

DESERT PREFERENCES AND MORAL HAZARD IN TEAMS

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DESERT PREFERENCES AND MORAL HAZARD IN TEAMS

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## DECLARATION OF ORIGINALITY

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## ABSTRACT

### Desert Preferences and Moral Hazard in Teams

In teams, an agent with a higher effort may feel that he is not getting what he *deserves* if he is paid the same as an agent who exerts lower effort. If agents exert the same effort levels, the one who fails due to factors beyond his reach may feel that he is not paid what he *deserves* if the other one succeeds and receives a higher wage. Also, low effort providers may feel *guilt* or *elation* over receiving more than they *deserve*. We consider a moral hazard problem within a team of two agents who have *desert preferences* à la Gill and Stone (2015). We find that the set of optimal wage schemes shrinks, and the optimal wage scheme exhibits JPE only. *Desert disutility* negatively affects an agent's incentive constraint when both agents put the same effort and only one of them succeeds and gets more. This forces the principal to eliminate any possible *desert disutility* by offering a JPE contract. Moreover, *desert preferences* have a quantitative effect on agents' expected payoffs and principal's expected wage payments through *desert guilt* component. The principal's expected payment decreases (increases) as *desert guilt (elation)* gets stronger.

## ÖZET

### Takımlarda Ahlaki Tehlike ve Hak Etme Tercihleri

Takımlarda, daha fazla çaba harcayan bir vekil, daha az çaba harcayan bir vekil ile aynı şekilde ödeme aldığında hak ettiğini alamadığını hissedebilir. Vekiller aynı çabayı gösteriyorsa, değiştiremeyeceği faktörler nedeniyle başarısız olan bir vekil, diğer vekil başarılı olur ve daha yüksek bir ücret alırsa, kendisine hak ettiği kadar ödeme yapılmadığını hissedebilir. Ayrıca, düşük çaba sarf eden vekiller, hak ettiklerinden daha fazlasını alma konusunda suçluluk veya sevinç hissedebilirler. Gill and Stone (2015) tarzında hak etme fayda fonksiyonları olan iki vekilden oluşan bir ekipte bir ahlaki tehlike problemini ele alıyoruz. Optimal ücret planları kümesinin küçüldüğünü ve optimal ücret planının yalnızca ortak performans değerlendirme özelliği sergilediğini bulduk. Her iki vekil de aynı çabayı gösterdiğinde ancak sadece biri başarılı olduğunda ve diğerinden daha fazlasını aldığında, bu durum hak etme fayda fonksiyonu olan bir vekilin teşvik kısıtlamasını olumsuz etkiler. Bu, asili bir ortak performans değerlendirme sözleşmesi sunarak olası bir fayda fonksiyonunun hak etme bileşeninden gelen olumsuz etkiyi ortadan kaldırmaya zorlar. Ayrıca, hak etme fayda fonksiyonlarının, vekillerin beklenen getirileri ve asilin beklenen ücret ödemeleri üzerinde hak etme suçluluğu bileşeni yoluyla nicel bir etkisi vardır. Hak etme suçluluğu (sevinci) güçlendikçe asilin beklenen ödemesi azalır (artar).

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## CHAPTER 1

### INTRODUCTION

Teams are prevalent in the work environment. In corporate firms, where employee performances are evaluated on a regular basis, teams are formed and designed to work in cooperation to improve the overall productivity.<sup>1</sup> In such environments, where employees work together in teams, their performances are usually evaluated taking into account the performances of their teammates. Consequently, team incentives, indicating the (positive or negative) dependence of team members' wages on the other teammates' success, become a prominent factor in analyzing optimal contracts.

Within a team, a member usually observes not only the *performance* of her teammates but also how hard they worked, that is, their *effort levels*, as well as their *wages*. Performance of each team member may be observed by the teammates as it is observed by the employer. For instance, employers may announce the best performing employee or a ranking of employees with respect to their performances. Or, team output, which depends on individual performances, may reveal teammates' performances. Teammates being able to see each other's effort levels is not only a common feature in the literature, but also realistic, because teammates usually work together in the same workplace, which lets them observe how much effort the others put in.<sup>2</sup> Moreover, effort levels being observed by teammates is a necessary assumption for *desert preferences*, which is our focus and is explained below, to be relevant. A possible rationale for the assumption that wages are also observed is that when similar team members face similar contracts, they may form an idea regarding the performance based wage scheme the teammates face. Thus, when performances are revealed, they would infer the wages each teammate receives.<sup>3</sup>

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<sup>1</sup>Che and Yoo (2001) provide examples in which corporate firms benefit largely from a team-based approach. Lazear and Shaw (2007) show evidence for the increased use of team-based organizational structures. While in 1987 the percentage of firms that have more than 20% of their employees in teams was 37%, this percentage increase to 61% by 1996.

<sup>2</sup>See Gill and Stone (2015), Che and Yoo (2001) and Kvaløy and Olsen (2006).

<sup>3</sup>In Akerlof and Yellen (1990), workers choose their coworkers' wages within the same firm for

In such environments depicted above, those who have exerted more effort into overall success of the team than others would naturally think that he *deserves* higher wages than others.<sup>4</sup> Thus, it is natural for members of a team to compare their own wages with their teammates' by taking exerted efforts into account. Variation among effort levels of team members may lead to disutility of high performers if their wages are the same as low performers, because they did not get what they *deserved*. Also, low performers may feel *guilt* over receiving more than they *deserve* (Gill & Stone, 2015).

Within this context, we consider a moral hazard problem within a team of two agents where agents have *desert preferences* à la Gill and Stone (2010, 2015). We analyze how the notion of *desert* affects the optimal contract offered to the agents in a team. We characterize the optimal performance evaluation schemes, whether the performance evaluation should be *relative*, *joint* or *independent*.<sup>5</sup> In our model, there is a team consisting of two identical risk-neutral agents who are each offered a contract by a risk-neutral principal. Agents are protected by limited liability. Both agents are able to see the contracts offered, the chosen efforts and individual outcomes. Agents' effort levels cannot be observed by the principal, however, the principal observes the individual outcomes of both agents separately. Thus, the contracts are based on the potential outcomes, success or failure, of the agents' efforts. After observing each other's efforts and wage contracts, each agent forms his reference point for each possible outcome based on what he thinks he *deserves* in that outcome. Agents' reference points are related to the effort levels exerted in the following sense. If an agent exerts more (less) effort than his teammate, his reference point is greater (smaller) than his teammate's reference point. An agent's *desert preference* stems from the discrepancy between his realized wage and his wage at his

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comparison. Although in some workplaces employers may ban their employees from disclosing their wage contract to each other, this policy may not function well in practice (Fang & Moscarini, 2005).

<sup>4</sup>See Berscheid, Boye, and Walster (1968) and (Rabin, 1998, p. 18).

<sup>5</sup>Relative performance evaluation (RPE) refers to the incentive scheme where the wage of a team member decreases in teammates' performance. Joint performance evaluation (JPE) refers to the incentive scheme where the wage of a team member increases in teammates' performance. And, independent performance evaluation (IPE) refers to the incentive scheme where teammates' performance is not relevant for the wage of a team member.

reference point: If an agent receives less than his reference point wage, he experiences a *desert disutility*. Conversely, if he receives more than his reference point wage, then he may either experience a disutility through *desert guilt*, or a utility through *desert elation* (Gill & Stone, 2015).

In the benchmark model without *desert preferences*, any performance evaluation, independent performance evaluation (IPE), relative performance evaluation (RPE) or joint performance evaluation (JPE) is optimal. When we introduce *desert preferences*, we find that the set of optimal wage schemes shrinks, and the optimal wage scheme exhibits *only* JPE (Proposition 1). *Desert disutility* negatively affects an agent's incentive constraint when both agents put the same effort but only one of them succeeds and gets more. Therefore, principal chooses to eliminate desert component which tightens the incentive constraint by offering non-zero wage only in the case when both agents succeed. Hence, introduction of *desert preferences* eliminates the RPE and IPE incentive schemes, when compared to the case without *desert preferences*. We also examine the effect of *desert preferences* on the principal's expected wage payment. Although the principal eliminates the *desert disutility* effect by opting for JPE incentive scheme, she cannot eliminate the *desert guilt/elation* component. Consequently, we show that *desert preferences* have a quantitative effect on agents' expected payoffs and principal's expected wage payments through *desert guilt/elation*: the principal's expected payment decreases (increases) as *desert guilt (elation)* is stronger (Proposition 2). We also consider possible technological dependence between the effort levels of the agents. If the effort levels exhibit complementarity, we show that our result, that the incentive schemes are in the form of only JPE, still holds (Proposition 3).

Moral hazard problem with multiple agents has been analyzed extensively in the literature. When a principal faces more than one agent, then the incentive scheme for an agent is potentially dependent on the performance of other agents. Mookherjee (1984) characterizes the optimal contracts for multiple agents and provides necessary and sufficient conditions for the incentives for an agent be independent of the

performance of other agents, as well as for the rank-order tournaments to be optimal. When multiple agents interact through a partnership, however, without a monitoring principal, if the budget is balanced (total output is fully shared among the agents), then the noncooperative outcome is inefficient due to free-riding problem. To achieve efficient outcome, a principal's role, beyond monitoring, is then to break the budget-balancedness (Holmstrom, 1982). When agents are risk-neutral, incentive schemes based on ordinal ranks achieve the same efficiency as the incentive schemes based on agents' output levels (Lazear & Rosen, 1981). With risk-averse agents, the optimality of rank-order tournaments depends on the number of agents: for a large enough group of agents incentive schemes based on ordinal ranks perform better than independent contracts (Green & Stokey, 1983). In a dynamic setting, where agents interact repeatedly, the agents may use peer sanctions, which help principal to provide incentives. Thus, a wage contract that increases with other agents' performance, that is, *joint performance evaluations* becomes optimal (Che & Yoo, 2001). In a relational contracting context, where agents' outputs are not verifiable, the structure of optimal incentives depend on the productivity of agents: with more productive agents, a wage scheme that decrease with other agents' performance, that is, *relative performance evaluations* is optimal, otherwise *joint performance evaluations* is optimal (Kvaløy & Olsen, 2006). When technological dependence is introduced, under complementarity of individual efforts, *joint performance evaluation* is optimal; and under substitutability, *relative performance evaluation* becomes optimal. Under informational dependence, however, mixed schemes are often optimal (Fleckinger, 2012).

The role of fairness has been analyzed in the literature as an explanation for deviations from the forecasts of standard self-interest models. Rabin (1993) develops an intention-based model and identifies the influence of fairness and reciprocity on economic outcomes. Konow (1996) introduces *accountability principle* which states that an individual's choice factors affect the fair distribution, but factors that cannot

be chosen do not affect it even though those factors may impact the output.<sup>6</sup> In their seminal paper, Fehr and Schmidt (1999) provide a simple representation for inequity-averse preferences and show that the impact of fairness may or may not be undone by the presence of competition, although if an individual is able to alter relative payoffs then equilibrium outcomes are affected by equity considerations regardless of competitive setting. Since their study, both theoretical and empirical studies that focus on other-regarding preferences, including inequity aversion, have been growing.<sup>7</sup>

The literature has mostly focused on the fairness concerns that stem from payoff distributions. However, along with the distribution of payoffs, the distribution of efforts and who deserves what based on their effort levels also concern agents. Gill and Stone (2010, 2015) generalize such distributional concerns by introducing *desert preferences*, which take inequity-aversion as a special case in their context of team production.<sup>8</sup> Gill and Stone (2015) focus primarily on strategic implications of *desert* for agents themselves in a setting where agents contribute to the team production, whereas our main focus is on the implications of *desert* over the optimal incentive contracts within a team under a moral hazard problem. In the context of moral hazard, when an agent exerts high effort, he still has a chance to fail due to factors beyond his control. We not only take into account the *desert disutility* resulting from differences in effort levels, we also capture *desert* that stems from these factors that are beyond the control of the agent. An agent, who exerts high effort and fails (an outcome beyond his control), may feel that he is not getting what he *deserves* if the other agent also exerts high effort, while succeeding and receiving a higher wage.<sup>9</sup>

There is a growing number of studies that analyze the effects of

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<sup>6</sup>See also Konow (2003). For experimental evidence, see also Cappelen, Hole, Sørensen, and Tungodden (2007); Frohlich, Oppenheimer, and Kurki (2004); Konow (2000) in which dictators distribute payoffs regarding the agents' effort levels.

<sup>7</sup>For empirical foundations and theoretical approaches of other-regarding preferences, see also Fehr and Schmidt (2006).

<sup>8</sup>In their model, the concept of *desert* does not specify the precise way of comparing material payoffs regarding exerted efforts, while inequity aversion over payoffs net of costs is one specific version of doing so.

<sup>9</sup>We show how desert preferences and inequity-aversion are different in our context of moral hazard in Section 2.1.

other-regarding preferences, especially inequity-aversion, in a moral hazard context. In a principal-agent setup in which the principal faces an agent who is inequity-averse and compares own payoff to that of the principal, the optimal contract involves linear sharing rules (Englmaier & Wambach, 2010). When principal faces multiple inequity-averse agents, the incentive schemes with joint performance evaluation and relative performance evaluations may be optimal (Itoh, 2004). Facing a team of inequity-averse agents, the principal may not need to pay bonuses covering the cost of extra effort, once the incentives are designed optimally taking inequity into account (Rey-Biel, 2008). When only team output is observable and agents contribute costly actions that contribute to the common output from which all agents benefit, the optimal contract with budget-balancedness involves equal distribution of the team output whenever the output is high, and a random punishment of some agent whenever the team output is low (Li, 2009). When inequity-averse agents are also risk-averse, then there is a tradeoff between risk reduction through a relative performance evaluation and inequality reduction through a joint performance evaluation, and the optimal incentives are low powered (Bartling, 2011). In a rank-order tournament setting, inequity aversion may induce higher efforts and endogenous prizes cannot be used to induce the first-best effort levels (Grund & Sliwka, 2005). In relational contracting, while rank-order tournament outperforms independent bonus contracts, the bonus contracts perform better when the agents are envious (Kragl, 2016).<sup>10</sup> On the other hand, if envious agents are risk-averse and not protected by limited liability then flat-wage contracts are optimal (Bartling & Von Siemens, 2010b).<sup>11</sup> Bonus contracts in which neither the agent is enforced to exert a specified effort level nor the principal is enforced to pay ex-ante announced bonus amount are preferred rather than standard flat-wage incentive contracts (Fehr, Klein, & Schmidt, 2007).<sup>12</sup>

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<sup>10</sup>See also Kragl and Schmid (2009) (relational contracts are more profitable with envious agents) and Kragl (2015) (group incentives are optimal when there is no commitment problem for the principal).

