception, a generous severance policy can be complementary to team incentives, and constitute an effective tool for maintaining a high team morale and fostering a corporate culture of teamwork. To deliver these messages as directly as possible, we have made a number of simplifying assumptions in the analysis. Below we discuss some alternative model specifications.

Stochastic termination Throughout our analysis, we have restricted to deterministic termination decision, which has the appeal of simplicity and easy enforcement. If stochastic termination is feasible, it may arise in the optimal contract to supplement the severance pay over voluntary exit. Specifically, suppose $f_0 \in [0, 1]$ now stands for the probability of firing agent i following $y_i = 0$. An increase in f_0 lowers both the benefit and the cost of JPE relative to the efficiency wage contract. The benefit goes down because the punishment of job loss is more likely based on an imprecise signal; whereas the cost also goes down because of the saving in expected severance pay. As the tradeoff here is similar to our main analysis, we expect the comparative statics suggested by Proposition 2 remains valid: the optimal value of f_0 increases in principal's signal precision r but decreases in agent's outside option $\bar{U}$.

Nonstationary contract The focus on stationary contracts simplifies the analysis of the repeated game between the agents as it makes their stage game time-invariant. It is known in the moral hazard literature that with risk-neutrality and limited liability, the optimal contract may bundle several tasks;[22] here, it translates into bundling performance across periods. Fong and Li (2015) consider a dynamic moral hazard setting with a single agent. The optimal contract has a probation phase in which no performance bonus is paid. Following a history of sufficiently favorable outcomes, the contract enters a bonus phase in which the agent is given "tenure". Following a history of sufficiently unfavorable outcomes, the agent is fired. The intuition is that the agency rent from the tenure phase can be used to motivate the agent in the probation phase, thus saving the overall agency cost. We conjecture that if the stationarity restriction is removed in our model, the optimal contract would have similar features. As our characterization is still relevant for the stationary bonus phase, we expect that severance pay is offered only after the agent

[22] See Laux (2001).

has performed sufficiently well in the past. A full analysis of the optimal nonstationary contract is left for future research.

Alternative signal/outcome structure It is assumed in the benchmark model that a bad signal $x_i = 0$ never leads to a good outcome $y_i = 1$. For instance, the agent's signal represents his work attitude displayed, and a positive displayed attitude is a necessary (though not sufficient) condition for a successful outcome. The implication of the assumption is that conditional on a good outcome, peer monitoring does not offer any extra information. Alternatively, one may consider an information structure in which a bad signal may still result in a good outcome with positive probability. Provided that a bad outcome is sufficiently indicative of a bad signal (i.e., r is sufficiently large), the optimal contract has a JPE scheme, as well as a combination of firing (following a bad outcome), and severance pay for voluntary exit (following a good outcome). Our main message that severance pay is complementary to the use of repeated-games incentives remains valid in this alternative setting.

In practice, there are other possible reasons for paying workers to quit, such as insurance provision and private information on match quality. Below we discuss how our theory is distinguished from these alternative explanations.

Insurance If the agent is more risk-averse than the principal, the optimal employment features a risk-incentive tradeoff. To insure the agent, he may receive a positive base wage following a poor performance, which can be interpreted as a severance pay following dismissal. In contrast, our model predicts that a positive severance pay may arise following voluntary quitting, but there is no severance pay if the agent is fired for poor performance. Moreover, if the individual rationality constraint binds, a moral hazard model with risk-incentive tradeoff would predict that the base wage (and consequently severance pay) is increasing in the agent's outside option. Our model predicts the severance pay moves in the opposite direction (see Lemma 1).

Private information on match quality As discussed in the literature review, severance pay in CEO contracting is usually attributed to the agent having superior information on his match quality with the firm. If we assume that the production technology is complementary in the match quality of each agent, and that the match quality is subject to exogenous shock privately observed by the agent, then under additional structures, one can construct a model in which a severance pay can help weed out agents that suffer negative shocks in match quality, thus improving the team output.[23] In contrast, our

[23] It is worth pointing out that some elements of moral hazard are likely to be still necessary in such a theory, see the discussion in Section 1.3 of Inderst and Mueller (2010).

model starts out in a pure moral hazard setting, and the agent's private information about his payoff of staying on the job arises endogenously because of his interaction with fellow coworkers. Below, we argue why our model is empirically relevant, and point out empirical predictions that distinguish the two theories.

As pointed out by Oyer and Schaefer (2011), because of the difficulties in obtaining clean data, rigorous empirical studies on the causes of voluntary quitting are lacking in labor and personnel economics. On the other hand, research in psychology and organizational behavior provide some hints to major causes of quitting. Humphrey, Nahrgang, and Morgeson (2007) summarize more than 250 articles in these fields and find that social factors such as task interdependence, feedback and social support from coworkers are key in employees' turnover intention and decision. On the other hand, the effect of job characteristics[24] on turnover intention is insignificant. Their findings therefore suggest that for regular employees (i.e., non-CEO), relation with coworkers plays a much more important role than match quality in their turnover decision. This may not be surprising as it has been shown that firms can hire the right workers effectively, by means of applicant screening (Huang and Cappelli (2010)) and self-selection (Dohmen and Falk (2010)).

Our model generates the following predictions that differ from a theory of turnover and teamwork based on mismatch. First, the analysis in endogenous job design in Section 4 shows that adopting teamwork can be optimal even if team synergy is absent. On the other hand, the mismatch theory relies crucially on the synergy in agents' match qualities. Second, in the mismatch theory, there is no apparent value in guaranteeing employment security, especially after a mismatch is revealed through poor performance. In contrast, Corollary 1 points out that the promise of employment security is complementary to the adoption of team incentives. The intuition is that employment security makes the use of repeated-games incentives feasible and more effective. The empirical study of Ichniowski, Shaw, and Prennushi (1997) has shown the value of employment security in facilitating the adoption of teamwork. Finally, as the benefit of teamwork in our model arises from peer monitoring and sanction, measures that improve the technology of peer monitoring is complementary to implementing teamwork and a generous severance policy (see Corollary 2). The detailed case study of Knez and Simester (2001) has illustrated the effectiveness of peer monitoring and sanction in practice, and discussed possible measures that facilitate them. On the other hand, the mismatch theory is silent on this issue.

[24]The job characteristics considered in their study include job autonomy, skill variety, task identity, task significance, and feedback from the job.

Appendix

Omitted Proofs

Proof of Lemma 1: It is obvious that constraint (6) holds with equality at the optimum. Substituting it into the objective and the incentive compatibility simplifies the problem into

$$\min_{w_{11},w_{10},w_{01},w_{00}\geq 0} (pr)^2 w_{11} + pr(1-pr)(w_{10}+w_{01}) + (1-pr)^2 w_{00}$$
$$+\frac{\delta}{1-\delta}(1-p)p\max\left\{\min\{\pi(0,0),\pi(0,1)\} - \bar{U}, 0\right\},$$

subject to

$$\begin{aligned} & (1-\delta+\delta p(1-q))\pi(1,1) - \left(1-\delta\left(p+(1-p)^2\right)\right)\pi(0,1) \\ \geq\ & c(1-\delta+\delta p(1-q)) + \delta p(p-q)\max\left\{\min\{\pi(0,0),\pi(0,1)\},\bar{U}\right\}. \end{aligned}$$

To solve the problem above, we consider the following three classes of wage schemes in turn, and solve for the cost-minimizing schemes within each class: (i) $\max\left\{\min\{\pi(0,0),\pi(0,1)\},\bar{U}\right\} = \pi(0,1)$; (ii) $\max\left\{\min\{\pi(0,0),\pi(0,1)\},\bar{U}\right\} = \bar{U}$; and (iii) $\max\left\{\min\{\pi(0,0),\pi(0,1)\},\bar{U}\right\} = \pi(0,0)$.

Case (i): $\max\left\{\min\{\pi(0,0),\pi(0,1)\},\bar{U}\right\} = \pi(0,1)$

Ignoring the requirement that the wage scheme must satisfy $\max\left\{\min\{\pi(0,0),\pi(0,1)\},\bar{U}\right\} = \pi(0,1)$, and replacing $\pi(\cdot,\cdot)$ with the corresponding expression involving wages, the problem above can be stated as choosing the wage scheme $\{w_{11}, w_{10}, w_{01}, w_{00}\}$ to minimize

$$\begin{aligned} & (pr)^2\left(1+\frac{\delta}{1-\delta}q(1-p)\right)w_{11} + (1-pr)pr\left(1+\frac{\delta}{1-\delta}q(1-p)\right)w_{10} \\ & +pr\left((1-pr)+\frac{\delta}{1-\delta}(1-p)p(1-qr)\right)w_{01} + (1-pr)\left((1-pr)+\frac{\delta}{1-\delta}(1-p)p(1-qr)\right)w_{00} \\ & -(1-p)p\frac{\delta}{1-\delta}\bar{U}, \end{aligned}$$

subject to

$$pr(w_{11}-w_{01}) + (1-pr)(w_{10}-w_{00}) \geq \frac{c}{r(p-q)}.$$

The coefficients of w_{00} and w_{01} are negative in the constraint; while those of w_{11} and w_{10} are positive. Thus, it is clear that $w_{00} = w_{01} = 0$ and the constraint binds at optimum. By comparing the coefficients of w_{11} and w_{10} in the objective and the constraint, it is clear that any nonnegative pair of w_{11} and w_{10} that satisfies the constraint with equality solves the problem. Thus, an optimal solution is $w_{11} = w_{10} = \frac{c}{r(p-q)}$, with corresponding severance payment being $s = \frac{\delta}{1-\delta}\left(\frac{pc}{p-q} - \bar{U}\right) > 0$. Finally, it is straightforward to check that this wage scheme satisfies $\pi(0,1) = \max\left\{\min\{\pi(0,0), \pi(0,1)\}, \bar{U}\right\}$.

Case (ii): $\max\left\{\min\{\pi(0,0), \pi(0,1)\}, \bar{U}\right\} = \bar{U}$.

Like case (i) above, we temporarily ignore the requirement $\max\left\{\min\{\pi(0,0), \pi(0,1)\}, \bar{U}\right\} = \bar{U}$. In this case, the severance payment $s = 0$. The principal's relaxed problem can be stated as choosing the wage scheme to minimize

$$(pr)^2 w_{11} + pr(1-pr)(w_{10} + w_{01}) + (1-pr)^2 w_{00},$$

subject to

$$\begin{aligned} & r(1-\delta+\delta p)(prw_{11} + (1-pr)w_{10}) + (p\delta(1-r) - r(1-\delta))(prw_{01} + (1-pr)w_{00}) \\ \geq \; & \frac{c}{p-q}(1-\delta+\delta p(1-q)) + \delta p\bar{U}. \end{aligned} \tag{11}$$

Again, by comparing coefficients in the objective and the constraint, it can be readily shown that $w_{01} = w_{00} = 0$, and the constraint must bind:

$$prw_{11} + (1-pr)w_{10} = \frac{\frac{c}{p-q}(1-\delta+p\delta-pq\delta) + \delta p\bar{U}}{r(1-\delta+\delta p)}. \tag{12}$$

Next we identify conditions that ensure $\min\{\pi(0,0), \pi(0,1)\} \leq \bar{U}$:

$$\min\{qrw_{11} + (1-qr)w_{10}, prw_{11} + (1-pr)w_{10}\} \leq \frac{\bar{U}}{qr}.$$

Direct algebraic manipulation shows that the right hand side of (12) exceeds $\frac{\bar{U}}{qr}$. Therefore, it is necessary that $qrw_{11} + (1-qr)w_{10} \leq \frac{\bar{U}}{qr}$. Using (12) again, the cost-minimizing schemes within this class is given by

$$\left\{ \begin{array}{c} (w_{11}, w_{10}, w_{01}, w_{00}) \geq 0 : w_{01} = w_{00} = 0, \\ w_{11} \in \left[\frac{1-qr}{r^2(p-q)}\left(\frac{1}{q} - \frac{\delta p}{p\delta-\delta+1}\right)\left(\frac{qc}{p-q} - \bar{U}\right) + \frac{\bar{U}}{qr}, \frac{1}{pr^2}\left(\frac{c}{p-q} - \frac{\delta p}{1-\delta+\delta p}\left(\frac{qc}{p-q} - \bar{U}\right)\right)\right], \\ w_{10} = \left(\frac{c}{r(p-q)} - \frac{p\delta}{r(1-\delta+\delta p)}\left(\frac{qc}{p-q} - \bar{U}\right) - prw_{11}\right)\frac{1}{1-pr} \end{array} \right\}. \tag{13}$$