<sup>11</sup>See also Demougin, Fluet, and Helm (2006) and Bartling and Von Siemens (2010a), who study the relative payoff comparisons between agents.

<sup>12</sup>See also Fehr and Schmidt (2000) for experimental evidence that shows principals prefer less

The literature on team incentives in the presence of other-regarding preferences has focused heavily on inequity-aversion in the form of Fehr and Schmidt (1999)-type utility functions. In contrast we consider *desert utilities* a la Gill and Stone (2015), where agents in a team form their deserved wages as their reference points for different possible outcomes taking into account the relative effort levels of all agents, and compare their realized wages with their reference points.<sup>13</sup> While we take this relatively more general approach in the form of *desert preferences*, we also allow for *desert elation/guilt*. Not only our study differs from the approaches taken in the literature in terms of other-regarding preferences in the context of team incentives, but also our findings are different than the existing ones regarding inequity-aversion preferences. We find that, under *desert preferences*, the only optimal incentive scheme is in the form of a JPE, whereas the existing studies under inequity aversion show that under certain parameter values, both JPE and RPE can be optimal.<sup>14</sup>

The paper is organized as follows. We present the model in Section 2. The details of the desert preferences are depicted in Section 2.1. Section 3 characterizes the optimal incentive schemes, without desert (Section 3.1), with desert (Section 3.2), and also with desert under technological dependence (Section 3.3). In Section 4, we discuss some extensions and further directions. Section 5 concludes. All of the proofs are in the Appendix.

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complete contracts over more complete ones, when there are fairness concerns.

<sup>13</sup>As for reference dependent preferences, a closely related study is Daido and Murooka (2016). They consider team incentives when the agents exhibit loss aversion and characterize the conditions for both JPE and RPE to be optimal.

<sup>14</sup>See Itoh (2004), Rey-Biel (2008), for instance.

## CHAPTER 2

### MODEL

A risk-neutral principal hires two identical agents, indexed  $i = 1, 2$ . Each agent  $i$  simultaneously chooses a binary effort  $e_i \in \{0, 1\}$ . For each agent  $i$ , cost of effort  $e_i$  is  $\psi e_i$ , where  $\psi > 0$ . The outcome of agent  $i$ 's effort is either *success* or *failure*:  $q_i \in \{S, F\}$ . For agent  $i$ , the probability of success if he has exerted effort  $e_i$  is  $\text{Prob}(S|e_i) = p_{e_i}$ : If he has chosen effort  $e = 1$ , then  $\text{Prob}(S|e_i = 1) = p_1$ , and if he has chosen effort  $e = 0$ , then  $\text{Prob}(S|e_i = 0) = p_0$ , where  $1 > p_1 > p_0 > 0$ . The probability of an outcome  $q_i$  for agent  $i$  given the effort levels  $(e_i, e_j)$  is  $\text{Prob}(q_i|e_i, e_j) = \text{Prob}(q_i|e_i)$ . Thus, the success/failure probability of an agent does not depend on the effort level of the other agent, that is, there is no complementarity or substitutability (no technological dependence). The probability of a joint outcome  $(q_1, q_2)$  given the effort levels  $(e_1, e_2)$  is  $\text{Prob}(q_1, q_2|e_1, e_2) = \text{Prob}(q_1|e_1, e_2)\text{Prob}(q_2|e_1, e_2)$ . Thus, outcomes  $q_1$  and  $q_2$  are conditionally independent (no informational dependence). Thus, given the effort levels  $e = (e_1, e_2)$ , the joint probability of a joint outcome  $q = (q_1, q_2)$  is

$$\text{Prob}(q|e) = \text{Prob}(q_1, q_2|e_1, e_2) = \text{Prob}(q_1|e_1)\text{Prob}(q_2|e_2)$$

A wage scheme for agent  $i$  is  $\omega^i = (w_{SS}^i, w_{SF}^i, w_{FS}^i, w_{FF}^i)$  where  $w_{q_i q_j}^i$  is the wage to be paid to agent  $i$  when the outcome of agent  $i$  is  $q_i$  and the outcome of agent  $j$  is  $q_j$ ,  $j \neq i$ .<sup>1</sup>

The timing is as follows. (1) The principal offers  $\omega^i$  to agent  $i$ , for  $i = 1, 2$ . (2) Agents observe the wage contracts, and each one accepts the contract offered to her or rejects it. (3) If accepted the contract, agents simultaneously choose own effort levels.<sup>2</sup> (4) Outcomes are realized and payments are made.

The agents are risk-neutral and have no wealth, that is, they both have limited

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<sup>1</sup>For instance,  $w_{SF}^1$  is the wage for agent 1 when he succeeds and agent 2 fails, and  $w_{FS}^2$  is the wage for agent 2 when he fails and agent 1 succeeds.

<sup>2</sup>If there is only one agent who has accepted his contract, then there is only one agent choosing effort.

liability. Thus, negative wages are not feasible:  $w_{q_i, q_j}^i \geq 0$  for each  $i, j$ . Agent  $i$ 's expected wage under the contract  $\omega^i$  is

$$\mathbb{E}w_i(e_i, e_j, \omega^i) = p_{e_i}p_{e_j}w_{SS}^i + p_{e_i}(1-p_{e_j})w_{SF}^i + (1-p_{e_i})p_{e_j}w_{FS}^i + (1-p_{e_i})(1-p_{e_j})w_{FF}^i$$

Thus, agent  $i$ 's *intrinsic utility* from a contract  $\omega^i$  is  $\mathbb{E}w_i(e_i, e_j, \omega^i) - \psi \cdot e_i$ .

## 2.1 Desert preferences

Each agent has *desert* preferences defined as follows. Agents observe each other's effort choice and contract. Then, each agent forms a reference point for each possible outcome (and the wages to be paid for that outcome) based on what he thinks he deserves. When effort choices are  $e = (e_i, e_j)$  and the outcome is  $q = (q_i, q_j)$ , under wage schemes  $\omega = (\omega^i, \omega^j)$ , agent  $i$ 's reference point is  $r_i(e_i, e_j, q_i, q_j, \omega^i, \omega^j)$ . We define  $r_i$  as follows<sup>3</sup>

$$r_i(e, q, \omega) = \frac{e_i}{e_i + e_j}(w_q^i + w_q^j)$$

Here,  $\frac{e_i}{e_i + e_j}$  represents the ratio that this agent  $i$  thinks he is entitled to, of the total wages when  $q$  is realized,  $(w_q^i + w_q^j)$ .<sup>4</sup> Then, agent  $i$  compares his reference point to the wage he actually receives under contract  $\omega^i$  when  $q$  is realized, that is,  $w_q^i$ .<sup>5</sup> Let

$$\Delta_i(e, q, \omega) = w_q^i - r_i(e, q, \omega)$$

$\Delta_i(e, q, \omega)$  is the source of desert utility/disutility, and we define

$$D(\Delta_i(e, q, \omega)) = \begin{cases} g \cdot \Delta_i(e, q, \omega) & \text{if } \Delta_i(e, q, \omega) \geq 0 \\ d \cdot \Delta_i(e, q, \omega) & \text{if } \Delta_i(e, q, \omega) < 0 \end{cases}$$

<sup>3</sup>This definition is similar to the definition of fair allocation in Konow (2000).

<sup>4</sup>Alternatively, one can take the ratio an agent thinks he is entitled to using the cost levels of each effort:  $\frac{\psi_i}{\psi_i + \psi_j}$ , where  $\psi_i$  is the cost of effort  $e_i$  (see Gill and Stone (2015)). However, when cost is linear in effort, this alternative version produces the same results.

<sup>5</sup>Note that since individual effort levels are observed by each agent, agents also know other agents' reference points. Thus, the agents agree on the deserved wages since the ratios that the agents think they are entitled to add up to 1. See Luo, Wang, and Li (2018) where agents have their subjective deserved wages and they do not necessarily agree on their deserved wages.

We assume  $d > 0$ , thus whenever an agent receives less than what he feels he deserves ( $\Delta < 0$ ), he experiences some *desert disutility*. When an agent receives more than what he feels he deserves ( $\Delta > 0$ ), if he dislikes getting more than what he feels he deserves, then he may feel *desert guilt* where  $g < 0$ . If he likes getting more than what he feels he deserves, then he may feel *desert elation* where  $g > 0$ . If  $g = 0$ , he experiences no extra utility/disutility whenever  $\Delta > 0$ . We also assume  $d > |g| \geq 0$ , that is, *desert disutility* is stronger than *desert guilt* or *desert elation*. Whenever the effort choices are  $e = (e_i, e_j)$  and the wage schemes are  $\omega = (\omega^i, \omega^j)$ , agent  $i$ 's overall utility is given by

$$\begin{aligned} \mathbb{E}u_i(e, \omega^i, \omega^j) &= \sum_q \text{Prob}(q|e) \left[ w_q^i + D(\Delta_i(e, q, \omega)) \right] - \psi \cdot e_i \\ &= p_{e_i} p_{e_j} w_{SS}^i + p_{e_i} (1 - p_{e_j}) w_{SF}^i + (1 - p_{e_i}) p_{e_j} w_{FS}^i + (1 - p_{e_i}) (1 - p_{e_j}) w_{FF}^i \\ &\quad + p_{e_i} p_{e_j} D(\Delta_i(e, SS, \omega)) + p_{e_i} (1 - p_{e_j}) D(\Delta_i(e, SF, \omega)) \\ &\quad + (1 - p_{e_i}) p_{e_j} D(\Delta_i(e, FS, \omega)) + (1 - p_{e_i}) (1 - p_{e_j}) D(\Delta_i(e, FF, \omega)) - \psi \cdot e_i \end{aligned}$$

*The difference between desert preferences and inequity-aversion.* In our model, agents form their reference points, given a contract, for each effort combinations and for each possible outcome combination:  $r_i(e, q, w)$ . After the agents observe other agent's effort level and the outcome pair is realized, each agent compares his realized wage to the wage in his reference point at that outcome pair. However, an agent, who is inequity averse à la Fehr and Schmidt (1999) taking effort costs into account, compares his realized wage to the realized wage net of his effort cost to that of the other agent. Then, a difference arises in terms of utilities. For instance, consider the effort levels  $(e_1, e_2) = (1, 0)$ , agent 1 exerts effort and agent 2 exerts no effort. In the potential outcome pair of (F, S), that is, agent 1 fails and agent 2 succeeds, the reference point of agent 1 is given by  $\frac{1+0}{1}(w_{FS} + w_{SF}) = w_{FS} + w_{SF}$ . His realized wage in this outcome is  $w_{FS}$ , and the comparison between his realized wage and his reference point is then  $w_{FS} - (w_{FS} + w_{SF}) = -w_{SF}$ . However, if agent 1 is instead inequity averse, he compares his realized wage net of his effort cost,

$w_{FS} - \psi$  to the other agent's wage net of his effort cost,  $w_{SF} - 0$ , which yields a difference of  $w_{FS} - \psi - w_{SF}$ , which is different than the difference  $-w_{SF}$ , unless  $w_{FS} = \psi$ .

## 2.2 Principal's problem

The principal wants to implement  $e = (e_1, e_2) = (1, 1)$ .<sup>6</sup> She minimizes the cost of implementing  $e = (1, 1)$  solving the following problem:

$$\begin{aligned}
& \min_{\{w_{SS}^i, w_{SF}^i, w_{FS}^i, w_{FF}^i\}_{i=1,2}} && p_1^2 w_{SS}^1 + p_1(1-p_1)w_{SF}^1 + (1-p_1)p_1 w_{FS}^1 + (1-p_1)^2 w_{FF}^1 \\
& && + p_1^2 w_{SS}^2 + p_1(1-p_1)w_{FS}^2 + (1-p_1)p_1 w_{SF}^2 + (1-p_1)^2 w_{FF}^2 \\
& \text{subject to} && \mathbb{E}u_1(e = (1, 1), \omega^1, \omega^2) \geq 0 && (\text{IR}_1) \\
& && \mathbb{E}u_2(e = (1, 1), \omega^1, \omega^2) \geq 0 && (\text{IR}_2) \\
& && \mathbb{E}u_1(e = (1, 1), \omega^1, \omega^2) \geq \mathbb{E}u_1(e = (0, 1), \omega^1, \omega^2) && (\text{IC}_1) \\
& && \mathbb{E}u_2(e = (1, 1), \omega^1, \omega^2) \geq \mathbb{E}u_2(e = (1, 0), \omega^1, \omega^2) && (\text{IC}_2) \\
& && w_q^i \geq 0 \text{ for each } i \in \{1, 2\} \text{ and } q \in \{SS, SF, FS, FF\} && (\text{LL})
\end{aligned}$$

where  $(\text{IR}_i)$  is the individual rationality constraint for agent  $i = 1, 2$  that makes sure that each agent finds it optimal to accept the wage contract offered, and  $(\text{IC}_i)$  is the incentive compatibility constraint for agent  $i = 1, 2$  that makes sure that each agent chooses to exert high effort given that the other agent exerts high effort, and,  $(\text{LL})$  is the limited liability constraint that ensures that wages are nonnegative. Note that since the agents are ex-ante symmetric, the wages in the wage contracts,  $\omega^1$  and  $\omega^2$  must be symmetric whenever the outcomes are symmetric: abusing notation,  $w_{qq'}^1 = w_{q'q}^2$ , for each  $q, q' \in \{S, F\}$ .<sup>7</sup> Thus, we drop the superscripts in the wages. Also, the constraints  $(\text{IR}_i)$  and  $(\text{IC}_i)$  are also symmetric. We drop the subscripts in these

<sup>6</sup>If she wants to implement  $e = (e_1, e_2) = (0, 0)$ , then she optimally sets each  $w_{q_i q_j}^i = 0$  for  $i, j = 1, 2$ . This is true regardless of whether there are desert preferences or not. We assume that success of each agent is valuable enough that the principal finds it optimal to implement  $e = (e_1, e_2) = (1, 1)$ .