It can be shown by direct algebraic manipulation that all schemes in (13) feature $w_{11} > w_{10}$. Moreover, the set (13) is nonempty if and only if $\bar{U}$ is sufficiently large. Specifically, within the set (13), the scheme that minimizes $qrw_{11} + (1-qr)w_{10}$ is $(w_{11}, w_{10}, w_{01}, w_{00}) = \left(\frac{1}{pr^2}\left(\frac{c}{p-q} - \frac{\delta p}{1-\delta+\delta p}\left(\frac{qc}{p-q} - \bar{U}\right)\right), 0, 0, 0\right)$. Thus, existence is guaranteed if and only if

$$\begin{aligned} & (qr)^2 \frac{1}{pr^2}\left(\frac{c}{p-q} - \frac{\delta p}{1-\delta+\delta p}\left(\frac{qc}{p-q} - \bar{U}\right)\right) \leq \bar{U} \\ \Leftrightarrow \quad & \bar{U} \geq \frac{q^2 c}{p-q}\frac{1-\delta+\delta p(1-q)}{p(1-\delta+\delta(p-q^2))} \equiv \bar{U}^*. \end{aligned}$$

If $\bar{U} < \bar{U}^*$, the class of scheme under consideration is never incentive compatible. To see this, direct algebraic manipulation shows that within this class of schemes that satisfy (11), both $\pi(0,0)$ and $\pi(0,1)$ are minimized by setting $w_{00} = w_{10} = w_{01} = 0$. Substituting these wages into (11) and rearranging shows that both $\pi(0,0)$ and $\pi(0,1)$ exceed $\bar{U}$.

Case (iii): $\max\left\{\min\{\pi(0,0), \pi(0,1)\}, \bar{U}\right\} = \pi(0,0)$.

We temporarily ignore the requirement $\pi(0,0) \geq \bar{U}$. The principal's relaxed problem can be stated as choosing the wage scheme to minimize

$$\left[(pr)^2 + \frac{\delta}{1-\delta}p(1-p)(qr)^2\right] w_{11} + \left[pr(1-pr) + \frac{\delta}{1-\delta}p(1-p)(qr)(1-qr)\right](w_{10}+w_{01})$$
$$+\left[(1-pr)^2 + \frac{\delta}{1-\delta}p(1-p)(1-qr)^2\right] w_{00} - \frac{\delta}{1-\delta}p(1-p)\bar{U},$$

subject to

$$\begin{aligned}
&\left[pr\left(1-\delta\left(p+(1-p)^2\right)\right) + \delta pr\left(p^2-q^2\right)\right] w_{11} \\
&+\left[(1-pr)\left(1-\delta\left(p+(1-p)^2\right)\right) + \delta p(p-q)(1-r(p+q))\right] w_{10} \\
&+\left[-pr\left(1-\delta\left(p+(1-p)^2\right)\right) + \delta p(p-q)(1-r(p+q))\right] w_{01} \\
&-\left[(1-pr)\left(1-\delta\left(p+(1-p)^2\right)\right) + \delta p(p-q)(2-r(p+q))\right] w_{00} \\
\geq\ & \frac{c}{r(p-q)}\left(1+\frac{\delta p(p-q)}{1-\delta\left(p+(1-p)^2\right)}\right),
\end{aligned} \tag{14}$$

and

$$0 \leq (qr)(w_{11}-w_{10}) + (1-qr)(w_{01}-w_{00}). \tag{15}$$

Since the coefficients of w_{00} in both constraints are negative, we have $w_{00} = 0$. Observe next that if (15) is not binding, then $w_{01} = 0$ at optimum since it shares the same coefficient with w_{10} in the objective function, but has a strictly smaller coefficient in constraint (14). It remains to check whether $w_{11} = 0$ or $w_{10} = 0$ is optimal. Setting $w_{10} = 0$ is optimal if

$$\frac{(pr)^2 + (1-p)p\frac{\delta}{1-\delta}(qr)^2}{pr + \frac{\delta pr(p^2-q^2)}{1-\delta\left(p+(1-p)^2\right)}} < \frac{pr(1-pr) + (1-p)p\frac{\delta}{1-\delta}(qr)(1-qr)}{(1-pr) + \frac{\delta p(p-q)(1-r(p+q))}{1-\delta\left(p+(1-p)^2\right)}}$$
$$\Leftrightarrow \quad r < \frac{(1-\delta)+\delta p(1-q)}{p\left(1-\delta+\delta\left(p-q^2\right)\right)} \equiv r_1^*.$$

Thus, if $r < r_1^*$, then it is clear that the optimal contract has $w_{00} = w_{01} = w_{10} = 0$, and

$$\begin{aligned}
w_{11} &= \frac{c}{pr^2(p-q)}\frac{1-\delta(1-p+pq)}{1-\delta(1-p+q^2)}; \text{ and} \\
s &= \frac{\delta}{1-\delta}\left(q^2\frac{c}{p(p-q)}\frac{1-\delta(1-p+pq)}{1-\delta(1-p+q^2)} - \bar{U}\right).
\end{aligned}$$

For later reference, we will call this Contract (*). With this contract, the value of the objective is

$$\frac{c}{p-q}\left(p+(1-p)\frac{\delta}{1-\delta}q^2\right)\frac{1-\delta(1-p+pq)}{1-\delta(1-p+q^2)}-p(1-p)\frac{\delta}{1-\delta}\bar{U}.$$

Note that Contract (*) satisfies $\max\left\{\min\{\pi(0,0),\pi(0,1)\},\bar{U}\right\}=\pi(0,0)$ if and only if $\bar{U}\leq\bar{U}^*$.

Next, we consider the case $r\geq r_1^*$ and show that as long as $\bar{U}\leq\bar{U}^*$, Contract (*) is optimal. Suppose $r>r_1^*$. Constraint (15) must bind (otherwise, only w_{01} is positive, a contradiction). This in turn implies that (14) must also bind (otherwise, every term equals zero, a contradiction).

Below we argue that in the optimal solution, $w_{10}=0$. Suppose at the optimum, $w_{10}>0$. Since constraint (15) must bind, we have $w_{10}=w_{11}+\left(\frac{1}{qr}-1\right)w_{01}$. Substitute this into the objective and the constraint (14) respectively:

$$\left[p\frac{r}{1-\delta}(1-\delta+\delta q(1-p))\right]w_{11}+\left[p(1-pr)+(1-p)qp\frac{\delta}{1-\delta}(1-qr)\right]\frac{1}{q}w_{01}-(1-p)p\frac{\delta}{1-\delta}\bar{U},$$

and

$$w_{11}+\frac{1}{qr}(1-r(p+q))w_{01}=\frac{c}{r(p-q)}.$$

Now if $1-r(p+q)\leq 0$, it is optimal to set $w_{01}=0$. This implies $w_{10}=w_{11}=\frac{c}{r(p-q)}$. The resulting value of the objective is

$$\frac{pc}{p-q}+\frac{\delta}{1-\delta}p(1-p)\left(\frac{qc}{p-q}-\bar{U}\right).$$

However, it is dominated by Contract (*):

$$\begin{aligned}&\frac{pc}{p-q}\left(1+\frac{\delta}{1-\delta}q(1-p)\right)-\frac{c}{p-q}\left(p+(1-p)\frac{\delta}{1-\delta}q^2\right)\frac{1-\delta(1-p+pq)}{1-\delta(1-p+q^2)}\\ =\;& cq\frac{\delta}{1-\delta}\frac{\delta p(1-p)+1-\delta}{\delta(p-q^2)+1-\delta}>0\end{aligned}$$

Next if $1-r(p+q)>0$, it is optimal to set $w_{11}=0$. This implies $w_{01}=\frac{qc}{(p-q)(1-r(p+q))}$ and $w_{10}=\left(\frac{1-qr}{qr}\right)\frac{qc}{(p-q)(1-r(p+q))}$. The resulting objective value is $\frac{p(1-pr)+(1-p)qp\frac{\delta}{1-\delta}(1-qr)}{1-r(p+q)}\frac{c}{p-q}-(1-p)p\frac{\delta}{1-\delta}\bar{U}$. Again, it is dominated by Contract (*):

$$\begin{aligned}&\frac{p(1-pr)+(1-p)qp\frac{\delta}{1-\delta}(1-qr)}{1-r(p+q)}\frac{c}{p-q}-\left(p+(1-p)\frac{\delta}{1-\delta}q^2\right)\frac{1-\delta(1-p+pq)}{1-\delta(1-p+q^2)}\frac{c}{p-q}\\ =\;&\frac{qc\left(\delta(p-q)+pr(1-\delta)+q^2r\delta(1-p)\right)}{(1-\delta)(p-q)(1-r(p+q))}\frac{\delta p(1-p)+1-\delta}{\delta(p-q^2)+1-\delta}>0.\end{aligned}$$

To summarize, provided that $\bar{U}\leq\bar{U}^*$ holds, the optimal scheme within the class under consideration is Contract (*).

Observe that if $\bar{U}>\bar{U}^*$, this class of scheme is dominated by the optimal schemes in case (ii) considered above. It is easy to see that the problem in case (ii) is relaxed version of the one considered here (the objective is weakly lower and the constraint set is weakly larger). Thus, if the optimal scheme in case (ii) is feasible, it must dominate schemes in case (iii) here.

Finally, the proof is finished by noting that the optimal scheme found in case (i) is always dominated by either the optimal scheme in case (ii) if $\bar{U} \geq \bar{U}^*$, or case (iii) if $\bar{U} < \bar{U}^*$. ■

Proof of Proposition 1: In the optimal scheme identified in case (i) of Lemma 1, it can be readily checked that both agents shirking is a stage-game Nash equilibrium:

$$\pi(0,0) \geq \pi(1,0) - c \Leftrightarrow w_{11} \leq \frac{c}{(p-q)\, qr^2} \Leftrightarrow (p-q)(1-\delta+\delta p) \geq 0.$$

The corresponding resignation payoff is

$$W = (qr)^2 w_{11} = \frac{q^2 c}{p(p-q)} \frac{1-\delta(1-p+pq)}{1-\delta(1-p+q^2)}.$$

The following strategy profile supports this payoff as a continuation PPE in the off-path punishment phase. If an agent deviates from resigning, both the deviating agent and his partner shirks. They keep shirking as long as the deviating agent stays on the job. The deviating agent voluntarily resigns at the end of every period (if he has not previously done so). If the deviating agent quits the job, his partner starts a fresh relationship with a newly hired agent in the employment phase. The fact that this is indeed a PPE can be readily seen from the finding that both agents shirking on the job is a stage-game Nash equilibrium.

The expected cost of the contract is

$$\Psi_1^G \equiv \frac{c}{p-q}\left(p + (1-p)\frac{\delta}{1-\delta} q^2\right) \frac{1-\delta(1-p+pq)}{1-\delta(1-p+q^2)} - p(1-p)\frac{\delta}{1-\delta}\bar{U}.$$

Similarly, in the optimal contract identified in case (ii) of Lemma 1, it can be readily checked that both agents shirking is a stage-game Nash equilibrium:

$$\pi(0,0) \geq \pi(1,0) - c \Leftrightarrow qrw_{11} + (1-qr)\, w_{10} \leq \frac{c}{r(p-q)},$$

which holds because of the assumption that $\frac{qc}{p-q} \leq \bar{U}$. The strategy profile stated for case (i) above also supports an a continuation PPE in the off-path punishment phase. Since $qr\,(qrw_{11} + (1-qr)\, w_{10}) \leq \bar{U}$ holds at the optimal scheme, both agents shirking results in a payoff lower than the outside option. Thus, deviating to stay on the job is unprofitable, and the corresponding resignation payoff is thus $W = \bar{U}$. The expected cost of the contract is

$$\Psi_2^G \equiv \frac{pc}{p-q} - \frac{\delta p^2}{1-\delta+\delta p}\left(\frac{qc}{p-q} - \bar{U}\right).$$

Finally, to determine the optimal contract with generous severance policy, it remains to pit the solutions in Lemma 1 against the simple IPE contract for the respective case of $\bar{U} < \bar{U}^*$ and $\bar{U} \geq \bar{U}^*$. First, in the case of $\bar{U} < \bar{U}^*$, direct computation shows that $\Psi_1^G \leq \Psi^{SI}$ if and only if

$$\bar{U} \geq \left(1 - \frac{(p-q)\left(1-\delta+\delta p\left(1-p\right)\right)}{p\left(1-p\right)\left(1-\delta\left(1-p+q^2\right)\right)}\right)\frac{qc}{p-q} \equiv \bar{U}_0.$$

It is straightforward to check that $\bar{U}_0 < \bar{U}^*$. Second, in the case of $\bar{U} \in [\bar{U}^*, \frac{qc}{p-q})$, direct computation shows that $\Psi_2^G < \Psi^{SI}$. ■

Proof of Proposition 2: Classify the values of $\bar{U}$ into 3 regions: (i) $\left[0, \bar{U}_0\right]$, (ii) $(\bar{U}_0, \bar{U}^*)$, and (iii) $[\bar{U}^*, \frac{qc}{p-q})$. First, the simple IPE contract is optimal in the class of contracts with generous severance policy if and only if $\bar{U} \in \left[0, \bar{U}_0\right]$. In this case, since the optimal efficiency wage contract outperforms the simple IPE contract, it also outperforms any contract with generous severance policy. Next, in region (iii), the expected cost of the optimal contract with generous severance policy is Ψ_2^G (defined in the proof of Proposition 1). Comparing it with the cost of the optimal efficiency wage contract Ψ^{EW}, it is less costly whenever $r \leq \frac{p}{1-\delta+\delta p}$. Finally, in the intermediate region $(\bar{U}_0, \bar{U}^*)$, the expected cost of optimal contract with generous severance policy is Ψ_1^G. Comparing it with the optimal efficiency wage contract Ψ^{EW}, it is less costly whenever $r \leq \frac{1-p}{1-\delta}\left(\frac{\bar{U}-\bar{U}_0}{\frac{qc}{p-q}-\bar{U}}\right)$. ■

Proof of Corollary 2: We write $\Psi^{\cdot}\left(\tilde{p}, \tilde{r}\right)$ to stand for the expected agency cost if the monitoring technology is $\left(\tilde{p}, \tilde{r}\right)$. Moreover, we write $\bar{U}^*\left(\tilde{p}, \tilde{r}\right)$ to stand for the cutoff outside option above which severance pay is not needed for voluntary quitting, when the monitoring technology is $\left(\tilde{p}, \tilde{r}\right)$. It is straightforward that $\bar{U}^*\left(p', r'\right) < \bar{U}^*\left(p, r\right)$.

First we consider the case $\bar{U} \in \left[0, \bar{U}^*\left(p, r\right)\right]$. Suppose $\Psi_1^G\left(p, r\right) \leq \Psi^{EW}\left(p, r\right)$. The difference between $\Psi^{EW}\left(p, r\right)$ and $\Psi_1^G\left(p, r\right)$ is given by

$$\begin{aligned} & \Psi^{EW}\left(p, r\right) - \Psi_1^G\left(p, r\right) \\ = \; & \frac{\delta pqc}{1-\delta\left(1-p+q^2\right)} - \delta\left[pr\left(\frac{qc}{p-q} - \bar{U}\right) + \frac{1}{1-\delta}\left(1-p\right)\left(\frac{q^2c}{p-q}\frac{1-\delta\left(1-p+pq\right)}{1-\delta\left(1-p+q^2\right)} - p\bar{U}\right)\right]. \end{aligned}$$

If $\bar{U} \leq \bar{U}^*\left(p', r'\right)$, then it is straightforward that $\Psi^{EW}\left(p', r'\right) - \Psi_1^G\left(p', r'\right) > \Psi^{EW}\left(p, r\right) - \Psi_1^G\left(p, r\right) \geq 0$. If $\bar{U} > \bar{U}^*\left(p', r'\right)$, then the relevant comparison is $\Psi^{EW}\left(p', r'\right)$ versus $\Psi_2^G\left(p', r'\right)$. Note that $\Psi_1^G\left(p, r\right) \leq \Psi^{EW}\left(p, r\right)$ implies $\Psi_2^G\left(p, r\right) \leq \Psi^{EW}\left(p, r\right)$. Therefore,

$$\Psi^{EW}\left(p', r'\right) - \Psi_2^G\left(p', r'\right) = \delta\left(\frac{\left(p'\right)^2}{1-\delta+\delta p'} - pr\right)\left(\frac{qc}{p'-q} - \bar{U}\right) > 0.$$

Next consider the case $\bar{U} \in \left[\bar{U}^*(p,r), \frac{qc}{p'-q}\right]$. Suppose $\Psi_2^G(p,r) \le \Psi^{EW}(p,r)$. The difference between $\Psi^{EW}(p,r)$ and $\Psi_1^G(p,r)$ is given by

$$\Psi^{EW}(p,r) - \Psi_2^G(p,r) = \delta\left(\frac{p^2}{1-\delta+\delta p} - pr\right)\left(\frac{qc}{p-q} - \bar{U}\right) \ge 0.$$

It is clear that $\Psi^{EW}(p',r') - \Psi_2^G(p',r') \ge 0$.

Finally, we show that the agency cost is lower with technology (p',r') than (p,r). Suppose $\bar{U} < \bar{U}^*(p',r')$. With (p,r), the expected wage cost and expected severance payment are respectively

$$\begin{aligned}(pr)^2 w_{11} &= \frac{pc}{p-q}\frac{1-\delta(1-p+pq)}{1-\delta(1-p+q^2)}; \text{ and}\\ p(1-p)s &= \frac{\delta}{1-\delta}(1-p)\left(\frac{q^2c}{p-q}\frac{1-\delta(1-p+pq)}{1-\delta(1-p+q^2)} - p\bar{U}\right).\end{aligned}$$

It is straightforward that both terms go down by replacing (p,r) with (p',r'). Next suppose $\bar{U} \in \left[\bar{U}^*(p',r'), \bar{U}^*(p,r)\right]$. The expected wage cost with (p',r') is

$$\begin{aligned}p'\left(\frac{c}{p'-q} - \frac{\delta p'}{1-\delta+\delta p'}\left(\frac{qc}{p'-q} - \bar{U}\right)\right) &\ge p'\left(\frac{c}{p'-q} - \frac{\delta p'}{1-\delta+\delta p'}\left(\frac{qc}{p'-q} - \bar{U}^*(p',r')\right)\right)\\ &= \frac{p'c}{p'-q}\frac{1-\delta(1-p'+p'q)}{1-\delta(1-p'+q^2)},\end{aligned}$$

which is strictly lower than $\frac{pc}{p-q}\frac{1-\delta(1-p+pq)}{1-\delta(1-p+q^2)}$, the expected wage cost under technology(p,r). Furthermore, with technology (p',r'), severance pay is not needed. Therefore, the overall agency cost is necessarily lower under (p',r').

Finally, for the case $\bar{U} \in \left[\bar{U}^*(p,r), \frac{qc}{p'-q}\right]$, it suffices to note that the derivative of $\Psi_2^G(\tilde{p},\tilde{r})$ with respect to $\tilde{p}$ is negative:

$$\frac{\partial \Psi_2^G(\tilde{p},\tilde{r})}{\partial \tilde{p}} = -qc\frac{1-\delta+\delta\tilde{p}(1-\tilde{p})}{(\tilde{p}-q)^2(1-\delta+\delta\tilde{p})} - \frac{\delta\tilde{p}(\delta\tilde{p}+2(1-\delta))}{(1-\delta+\delta\tilde{p})^2}\left(\frac{qc}{\tilde{p}-q} - \bar{U}\right) < 0.$$

■

Proof of Lemma 2: If the contract does not induce voluntary resignation in any circumstance, the agent never quits as the value on the job exceeds the outside option by assumption. The problem is then reduced to one of a static setting, and the optimal contract within this class of contracts is $w_1 = \frac{c}{(p-q)(pl_2+(1-2p)l_1)}$. For the remainder of the proof, we focus on contracts that induce voluntary resignation whenever the agent produces a bad signal while his partner has a good signal.

It is immediate that the constraints (9) and (10) bind at the optimum. Thus,

$$\begin{aligned}&\left((l_1 - 2pl_1 + pl_2)\left(1-\delta\left(p+(1-p)^2\right)\right) + \delta p^2(pl_2 + 2(1-p)l_1)\right)w_1\\ =\;& \frac{c}{p-q}(1-\delta+\delta p(1-q)) + \delta p \max\left\{\bar{U}, \left(q^2 l_2 + 2q(1-q)l_1\right)w_1\right\}. \qquad (16)\end{aligned}$$

Consider first w such that $\bar{U} \geq \left(q^2 l_2 + 2q(1-q) l_1\right) w_1$. Then (16) implies that

$$w_1 = \frac{\frac{c}{p-q}\left(1-\delta+\delta p(1-q)\right)+\delta p \bar{U}}{\left(l_1 - 2pl_1 + pl_2\right)\left(1-\delta\left(p+(1-p)^2\right)\right)+\delta p^2\left(pl_2 + 2(1-p) l_1\right)}.$$

This wage indeed satisfies $\bar{U} \geq \left(q^2 l_2 + 2q(1-q) l_1\right) w_1$ if and only if $\bar{U} \geq \bar{U}_T$. In this case, severance payment is zero as the resignation payoff is $\bar{U}$. The strategy profile stated in the proof of Proposition 1 supports this resignation payoff as a continuation PPE payoff.

Next, consider a w_1 such that $\bar{U} < \left(q^2 l_2 + 2q(1-q) l_1\right) w_1$. Then (16) implies that

$$w_1 = \frac{1-\delta+\delta p(1-q)}{\left((1-2p) l_1 + pl_2\right)\left(1-\delta\left(p+(1-p)^2\right)\right)+\delta p(p-q)\left(2l_1(1-p-q)+(p+q) l_2\right)} \frac{c}{p-q}.$$

This wage indeed satisfies $\bar{U} < \left(q^2 l_2 + 2q(1-q) l_1\right) w_1$ if and only if $\bar{U} < \bar{U}^T$. In this case, positive severance payment is needed to induce voluntary resignation, as the lowest possible continuation payoff exceeds $\bar{U}$. The strategy profile stated in the proof of Proposition 1 supports the resignation payoff of $\left(q^2 l_2 + 2q(1-q) l_1\right) w_1$ as a continuation PPE payoff.

The expected payoff of this class of contracts is given by

$$\Psi^{GT} = \begin{cases} \frac{\left(p^2 l_2 + 2p(1-p) l_1 + \frac{\delta}{1-\delta} p(1-p)\left(q^2 l_2 + 2q(1-q) l_1\right)\right)(1-\delta+p\delta(1-q))}{\left(l_1(1-2p)+pl_2\right)\left(1-\delta\left(p+(1-p)^2\right)\right)+\delta p(p-q)(2l_1(1-p-q)+(p+q) l_2)} \frac{c}{p-q} - \frac{\delta}{1-\delta} p(1-p) \bar{U} & \text{if } \bar{U} \in [0, \bar{U}_T) \\ \left(\frac{(pl_2 + 2(1-p) l_1)(1-\delta+\delta p)}{\left(l_1(1-2p)+pl_2\right)\left(1-\delta\left(p+(1-p)^2\right)\right)+\delta p(p^2 l_2 + 2p(1-p) l_1)}\right)\left(\frac{pc}{p-q} - \frac{\delta p^2}{1-\delta+\delta p}\left(\frac{qc}{p-q} - \bar{U}\right)\right) & \text{if } \bar{U} \in [\bar{U}_T, \frac{qc}{p-q}) \end{cases}.$$

■

Proof of Proposition 3: Below we compare the agency cost of team production with generous severance policy, written as $\Psi^{GT}\left(\bar{U}, l_1\right)$, against individual production with harsh severance policy, written as $\Psi^{HI}\left(\bar{U}, l_1\right)$. It is immediate by inspection that both functions are continuous in both $\bar{U}$ and l_1.