<sup>7</sup>For instance,  $w_{SF}^1 = w_{SF}^2$  where the wage agent 1 receives when he (agent 1) succeeds and the other agent fails is the same as the wage agent 2 receives when he (agent 2) succeeds and the other agent fails. Likewise,  $w_{FS}^1 = w_{FS}^2$ ,  $w_{SS}^1 = w_{SS}^2$  and  $w_{FF}^1 = w_{FF}^2$ .

constraints as well. Thus, the principal's problem is reduced to

$$\begin{aligned}
& \min_{\{w_{SS}, w_{SF}, w_{FS}, w_{FF}\}} && p_1^2 w_{SS} + p_1(1-p_1)[w_{SF} + w_{FS}] + (1-p_1)^2 w_{FF} \\
& \text{subject to} && \mathbb{E}u(e = (1, 1), \omega^1, \omega^2) \geq 0 && \text{(IR)} \\
& && \mathbb{E}u(e = (1, 1), \omega^1, \omega^2) \geq \mathbb{E}u(e = (0, 1), \omega^1, \omega^2) && \text{(IC)} \\
& && w_q \geq 0 \text{ for each } q \in \{SS, SF, FS, FF\} && \text{(LL)}
\end{aligned}$$

Before we proceed with the analysis of optimal contracts, we provide the standard definitions of different incentive schemes with respect to how an agent's wage depends on the other agent's outcome/performance.

*Definition 1.* A wage scheme  $(w_{SS}, w_{SF}, w_{FS}, w_{FF})$  exhibits

- (i) *relative performance evaluation (RPE)* when  $(w_{SF}, w_{FF}) > (w_{SS}, w_{FS})$ ,
- (ii) *joint performance evaluation (JPE)* when  $(w_{SS}, w_{FS}) > (w_{SF}, w_{FF})$ ,
- (iii) *independent performance evaluation (IPE)* when  $(w_{SS}, w_{FS}) = (w_{SF}, w_{FF})$ .

The inequalities in Definition 1 are component-wise comparisons where at least one of the component comparison holds with strict inequality. If an agent is weakly better off when the other agent fails, the wages exhibit *RPE*. If an agent is weakly better off when the other agent succeeds, the wages exhibit *JPE*. *RPE* provides competitive incentives while *JPE* provides collective incentives.<sup>8</sup>

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<sup>8</sup>Definition 1 is standard. See, for instance, Che and Yoo (2001) and Fleckinger (2012).

CHAPTER 3  
OPTIMAL CONTRACTS

3.1 Without desert preferences

As a benchmark, we first depict the optimal wage contracts when there is no desert preferences. When the principal is implementing  $e = (e_1, e_2) = (1, 1)$ , her problem is the following:

$$\begin{aligned}
 & \min_{\{w_{SS}, w_{SF}, w_{FS}, w_{FF}\}} && p_1^2 w_{SS} + p_1(1-p_1)[w_{SF} + w_{FS}] + (1-p_1)^2 w_{FF} \\
 & \text{subject to (IR)} && p_1^2 w_{SS} + p_1(1-p_1)[w_{SF} + w_{FS}] + (1-p_1)^2 w_{FF} \geq \psi \\
 & && \text{(IC)} \quad p_1 w_{SS} + (1-p_1)w_{SF} - p_1 w_{FS} - (1-p_1)w_{FF} \geq \frac{\psi}{p_1 - p_0} \\
 & && \text{(LL)} \quad w_{SS}, w_{SF}, w_{FS}, w_{FF} \geq 0
 \end{aligned}$$

First note that because of limited liability constraint, the (IR) constraint is implied by the (IC) constraint. Second, the left-hand side of (IC) is decreasing in both  $w_{FS}$  and  $w_{FF}$ , while the expected payment of the principal is increasing in both  $w_{FS}$  and  $w_{FF}$ . Thus, the optimal wage scheme must satisfy  $w_{FS}^* = w_{FF}^* = 0$ . Finally, the fraction of the coefficient of  $w_{SS}$  in the objective function to the coefficient of  $w_{SS}$  in the (IC) is also same for  $w_{SF}$ . Thus, any wage scheme,  $(w_{SS}, w_{SF}, w_{FS}, w_{FF})$ , satisfying (IC) with equality and  $w_{FS}^* = w_{FF}^* = 0$  is optimal.<sup>1</sup>

Note that (IC) with  $w_{FS}^* = w_{FF}^* = 0$  becomes  $p_1 w_{SS} + (1-p_1)w_{SF} = \frac{\psi}{p_1 - p_0}$ . Thus, among the optimal wage schemes we have  $w_{SS} = w_{SF} = \frac{\psi}{p_1 - p_0}$ , which together with  $w_{FS}^* = w_{FF}^* = 0$  exhibit *IPE*. Alternatively, the wage scheme  $w_{SS} = 0$  and  $w_{SF} = \frac{\psi}{(1-p_1)(p_1 - p_0)}$  with  $w_{FS}^* = w_{FF}^* = 0$  is also optimal. This wage scheme exhibits *RPE*. Finally, the wage scheme  $w_{SS} = \frac{\psi}{p_1(p_1 - p_0)}$  and  $w_{SF} = 0$  with  $w_{FS}^* = w_{FF}^* = 0$  is also optimal. This wage scheme exhibits *JPE*. Thus, any type of performance evaluation is optimal when there is no *desert* preferences, under

<sup>1</sup>This argument is fairly standard. See, for instance, Daido and Murooka (2016).

risk-neutrality and limited liability.

### 3.2 With desert preferences

When an agent has *desert preferences*, the principal's problem, implementing  $e = (e_1, e_2) = (1, 1)$ , becomes the following:

$$\begin{aligned}
& \min_{\{w_{SS}, w_{SF}, w_{FS}, w_{FF}\}} && p_1^2 w_{SS} + p_1(1-p_1)[w_{SF} + w_{FS}] + (1-p_1)^2 w_{FF} \\
& \text{subject to (IR)} && p_1^2 w_{SS} + p_1(1-p_1) \left[ w_{SF} + D \left( w_{SF} - \frac{w_{SF} + w_{FS}}{2} \right) \right] \\
& && + p_1(1-p_1) \left[ w_{FS} + D \left( w_{FS} - \frac{w_{FS} + w_{SF}}{2} \right) \right] + (1-p_1)^2 w_{FF} \geq \psi \\
& \text{(IC)} && p_1^2 w_{SS} + p_1(1-p_1) \left[ w_{SF} + D \left( w_{SF} - \frac{w_{SF} + w_{FS}}{2} \right) \right] \\
& && + p_1(1-p_1) \left[ w_{FS} + D \left( w_{FS} - \frac{w_{FS} + w_{SF}}{2} \right) \right] + (1-p_1)^2 w_{FF} - \psi \\
& && \geq p_1 p_0 (1+g) w_{SS} + (1-p_1) p_0 (1+g) w_{SF} + p_1 (1-p_0) (1+g) w_{FS} \\
& && + (1-p_1) (1-p_0) (1+g) w_{FF} \\
& \text{(LL)} && w_{SS}, w_{SF}, w_{FS}, w_{FF} \geq 0
\end{aligned}$$

After rearranging for (IC) and (IR), the principal's problem becomes the following:

$$\begin{aligned}
& \min_{\{w_{SS}, w_{SF}, w_{FS}, w_{FF}\}} && p_1^2 w_{SS} + p_1(1-p_1)[w_{SF} + w_{FS}] + (1-p_1)^2 w_{FF} \\
& \text{subject to} && \\
& \text{(IR)} && p_1^2 w_{SS} + p_1(1-p_1) [w_{SF} + w_{FS}] + (1-p_1)^2 w_{FF} \\
& && + p_1(1-p_1)(g-d) \left| \frac{w_{SF} - w_{FS}}{2} \right| \geq \psi \\
& \text{(IC)} && p_1 [p_1 - p_0(1+g)] w_{SS} + (1-p_1) [p_1 - p_0(1+g)] w_{SF} \\
& && + p_1 [(1-p_1) - (1-p_0)(1+g)] w_{FS} \\
& && + (1-p_1) [(1-p_1) - (1-p_0)(1+g)] w_{FF} \\
& && + p_1(1-p_1)(g-d) \left| \frac{w_{FS} - w_{SF}}{2} \right| \geq \psi \\
& \text{(LL)} && w_{SS}, w_{SF}, w_{FS}, w_{FF} \geq 0
\end{aligned}$$

*Lemma 1.* (i) If  $g \leq -1$ , then (IC) becomes redundant.

(ii) If  $-1 < g < \frac{p_1 - p_0}{p_0}$ , then (IC) binds.

(iii) If  $\frac{p_1 - p_0}{p_0} \leq g$ , then (IC) cannot be satisfied.

*Proof.* See the Appendix. ■

When  $g < 0$ , as the guilt parameter gets closer to -1, the guilt disutility of not exerting high effort increases for the agent choosing low effort. So, when the guilt parameter  $g \leq -1$ , the disutility caused by exerting the high effort is less than the disutility caused by the guilt of not exerting high effort to the agent. Therefore, once the participation constraint is satisfied, the agent chooses the high effort to avoid the disutility of guilt.

Conversely, when  $g > 0$ , agent's utility from receiving more than his reference point increases as  $g$  gets closer to  $\frac{p_1 - p_0}{p_0}$ . As a result, it gets harder for principal to induce high effort. When  $g \geq \frac{p_1 - p_0}{p_0}$ , only option left to principal is to offer zero wages for all outcomes, and agents choose low effort level if they accept the offer. Thus, we will consider the case  $-1 < g < \frac{p_1 - p_0}{p_0}$ .

*Proposition 1.* With desert preferences, the optimal wage scheme,

$\omega^* = (w_{SS}^*, w_{SF}^*, w_{FS}^*, w_{FF}^*)$ , is

$$\omega^* = (w_{SS}^*, 0, 0, 0)$$

where

$$w_{SS}^* = \frac{\psi}{p_1(p_1 - p_0(1 + g))}$$

*Proof.* See the Appendix. ■

*Desert disutility* appears in cases where agents get less than they think they deserve. In our setting, this occurs when both agents provide the same effort level but only one of them succeeds and the other fails. In such cases, the agent who fails feels *desert disutility* and the incentives are hurt. Intuitively, to overcome this adverse effect of *desert disutility* on incentives, principal needs to provide more incentive to an agent who provided the same effort level as his teammate but failed to succeed

compared to the case without desert preferences. Therefore, cost-minimizing principal opts to eliminate desert component which tightens the incentive constraint by offering non-zero wage only in the case when both agents succeed. It is critical to emphasize that optimal wage scheme exhibiting JPE when agents have desert preferences solely depends on the presence of desert component. Our main result does not depend on whether there is elation or guilt component.

A direct implication of the above result is that the optimal contract involves JPE, unlike the standard model where RPE and IPE can also be optimal. This is one of the key differences we have compared to the literature that focuses on inequity-aversion, where it is possible to have both JPE and RPE to be optimal.

*Corollary 1.* When agents have desert preferences, the only optimal wage scheme is JPE.<sup>2</sup>

*Proof.* This follows immediately from Proposition 1 and the analysis in Section 3.1.

■

The principal's expected payment,  $\mathbb{E}\omega$ , may increase or decrease when the agents have desert preferences, relative to when they do not have desert preferences. It changes with  $g$  and the direction of change depends on whether there is desert guilt or desert elation. Although the degree of desert disutility,  $d$ , does not affect the principal's expected payment quantitatively, it alters the set of optimal wages and eliminates IPE and RPE type of wage schemes. In the case of  $g = 0$ , optimal wage scheme would still exhibit JPE.

*Proposition 2.* The principal's expected payment,  $\mathbb{E}\omega$ , is not affected by  $d$ , but it decreases as  $g$  gets closer to -1 in the case of desert guilt, and increases as  $g$  gets closer to  $\frac{p_1 - p_0}{p_0}$  in the case of desert elation.

*Proof.* See the Appendix. ■

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<sup>2</sup>Any performance evaluation, RPE, JPE or IPE, is optimal when agents have no desert preferences.

### 3.3 Technological dependence

In Sections 3.1 and 3.2, we assume away any technological dependence between the efforts of the agents: the probability of an outcome  $q_i$  for agent  $i$  given the effort levels  $(e_i, e_j)$  is  $\text{Prob}(q_i|e_i, e_j) = \text{Prob}(q_i|e_i)$ . We extend our analysis to include possible technological dependence between the effort choices of the agents. When the effort levels are complements we have  $\text{Prob}(S|e_1, 1) > \text{Prob}(S|e_1, 0)$  which in our case implies  $p_{11} > p_{10}$  and  $p_{01} > p_{00}$  and  $p_{10} \geq p_{01}$ . Thus, under complementarity the higher effort choice of one agent increases the success probability of the other agents.