First, on $\bar{U} \in [\bar{U}_T, \frac{qc}{p-q})$, both $\frac{\partial \Psi^{GT}}{\partial \bar{U}}$ and $\frac{\partial \Psi^{HI}}{\partial \bar{U}}$ are constant and given by

$$\begin{aligned} \frac{\partial \Psi^{GT}}{\partial \bar{U}} &= \frac{\delta p^2\left(pl_2 + 2(1-p) l_1\right)}{\left(l_1(1-2p)+pl_2\right)\left(1-\delta\left(p+(1-p)^2\right)\right)+\delta p\left(p^2 l_2 + 2p(1-p) l_1\right)}; \text{ and} \\ \frac{\partial \Psi^{HI}}{\partial \bar{U}} &= \delta p\left(2l_1(1-p)+pl_2\right). \end{aligned}$$

Note that if l_1 is sufficiently small and $l_2 < \frac{p}{1-\delta+\delta p}$, then we have $\frac{\partial \Psi^{GT}}{\partial \bar{U}} > \frac{\partial \Psi^{HI}}{\partial \bar{U}}$.

Second, for each $l_1 > 0$, direct computation gives $\Psi^{GT}\left(\frac{qc}{p-q}, l_1\right) > \Psi^{HI}\left(\frac{qc}{p-q}, l_1\right)$. In this case, dynamic incentive is ineffective and the reason for the superiority of individual production is the same as that pointed out in the static setting. Together with the first observation above that both $\frac{\partial \Psi^{GT}}{\partial \bar{U}}$ and $\frac{\partial \Psi^{HI}}{\partial \bar{U}}$ are constant, there exists some $\bar{U}_{T,1} < \frac{qc}{p-q}$ such that $\Psi^{TT}\left(\bar{U}, l_1\right) \geq \Psi^{EI}\left(\bar{U}, l_1\right)$ if and only if $\bar{U} \in [\bar{U}_{T,1}, \frac{qc}{p-q})$.

Next, by direct computation again, $\Psi^{GT}\left(\bar{U},0\right) < \Psi^{HI}\left(\bar{U},0\right)$ for all $\bar{U} \in [\bar{U}_T, \frac{qc}{p-q})$, provided that $l_2 = \frac{r}{p} < \frac{1}{1-\delta+\delta p}$. Combined with the two observations above, if l_1 is sufficiently small, there exists a $\bar{U}_{T,1} \in [\bar{U}_T, \frac{qc}{p-q})$ such that $\Psi^{GT}\left(\bar{U},l_1\right) < \Psi^{HI}\left(\bar{U},l_1\right)$ holds for $\bar{U} \in [\bar{U}_T, \bar{U}_{T,1})$. Finally, since Ψ^{HI} and Ψ^{GT} are both continuous in $\bar{U}$, the lower bound in which $\Psi^{GT} < \Psi^{HI}$ holds can be extended to some $\bar{U}_{T,0} < \bar{U}_T$. ■

Flexible Termination Clauses

In this subsection of the appendix, we consider a modified version of the benchmark model analyzed in Section 3. Here, we allow the termination clauses to be conditioned on the outcomes of both the agent and his partner. We write f_{y_i,y_j} to stand for the firing decision of outcome profile $(y_i, y_j) \in \{0,1\}^2$, and allow $f_{y_i,0} \neq f_{y_i,1}$ for any $y_i \in \{0,1\}$. The main purpose of this investigation is to illustrate the insight obtained in Section 3 is robust to a more general class of contracts. The main complication arises from the increase in the number of contract classes needed to be considered. We do not attempt a full characterization of the optimal contract for all parameter configurations; instead, we focus on identifying sufficient conditions under which the optimal contract features a JPE wage scheme and severance pay for voluntary exit.

We begin with a couple of observations. First, as pointed out at the beginning of Section 3, the agent is always retained after producing a good outcome, i.e., $f_1 = 0$; and the severance payment following forced termination is zero, i.e., $\sigma_{y_i,y_j} = 0$. Second, note that if $f_{0,1} = f_{0,0} = 1$, the contracts belong to the class studied in Section 3.1, while if $f_{0,1} = f_{0,0} = 0$, the contract belongs to the class studied in Section 3.2. Therefore, only two possibilities remain to be considered: (a) $f_{0,1} = 0$, $f_{0,0} = 1$; and (b) $f_{0,1} = 1$, $f_{0,0} = 0$.

Case (a): $f_{0,1} = 0,\ f_{0,0} = 1$

This is the class of contracts that fire an agent if and only if both team members produce bad outcomes. In our search for the candidate optimal contracts within this class, we focus only on contracts that induce voluntary resignation following a poor signal. This is because contracts that do not involve voluntary resignation in the PPE are more costly than the optimal efficiency wage contract. Following the same arguments in Section 3.2, it is without loss to focus on PPE with a structure similar to the one considered there.

Since agent i is fired whenever $(y_i, y_j) = (0,0)$, his continuation payoff in the employment phase V is given by

$$V = (1-\delta)\left(\pi(1,1) - c\right) + \delta\left[pr\left(1 + p\left(1-r\right)\right)V + pr\left(1-p\right)W + \left(1-pr\right)^2\bar{U}\right].$$

The agent is willing to put in effort if and only if

$$V \geq (1-\delta)\pi(0,1) + \delta\left[qr\left(1+p\left(1-r\right)\right)V + pr\left(1-q\right)W + \left(1-pr\right)\left(1-qr\right)\bar{U}\right].$$

Combining and rearranging the two conditions above gives

$$\begin{aligned}
& \left(1 - qr\delta\left(1+p-pr\right)\right)\pi(1,1) - \left(1 - \delta pr\left(1+p\left(1-r\right)\right)\right)\pi(0,1) \\
\geq\ & c\left(1 - qr\delta\left(1+p-pr\right)\right) \\
& + \frac{\delta}{1-\delta} r\left(p-q\right)\left[\left(1-pr\right)\left(1-\delta-\delta p\left(1-r\right)\right)\bar{U} + p\left(1-\delta r\left(1+p-pr\right)\right)W\right].
\end{aligned} \tag{17}$$

Suppose the agent's partner produces a good outcome, and the agent himself produces a bad signal but declines to leave. One feasible strategy for the deviating agent is to stay on the job and exert no effort for the rest of the game until he is fired. Denote the continuation payoff of such a strategy by W'. It is necessary that

$$W' \geq \min\left\{\begin{array}{c} (1-\delta)\pi(0,0) + \delta\left(\left(1-\left(1-qr\right)^2\right)W' + \left(1-qr\right)^2\bar{U}\right), \\ (1-\delta)\pi(0,1) + \delta\left(\left(1-\left(1-qr\right)\left(1-pr\right)\right)W' + \left(1-qr\right)\left(1-pr\right)\bar{U}\right) \end{array}\right\}.$$

Rearranging the inequality above implies a lower bound for the payoff for voluntary resignation W:

$$W \geq \max\left\{\bar{U}, \min\left\{\frac{(1-\delta)\pi(0,0) + \delta\left(1-qr\right)^2\bar{U}}{1-\delta\left(1-\left(1-qr\right)^2\right)}, \frac{(1-\delta)\pi(0,1) + \delta\left(1-qr\right)\left(1-pr\right)\bar{U}}{1-\delta\left(1-\left(1-qr\right)\left(1-pr\right)\right)}\right\}\right\}. \tag{18}$$

Similar to Section 3.2, we consider a relaxed problem in which the lower bound on W can be achieved as a PPE payoff. Formally, the principal chooses wages and W to minimize

$$\left(pr\right)^2 w_{11} + pr\left(1-pr\right)\left(w_{10} + w_{01}\right) + \left(1-pr\right)^2 w_{00} + \frac{\delta}{1-\delta}\left(1-p\right)pr\left(W - \bar{U}\right),$$

subject to constraints (17) and (18). The following lemma analyzes this relaxed problem and identifies the candidate optimal contract that arises from this class.[25]

[25] That is, if the overall optimal contract indeed arises from the class considered here, it must take the form shown below.

Lemma 3 *Define* $\bar{U}_{00}^{*} \equiv \frac{q^2 c}{p-q}\frac{1-\delta qr(1+p(1-r))}{p-\delta q^2 r(1+p(1-r))} > 0$. *If* $\bar{U} < \bar{U}_{00}^{*}$, *the candidate optimal contract is* $w_{00} = w_{01} = w_{10} = 0$, *and*

$$\begin{aligned} w_{11} &= \frac{\left(\begin{array}{c} \frac{c}{r(p-q)}\left(1 - qr\delta\left(1+p-pr\right)\right)\left(1-\delta\left(1-\left(1-qr\right)^2\right)\right) \\ +\delta\left(\left(1-pr\right)\left(1-\delta-\delta p\left(1-r\right)\right)+\delta\left(1-qr\right)^2\left(1+p-pr\right)\right)\bar{U} \end{array}\right)}{pr\left(1-\delta\left(1-\left(1-qr\right)^2\right)\right)-\delta p\left(1-\delta r\left(1+p-pr\right)\right)\left(qr\right)^2}; \\ s &= \delta\frac{\frac{q^2 c}{p-q}\left(1-qr\delta\left(1+p-pr\right)\right)-\left(p-q^2 r\delta\left(1+p-pr\right)\right)\bar{U}}{p\left(1-\delta\left(1-\left(1-qr\right)^2\right)-\delta\left(1-\delta r\left(1+p-pr\right)\right)q^2 r\right)}. \end{aligned}$$

If $\bar{U} \geq \bar{U}_{00}^{*}$, *the set of all candidate optimal contracts is given by* $w_{00} = w_{01} = s = 0$, *and* (w_{11}, w_{10}) *satisfying*

$$prw_{11} + \left(1-pr\right)w_{10} = \frac{c}{r\left(p-q\right)}\left(1-qr\delta\left(1+p-pr\right)\right)+\delta\left(1+p-pr\right)\bar{U}; \text{ and}$$

$$w_{11} \in \left[\frac{1-qr}{r\left(p-q\right)}\left(\frac{1}{qr}-\delta\left(1+p-pr\right)\right)\left(\frac{qc}{p-q}-\bar{U}\right)+\frac{\bar{U}}{qr}, \frac{1}{pr}\left(\frac{c}{r\left(p-q\right)}-\delta\left(1+p-pr\right)\left(\frac{qc}{p-q}-\bar{U}\right)\right)\right].$$

Proof of Lemma 3:. It is immediate that W is chosen such that (18) holds with equality. Depending on the values of W, there are three distinct classes of wage schemes: (i) $W = \frac{(1-\delta)\pi(0,1)+\delta(1-qr)(1-pr)\bar{U}}{1-\delta(1-(1-qr)(1-pr))}$; (ii) $W = \bar{U}$; and (iii) $W = \frac{(1-\delta)\pi(0,0)+\delta(1-qr)^2\bar{U}}{1-\delta\left(1-(1-qr)^2\right)}$.

Case (i): $W = \frac{(1-\delta)\pi(0,1)+\delta(1-qr)(1-pr)\bar{U}}{1-\delta(1-(1-qr)(1-pr))}$

Ignoring the requirement that the schemes must satisfy $W = \frac{(1-\delta)\pi(0,1)+\delta(1-qr)(1-pr)\bar{U}}{1-\delta(1-(1-qr)(1-pr))}$, and replacing $\pi(\cdot,\cdot)$ with the corresponding expressions involving wages, the problem above can be stated as choosing nonnegative wages $\{w_{11}, w_{10}, w_{01}, w_{00}\}$ to minimize

$$\begin{aligned} &\left(\left(pr\right)^2 + \frac{\delta pr\left(1-p\right)\left(pr\right)\left(qr\right)}{1-\delta\left(1-\left(1-qr\right)\left(1-pr\right)\right)}\right)w_{11} + \left(pr\left(1-pr\right)+\frac{\delta pr\left(1-p\right)\left(qr\right)\left(1-pr\right)}{1-\delta\left(1-\left(1-qr\right)\left(1-pr\right)\right)}\right)w_{10} \\ &+\left(pr\left(1-pr\right)+\frac{\delta pr\left(1-p\right)\left(1-qr\right)\left(pr\right)}{1-\delta\left(1-\left(1-qr\right)\left(1-pr\right)\right)}\right)w_{01} + \left(\left(1-pr\right)^2+\frac{\delta pr\left(1-p\right)\left(1-qr\right)\left(1-pr\right)}{1-\delta\left(1-\left(1-qr\right)\left(1-pr\right)\right)}\right)w_{00} \\ &-\frac{\delta pr\left(1-p\right)}{1-\delta\left(1-\left(1-qr\right)\left(1-pr\right)\right)}\bar{U}, \end{aligned}$$

subject to

$$\begin{aligned} &\left(pr\left(1-\delta qr\left(1+p-pr\right)\right)-qr\left(\frac{\left(p^2r^2\delta-2pr\delta+1\right)\left(1-qr\delta+pqr^2\delta-pqr\delta\right)}{1-\delta\left(1-\left(1-qr\right)\left(1-pr\right)\right)}\right)\right)\left(prw_{11}+\left(1-pr\right)w_{10}\right) \\ &+\left(\left(1-pr\right)\left(1-\delta qr\left(1+p-pr\right)\right)-\left(1-qr\right)\left(\frac{\left(1-2pr\delta+\delta p^2r^2\right)\left(1-\delta qr-\delta pqr\left(1-r\right)\right)}{1-\delta\left(1-\left(1-qr\right)\left(1-pr\right)\right)}\right)\right) \\ &\times\left(prw_{01}+\left(1-pr\right)w_{00}\right) \\ \geq\ & c\left(1-qr\delta\left(1+p-pr\right)\right)+\delta r\left(p-q\right)\left(1-pr\right)\left(\frac{1-qr\delta+pqr^2\delta-pqr\delta}{1-\delta\left(1-\left(1-qr\right)\left(1-pr\right)\right)}\right)\bar{U}. \end{aligned}$$

The observations below follow from straightforward algebraic manipulation. First, the coefficient of w_{00} in the objective function is negative. Second, the coefficient of w_{10} in the objective is less than that of w_{01}; while the opposite holds in the constraint. Third, the coefficients of w_{11} and w_{10} in the constraint are positive. These three observations imply that at optimum, $w_{01} = w_{00} = 0$ and the constraint binds. Finally, wages w_{11} and w_{10} share equal ratio of the coefficient in the objective and the constraint. Thus, a solution is to have $w_{11} = w_{01} = w_{00} = 0$ and

$$w_{10} = \frac{\frac{c}{p-q}\left(1-qr\delta\left(1+p-pr\right)\right)\left(1-\delta\left(1-\left(1-qr\right)\left(1-pr\right)\right)\right)+\delta r\left(1-pr\right)\left(1-qr\delta\left(1+p-pr\right)\right)\bar{U}}{r\left(1-pr\right)\left(1-pr\delta\right)\left(1-qr\delta\left(1+p-pr\right)\right)}.$$

It can be shown that the expected cost of this contract exceeds that of the efficiency wage contract:

$$\begin{aligned} & p\frac{\frac{c}{p-q}\left(1-qr\delta\left(1+p-pr\right)\right)\left(1-\delta\left(1-\left(1-qr\right)\left(1-pr\right)\right)\right)+\delta r\left(1-pr\right)\left(1-qr\delta\left(1+p-pr\right)\right)\bar{U}}{\left(1-pr\delta\right)\left(1-qr\delta\left(1+p-pr\right)\right)} \\ & -\left(\frac{pc}{p-q}-\delta pr\left(\frac{qc}{p-q}-\bar{U}\right)\right) \\ = & \frac{\delta\left(1-\delta\right)p^2r^2}{1-pr\delta}\left(\frac{qc}{p-q}-\bar{U}\right)>0. \end{aligned}$$

Thus, there is no contract from this class that can be an overall optimal contract.

Case (ii): $W = \bar{U}$

Like case (i) above, we temporarily ignore the requirement $W = \bar{U}$. In this case, the severance payment $s = 0$. The principal's relaxed problem can be stated as choosing wages to minimize

$$(pr)^2 w_{11} + pr\left(1-pr\right)\left(w_{10}+w_{01}\right) + \left(1-pr\right)^2 w_{00},$$

subject to

$$\begin{aligned} & prw_{11} + \left(1-pr\right)w_{10} - \left(1-\delta-\delta p\left(1-r\right)\right)\left(prw_{01} + \left(1-pr\right)w_{00}\right) \\ \geq\; & \frac{c}{r\left(p-q\right)}\left(1-qr\delta\left(1+p-pr\right)\right) + \delta\left(1+p-pr\right)\bar{U}. \end{aligned}$$

We first show that at the solution to the problem above, we have $w_{01} = w_{00} = 0$. This is clearly the case if $1-\delta-\delta p\left(1-r\right) \geq 0$, so suppose otherwise. In this case, the ratios of coefficients for w_{11} (which equals that of w_{10}) and w_{01} (which equals that of w_{00}) are respectively pr and $\frac{1-pr}{-(1-\delta-p\delta+pr\delta)}$. We have

$$pr - \frac{1-pr}{-\left(1-\delta-p\delta+pr\delta\right)} = \frac{1-pr\delta\left(1+p-pr\right)}{1-\delta-\delta p\left(1-r\right)} < 0.$$

The denominator is negative by assumption, and the numerator is positive as $1-pr\delta\left(p-pr+1\right) > 1-\delta p > 0$. Therefore, $w_{01} = w_{00} = 0$ at optimum. Since $w_{01} = w_{00} = 0$, the constraint of the problem must bind:

$$prw_{11} + \left(1-pr\right)w_{10} = \frac{c}{r\left(p-q\right)}\left(1-qr\delta\left(1+p-pr\right)\right) + \delta\left(1+p-pr\right)\bar{U}. \tag{19}$$

Next note that $W = \bar{U}$ if and only if $\min\{\pi(0,0), \pi(0,1)\} \le \bar{U}$. Below we identify conditions that ensure $\min\{\pi(0,0), \pi(0,1)\} \le \bar{U}$:

$$\min\{qrw_{11} + (1-qr)\,w_{10}, prw_{11} + (1-pr)\,w_{10}\} \le \frac{\bar{U}}{qr}.$$

Direct algebraic manipulation shows that the right hand side of (19) exceeds $\frac{\bar{U}}{qr}$. Therefore, it is necessary that $qrw_{11} + (1-qr)\,w_{10} \le \frac{\bar{U}}{qr}$. Using (19) again, the cost-minimizing contracts within this class is given by

$$\left\{ \begin{array}{c} (w_{11}, w_{10}, w_{01}, w_{00}) : w_{01} = w_{00} = 0, \\ w_{11} \in \left[\frac{1-qr}{r(p-q)}\left(\frac{1}{qr} - \delta(1+p-pr)\right)\left(\frac{qc}{p-q} - \bar{U}\right) + \frac{\bar{U}}{qr}, \frac{1}{pr}\left(\frac{c}{r(p-q)} - \delta(1+p-pr)\left(\frac{qc}{p-q} - \bar{U}\right)\right)\right], \\ w_{10} = \frac{1}{1-pr}\left(\frac{c}{r(p-q)} - \delta(1+p-pr)\left(\frac{qc}{p-q} - \bar{U}\right) - prw_{11}\right). \end{array} \right\}. \tag{20}$$

It can be directly shown that all contracts in (20) feature $w_{11} > w_{10}$. The set (20) is nonempty if and only if $\bar{U}$ is sufficiently large. Specifically, within the set (20), the scheme that minimizes $qrw_{11} + (1-qr)\,w_{10}$ is $(w_{11}, w_{10}, w_{01}, w_{00}) = \left(\frac{1}{pr}\left(\frac{c}{r(p-q)} - \delta(1+p-pr)\left(\frac{qc}{p-q} - \bar{U}\right)\right), 0, 0, 0\right)$. Thus, existence is guaranteed if and only if

$$\begin{aligned} \frac{\bar{U}}{(qr)^2} &\ge \frac{\frac{c}{r(p-q)}\left(1 - qr\delta(1+p-pr)\right) + \delta(p-pr+1)\,\bar{U}}{pr} \\ \Leftrightarrow \quad \bar{U} &\ge \frac{q^2c}{p-q}\frac{1-qr\delta(1+p-pr)}{p-\delta q^2 r(p-pr+1)} \equiv \bar{U}^*_{00}. \end{aligned}$$

If $\bar{U} < \bar{U}^*_{00}$, the class of schemes under consideration is never incentive compatible. It can be shown by noting that within this class of contracts that satisfy (11), the minimums of both $\pi(0,0)$ and $\pi(0,1)$ exceed $\bar{U}$.

Case (iii): $W = \frac{(1-\delta)\pi(0,0) + \delta(1-qr)^2\bar{U}}{1-\delta\left(1-(1-qr)^2\right)}$

Like the cases above, we temporarily ignore the requirement $W = \frac{(1-\delta)\pi(0,0)+\delta(1-qr)^2\bar{U}}{1-\delta\left(1-(1-qr)^2\right)}$. The principal's relaxed problem can be stated as choosing wages to minimize

$$\begin{aligned} &\left((pr)^2 + \frac{\delta(qr)^2 pr(1-p)}{1-\delta\left(1-(1-qr)^2\right)}\right) w_{11} + \left((pr)(1-pr) + \frac{\delta(qr)(1-qr)pr(1-p)}{1-\delta\left(1-(1-qr)^2\right)}\right) w_{10} \\ &+ \left((pr)(1-pr) + \frac{\delta(qr)(1-qr)pr(1-p)}{1-\delta\left(1-(1-qr)^2\right)}\right) w_{01} + \left((1-pr)^2 + \frac{\delta(1-qr)^2 pr(1-p)}{1-\delta\left(1-(1-qr)^2\right)}\right) w_{00} \\ &- \frac{\delta pr(1-p)}{1-\delta\left(1-(1-qr)^2\right)}\bar{U}, \end{aligned}$$

subject to constraint

$$\left(pr-\frac{\delta p\left(1-\delta r\left(1+p-pr\right)\right)\left(qr\right)^2}{1-\delta\left(1-\left(1-qr\right)^2\right)}\right)w_{11}+\left(\left(1-pr\right)-\frac{\delta p\left(1-\delta r\left(1+p-pr\right)\right)\left(qr\right)\left(1-qr\right)}{1-\delta\left(1-\left(1-qr\right)^2\right)}\right)w_{10}$$
$$+\left(-pr\left(1-\delta-\delta p\left(1-r\right)\right)-\frac{\delta p\left(1-\delta r\left(1+p-pr\right)\right)\left(qr\right)\left(1-qr\right)}{1-\delta\left(1-\left(1-qr\right)^2\right)}\right)w_{01}$$
$$+\left(-\left(1-pr\right)\left(1-\delta-\delta p\left(1-r\right)\right)-\frac{\delta p\left(1-\delta r\left(1+p-pr\right)\right)\left(1-qr\right)^2}{1-\delta\left(1-\left(1-qr\right)^2\right)}\right)w_{00}$$
$$\geq\frac{c}{r\left(p-q\right)}\left(1-qr\delta\left(1+p-pr\right)\right)+\delta\frac{\left(1-pr\right)\left(1-\delta-\delta p\left(1-r\right)\right)+\delta\left(1-qr\right)^2\left(1+p-pr\right)}{1-\delta\left(1-\left(1-qr\right)^2\right)}\bar{U}.$$