When agents have *desert preferences* and there is *complementarity* of effort levels, the principal's problem, implementing  $e = (e_1, e_2) = (1, 1)$ , becomes the following:

$$\begin{aligned}
 & \min_{\{w_{SS}, w_{SF}, w_{FS}, w_{FF}\}} && p_{11}^2 w_{SS} + p_{11}(1 - p_{11})w_{SF} + p_{11}(1 - p_{11})w_{FS} + (1 - p_{11})(1 - p_{11})w_{FF} \\
 & \text{subject to} && \\
 & \text{(IR)} && p_{11}^2 w_{SS} + p_{11}(1 - p_{11}) \left( w_{SF} + D \left( \frac{w_{SF} - w_{FS}}{2} \right) \right) \\
 & && + p_{11}(1 - p_{11}) \left( w_{FS} + D \left( \frac{w_{FS} - w_{SF}}{2} \right) \right) + (1 - p_{11})(1 - p_{11})w_{FF} \geq \psi \\
 & \text{(IC)} && (p_{11}^2 - p_{01}p_{10}(1 + g))w_{SS} + (p_{11}(1 - p_{11}) - p_{01}(1 - p_{10})(1 + g))w_{SF} \\
 & && + (p_{11}(1 - p_{11}) - p_{10}(1 - p_{01})(1 + g))w_{FS} \\
 & && + ((1 - p_{11})^2 - (1 - p_{01})(1 - p_{10})(1 + g))w_{FF} \\
 & && + p_{11}(1 - p_{11}) \left[ D \left( \frac{w_{SF} - w_{FS}}{2} \right) + D \left( \frac{w_{FS} - w_{SF}}{2} \right) \right] \geq \psi
 \end{aligned}$$

Below proposition provides the solution to the cost minimization problem of the principal above.

*Proposition 3.* With desert preferences, the optimal wage scheme,

$\omega^* = (w_{SS}^*, w_{SF}^*, w_{FS}^*, w_{FF}^*)$ , is

$$\omega^* = (w_{SS}^*, 0, 0, 0)$$

where

$$w_{SS}^* = \frac{\psi}{(p_{11}^2 - p_{01}p_{10}(1 + g))}$$

*Proof.* See the Appendix. ■

Proposition 3 shows that our main result is robust to complementarity of effort levels. Similar to the benchmark case, principal again opts to remove the desert component by offering zero wage in every case unless both agents are successful. Thus, again the only form of incentives is JPE. This is not surprising, since with complementarity of effort levels provide the principal with more reasons to adopt JPE type of incentive schemes.

## CHAPTER 4

### DISCUSSION AND EXTENSIONS

*Other reference points.* In our model, agents' reference points are equal to a portion of the total payment made by principal and, that portion is determined by the ratio of agent's own effort level to the sum of efforts of whole team. As Gill and Stone (2015) also points out there could be other possible definitions of reference point other than the form we assumed in our model. Even if we adopt another form of reference point, as long as that form satisfies that reference point of an agent increases in agent's own effort level and decreases in his teammate's effort level, our result would remain valid.

*Risk aversion.* We assumed risk-neutral agents who have limited liability in our baseline model with desert preferences. One may also consider a version in which agents are risk-averse and are not protected by limited liability. We formulate the principal's problem along with the Lagrangian and the set of first-order conditions in the Appendix. However, the first order conditions of the Lagrangian equation do not yield a result to reach a clear conclusion regarding the comparison between  $W_{SS}$ ,  $W_{SF}$ ,  $W_{FS}$ ,  $W_{FF}$ .

Intuitively speaking, presence of risk-averse agents may offset the effect of desert preferences on optimal wage contracts to some extent since principal may now punish under-performing agents. Meanwhile, low effort providers would feel they do not deserve a punishment and get additional desert disutility compared to the case without desert preferences. In the end, desert preferences would surely mitigate the punishment for low performers but it is not clear if the principal would be better off without punishment altogether.

*Rank-order tournaments.* We have considered the standard incentive problem under moral hazard, without imposing any structure on the wages to be paid (except limited liability constraints). Analyzing the incentive schemes when the focus is on rank-order tournaments where the incentives are based on the ordinal ranking of the

performances of the agents rather than their cardinality could be another path to follow. Nevertheless, binary output and effort spaces would lead to the similar result we have in our original model with desert preferences. Therefore, we opt out from analyzing rank-order tournament. On the other hand, it may be an interesting extension to study, if the baseline model is constructed with continuum of output and effort spaces in the beginning.

## CHAPTER 5

### CONCLUDING REMARKS

Agents working in a team may have a concern for fairness regarding their payoffs net of effort costs. If an agent and his teammate put the same effort level into production, then an agent thinks he *deserves* to receive equal payoffs as his teammate even if he fails and his teammate succeeds. In a situation as this, if agents are not paid equally, agent with lower payment may get upset because he did not receive what he thinks he *deserves*. Furthermore, an agent who chooses to exert lower effort compared to their teammates may get disutility due to *guilt* or get utility due to *elation* if they receive more than their teammates who put higher effort.

In this paper, we consider a moral hazard problem within a team of two agents who have *desert preferences* à la Gill and Stone (2015) and characterize the optimal wage scheme. We find that optimal wage scheme exhibits JPE when desert preferences are introduced into the model. Moreover, this result does not change when there is technological dependence and tasks are complements. If two agents choose the same effort level but end up receiving different wages, then principal needs to provide more incentive to reduce the effect of *desert disutility*. Therefore, principal is compelled to offer a JPE contract in order to remove any negative effect of *desert disutility*. In our characterization of the optimal wage scheme, we find that agents get nonzero payoff only when both of them are successful in their tasks. Also, our result shows that expected payment of the principal decreases (increases) as *desert guilt (elation)* gets stronger. Lastly, although the degree of desert disutility,  $d$ , does not affect expected wage payment of the principal, its presence ensures that the optimal wage scheme is JPE, rather than a RPE or IPE.

## APPENDIX

*Proof of LEMMA 1.* First note that (IC) – (IR) is given by

$$\begin{aligned}
 & -p_1 p_0 (1 + g) w_{SS} - (1 - p_1) p_0 (1 + g) w_{SF} - p_1 (1 - p_0) (1 + g) w_{FS} \\
 & - (1 - p_1) (1 - p_0) (1 + g) w_{FF} \\
 & = (1 + g) \left[ -p_1 p_0 w_{SS} - (1 - p_1) p_0 w_{SF} - p_1 (1 - p_0) w_{FS} - (1 - p_1) (1 - p_0) w_{FF} \right]
 \end{aligned}$$

(i) If  $g \leq -1$  then (IC) – (IR) is always positive. Thus, if (IR) holds then (IC) also holds. Thus, (IC) becomes redundant and it does not bind, while (IR) binds.

(ii) If  $-1 < g < \frac{p_1 - p_0}{p_0}$  then (IC) – (IR) is always negative. Thus, if (IC) holds then (IR) also holds. Thus, (IR) becomes redundant and it does not bind, while (IC) binds.

(iii) If  $\frac{p_1 - p_0}{p_0} \leq g$  then (IC) becomes

$$\begin{aligned}
 & p_1 p_0 \left[ \frac{p_1 - p_0}{p_0} - g \right] w_{SS} + (1 - p_1) p_0 \left[ \frac{p_1 - p_0}{p_0} - g \right] w_{SF} \\
 & - p_1 (1 - p_0) \left[ \frac{p_1 - p_0}{1 - p_0} + g \right] w_{FS} - (1 - p_1) (1 - p_0) \left[ \frac{p_1 - p_0}{1 - p_0} + g \right] w_{FF} \\
 & - p_1 (1 - p_1) (d - g) \left| \frac{w_{SF} - w_{FS}}{2} \right| \geq \psi
 \end{aligned}$$

However, the lefthand side of above (IC) is nonpositive since  $\frac{p_1 - p_0}{p_0} - g \leq 0$  and  $\frac{p_1 - p_0}{1 - p_0} + g > 0$ , while  $\psi > 0$ . Thus, (IC) cannot be satisfied in this case. Thus,  $e = (1, 1)$  is not incentive feasible. ■

*Proof of PROPOSITION 1.* We first show that in the optimal contract,  $w_{SS} \geq w_{SF} \geq w_{FS} \geq w_{FF}$ , through Lemmas 2, 3 and 4. Then, we show that the expected wage payment to implement  $e = (1, 1)$  is minimized when  $w_{SF} = w_{FS} = w_{FF} = 0$ , by comparing possible wage structures given  $w_{SS} \geq w_{SF} \geq w_{FS} \geq w_{FF}$  and limited liability constraints, in Lemma 5.

*Lemma 2.*  $w_{SF} \geq w_{FS}$ . *Proof.* Suppose  $\omega = (w_{SS}, w_{SF}, w_{FS}, w_{FF})$  is a wage scheme with  $w_{FS} > w_{SF}$ . Let  $\Delta_w = w_{FS} - w_{SF}$ . We can subtract  $\Delta_w$  from  $w_{FS}$  and add

$\Delta_w$  to the  $w_{SF}$  without changing the expected wage payment as both outcomes have the same joint probability under  $e = (1, 1)$ . Thus, this new wage scheme is  $\omega' = (w_{SS}, w_{SF} + \Delta_w, w_{FS} - \Delta_w, w_{FF})$ . Now, the left-hand sides of the (IC) constraints with  $\omega$  and with  $\omega'$  become, respectively,

$$\begin{aligned} (\text{IC}_\omega) \quad & p_1 [p_1 - p_0(1 + g)] w_{SS} + (1 - p_1) [p_1 - p_0(1 + g)] w_{SF} \\ & + p_1 [(1 - p_1) - (1 - p_0)(1 + g)] w_{FS} + (1 - p_1) [(1 - p_1) - (1 - p_0)(1 + g)] w_{FF} \\ & + p_1(1 - p_1)(g - d) \left( \frac{w_{FS} - w_{SF}}{2} \right) \geq \psi \end{aligned}$$

$$\begin{aligned} (\text{IC}_{\omega'}) \quad & p_1 [p_1 - p_0(1 + g)] w_{SS} + (1 - p_1) [p_1 - p_0(1 + g)] (w_{SF} + \Delta_w) \\ & + p_1 [(1 - p_1) - (1 - p_0)(1 + g)] (w_{FS} - \Delta_w) + (1 - p_1) [(1 - p_1) - (1 - p_0)(1 + g)] w_{FF} \\ & + p_1(1 - p_1)(g - d) \left( \frac{w_{FS} - \Delta_w - w_{SF} + \Delta_w}{2} \right) \geq \psi \end{aligned}$$

Now, subtracting  $(\text{IC}_\omega)$  from  $(\text{IC}_{\omega'})$ , we get

$$\begin{aligned} (\text{IC}_{\omega'}) - (\text{IC}_\omega) &= \Delta_w (p_1(1 - p_0)(1 + g) - (1 - p_1)p_0(1 + g)) \\ &= \Delta_w(1 + g)(p_1 - p_1p_0 - p_0 + p_1p_0) \\ &= \Delta_w(1 + g)(p_1 - p_0) \\ &> 0 \end{aligned}$$

which implies that the (IC) constraint can be relaxed as the expected wage payment remains the same. Thus, the principal can lower the expected wage payment by reducing the slack on (IC). Thus, a wage scheme  $\omega = (w_{SS}, w_{SF}, w_{FS}, w_{FF})$  with  $w_{FS} > w_{SF}$  cannot be expected cost minimizing. Thus, in an optimal wage scheme it must be  $w_{SF} \geq w_{FS}$ . ■

*Lemma 3.*  $w_{SS} \geq w_{SF}$ . *Proof.* Suppose  $\omega = (w_{SS}, w_{SF}, w_{FS}, w_{FF})$  is a wage scheme with  $w_{SF} > w_{SS}$ . By Lemma 2, we have  $w_{SF} \geq w_{FS}$ . We show that  $\omega$  cannot be optimal for the two cases:  $w_{SF} > w_{FS}$  and  $w_{SF} = w_{FS}$ .

*Case I.*  $w_{SF} > w_{FS}$ . Let  $\Delta_w = w_{SF} - w_{FS}$ . We can subtract  $p_1 \Delta_w$  from  $w_{SF}$

and add  $(1 - p_1)\Delta_w$  to  $w_{SS}$  without changing the expected wage payment. Thus, this new wage scheme is

$$\omega' = (w_{SS} + (1 - p_1)\Delta_w, w_{SF} - p_1\Delta_w, w_{FS}, w_{FF})$$

Now, the left-hand sides of the (IC) constraints with  $\omega$  and with  $\omega'$  become, respectively,

$$\begin{aligned} (\text{IC}_\omega) \quad & p_1 [p_1 - p_0(1 + g)] w_{SS} + (1 - p_1) [p_1 - p_0(1 + g)] w_{SF} \\ & + p_1 [(1 - p_1) - (1 - p_0)(1 + g)] w_{FS} + (1 - p_1) [(1 - p_1) - (1 - p_0)(1 + g)] w_{FF} \\ & + p_1(1 - p_1)(g - d) \left( \frac{w_{SF} - w_{FS}}{2} \right) \geq \psi \end{aligned}$$

$$\begin{aligned} (\text{IC}_{\omega'}) \quad & p_1 [p_1 - p_0(1 + g)] [w_{SS} + (1 - p_1)\Delta_w] + (1 - p_1) [p_1 - p_0(1 + g)] [w_{SF} - p_1\Delta_w] \\ & + p_1 [(1 - p_1) - (1 - p_0)(1 + g)] w_{FS} + (1 - p_1) [(1 - p_1) - (1 - p_0)(1 + g)] w_{FF} \\ & + p_1(1 - p_1)(g - d) \left| \frac{(w_{SF} - p_1\Delta_w) - w_{FS}}{2} \right| \geq \psi \end{aligned}$$

Note that  $(w_{SF} - p_1\Delta_w) - w_{FS} > 0$ , because  $w_{SF} - p_1\Delta_w - w_{FS} = \Delta_w - p_1\Delta_w > 0$ .