The observations below follow from straightforward algebraic manipulation. First, the coefficient of $\bar{U}$ in the constraint is positive. Second, the coefficient of w_{11} in the constraint is positive. Third, the coefficient of w_{00} in the constraint is negative. Fourth, the coefficient of w_{10} in the constraint exceeds that of w_{01}. These observations imply that at the optimum, $w_{00}=w_{01}=0$ and the constraint binds. Finally, putting all weights on w_{11} rather than w_{01} minimizes the cost because the ratio of the coefficient in the objective to that of the constraint is lower for w_{11}:

$$\frac{\left(pr\right)^2+\frac{\delta pr(1-p)}{1-\delta\left(1-(1-qr)^2\right)}\left(qr\right)^2}{pr-\frac{\delta p(1-\delta r(1+p-pr))(qr)^2}{1-\delta\left(1-(1-qr)^2\right)}}<\frac{\left(pr\right)\left(1-pr\right)+\frac{\delta pr(1-p)}{1-\delta\left(1-(1-qr)^2\right)}\left(qr\right)\left(1-qr\right)}{\left(1-pr\right)-\left(\frac{\delta p(1-\delta r(1+p-pr))(qr)(1-qr)}{1-\delta\left(1-(1-qr)^2\right)}\right)}.$$

In sum, the solution to the problem is $w_{00}=w_{01}=w_{10}=0$, and

$$w_{11}=\frac{\left[\begin{array}{c}\frac{c}{r(p-q)}\left(1-qr\delta\left(1+p-pr\right)\right)\left(1-\delta\left(1-\left(1-qr\right)^2\right)\right)\\+\delta\left(\left(1-pr\right)\left(1-\delta-\delta p\left(1-r\right)\right)+\delta\left(1-qr\right)^2\left(p-pr+1\right)\right)\bar{U}\end{array}\right]}{pr\left(1-\delta\left(1-\left(1-qr\right)^2\right)\right)-\delta p\left(1-\delta r\left(1+p-pr\right)\right)\left(qr\right)^2}.$$

Next, we show that $W=\frac{(1-\delta)\pi(0,0)+\delta(1-qr)^2\bar{U}}{1-\delta\left(1-(1-qr)^2\right)}$ holds if $\bar{U}\leq\bar{U}^*_{00}$. To ensure $W=\frac{(1-\delta)\pi(0,0)+\delta(1-qr)^2\bar{U}}{1-\delta\left(1-(1-qr)^2\right)}$, we need both (i) $\pi\left(0,0\right)\geq\bar{U}$, and

$$\frac{\left(1-\delta\right)\pi\left(0,0\right)+\delta\left(1-qr\right)^2\bar{U}}{1-\delta\left(1-\left(1-qr\right)^2\right)}\leq\frac{\left(1-\delta\right)\pi\left(0,1\right)+\delta\left(1-qr\right)\left(1-pr\right)\bar{U}}{1-\delta\left(1-\left(1-qr\right)\left(1-pr\right)\right)}. \tag{21}$$

Straightforward algebraic manipulation shows that the optimal scheme found above satisfies $\pi\left(0,0\right)\geq\bar{U}$ whenever $\bar{U}\leq\bar{U}^*_{00}$. Next, the optimal scheme satisfies (21) if and only if

$$w_{11}\geq\frac{\delta\left(1-qr\right)}{qr\left(1-\delta qr\right)}\bar{U}\Leftrightarrow\bar{U}\leq\frac{1-\delta qr}{\delta r\left(p-q\right)}\frac{qc}{p-q}.$$

The last inequality holds because of the assumption that $\bar{U} < \frac{qc}{p-q}$.Finally, observe that if $\bar{U} > \bar{U}_{00}^*$, this class of schemes is dominated by the optimal schemes found in case (ii) considered above. It is easy to see that the problem in case (ii) is relaxed version of the one considered here (the objective is weakly lower and the constraint set is weakly larger). Thus, if the optimal scheme in case (ii) is feasible, it must dominate the one computed here.

To summarize, there are two cases to consider: (i) $\bar{U} < \bar{U}_{00}^*$ and (ii) $\bar{U} \geq \bar{U}_{00}^*$. In the first case of $\bar{U} < \bar{U}_{00}^*$, a candidate optimal contract is as stated in part (i) of Lemma 3, with an expected agency cost of

$$\Psi_{00} = \frac{\left[\begin{array}{c} \left(p\left(1-\delta\left(1-(1-qr)^2\right)\right)+(1-p)\,\delta q^2 r\right)(1-qr\delta\,(1+p-pr))\,\frac{c}{p-q} \\ +\delta r\left(\begin{array}{c} p\left((1-pr)\,(1-\delta-\delta p\,(1-r))+\delta\,(1-qr)^2\,(p-pr+1)\right) \\ -(1-p)\left(p-q^2 r\delta\,(1+p-pr)\right)\end{array}\right)\bar{U}\end{array}\right]}{1-\delta\left(1-(1-qr)^2\right)-\delta\,(1-\delta r\,(1+p-pr))\,q^2 r}.$$

We claim that the following strategy profile supports $W = \frac{(1-\delta)\pi(0,0)+\delta(1-qr)^2\bar{U}}{1-\delta\left(1-(1-qr)^2\right)}$ as a continuation PPE in the off-path punishment phase. If an agent deviates from resigning, both the deviating agent and his partner shirk. They keep shirking as long as the deviating agent stays on the job. The deviating agent voluntarily resigns at the end of every period (provided that he has not done so). If the deviating agent quits the job, his partner starts a fresh relationship with a newly hired agent in the employment phase. To check that is no profitable one-shot deviation, first consider the nondeviating agent's incentive to shirk. He is willing to shirk if and only if

$$\begin{aligned} & (1-\delta)\,\pi\,(0,0)+\delta\left(\left(1-(1-qr)^2\right)V+(1-qr)^2\,\bar{U}\right) \\ \geq\; & (1-\delta)\,(\pi\,(1,0)-c)+\delta\left((1-(1-qr)\,(1-pr))\,V+(1-qr)\,(1-pr)\,\bar{U}\right). \end{aligned} \tag{22}$$

Substitute in the optimal contract and rearrange, we get

$$\frac{\left[\begin{array}{c} c\left(\frac{(1-\delta pr(1+p(1-r)))}{p-q}+\delta r\,(1-qr)\right)\left(1-\delta\left(1-(1-qr)^2\right)\right) \\ +\delta r\,(1-qr)\left(1-\delta\left(1-(1-qr)^2\right)+\delta pr\,(1-p)\right)\bar{U}\end{array}\right]}{\left((q+\delta pr\,(p-q-pq))\left(1-\delta\left(1-(1-qr)^2\right)\right)+\delta^2 pq^2r^2\,(1-p)\,(1-qr)\right)r^2}-w_{11}\geq 0.$$

Direct algebraic manipulation shows that the coefficients of both c and $\bar{U}$ on the left hand side are positive. Next, the deviating agent is willing to shirk if and only if

$$\begin{aligned} & (1-\delta)\,\pi\,(0,0)+\delta\left(\left(1-(1-qr)^2\right)W+(1-qr)^2\,\bar{U}\right) \\ \geq\; & (1-\delta)\,(\pi\,(1,0)-c)+\delta\left((1-(1-qr)\,(1-pr))\,W+(1-qr)\,(1-pr)\,\bar{U}\right). \end{aligned}$$

Since $V > W$, the inequality holds because of (22).

In the second case of $\bar{U} \geq \bar{U}^*_{00}$, a candidate optimal contract is as stated in part (ii) of Lemma 3, with an expected agency cost of

$$\Psi_{00} = pr\left(\frac{c}{r(p-q)} - \delta(1+p-pr)\left(\frac{qc}{p-q} - \bar{U}\right)\right).$$

A similar strategy profile as above supports the off-path punishment payoff provided that both agents are willing to shirk. The nondeviating agent is willing to shirk provided that

$$\begin{aligned} & (1-\delta)\pi(0,0) + \delta\left(\left(1-(1-qr)^2\right)V + (1-qr)^2\bar{U}\right) \\ \geq\ & (1-\delta)(\pi(1,0)-c) + \delta\left((1-(1-qr)(1-pr))V + (1-qr)(1-pr)\bar{U}\right) \\ \Leftrightarrow\ & c \geq \pi(1,0) - \pi(0,0) + \frac{\delta}{1-\delta}r(p-q)(1-qr)\left(V-\bar{U}\right). \end{aligned} \tag{23}$$

At the solution found above, constraint (19) holds with equality:

$$c = \pi(1,1) - \pi(0,1) + \frac{\delta}{1-\delta}r(p-q)(1+p-pr)\left(V-\bar{U}\right).$$

To see that (23) holds, it suffices to note that (i) $\pi(1,1)-\pi(0,1) \geq \pi(1,0)-\pi(0,0)$, and (ii) $1+p-pr \geq 1-qr$. Inequality (i) is equivalent to $w_{11}-w_{10} \geq w_{01}-w_{00}$, which clearly holds at the solution. Finally, the deviating shirks because by (23), $\pi(0,0) \geq \pi(1,0)-c$. ■

Case (b): $f_{0,1} = 1,\ f_{0,0} = 0$

This class of contracts fires the agent if and only if he produces a bad outcome while his partner produces a good outcome. The following lemma provides a lower bound on the agency costs of this class of contracts.

Lemma 4 *Consider the class of contracts such that $f_{y_i,y_j} = 1$ if and only if $(y_i,y_j) = (0,1)$. Suppose $r \in [r^*_{01}, 1]$, where $r^*_{01} \equiv \frac{1}{2\delta p}\left(1-\delta+2\delta p - \sqrt{(1-\delta)(1-\delta+4\delta p)}\right)$. Define*

$$\bar{U}^*_{01} \equiv \frac{\left[\begin{array}{c} \left((1-\delta pr(1+p(1-r)))q + \delta r(1-qr)p^2\right)\left((1-\delta+\delta p) - \delta p\left(1-r+r^2\right)q\right) \\ -\delta pr(p-q)(1-\delta+\delta p)(1-qr) \end{array}\right]}{\left[\begin{array}{c} (1-\delta+\delta p)(1-\delta pr(1+p(1-r)) + \delta qr(1-qr)) \\ -\delta q\left(1-r+r^2\right)\left((1-\delta pr(1+p(1-r)))q + \delta(1-qr)p^2 r\right) \end{array}\right]}\frac{qc}{p(p-q)}.$$

If $\bar{U} \geq \bar{U}^*_{01}$, a lower bound on the agency cost of this class of contract is the minimum of

$$\begin{aligned} \Psi^{NQ}_{01} \ &\equiv\ \frac{\frac{pc}{p-q}\left(1-\delta\left(pr+(1-pr)^2\right)\right) + \delta(pr)^2\left(c+\bar{U}\right)}{1-\delta+\delta pr},\ \textit{and} \\ & (pr)^2\left(\frac{c}{pr^2(p-q)} - \frac{\delta\left(1-r+r^2\right)}{r^2(1-\delta+\delta p)}\left(\frac{qc}{p-q} - \bar{U}\right)\right). \end{aligned}$$

If $\bar{U} < \bar{U}^*_{01}$, a lower bound on the agency cost of this class of contract is the minimum of Ψ^{NQ}_{01} and

$$\frac{p^2}{q^2}\left(\frac{\left(1-\delta+\delta p\left(1-q\right)+\delta pqr\left(1-r\right)\right)\frac{q^2 c}{p-q}\frac{1}{p}-\left(1-\delta+\delta\left(p-q^2\right)+\delta q^2 r\left(1-r\right)\right)\bar{U}}{\left(1-\delta+\delta p\right)-\delta q^2\left(1-r\right)\frac{1-\delta+\delta pr(1-r)}{1-\delta(1-(1-qr)qr)}}+\bar{U}\right).$$

Proof of Lemma 4: . If the contract does not induce voluntary resignation, because of the risk-neutrality assumption, it is without loss to focus on the IPE wage schemes. Denote the wages by $w_{11} = w_{10} = w$. The agent is willing to put in effort if and only if

$$\begin{aligned} V &= \left(1-\delta\right)\left(prw-c\right)+\delta\left[\left(pr+\left(1-pr\right)^2\right)V+pr\left(1-pr\right)\bar{U}\right] \\ &\geq \left(1-\delta\right)qrw+\delta\left[\left(qr+\left(1-pr\right)\left(1-qr\right)\right)V+pr\left(1-qr\right)\bar{U}\right]. \end{aligned}$$

Upon simplification and rearranging, we get

$$w \geq \frac{\frac{c}{r(p-q)}\left(1-\delta\left(pr+\left(1-pr\right)^2\right)\right)+\delta pr\left(c+\bar{U}\right)}{1-\delta+\delta pr}.$$

The resulting agency cost is thus $\Psi^{NQ}_{01} \equiv \frac{\frac{pc}{p-q}\left(1-\delta\left(pr+(1-pr)^2\right)\right)+\delta(pr)^2\left(c+\bar{U}\right)}{1-\delta+\delta pr}$. Note that Ψ^{NQ}_{01} is a lower bound for all values of $\bar{U}$. Moreover, $\Psi^{NQ}_{01} > \Psi^{EW}$, so this type of contract is never an overall optimal contract.

Now, we consider contracts that induce agent i to voluntarily resign if and only if $(x_i, x_j) = (0, 1)$ and $(y_i, y_j) = (0, 0)$. Similar to cases analyzed before, it is without loss to focus on PPE with a structure similar to that stated in Section 3.2. Since agent i is fired whenever $(y_i, y_j) = (0, 1)$, his continuation payoff in the employment phase V is given by

$$V = \left(1-\delta\right)\left(\pi\left(1,1\right)-c\right)+\delta\left[\left(pr+\left(1-pr\right)p\left(1-r\right)+\left(1-p\right)^2\right)V+p\left(1-r\right)\left(1-p\right)W+\left(1-pr\right)pr\bar{U}\right].$$

The agent is willing to put in effort if

$$V \geq \left(1-\delta\right)\pi\left(0,1\right)+\delta\left[\left(qr+\left(1-pr\right)q\left(1-r\right)+\left(1-p\right)\left(1-q\right)\right)V+p\left(1-r\right)\left(1-q\right)W+pr\left(1-qr\right)\bar{U}\right].$$

Combining and rearranging the two conditions above gives

$$\begin{aligned} & \pi\left(1,1\right)\left(1-\delta+\delta p\left(1-q\right)+\delta pqr\left(1-r\right)\right)-\pi\left(0,1\right)\left(1-\delta+\delta p\left(1-p\right)+\delta p^2 r\left(1-r\right)\right) \\ \geq\ & c\left(1-\delta+\delta p\left(1-q\right)+\delta pqr\left(1-r\right)\right)+\frac{\delta}{1-\delta}\left(p-q\right)p\left(1-r\right)\left(1-\delta+\delta pr\left(1-r\right)\right)W \\ & -\frac{\delta}{1-\delta}\left(p-q\right)pr\left(\delta p\left(1-r\right)^2-r\left(1-\delta\right)\right)\bar{U}. \end{aligned} \tag{24}$$

Suppose the agent's partner produces a good signal and a bad outcome, the agent produces a bad signal but declines to quit. One feasible strategy for the deviating agent is to stay on the job, and exert no effort for the rest of the game until he is fired. Denote the continuation payoff of such strategy by W'. Then it is necessary that

$$W' \geq \min \left\{ \begin{array}{c} (1-\delta)\,\pi(0,0) + \delta\left((1-2qr(1-qr))\,W' + qr(1-qr)\,V + qr(1-qr)\,\bar{U}\right), \\ (1-\delta)\,\pi(0,1) + \delta\left((1-(1-qr)\,pr - (1-pr)\,qr)\,W' + (1-pr)\,qrV + (1-qr)\,pr\bar{U}\right) \end{array} \right\}.$$

Rearranging the inequality implies a lower bound for the payoff for voluntary resignation W:

$$W \geq \max\left\{\bar{U}, \min\{W_{00}, W_{01}\}\right\}, \tag{25}$$

where

$$\begin{aligned} W_{00} &= \frac{\left\{ \begin{array}{c} (1-\delta)\left[(1-\delta pr(1+p(1-r)))\,\pi(0,0) + \delta qr(1-qr)(\pi(1,1)-c)\right] \\ +\delta qr(1-qr)\left((1-\delta pr(1+p(1-r))) + \delta(1-pr)^2\right)\bar{U} \end{array} \right\}}{(1-\delta(1-2qr(1-qr)))(1-\delta pr(1+p(1-r))) - \delta^2 pqr^2(1-p)(1-qr)}; \text{ and} \\ W_{01} &= \frac{\left\{ \begin{array}{c} (1-\delta)\left[(1-\delta pr(1+p(1-r)))\,\pi(0,1) + \delta qr(1-pr)(\pi(1,1)-c)\right] \\ +\delta\left(pr(1-qr)(1-\delta pr(1+p(1-r))) + \delta qr(1-pr)(1-pr)^2\right)\bar{U} \end{array} \right\}}{(1-\delta(1-(1-qr)\,pr-(1-pr)\,qr))(1-\delta pr(1+p(1-r))) - \delta^2 pqr^2(1-p)(1-pr)}. \end{aligned}$$

Consider the following relaxed problem: choose wage scheme and W to minimize

$$(pr)^2\,w_{11} + pr(1-pr)(w_{10}+w_{01}) + (1-pr)^2\,w_{00} + (1-p)\,p(1-r)\,\frac{\delta}{1-\delta}\left(W-\bar{U}\right)$$

subject to (24) and (25). It is immediate that W is chosen such that (25) holds with equality. Depending on the values of W, there are three distinct classes of contracts to consider: (i) $W = W_{01}$; (ii) $W = \bar{U}$; and (iii) $W = W_{00}$.

Case (i): $W = W_{01}$.

Ignoring the requirement that the contracts must satisfy $W = W_{01}$, and replacing $\pi(\cdot,\cdot)$ with the corresponding expression involving wages, the problem above can be stated as choosing wages to minimize

$$\pi(1,1) + \frac{\delta}{1-\delta}\frac{p(1-p)(1-r)\left[(1-\delta)(1-\delta pr(1+p(1-r)))\,\pi(0,1) + \delta(1-pr)\,qr(1-\delta)\,\pi(1,1)\right]}{(1-\delta(1-(1-qr)\,pr-(1-pr)\,qr))(1-\delta pr(1+p(1-r))) - \delta^2 pqr^2(1-p)(1-pr)},$$

subject to the constraint

$$\begin{aligned}
&\left(\begin{array}{c} 1-\delta+\delta p\left(1-q\right)+\delta pqr\left(1-r\right) \\ -\frac{(p-q)p(1-r)(1-\delta+\delta pr(1-r))\delta^2(1-pr)qr}{(1-\delta(1-(1-qr)pr-(1-pr)qr))(1-\delta pr(1+p(1-r)))-\delta^2 pqr^2(1-p)(1-pr)} \end{array}\right)\pi\left(1,1\right) \\
&-\left(\begin{array}{c} 1-\delta+\delta p\left(1-p\right)+\delta p^2 r\left(1-r\right) \\ +\frac{\delta(p-q)p(1-r)(1-\delta+\delta pr(1-r))(1-\delta pr(1+p(1-r)))}{(1-\delta(1-(1-qr)pr-(1-pr)qr))(1-\delta pr(1+p(1-r)))-\delta^2 pqr^2(1-p)(1-pr)} \end{array}\right)\pi\left(0,1\right) \\
\geq\ & c\left(1-\delta+\delta p\left(1-q\right)+\delta pqr\left(1-r\right)\right) \\
&-\frac{\delta^2\left(p-q\right)p\left(1-r\right)\left(1-\delta+\delta pr\left(1-r\right)\right)\left(1-pr\right)qrc}{\left(1-\delta\left(1-\left(1-qr\right)pr-\left(1-pr\right)qr\right)\right)\left(1-\delta pr\left(1+p\left(1-r\right)\right)\right)-\delta^2 pqr^2\left(1-p\right)\left(1-pr\right)} \\
&+\frac{\delta}{1-\delta}p\left(p-q\right)\left(\begin{array}{c} \frac{\delta(1-r)(1-\delta+\delta pr(1-r))\left((1-qr)pr(1-\delta pr(1+p(1-r)))+\delta(1-pr)qr(1-pr)^2\right)}{(1-\delta(1-(1-qr)pr-(1-pr)qr))(1-\delta pr(1+p(1-r)))-\delta^2 pr(1-p)(1-pr)qr} \\ -r\left(\delta p\left(1-r\right)^2-r\left(1-\delta\right)\right) \end{array}\right)\bar{U}.
\end{aligned}$$

The assumption $r \geq r_{01}^*$ ensures that $\delta p\left(1-r\right)^2 - r\left(1-\delta\right) \leq 0$. This implies the coefficients of w_{00} and w_{01} in the constraint are negative; while those of w_{11} and w_{10} are positive. Moreover, for w_{11} and w_{10}, the ratio of the coefficient in the objective to that of the constraint are equal. Thus, a solution is to assign all weight on w_{10} such that the constraint binds. The resulting agency cost is no less than Ψ_{01}^{NQ}.

Case (ii): $W = \bar{U}$

Like case (i) above, we temporarily ignore the requirement $W = \bar{U}$. In this case, the severance payment $s = 0$. The principal's relaxed problem can be stated as choosing wages to minimize

$$\left(pr\right)^2 w_{11} + pr\left(1-pr\right)\left(w_{10}+w_{01}\right) + \left(1-pr\right)^2 w_{00},$$

subject to

$$\begin{aligned}
& r\left(1-\delta+p\delta\right)\left(prw_{11}+\left(1-pr\right)w_{10}\right) - \left(r\left(1-\delta\right)-p\delta\left(1-r\right)^2\right)\left(prw_{01}+\left(1-pr\right)w_{00}\right) \\
\geq\ & \frac{c}{p-q}\left(1-\delta+\delta p\left(1-q\right)+pq\delta r\left(1-r\right)\right)+\delta p\left(r^2-r+1\right)\bar{U}.
\end{aligned}$$

The coefficients of w_{00} and w_{01} in the constraint are negative; while those of w_{11} and w_{10} are positive. Moreover, for w_{11} and w_{10}, the ratio of the coefficient in the objective to that of the constraint are equal. Thus, any pair of nonnegative wages w_{11} and w_{10} that satisfy

$$prw_{11}+\left(1-pr\right)w_{10} = \frac{\frac{c}{p-q}\left(1-\delta+\delta p\left(1-q\right)+\delta pqr\left(1-r\right)\right)+\delta p\left(r^2-r+1\right)\bar{U}}{r\left(1-\delta+p\delta\right)}, \tag{26}$$

solves the problem.

Next we identify condition that ensures $W = \bar{U}$. Condition (26) above implies that $W_{01} > \bar{U}$. Thus, it is necessary that $W_{00} \leq \bar{U}$, which can be simplified as

$$\bar{U} \geq \frac{\left(1-\delta pr\left(1+p\left(1-r\right)\right)\right)\left(\left(qr\right)^2 w_{11}+qr\left(1-qr\right)w_{10}\right)+\delta qr\left(1-qr\right)\left(\left(pr\right)^2 w_{11}+pr\left(1-pr\right)w_{10}-c\right)}{1-\delta pr\left(1+p\left(1-r\right)\right)+\delta qr\left(1-qr\right)}. \tag{27}$$

The cost-minimizing contract within this class is thus

$$\{(w_{11}, w_{10}, w_{01}, w_{00}) : w_{01} = w_{00} = 0, \text{ (26) and (27) hold}\}.$$

It can be shown that all contracts in the set above satisfy $w_{11} > w_{10}$. The set above is nonempty if and only if $\bar{U}$ is sufficiently large. Specifically, within the set of contracts, the one that minimizes $qrw_{11} + (1 - qr)\, w_{10}$ is $(w_{11}, w_{10}, w_{01}, w_{00}) = \left(\left(\frac{c}{p(p-q)} - \frac{\delta(1-r+r^2)}{(1-\delta+p\delta)}\left(\frac{qc}{p-q} - \bar{U}\right)\right)\frac{1}{r^2}, 0, 0, 0\right)$. Substituting and rearranging shows that existence is guaranteed if and only if $\bar{U} \geq \bar{U}^*_{01}$.