Now, subtracting  $(\text{IC}_\omega)$  from  $(\text{IC}_{\omega'})$ , we get

$$\begin{aligned} (\text{IC}_{\omega'}) - (\text{IC}_\omega) &= \Delta_w p_1 (1 - p_1) \left( p_1 - p_0(1 + g) - p_1 + p_0(1 + g) - \frac{p_1(g - d)}{2} \right) \\ &= \Delta_w p_1^2 (1 - p_1) \left( \frac{d - g}{2} \right) \\ &> 0 \end{aligned}$$

*Case 2.*  $w_{SF} = w_{FS}$ . Since  $w_{SF} > w_{SS}$ , we also have  $w_{FS} > w_{SS}$ . Let  $\Delta_w = w_{SF} - w_{SS}$ . We can subtract  $\frac{p_1\Delta_w}{2}$  from  $w_{SF}$  and  $w_{FS}$  and, add  $(1 - p_1)\Delta_w$  to  $w_{SS}$  without changing the expected wage payment. Thus, this new wage scheme is

$$\omega' = (w_{SS} + (1 - p_1)\Delta_w, w_{SF} - \frac{p_1\Delta_w}{2}, w_{FS} - \frac{p_1\Delta_w}{2}, w_{FF})$$

Now, the left-hand sides of the (IC) constraints with  $\omega$  and with  $\omega'$  become, respectively,

$$\begin{aligned}
(\text{IC}_\omega) \quad & p_1 [p_1 - p_0(1 + g)] w_{SS} + (1 - p_1) [p_1 - p_0(1 + g)] w_{SF} \\
& + p_1 [(1 - p_1) - (1 - p_0)(1 + g)] w_{FS} + (1 - p_1) [(1 - p_1) - (1 - p_0)(1 + g)] w_{FF} \\
& \geq \psi \\
(\text{IC}_{\omega'}) \quad & p_1 [p_1 - p_0(1 + g)] [w_{SS} + (1 - p_1) \Delta_w] + (1 - p_1) [p_1 - p_0(1 + g)] [w_{SF} - \frac{p_1 \Delta_w}{2}] \\
& + p_1 [(1 - p_1) - (1 - p_0)(1 + g)] [w_{FS} - \frac{p_1 \Delta_w}{2}] \\
& + (1 - p_1) [(1 - p_1) - (1 - p_0)(1 + g)] w_{FF} \geq \psi
\end{aligned}$$

Note that  $(w_{SF} - \frac{p_1 \Delta_w}{2}) - (w_{FS} - \frac{p_1 \Delta_w}{2}) = 0$ , since  $w_{SF} = w_{FS}$ . Now, subtracting  $(\text{IC}_\omega)$  from  $(\text{IC}_{\omega'})$

$$\begin{aligned}
(\text{IC}_{\omega'}) - (\text{IC}_\omega) &= \Delta_w p_1 (1 - p_1) (p_1 - p_0(1 + g)) - \frac{p_1 \Delta_w}{2} (1 - p_1) (p_1 - p_0(1 + g)) \\
&\quad - \frac{p_1 \Delta_w}{2} p_1 ((1 - p_1) - (1 - p_0)(1 + g)) \\
&= \frac{p_1 \Delta_w}{2} (p_1 - p_0) (1 + g) > 0
\end{aligned}$$

Thus, the principal can lower the expected wage payment by reducing the slack on (IC). Thus, a wage scheme  $\omega = (w_{SS}, w_{SF}, w_{FS}, w_{FF})$  with  $w_{SF} > w_{SS}$  cannot be expected cost minimizing. Thus, in an optimal wage scheme it must be  $w_{SS} \geq w_{SF}$ . ■

*Lemma 4.*  $w_{FS} \geq w_{FF}$ . *Proof.* Suppose  $((1 - p_1) - (1 - p_0)(1 + g)) \leq 0$ . Then, the left-hand side of the (IC) is decreasing in  $w_{FF}$  while the expected wage payment is increasing in  $w_{FF}$ . Thus,  $w_{FF} = 0$  is optimal in this case, which implies  $w_{FS} \geq w_{FF}$ , by limited liability. Now, suppose  $((1 - p_1) - (1 - p_0)(1 + g)) > 0$ . Suppose  $\omega = (w_{SS}, w_{SF}, w_{FS}, w_{FF})$  is a wage scheme with  $w_{FF} > w_{FS}$ .

*Case 1.*  $w_{SF} > w_{FS}$ . Let  $\Delta_w = w_{SF} - w_{FS}$ . We can subtract  $p_1 \Delta_w$  from  $w_{FF}$  and add  $(1 - p_1) \Delta_w$  to  $w_{FS}$  without changing the expected wage payment. Thus, this

new wage scheme is

$$\omega' = (w_{SS}, w_{SF}, w_{FS} + (1 - p_1)\Delta_w, w_{FF} - p_1\Delta_w)$$

Now, the left-hand sides of the (IC) constraints with  $\omega$  and with  $\omega'$  become, respectively,

$$\begin{aligned} (\text{IC}_\omega) \quad & p_1(p_1 - p_0(1 + g))w_{SS} + (1 - p_1)(p_1 - p_0(1 + g))w_{SF} \\ & + p_1((1 - p_1) - (1 - p_0)(1 + g))w_{FS} + (1 - p_1)((1 - p_1) - (1 - p_0)(1 + g))w_{FF} \\ & + p_1(1 - p_1)(g - d) \left( \frac{w_{SF} - w_{FS}}{2} \right) \geq \psi \end{aligned}$$

$$\begin{aligned} (\text{IC}_{\omega'}) \quad & p_1(p_1 - p_0(1 + g))w_{SS} + (1 - p_1)(p_1 - p_0(1 + g))w_{SF} \\ & + p_1((1 - p_1) - (1 - p_0)(1 + g))(w_{FS} + (1 - p_1)\Delta_w) \\ & + (1 - p_1)((1 - p_1) - (1 - p_0)(1 + g))(w_{FF} - p_1\Delta_w) \\ & + p_1(1 - p_1)(g - d) \left| \frac{w_{SF} - (w_{FS} + (1 - p_1)\Delta_w)}{2} \right| \geq \psi \end{aligned}$$

Note that  $(w_{SF} - (w_{FS} + (1 - p_1)\Delta_w)) > 0$ . Now, subtracting  $(\text{IC}_\omega)$  from  $(\text{IC}_{\omega'})$ , we get

$$\begin{aligned} (\text{IC}_{\omega'}) - (\text{IC}_\omega) &= \Delta_w p_1(1 - p_1) \left( (1 - p_1) - (1 - p_0)(1 + g) \right) - \frac{p_1(1 - p_1)(g - d)(1 - p_1)\Delta_w}{2} \\ &= \Delta_w p_1(1 - p_1) \left( (1 - p_1) - (1 - p_0)(1 + g) - \frac{(g - d)(1 - p_1)\Delta_w}{2} \right) \\ &> 0 \end{aligned}$$

*Case 2.*  $w_{SF} = w_{FS}$ . Since  $w_{FF} > w_{FS}$ , we also have  $w_{FF} > w_{SF}$ . Let  $\Delta_w = w_{FF} - w_{FS}$ . We can add  $\frac{(1 - p_1)\Delta_w}{2}$  to  $w_{SF}$  and  $w_{FS}$  and, subtract  $p_1\Delta_w$  from  $w_{FF}$  without changing the expected wage payment. Thus, this new wage scheme is

$$\omega' = (w_{SS}, w_{SF} + \frac{(1 - p_1)\Delta_w}{2}, w_{FS} + \frac{(1 - p_1)\Delta_w}{2}, w_{FF} - p_1\Delta_w)$$

Now, the left-hand sides of the (IC) constraints with  $\omega$  and with  $\omega'$  become,

respectively,

$$\begin{aligned}
(\text{IC}_\omega) \quad & p_1 [p_1 - p_0(1 + g)] w_{SS} + (1 - p_1) [p_1 - p_0(1 + g)] w_{SF} \\
& + p_1 [(1 - p_1) - (1 - p_0)(1 + g)] w_{FS} + (1 - p_1) [(1 - p_1) - (1 - p_0)(1 + g)] w_{FF} \\
& \geq \psi
\end{aligned}$$

$$\begin{aligned}
(\text{IC}_{\omega'}) \quad & p_1 [p_1 - p_0(1 + g)] w_{SS} + (1 - p_1) [p_1 - p_0(1 + g)] \left[ w_{SF} + \frac{(1 - p_1)\Delta_w}{2} \right] \\
& + p_1 [(1 - p_1) - (1 - p_0)(1 + g)] \left[ w_{FS} + \frac{(1 - p_1)\Delta_w}{2} \right] \\
& + (1 - p_1) [(1 - p_1) - (1 - p_0)(1 + g)] [w_{FF} - p_1 \Delta_w] \geq \psi
\end{aligned}$$

Note that  $(w_{SF} - \frac{(1-p_1)\Delta_w}{2}) - (w_{FS} - \frac{(1-p_1)\Delta_w}{2}) = 0$ . Now, subtracting  $(\text{IC}_\omega)$  from  $(\text{IC}_{\omega'})$ , we get

$$\begin{aligned}
(\text{IC}_{\omega'}) - (\text{IC}_\omega) &= \Delta_w(1 - p_1)(1 - p_1)(p_1 - p_0(1 + g)) \\
&+ \frac{(1 - p_1)\Delta_w}{2} p_1 ((1 - p_1) - (1 - p_0)(1 + g)) \\
&- \frac{p_1 \Delta_w}{2} (1 - p_1) ((1 - p_1) - (1 - p_0)(1 + g)) \\
&= \frac{(1 - p_1)\Delta_w}{2} [(1 - p_1)(p_1 - p_0(1 + g)) - p_1 ((1 - p_1) - (1 - p_0)(1 + g))] \\
&= \frac{(1 - p_1)\Delta_w}{2} (p_1 - p_0)(1 + g) \\
&> 0
\end{aligned}$$

Thus, the principal can lower the expected wage payment by reducing the slack on (IC). Thus, a wage scheme  $\omega = (w_{SS}, w_{SF}, w_{FS}, w_{FF})$  with  $w_{FF} > w_{FS}$  cannot be expected cost minimizing. Thus, in an optimal wage scheme it must be  $w_{FS} \geq w_{FF}$ . ■

Thus, in the optimal contract, we have  $w_{SS} \geq w_{SF} \geq w_{FS} \geq w_{FF}$ . By limited liability constraints, there are four possible wage configurations:

1.  $w_{SS} > 0$  and  $w_{SF} = w_{FS} = w_{FF} = 0$ .
2.  $w_{SS}, w_{SF} > 0$  and  $w_{FS} = w_{FF} = 0$ .

3.  $w_{SS}, w_{SF}, w_{FS} > 0$  and  $w_{FF} = 0$ .

4.  $w_{SS}, w_{SF}, w_{FS}, w_{FF} > 0$ .

*Lemma 5.* The expected wage payment is minimized when  $w_{SS} > 0$  and  $w_{SF} = w_{FS} = w_{FF} = 0$ . *Proof.* We compare the expected wage payments of the four different wage scheme configurations. We first find the minimized expected wage payment when  $w_{SS} > 0$  and  $w_{SF} = w_{FS} = w_{FF} = 0$ , and then we show that in all three other cases, the expected wage payment is larger than the one with  $w_{SS} > 0$  and  $w_{SF} = w_{FS} = w_{FF} = 0$ .

*Case 1.*  $w_{SS} > 0$  and  $w_{SF} = w_{FS} = w_{FF} = 0$ .

(IC) in this case becomes

$$p_1(p_1 - p_0(1 + g))w_{SS} \geq \psi$$

which must bind. Thus, we get

$$w_{SS} = \frac{\psi}{p_1(p_1 - p_0(1 + g))}$$

Thus, the expected wage payment is

$$\mathbb{E}w(1) = p_1^2 w_{SS} = \frac{p_1 \psi}{p_1(p_1 - p_0(1 + g))}$$

*Case 2.*  $w_{SS}, w_{SF} > 0$  and  $w_{FS} = w_{FF} = 0$ .

(IC) in this case becomes

$$p_1 w_{SS} + (1 - p_1)w_{SF} - \frac{p_1(1 - p_1)(d - g)w_{SF}}{2(p_1 - p_0(1 + g))} \geq \frac{\psi}{p_1 - p_0(1 + g)}$$

Since

$$\frac{p_1(1 - p_1)(d - g)w_{SF}}{2(p_1 - p_0(1 + g))} > 0$$

we have,

$$p_1 w_{SS} + (1 - p_1) w_{SF} > \frac{\psi}{p_1 - p_0(1 + g)}$$

That is,

$$p_1^2 w_{SS} + p_1(1 - p_1) w_{SF} > \frac{p_1 \psi}{p_1 - p_0(1 + g)}$$

The left-hand side of above inequality is the expected wage payment in this case,  $\mathbb{E}w(2)$ . The right-hand side is  $\mathbb{E}w(1)$ . Thus,  $\mathbb{E}w(2) > \mathbb{E}w(1)$ . Thus, a wage schedule  $\omega = (w_{SS}, w_{SF}, 0, 0)$  with  $w_{SS}, w_{SF} > 0$  cannot be minimizing the expected wage payment.

*Case 3.*  $w_{SS}, w_{SF}, w_{FS} > 0$  and  $w_{FF} = 0$ .