If $\bar{U} < \bar{U}^*_{01}$, the class of contract under consideration is never incentive compatible. It can be shown by noting that within this class of contracts that satisfy effort IC, the minimums of both W_{00} and W_{01} exceed $\bar{U}$.

Recall the problem above is a relaxation of the principal's problem, as it does not guarantee $\bar{U}$ can be supported as a voluntary resignation payoff in some PPE. Nonetheless, it provides a lower bound on the expected cost of this class of contract as stated in the lemma statement.

Case (iii): $W = W_{00}$

Like case (i) above, we temporarily ignore the requirement $W = W_{00}$. The principal's relaxed problem can be stated as choosing wages to minimize

$$\pi(1,1) + \frac{\delta}{1-\delta}(1-p)\, p\,(1-r) \times \left(\frac{\begin{array}{c}(1-\delta)\left[(1-\delta pr(1+p(1-r)))\,\pi(0,0) + \delta qr(1-qr)(\pi(1,1)-c)\right] \\ + \delta qr(1-qr)\left(1 - \delta pr(1+p(1-r)) + \delta(1-pr)^2\right)\bar{U}\end{array}}{(1-\delta(1-2qr(1-qr)))(1-\delta pr(1+p(1-r))) - \delta qr(1-qr)\,\delta pr(1-p)} - \bar{U} \right),$$

subject to

$$\begin{aligned}
&(1-\delta+\delta p(1-q)+pq\delta r(1-r)) - \pi(0,1)\left(1-\delta+\delta p(1-p)+\delta p^2 r(1-r)\right)\pi(1,1) \\
&- \frac{\delta(p-q)\,p(1-r)(1-\delta+\delta pr(1-r))(1-\delta pr(1+p(1-r)))}{(1-\delta(1-2qr(1-qr)))(1-\delta pr(1+p(1-r))) - \delta qr(1-qr)\,\delta pr(1-p)}\pi(0,0) \\
&- \frac{\delta^2(p-q)\,p(1-r)(1-\delta+p\delta r(1-r))\,qr(1-qr)}{(1-\delta(1-2qr(1-qr)))(1-\delta pr(1+p(1-r))) - \delta qr(1-qr)\,\delta pr(1-p)}\pi(1,1) \\
\geq\; &\left(\begin{array}{c} (1-\delta+\delta p(1-q)+pq\delta r(1-r)) \\ -\frac{(p-q)p(1-r)(1-\delta+p\delta r(1-r))\delta^2 qr(1-qr)}{(1-\delta(1-2qr(1-qr)))(1-\delta pr(1+p(1-r)))-\delta^2 pqr^2(1-p)(1-qr)} \end{array} \right) c \\
&- \frac{\delta}{1-\delta}p(p-q)\,r \left(\begin{array}{c} \left(\delta p(1-r)^2 - r(1-\delta)\right) \\ +\frac{\delta q(1-r)(1-qr)(1-\delta+p\delta r(1-r))\left((1-\delta pr(1+p(1-r)))+\delta(1-pr)^2\right)}{(1-\delta(1-2qr(1-qr)))(1-\delta pr(1+p(1-r)))-\delta^2 pqr^2(1-p)(1-qr)} \end{array} \right)\bar{U}. \qquad (28)
\end{aligned}$$

The observations below follow from straightforward computation. First, the coefficient of w_{00} in the constraint is negative. Second, the coefficient of w_{10} in the constraint exceeds that of w_{01}. Third, the coefficient of w_{11} in the constraint is positive. These three observations imply that in the solution $w_{00} = w_{01} = 0$. Finally, comparing the ratios of coefficients in the objective and the constraint, tedious algebra shows that it is optimal to put all weights on w_{11}. Thus, the optimal solution of the problem above is to set $w_{00} = w_{01} = w_{10} = 0$, and w_{11} is chosen such that (28) binds. Denote the solution by w_{11}^*.This contract satisfies the requirement $W_{00} \geq \bar{U}$ whenever $\bar{U} \leq \bar{U}_{01}^*$. In sum, if $\bar{U} \leq \bar{U}_{01}^*$, then a lower bound on the expected cost of this class of contracts is $(pr)^2 w_{11}^*$, with the full expression stated in the lemma statement. ■

Comparison

Using the results above, we can compare the performance of all contracts. The following proposition states sufficient conditions for the optimality of a JPE wage scheme.

Proposition 4 *Denote* $r^* \equiv \frac{1}{2p}\left((1+p) - \sqrt{(1+p)^2 - \frac{4p^2}{1-\delta+\delta p}}\right) \in (r_{01}^*, 1)$.

(i) For each $r \in [r_{01}^*, r^*)$*, there exists a* $\hat{U}(r)$ *such that for all* $\bar{U} \in \left(\hat{U}(r), \frac{qc}{p-q}\right)$*, the optimal contract has a JPE wage scheme and never fires the agent.*

(ii) For each $r \in (r^*, 1)$*, there exists a* $\hat{U}(r)$ *such that for all* $\bar{U} \in \left(\hat{U}(r), \frac{qc}{p-q}\right)$*, the optimal contract has a JPE scheme and fires the agent if and only if both agents in the team produce* $y = 0$*.*

In both cases, the optimal contracts involve positive severance payment upon voluntary exit if $\bar{U}$ *is close to* $\hat{U}(r)$*.*

Proof of Proposition 4. We need to compare the expected costs of various contracts. Denote the lower bounds found in Lemma 4 for $\bar{U} < \bar{U}_{01}^*$ and $\bar{U} \geq \bar{U}_{01}^*$ by Ψ_1^{01} and Ψ_2^{01} respectively. Suppose $r \geq r_{01}^*$ and $\bar{U} \geq \max\left\{\bar{U}_{01}^*, \bar{U}_{00}^*, \bar{U}^*\right\} \equiv \tilde{U}(r)$. The expected costs of the optimal contract for different severance policies are list below:

Severance Policy	Agency cost
Fire agent i if and only if $y_i = 0$	Ψ^{EW}
Never fire	Ψ_2^G
Fire agent i if and only if $y_i = y_j = 0$	Ψ_2^{00}
Fire agent i if and only if $y_i = 1$ and $y_j = 0$	at least Ψ_2^{01}

It is immediate that $\min\left\{\Psi_2^G, \Psi^{EW}\right\} < \Psi_2^{01}$ and $\Psi_2^{00} < \Psi^{EW}$. Thus, the severance policy of never firing is strictly optimal if and only if $\Psi_2^G < \Psi_2^{00}$, which is equivalent to $r < r^*$. On the other hand, if $r > r^*$, the optimal severance policy is to fire the team if both produce bad signals. It can be shown by direct computation that $r^* > r_{01}^*$.

Suppose $r > r^*$ and $\bar{U}$ is slightly below $\tilde{U}(r)$. The policy of firing the team if both have bad outcomes is still optimal because of the continuity in $\bar{U}$ of the cost functions (or the bounding function in the final case). Furthermore, if $\tilde{U}(r) = \bar{U}_{00}^*$, then optimal contract contains positive severance payment; otherwise, the policy of firing the team if both have bad outcomes remains optimal until $\bar{U}$ is slightly below $\bar{U}_{00}^*$, since both Ψ_1^G and Ψ_1^{01} increase as $\bar{U}$ decreases, and $\Psi_2^{00} < \Psi^{EW}$. To summarize, if $r > r^*$, then there is a region of intermediate values of $\bar{U}$ such that the optimal severance policy is as follows: if both have bad outcomes, fire the team; if only one agent produces bad outcome, he is given positive severance payment for quitting voluntarily.

An analogous argument can be made for the severance policy of never firing in the case $r \in [r_{01}^*, r^*)$ and is omitted. ■

Proposition 4 states that if both r and $\bar{U}$ are large enough, then the optimal contract is a JPE scheme that fires both agents if and only if they both produce bad outcomes. Intuitively, a large value of $\bar{U}$ lowers the principal's cost in severance payments. Moreover, if r is large, firing both agents when both produce bad outcomes helps save the agency costs. This is because under a contract in which agents are never fired, the corresponding PPE has the agents forgoing punishment if both of them have bad signals. If the outcome is an accurate performance measure, i.e., r close to one, then in the event that both agents have bad outcomes, it is very likely that they both also have bad signals; firing the team is a "correct" punishment with a high probability.

Finally, if $\bar{U}$ is small, the severance payment needed to induce voluntary resignation is large, making any generous severance policy very costly. Thus, if r is sufficiently large, it is optimal to adopt the individual-based efficiency wage contract, i.e., $f_{0,y_j} = 1$ for all $y_j \in \{0, 1\}$.

Corollary 3 *Suppose* $\bar{U} \leq \frac{q^2 c}{p-q} \frac{1-\delta q}{p-\delta q^2}$. *If* r *is close to* 1,*the optimal contract is the optimal efficiency wage contract.*

Proof of Corollary 3. For small values of $\bar{U}$, severance payment is needed to induce voluntary exit. Specifically, it arises if $\bar{U} \leq \min\left\{\bar{U}_{00}^*, \bar{U}_{01}^*, \bar{U}^*\right\}$. While $\bar{U}^*$ is constant in r, both $\bar{U}_{00}^*$ and $\bar{U}_{01}^*$ are decreasing in r for $r > \frac{1}{2}$. Thus, a lower bound for $\min\left\{\bar{U}_{00}^*, \bar{U}_{01}^*, \bar{U}^*\right\}$ is achieved at $r = 1$:

$$\min\left\{\bar{U}_{00}^*, \bar{U}_{01}^*, \bar{U}^*\right\} \geq \frac{q^2 c}{p-q} \min\left\{\frac{1-\delta q}{p-\delta q^2}, \frac{1}{p}, \frac{1}{p}\frac{1-\delta(1-p+pq)}{1-\delta(1-p+q^2)}\right\} = \frac{q^2 c}{p-q}\frac{1-\delta q}{p-\delta q^2}.$$

Suppose $\bar{U} < \frac{q^2 c}{p-q}\frac{1-\delta q}{p-\delta q^2}$. The expected costs of the optimal contract for different severance policies are list below:

Severance Policy	Agency cost
Fire agent i if and only if $y_i = 0$	Ψ^{EW}
Never fire	Ψ_1^G
Fire agent i if and only if $y_i = y_j = 0$	Ψ_1^{00}
Fire agent i if and only if $y_i = 1$ and $y_j = 0$	at least Ψ_1^{01}

Evaluating these cost functions at $r = 1$ gives:

Severance Policy	Agency cost
Fire agent i if and only if $y_i = 0$	$\frac{pc}{p-q} - \delta p \left(\frac{qc}{p-q} - \bar{U}\right)$
Never fire	$\frac{c}{p-q}\left(p + (1-p)\frac{\delta}{1-\delta}q^2\right)\frac{1-\delta(1-p+pq)}{1-\delta(1-p+q^2)} - p(1-p)\frac{\delta}{1-\delta}\bar{U}$
Fire agent i if and only if $y_i = y_j = 0$	$\frac{\left(p+\delta q^2 - 2\delta pq\right)(1-\delta q)\frac{c}{p-q} + \delta^2 (p-q)^2 \bar{U}}{(1-\delta q)^2}$
Fire agent i if and only if $y_i = 1$ and $y_j = 0$	at least $p\frac{(1-\delta+\delta p(1-q))\frac{c}{p-q} + \delta p \bar{U}}{1-\delta+\delta p}$

Direct computation shows that $\frac{pc}{p-q} - \delta p\left(\frac{qc}{p-q} - \bar{U}\right)$ is the strictly smallest. The corollary follows from the fact that the expected costs are continuous in r. ■

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