Suppose

$$\mathbb{E}w(3) = p_1^2 w_{SS} + p_1(1 - p_1) w_{SF} + p_1(1 - p_1) w_{FS} \leq \frac{p_1 \psi}{p_1 - p_0(1 + g)} = \mathbb{E}w(1)$$

Then, it must be that

$$p_1 w_{SS} + (1 - p_1) w_{SF} + (1 - p_1) w_{FS} \leq \frac{\psi}{p_1 - p_0(1 + g)}$$

(IC) in this case becomes

$$\begin{aligned} p_1 w_{SS} + (1 - p_1) w_{SF} + \frac{p_1((1 - p_1) - (1 - p_0)(1 + g))}{p_1 - p_0(1 + g)} w_{FS} + \frac{p_1(1 - p_1)(g - d)}{2(p_1 - p_0(1 + g))} (w_{SF} - w_{FS}) \\ \geq \frac{\psi}{p_1 - p_0(1 + g)} \end{aligned}$$

By our supposition, we have

$$\begin{aligned} p_1 w_{SS} + (1 - p_1) w_{SF} + \frac{p_1((1 - p_1) - (1 - p_0)(1 + g))}{p_1 - p_0(1 + g)} w_{FS} + \frac{p_1(1 - p_1)(g - d)}{2(p_1 - p_0(1 + g))} (w_{SF} - w_{FS}) \\ \geq p_1 w_{SS} + (1 - p_1) w_{SF} + (1 - p_1) w_{FS} \end{aligned}$$

That is,

$$\frac{p_1((1-p_1)-(1-p_0)(1+g))}{p_1-p_0(1+g)}w_{FS} + \frac{p_1(1-p_1)(g-d)}{2(p_1-p_0(1+g))}(w_{SF}-w_{FS}) \geq (1-p_1)w_{FS}$$

That is,

$$\begin{aligned} & \frac{p_1(1-p_1)(g-d)}{2(p_1-p_0(1+g))}w_{SF} \\ & \geq \left[ (1-p_1) + \frac{p_1(1-p_1)(g-d)}{2(p_1-p_0(1+g))} - \frac{p_1((1-p_1)-(1-p_0)(1+g))}{p_1-p_0(1+g)} \right] w_{FS} \end{aligned}$$

That is,

$$\begin{aligned} & \frac{p_1(1-p_1)(g-d)}{2}w_{SF} \\ & \geq \left[ (1-p_1)(p_1-p_0(1+g)) + \frac{p_1(1-p_1)(g-d)}{2} - p_1((1-p_1)-(1-p_0)(1+g)) \right] w_{FS} \end{aligned}$$

That is,

$$\begin{aligned} & p_1(1-p_1)(g-d)(w_{SF}-w_{FS}) \\ & \geq 2 \left[ (1-p_1)(p_1-p_0(1+g)) - p_1((1-p_1)-(1-p_0)(1+g)) \right] w_{FS} \end{aligned}$$

That is,

$$\begin{aligned} & p_1(1-p_1)(g-d)(w_{SF}-w_{FS}) \\ & \geq 2 \left[ (1-p_1)p_1 - (1-p_1)p_0(1+g) - p_1(1-p_1) + p_1(1-p_0)(1+g) \right] w_{FS} \end{aligned}$$

That is,

$$p_1(1-p_1)(g-d)(w_{SF}-w_{FS}) \geq 2(1+g)[p_1-p_0]w_{FS}$$

The left-hand side of the inequality is strictly negative since  $g-d < 0$  as  $g < d$ .

The right-hand side of the inequality is non-negative since  $\frac{p_1-p_0}{p_0} > g > -1$ . Thus,

the above inequality cannot hold and our supposition must be false. Thus, a wage schedule  $\omega = (w_{SS}, w_{SF}, w_{FS}, 0)$  with  $w_{SS}, w_{SF}, w_{FS} > 0$  cannot be minimizing the expected wage payment.

*Case 4.*  $w_{SS}, w_{SF}, w_{FS}, w_{FF} > 0$ .

Suppose

$$\mathbb{E}w(4) = p_1^2 w_{SS} + p_1(1-p_1)w_{SF} + p_1(1-p_1)w_{FS} + (1-p_1)^2 w_{FF} \leq \frac{p_1 \psi}{p_1 - p_0(1+g)} = \mathbb{E}w(1)$$

Then, it must be that

$$p_1 w_{SS} + (1-p_1)w_{SF} + (1-p_1)w_{FS} + \frac{(1-p_1)^2}{p_1} w_{FF} \leq \frac{\psi}{p_1 - p_0(1+g)}.$$

(IC) in this case becomes

$$\begin{aligned} p_1 w_{SS} + (1-p_1)w_{SF} + \frac{p_1((1-p_1) - (1-p_0)(1+g))}{p_1 - p_0(1+g)} w_{FS} + \frac{p_1(1-p_1)(g-d)}{2(p_1 - p_0(1+g))} (w_{SF} - w_{FS}) \\ + \frac{(1-p_1)((1-p_1) - (1-p_0)(1+g))}{p_1 - p_0(1+g)} w_{FF} \geq \frac{\psi}{p_1 - p_0(1+g)} \end{aligned}$$

By our supposition, we have

$$\begin{aligned} p_1 w_{SS} + (1-p_1)w_{SF} + \frac{p_1((1-p_1) - (1-p_0)(1+g))}{p_1 - p_0(1+g)} w_{FS} + \frac{p_1(1-p_1)(g-d)}{2(p_1 - p_0(1+g))} (w_{SF} - w_{FS}) \\ + \frac{(1-p_1)((1-p_1) - (1-p_0)(1+g))}{p_1 - p_0(1+g)} w_{FF} \\ \geq p_1 w_{SS} + (1-p_1)w_{SF} + (1-p_1)w_{FS} + \frac{(1-p_1)^2}{p_1} w_{FF} \end{aligned}$$

That is,

$$\begin{aligned} \frac{p_1((1-p_1) - (1-p_0)(1+g))}{p_1 - p_0(1+g)} w_{FS} + \frac{p_1(1-p_1)(g-d)}{2(p_1 - p_0(1+g))} (w_{SF} - w_{FS}) \\ + \frac{(1-p_1)((1-p_1) - (1-p_0)(1+g))}{p_1 - p_0(1+g)} w_{FF} \geq (1-p_1)w_{FS} + \frac{(1-p_1)^2}{p_1} w_{FF} \end{aligned}$$

That is,

$$\begin{aligned} & p_1((1-p_1) - (1-p_0)(1+g))w_{FS} + \frac{p_1(1-p_1)(g-d)}{2}(w_{SF} - w_{FS}) \\ & + (1-p_1)((1-p_1) - (1-p_0)(1+g))w_{FF} \\ & \geq (1-p_1)(p_1 - p_0(1+g))w_{FS} + \frac{(1-p_1)^2}{p_1}(p_1 - p_0(1+g))w_{FF} \end{aligned}$$

That is,

$$\begin{aligned} & \frac{p_1(1-p_1)(g-d)}{2}(w_{SF} - w_{FS}) \\ & \geq (p_1 - p_0)(1+g)w_{FS} + (1+g)((1-p_1)(1-p_0) - \frac{(1-p_1)^2}{p_1}p_0)w_{FF} \end{aligned}$$

That is,

$$p_1(1-p_1)(g-d)(w_{SF} - w_{FS}) \geq 2(p_1 - p_0)(1+g) \left[ w_{FS} + \frac{1-p_1}{p_1}w_{FF} \right]$$

The left-hand side of the inequality is strictly negative since  $g - d < 0$  as  $g < d$ . The right-hand side of the inequality is non-negative since  $\frac{p_1-p_0}{p_0} > g > -1$ . Thus, the above inequality cannot hold and our supposition must be false. Thus, a wage schedule  $\omega = (w_{SS}, w_{SF}, w_{FS}, w_{FF})$  with  $w_{SS}, w_{SF}, w_{FS}, w_{FF} > 0$  cannot be minimizing the expected wage payment. ■

Thus, we have shown that the optimal wage contracts must have  $w_{SS} > 0$  and  $w_{SF} = w_{FS} = w_{FF} = 0$  as in Case 1. The (IC) constraint in this case is  $p_1(p_1 - p_0(1+g))w_{SS} \geq \psi$  and it binds. Thus, in the optimal wage scheme we have

$$w_{SS}^* = \frac{\psi}{p_1(p_1 - p_0(1+g))}$$

along with  $w_{SF}^* = w_{FS}^* = w_{FF}^* = 0$ . This finishes the proof of Proposition 1. ■

*Proof of PROPOSITION 2.* If the agents do not have desert preferences, then under the optimal wage scheme  $\omega^* = (w_{SS}^*, w_{SF}^*, w_{FS}^*, w_{FF}^*) = (w_{SS}^*, w_{SF}^*, 0, 0)$ , the

principal's expected payment becomes

$$\mathbb{E}\omega_{\text{nodesert}} = p_1^2 w_{SS}^* + (1 - p_1)p_1 w_{SF}^* = \frac{p_1 \psi}{p_1 - p_0}$$

If the agents have desert preferences, then under the optimal wage scheme

$\omega^* = (w_{SS}, w_{SF}, w_{FS}, w_{FF}) = \left( \frac{\psi}{p_1(p_1 - p_0(1 + g))}, 0, 0, 0 \right)$ , the principal's expected payment becomes

$$\mathbb{E}\omega_{\text{desert}} = p_1^2 \left( \frac{\psi}{p_1(p_1 - p_0(1 + g))} \right) = \frac{p_1 \psi}{p_1 - p_0(1 + g)}$$

Thus, the principal's expected payment does not depend on  $d$ . However, it depends on  $g$  as follows.

(i) If  $-1 < g < 0$ , which is the case of desert guilt, then

$$\mathbb{E}\omega_{\text{desert}} = \frac{p_1 \psi}{p_1 - p_0(1 + g)} < \frac{p_1 \psi}{p_1 - p_0} = \mathbb{E}\omega_{\text{nodesert}}$$

(ii) If  $g = 0$ , then

$$\mathbb{E}\omega_{\text{desert}} = \frac{p_1 \psi}{p_1 - p_0(1 + g)} = \frac{p_1 \psi}{p_1 - p_0} = \mathbb{E}\omega_{\text{nodesert}}$$

(iii) If  $0 < g < \frac{p_1 - p_0}{p_0}$ , which is the case of desert elation, then

$$\mathbb{E}\omega_{\text{desert}} = \frac{p_1 \psi}{p_1 - p_0(1 + g)} > \frac{p_1 \psi}{p_1 - p_0} = \mathbb{E}\omega_{\text{nodesert}}$$

It is straightforward that in the case of desert guilt,  $g < 0$ , the expected wage payment decreases as  $g$  gets closer to  $-1$  (as  $|g|$  increases), and in the case of desert elation,  $g > 0$ , it increases as  $g$  increases and gets closer to its upper bound  $\frac{p_1 - p_0}{p_0}$ . ■

*Proof of PROPOSITION 3.* We first prove a result similar to the one in Lemma 1.

Then, we proceed with a series of lemmas as we did in the proof of Proposition 1.

*Lemma 6.* (i) If  $g \leq -1$ , then (IC) becomes redundant.

(ii) If  $-1 < g < \frac{p_{11}^2}{p_{01}p_{10}} - 1$ , then (IC) binds.

(iii) If  $\frac{p_{11}^2 - p_{01}p_{10}}{p_{01}p_{10}} \leq g$ , then (IC) cannot be satisfied.

*Proof.* First note that,

$$\begin{aligned}
(\text{IC}) &= (p_{11}^2 - p_{01}p_{10}(1+g))w_{SS} + (p_{11}(1-p_{11}) - p_{01}(1-p_{10})(1+g))w_{SF} \\
&\quad + (p_{11}(1-p_{11}) - p_{10}(1-p_{01})(1+g))w_{FS} \\
&\quad + ((1-p_{11})^2 - (1-p_{01})(1-p_{10})(1+g))w_{FF} \\
&\quad + p_{11}(1-p_{11}) \left[ D \left( \frac{w_{SF} - w_{FS}}{2} \right) + D \left( \frac{w_{FS} - w_{SF}}{2} \right) \right] \geq \psi, \\
(\text{IC}) - (\text{IR}) &= -(1+g)(p_{01}p_{10}w_{SS} + p_{01}(1-p_{10})w_{SF} + p_{10}(1-p_{01})w_{FS} \\
&\quad + (1-p_{01})(1-p_{10})w_{FF}).
\end{aligned}$$

(i) If  $g \leq -1$  then (IC) – (IR) is always positive. Thus, if (IR) holds then (IC) also holds. Thus, (IC) becomes redundant and it does not bind, while (IR) binds.

(ii) When  $-1 < g < \frac{p_{11}^2}{p_{01}p_{10}}$ , (IC) – (IR) is always negative. Thus, (IR) becomes redundant and it does not bind, while (IC) binds.

(iii) Coefficients of  $\{w_{SS}, w_{SF}, w_{FS}, w_{FF}\}$  are respectively,

$$\left\{ \frac{p_{11}^2}{p_{01}p_{10}} - 1 - g, \frac{p_{11}(1-p_{11})}{p_{01}(1-p_{10})} - 1 - g, \frac{p_{11}(1-p_{11})}{p_{10}(1-p_{01})} - 1 - g, \frac{(1-p_{11})^2}{(1-p_{01})(1-p_{10})} - 1 - g \right\}.$$

If the greatest of these coefficients is smaller than 0, then (IC) cannot be satisfied. Since we have  $p_{11} > p_{10} \geq p_{01} > p_{00}$ , coefficient of  $w_{SS}$  is the greatest. Therefore,  $g$  cannot be greater than or equal to  $\frac{p_{11}^2 - p_{01}p_{10}}{p_{01}p_{10}}$  since it would be impossible for (IC) to hold. ■

*Lemma 7.*  $w_{SF} \geq w_{FS}$ .

*Proof.* Suppose  $\omega = (w_{SS}, w_{SF}, w_{FS}, w_{FF})$  is a wage scheme with  $w_{FS} > w_{SF}$ . Let  $\Delta_w = w_{FS} - w_{SF}$ . We can subtract  $\Delta_w$  from  $w_{FS}$  and add  $\Delta_w$  to the  $w_{SF}$  without changing the expected wage payment as both outcomes have the same joint probability under  $e = (1, 1)$ . Thus, this new wage scheme is  $\omega' = (w_{SS}, w_{SF} + \Delta_w, w_{FS} - \Delta_w, w_{FF})$ . Now, the left-hand sides of the (IC)

constraints with  $\omega$  and with  $\omega'$  become, respectively,

$$\begin{aligned}
(\text{IC}_\omega) \quad & (p_{11}^2 - p_{01}p_{10}(1+g))w_{SS} + (p_{11}(1-p_{11}) - p_{01}(1-p_{10})(1+g))w_{SF} \\
& + (p_{11}(1-p_{11}) - p_{10}(1-p_{01})(1+g))w_{FS} \\
& + ((1-p_{11})^2 - (1-p_{01})(1-p_{10})(1+g))w_{FF} \\
& + p_{11}(1-p_{11}) \left[ D \left( \frac{w_{SF} - w_{FS}}{2} \right) + D \left( \frac{w_{FS} - w_{SF}}{2} \right) \right] \geq \psi \\
(\text{IC}_{\omega'}) \quad & (p_{11}^2 - p_{01}p_{10}(1+g))w_{SS} + (p_{11}(1-p_{11}) - p_{01}(1-p_{10})(1+g))(w_{SF} + \Delta_w) \\
& + (p_{11}(1-p_{11}) - p_{10}(1-p_{01})(1+g))(w_{FS} - \Delta_w) \\
& + ((1-p_{11})^2 - (1-p_{01})(1-p_{10})(1+g))w_{FF} \\
& + p_{11}(1-p_{11}) \left[ D \left( \frac{w_{SF} + \Delta_w - w_{FS} + \Delta_w}{2} \right) + D \left( \frac{w_{FS} - \Delta_w - w_{SF} - \Delta_w}{2} \right) \right] \\
& \geq \psi
\end{aligned}$$

Now, subtracting  $(\text{IC}_\omega)$  from  $(\text{IC}_{\omega'})$ , we get

$$\begin{aligned}
(\text{IC}_{\omega'}) - (\text{IC}_\omega) &= \Delta_w(1+g)(p_{10} - p_{01}) \\
&> 0
\end{aligned}$$

which implies that the (IC) constraint can be relaxed as the expected wage payment remains the same. Thus, the principal can lower the expected wage payment by reducing the slack on (IC). Thus, a wage scheme  $\omega = (w_{SS}, w_{SF}, w_{FS}, w_{FF})$  with  $w_{FS} > w_{SF}$  cannot be expected cost minimizing. Thus, in an optimal wage scheme it must be  $w_{SF} \geq w_{FS}$ . ■

*Lemma 8.*  $w_{SS} \geq w_{SF}$ . *Proof.* Suppose  $\omega = (w_{SS}, w_{SF}, w_{FS}, w_{FF})$  is a wage scheme with  $w_{SF} > w_{SS}$ . By Lemma 2, we have  $w_{SF} \geq w_{FS}$ . We show that  $\omega$  cannot be optimal for the two cases:  $w_{SF} > w_{FS}$  and  $w_{SF} = w_{FS}$ .

*Case 1.*  $w_{SF} > w_{FS}$ . Let  $\Delta_w = w_{SF} - w_{FS}$ . We can subtract  $p_{11}\Delta_w$  from  $w_{SF}$  and add  $(1-p_{11})\Delta_w$  to  $w_{SS}$  without changing the expected wage payment. Thus, this

new wage scheme is

$$\omega' = (w_{SS} + (1 - p_{11})\Delta_w, w_{SF} - p_{11}\Delta_w, w_{FS}, w_{FF})$$

Now, the left-hand sides of the (IC) constraints with  $\omega$  and with  $\omega'$  become, respectively,

$$\begin{aligned} (\text{IC}_\omega) \quad & (p_{11}^2 - p_{01}p_{10}(1 + g))w_{SS} + (p_{11}(1 - p_{11}) - p_{01}(1 - p_{10})(1 + g))w_{SF} \\ & + (p_{11}(1 - p_{11}) - p_{10}(1 - p_{01})(1 + g))w_{FS} \\ & + ((1 - p_{11})^2 - (1 - p_{01})(1 - p_{10})(1 + g))w_{FF} \\ & + p_{11}(1 - p_{11}) \left[ D \left( \frac{w_{SF} - w_{FS}}{2} \right) + D \left( \frac{w_{FS} - w_{SF}}{2} \right) \right] \geq \psi \end{aligned}$$

$$\begin{aligned} (\text{IC}_{\omega'}) \quad & (p_{11}^2 - p_{01}p_{10}(1 + g))(w_{SS} + (1 - p_{11})\Delta_w) \\ & + (p_{11}(1 - p_{11}) - p_{01}(1 - p_{10})(1 + g))(w_{SF} - p_{11}\Delta_w) \\ & + (p_{11}(1 - p_{11}) - p_{10}(1 - p_{01})(1 + g))w_{FS} \\ & + ((1 - p_{11})^2 - (1 - p_{01})(1 - p_{10})(1 + g))w_{FF} \\ & + p_{11}(1 - p_{11}) \left[ D \left( \frac{w_{SF} - p_{11}\Delta_w - w_{FS}}{2} \right) + D \left( \frac{w_{FS} - w_{SF} + p_{11}\Delta_w}{2} \right) \right] \geq \psi \end{aligned}$$

Note that  $(w_{SF} - p_{11}\Delta_w) - w_{FS} > 0$ , because  $w_{SF} - p_{11}\Delta_w - w_{FS} = \Delta_w - p_{11}\Delta_w > 0$ .

Now, subtracting  $(\text{IC}_\omega)$  from  $(\text{IC}_{\omega'})$ , we get

$$\begin{aligned} (\text{IC}_{\omega'}) - (\text{IC}_\omega) &= \Delta_w(1 + g)p_{01}(p_{11} - p_{10}) + \Delta_w p_{11}^2(1 - p_{11}) \left( \frac{d - g}{2} \right) \\ &> 0 \end{aligned}$$

*Case 2.*  $w_{SF} = w_{FS}$ . Since  $w_{SF} > w_{SS}$ , we also have  $w_{FS} > w_{SS}$ . Let  $\Delta_w = w_{SF} - w_{SS}$ . We can subtract  $\frac{p_{11}\Delta_w}{2}$  from  $w_{SF}$  and  $w_{FS}$  and, add  $(1 - p_{11})\Delta_w$  to  $w_{SS}$  without changing the expected wage payment. Thus, this new wage scheme is

$$\omega' = (w_{SS} + (1 - p_{11})\Delta_w, w_{SF} - \frac{p_{11}\Delta_w}{2}, w_{FS} - \frac{p_{11}\Delta_w}{2}, w_{FF})$$

Now, the left-hand sides of the (IC) constraints with  $\omega$  and with  $\omega'$  become, respectively,

$$\begin{aligned}
(\text{IC}_\omega) \quad & (p_{11}^2 - p_{01}p_{10}(1+g))w_{SS} + (p_{11}(1-p_{11}) - p_{01}(1-p_{10})(1+g))w_{SF} \\
& + (p_{11}(1-p_{11}) - p_{10}(1-p_{01})(1+g))w_{FS} \\
& + ((1-p_{11})^2 - (1-p_{01})(1-p_{10})(1+g))w_{FF} \\
& \geq \psi
\end{aligned}$$

$$\begin{aligned}
(\text{IC}_{\omega'}) \quad & (p_{11}^2 - p_{01}p_{10}(1+g))(w_{SS} + (1-p_{11})\Delta_\omega) \\
& + (p_{11}(1-p_{11}) - p_{01}(1-p_{10})(1+g))\left[w_{SF} - \frac{p_{11}}{2}\Delta_\omega\right] \\
& + (p_{11}(1-p_{11}) - p_{10}(1-p_{01})(1+g))\left[w_{FS} - \frac{p_{11}}{2}\Delta_\omega\right] \\
& + ((1-p_{11})^2 - (1-p_{01})(1-p_{10})(1+g))w_{FF} \\
& \geq \psi
\end{aligned}$$

Note that  $(w_{SF} - \frac{p_{11}\Delta_\omega}{2}) - (w_{FS} - \frac{p_{11}\Delta_\omega}{2}) = 0$ , since  $w_{SF} = w_{FS}$ . Now, subtracting  $(\text{IC}_\omega)$  from  $(\text{IC}_{\omega'})$

$$\begin{aligned}
(\text{IC}_{\omega'}) - (\text{IC}_\omega) &= \Delta_\omega(1-p_{11})(p_{11}^2 - p_{01}p_{10}(1+g)) \\
&\quad - \frac{p_{11}\Delta_\omega}{2}((1-p_{11})p_{11} - p_{01}(1-p_{10})(1+g)) \\
&\quad - \frac{p_{11}\Delta_\omega}{2}(p_{11}(1-p_{11}) - (1-p_{01})p_{10}(1+g)) \\
&= \frac{\Delta_\omega}{2}(p_{11}(p_{01} + p_{10}) - 2p_{01}p_{10})(1+g) > 0
\end{aligned}$$

Thus, the principal can lower the expected wage payment by reducing the slack on (IC). Thus, a wage scheme  $\omega = (w_{SS}, w_{SF}, w_{FS}, w_{FF})$  with  $w_{SF} > w_{SS}$  cannot be expected cost minimizing. Thus, in an optimal wage scheme it must be  $w_{SS} \geq w_{SF}$ . ■

*Lemma 9.*  $w_{FS} \geq w_{FF}$ . *Proof.* Suppose  $((1-p_{11})^2 - (1-p_{01})(1-p_{10})(1+g)) \leq 0$ .

Then, the left-hand side of the (IC) is decreasing in  $w_{FF}$  while the expected wage

payment is increasing in  $w_{FF}$ . Thus,  $w_{FF} = 0$  is optimal in this case, which implies  $w_{FS} \geq w_{FF}$ , by limited liability. Now, suppose  $((1-p_{11})^2 - (1-p_{01})(1-p_{10})(1+g)) > 0$ . Suppose  $\omega = (w_{SS}, w_{SF}, w_{FS}, w_{FF})$  is a wage scheme with  $w_{FF} > w_{FS}$ .

*Case 1.*  $w_{SF} > w_{FS}$ . Let  $\Delta_w = w_{SF} - w_{FS}$ . We can subtract  $p_{11}\Delta_w$  from  $w_{FF}$  and add  $(1-p_{11})\Delta_w$  to  $w_{FS}$  without changing the expected wage payment. Thus, this new wage scheme is

$$\omega' = (w_{SS}, w_{SF}, w_{FS} + (1-p_{11})\Delta_w, w_{FF} - p_{11}\Delta_w)$$

Now, the left-hand sides of the (IC) constraints with  $\omega$  and with  $\omega'$  become, respectively,

$$\begin{aligned} (\text{IC}_\omega) \quad & (p_{11}^2 - p_{01}p_{10}(1+g))w_{SS} + (p_{11}(1-p_{11}) - p_{01}(1-p_{10})(1+g))w_{SF} \\ & + (p_{11}(1-p_{11}) - p_{10}(1-p_{01})(1+g))w_{FS} \\ & + ((1-p_{11})^2 - (1-p_{01})(1-p_{10})(1+g))w_{FF} \\ & + p_{11}(1-p_{11}) \left[ D \left( \frac{w_{SF} - w_{FS}}{2} \right) + D \left( \frac{w_{FS} - w_{SF}}{2} \right) \right] \geq \psi \\ (\text{IC}_{\omega'}) \quad & (p_{11}^2 - p_{01}p_{10}(1+g))w_{SS} + (p_{11}(1-p_{11}) - p_{01}(1-p_{10})(1+g))w_{SF} \\ & + (p_{11}(1-p_{11}) - p_{10}(1-p_{01})(1+g))(w_{FS} + (1-p_{11})\Delta_w) \\ & + ((1-p_{11})^2 - (1-p_{01})(1-p_{10})(1+g))(w_{FF} - p_{11}\Delta_w) \\ & + p_{11}(1-p_{11}) \left[ D \left( \frac{w_{SF} - w_{FS} - (1-p_{11})\Delta_w}{2} \right) \right] \\ & + p_{11}(1-p_{11}) \left[ D \left( \frac{w_{FS} + (1-p_{11})\Delta_w - w_{SF}}{2} \right) \right] \\ & \geq \psi \end{aligned}$$

Note that  $(w_{SF} - (w_{FS} + (1-p_1)\Delta_w)) > 0$ . Now, subtracting  $(\text{IC}_\omega)$  from  $(\text{IC}_{\omega'})$ , we get

$$(\text{IC}_{\omega'}) - (\text{IC}_\omega) = \Delta_w(1+g)(1-p_{01})(p_{11} - p_{10}) + \Delta_w p_{11}(1-p_{11})^2 \left( \frac{d-g}{2} \right) > 0$$

*Case 2.*  $w_{SF} = w_{FS}$ . Since  $w_{FF} > w_{FS}$ , we also have  $w_{FF} > w_{SF}$ . Let

$\Delta_w = w_{FF} - w_{FS}$ . We can add  $\frac{(1-p_{11})\Delta_w}{2}$  to  $w_{SF}$  and  $w_{FS}$  and, subtract  $(p_{11})\Delta_w$  from  $w_{FF}$  without changing the expected wage payment. Thus, this new wage scheme is

$$\omega' = (w_{SS}, w_{SF} + \frac{(1-p_{11})\Delta_w}{2}, w_{FS} + \frac{(1-p_{11})\Delta_w}{2}, w_{FF} - p_{11}\Delta_w)$$

Now, the left-hand sides of the (IC) constraints with  $\omega$  and with  $\omega'$  become, respectively,

$$\begin{aligned} (\text{IC}_\omega) \quad & (p_{11}^2 - p_{01}p_{10}(1+g))w_{SS} + (p_{11}(1-p_{11}) - p_{01}(1-p_{10})(1+g))w_{SF} \\ & + (p_{11}(1-p_{11}) - p_{10}(1-p_{01})(1+g))w_{FS} \\ & + ((1-p_{11})^2 - (1-p_{01})(1-p_{10})(1+g))w_{FF} \\ & \geq \psi \end{aligned}$$

$$\begin{aligned} (\text{IC}_{\omega'}) \quad & (p_{11}^2 - p_{01}p_{10}(1+g))w_{SS} \\ & + (p_{11}(1-p_{11}) - p_{01}(1-p_{10})(1+g))\left[w_{SF} + \frac{1-p_{11}}{2}\Delta_w\right] \\ & + (p_{11}(1-p_{11}) - p_{10}(1-p_{01})(1+g))\left[w_{FS} + \frac{1-p_{11}}{2}\Delta_w\right] \\ & + ((1-p_{11})^2 - (1-p_{01})(1-p_{10})(1+g))(w_{FF} - p_{11}\Delta_w) \\ & \geq \psi \end{aligned}$$

Note that  $(w_{SF} + \frac{(1-p_{11})\Delta_w}{2}) - (w_{FS} + \frac{(1-p_{11})\Delta_w}{2}) = 0$ .

Now, subtracting  $(IC_\omega)$  from  $(IC_{\omega'})$ , we get

$$\begin{aligned}
(IC_{\omega'}) - (IC_\omega) &= (p_{11}(1 - p_{11}) - p_{01}(1 - p_{10})(1 + g)) \left[ \frac{1 - p_{11}}{2} \Delta_\omega \right] \\
&\quad + (p_{11}(1 - p_{11}) - p_{10}(1 - p_{01})(1 + g)) \left[ \frac{1 - p_{11}}{2} \Delta_\omega \right] \\
&\quad - ((1 - p_{11})^2 - (1 - p_{01})(1 - p_{10})(1 + g))(p_{11} \Delta_w) \\
&= p_{11}(1 - p_{11})^2 \Delta_w - p_{11}(1 - p_{11})^2 \Delta_w + p_{11} \Delta_w (1 - p_{01})(1 - p_{10})(1 + g) \\
&\quad - (1 - p_{11}) \frac{\Delta_w}{2} (1 + g) [p_{01}(1 - p_{10}) + p_{10}(1 - p_{01})] \\
&= (1 - p_{11}) \Delta_w (1 + g) (p_{01} p_{10}) - (1 - p_{11}) \frac{\Delta_w}{2} (1 + g) (p_{01} + p_{10}) \\
&\quad + p_{11} \Delta_w (1 - p_{01})(1 - p_{10})(1 + g) \\
&\geq (1 - p_{11}) \Delta_w (1 + g) [p_{01} p_{10} + p_{11}(1 - p_{01})] \\
&\quad - (1 - p_{11}) \frac{\Delta_w}{2} (1 + g) (p_{01} + p_{10}) \\
&= (1 - p_{11}) \frac{\Delta_w}{2} (1 + g) (2p_{01} p_{10} + 2p_{11} - 2p_{11} p_{01} - p_{01} - p_{10}) > 0
\end{aligned}$$

Thus, the principal can lower the expected wage payment by reducing the slack on  $(IC)$ . Thus, a wage scheme  $\omega = (w_{SS}, w_{SF}, w_{FS}, w_{FF})$  with  $w_{FF} > w_{FS}$  cannot be expected cost minimizing. Thus, in an optimal wage scheme it must be  $w_{FS} \geq w_{FF}$ .

■

Thus, in the optimal contract, we have  $w_{SS} \geq w_{SF} \geq w_{FS} \geq w_{FF}$ . By limited liability constraints, there are four possible wage configurations:

1.  $w_{SS} > 0$  and  $w_{SF} = w_{FS} = w_{FF} = 0$ .
2.  $w_{SS}, w_{SF} > 0$  and  $w_{FS} = w_{FF} = 0$ .
3.  $w_{SS}, w_{SF}, w_{FS} > 0$  and  $w_{FF} = 0$ .
4.  $w_{SS}, w_{SF}, w_{FS}, w_{FF} > 0$ .

*Lemma 10.* The expected wage payment is minimized when  $w_{SS} > 0$  and  $w_{SF} = w_{FS} = w_{FF} = 0$ . *Proof.* We compare the expected wage payments of the four different wage scheme configurations. We first find the minimized expected wage

payment when  $w_{SS} > 0$  and  $w_{SF} = w_{FS} = w_{FF} = 0$ , and then we show that in all three other cases, the expected wage payment is larger than the one with  $w_{SS} > 0$  and  $w_{SF} = w_{FS} = w_{FF} = 0$ .

*Case 1.*  $w_{SS} > 0$  and  $w_{SF} = w_{FS} = w_{FF} = 0$ . (IC) in this case becomes

$$(p_{11}^2 - p_{01}p_{10}(1 + g))w_{SS} \geq \psi$$

which must bind. Thus, we get

$$w_{SS} = \frac{\psi}{p_{11}^2 - p_{01}p_{10}(1 + g)}$$

Thus, the expected wage payment is

$$\mathbb{E}w(1) = p_{11}^2 w_{SS} = \frac{p_{11}^2 \psi}{p_{11}^2 - p_{01}p_{10}(1 + g)}$$

*Case 2.*  $w_{SS}, w_{SF} > 0$  and  $w_{FS} = w_{FF} = 0$ .

(IC) in this case becomes

$$\begin{aligned} & w_{SS} + \frac{p_{11}(1 - p_{11}) - p_{01}(1 - p_{10})(1 + g)}{p_{11}^2 - p_{01}p_{10}(1 + g)} w_{SF} - \frac{p_{11}(1 - p_{11})(d - g)w_{SF}}{2(p_{11}^2 - p_{01}p_{10}(1 + g))} \\ & \geq \frac{\psi}{p_{11}^2 - p_{01}p_{10}(1 + g)} \end{aligned}$$

Since

$$\frac{p_{11}(1 - p_{11})(d - g)w_{SF}}{2(p_{11}^2 - p_{01}p_{10}(1 + g))} > 0$$

we have,

$$w_{SS} + \frac{p_{11}(1 - p_{11}) - p_{01}(1 - p_{10})(1 + g)}{p_{11}^2 - p_{01}p_{10}(1 + g)} w_{SF} > \frac{\psi}{p_{11}^2 - p_{01}p_{10}(1 + g)}$$

That is,

$$p_{11}^2 w_{SS} + p_{11}^2 \frac{p_{11}(1 - p_{11}) - p_{01}(1 - p_{10})(1 + g)}{p_{11}^2 - p_{01}p_{10}(1 + g)} w_{SF} > \frac{p_{11}^2 \psi}{p_{11}^2 - p_{01}p_{10}(1 + g)}$$

Notice that,

$$\begin{aligned}
p_{11}^2 w_{SS} + p_{11}(1 - p_{11})w_{SF} &= p_{11}^2 w_{SS} + \frac{p_{11}(1 - p_{11})(p_{11} - p_{01}(1 + g))}{p_{11} - p_{01}(1 + g)} w_{SF} \\
&= p_{11}^2 w_{SS} + p_{11}^2 \frac{p_{11}(1 - p_{11}) - p_{01}(1 - p_{11}(1 + g))}{p_{11}(p_{11} - p_{01}(1 + g))} w_{SF} \\
&> p_{11}^2 w_{SS} + p_{11}^2 \frac{p_{11}(1 - p_{11}) - p_{01}(1 - p_{10})(1 + g)}{p_{11}^2 - p_{01}p_{10}(1 + g)} w_{SF} \\
&> \frac{p_{11}^2 \psi}{p_{11}^2 - p_{01}p_{10}(1 + g)}
\end{aligned}$$

The left-hand side of above inequality is the expected wage payment in this case,  $\mathbb{E}w(2)$ . The right-hand side is  $\mathbb{E}w(1)$ . Thus,  $\mathbb{E}w(2) > \mathbb{E}w(1)$ . Thus, a wage schedule  $\omega = (w_{SS}, w_{SF}, 0, 0)$  with  $w_{SS}, w_{SF} > 0$  cannot be minimizing the expected wage payment.

*Case 3.*  $w_{SS}, w_{SF}, w_{FS} > 0$  and  $w_{FF} = 0$ .

(IC) in this case becomes

$$\begin{aligned}
w_{SS} + \frac{p_{11}(1 - p_{11}) - p_{01}(1 - p_{10})(1 + g)}{p_{11}^2 - p_{01}p_{10}(1 + g)} w_{SF} + \frac{p_{11}(1 - p_{11}) - p_{10}(1 - p_{01})(1 + g)}{p_{11}^2 - p_{01}p_{10}(1 + g)} w_{FS} \\
- \frac{p_{11}(1 - p_{11})(d - g)(w_{SF} - w_{FS})}{2(p_{11}^2 - p_{01}p_{10}(1 + g))} \geq \frac{\psi}{p_{11}^2 - p_{01}p_{10}(1 + g)}
\end{aligned}$$

Since

$$\frac{p_{11}(1 - p_{11})(d - g)(w_{SF} - w_{FS})}{2(p_{11}^2 - p_{01}p_{10}(1 + g))} > 0$$

we have,

$$\begin{aligned}
w_{SS} + \frac{p_{11}(1 - p_{11}) - p_{01}(1 - p_{10})(1 + g)}{p_{11}^2 - p_{01}p_{10}(1 + g)} w_{SF} \\
+ \frac{p_{11}(1 - p_{11}) - p_{10}(1 - p_{01})(1 + g)}{p_{11}^2 - p_{01}p_{10}(1 + g)} w_{FS} > \frac{\psi}{p_{11}^2 - p_{01}p_{10}(1 + g)}
\end{aligned}$$

That is,

$$p_{11}^2 w_{SS} + p_{11}^2 \frac{p_{11}(1-p_{11}) - p_{01}(1-p_{10})(1+g)}{p_{11}^2 - p_{01}p_{10}(1+g)} w_{SF} \\ + p_{11}^2 \frac{p_{11}(1-p_{11}) - p_{10}(1-p_{01})(1+g)}{p_{11}^2 - p_{01}p_{10}(1+g)} w_{FS} > \frac{p_{11}^2 \psi}{p_{11}^2 - p_{01}p_{10}(1+g)}$$

Notice that,

$$p_{11}^2 w_{SS} + p_{11}(1-p_{11})w_{SF} + p_{11}(1-p_{11})w_{FS} \\ = p_{11}^2 w_{SS} + \frac{p_{11}(1-p_{11})(p_{11} - p_{01}(1+g))}{p_{11} - p_{01}(1+g)} w_{SF} + \frac{p_{11}(1-p_{11})(p_{11} - p_{10}(1+g))}{p_{11} - p_{10}(1+g)} w_{FS} \\ = p_{11}^2 w_{SS} + p_{11}^2 \frac{p_{11}(1-p_{11}) - p_{01}(1-p_{11})(1+g)}{p_{11}(p_{11} - p_{01}(1+g))} w_{SF} \\ + p_{11}^2 \frac{p_{11}(1-p_{11}) - p_{10}(1-p_{11})(1+g)}{p_{11}(p_{11} - p_{10}(1+g))} w_{FS} \\ > p_{11}^2 w_{SS} + p_{11}^2 \frac{p_{11}(1-p_{11}) - p_{01}(1-p_{10})(1+g)}{p_{11}^2 - p_{01}p_{10}(1+g)} w_{SF} \\ + p_{11}^2 \frac{p_{11}(1-p_{11}) - p_{01}(1-p_{10})(1+g)}{p_{11}^2 - p_{01}p_{10}(1+g)} w_{FS} \\ > \frac{p_{11}^2 \psi}{p_{11}^2 - p_{01}p_{10}(1+g)}$$

The left-hand side of above inequality is the expected wage payment in this case,  $\mathbb{E}w(3)$ . The right-hand side is  $\mathbb{E}w(1)$ . Thus,  $\mathbb{E}w(3) > \mathbb{E}w(1)$ . Thus, a wage schedule  $\omega = (w_{SS}, w_{SF}, w_{FS}, 0)$  with  $w_{SS}, w_{SF}, w_{FS} > 0$  cannot be minimizing the expected wage payment.

*Case 4.*  $w_{SS}, w_{SF}, w_{FS}, w_{FF} > 0$ .

(IC) in this case becomes

$$w_{SS} + \frac{p_{11}(1-p_{11}) - p_{01}(1-p_{10})(1+g)}{p_{11}^2 - p_{01}p_{10}(1+g)} w_{SF} + \frac{p_{11}(1-p_{11}) - p_{10}(1-p_{01})(1+g)}{p_{11}^2 - p_{01}p_{10}(1+g)} w_{FS} \\ + \frac{(1-p_{11})^2 - (1-p_{10})(1-p_{01})(1+g)}{p_{11}^2 - p_{01}p_{10}(1+g)} w_{FF} - \frac{p_{11}(1-p_{11})(d-g)(w_{SF} - w_{FS})}{2(p_{11}^2 - p_{01}p_{10}(1+g))} \\ \geq \frac{\psi}{p_{11}^2 - p_{01}p_{10}(1+g)}$$

Since

$$\frac{p_{11}(1-p_{11})(d-g)(w_{SF}-w_{FS})}{2(p_{11}^2-p_{01}p_{10}(1+g))} > 0$$

we have,

$$\begin{aligned} w_{SS} + \frac{p_{11}(1-p_{11})-p_{01}(1-p_{10})(1+g)}{p_{11}^2-p_{01}p_{10}(1+g)}w_{SF} + \frac{p_{11}(1-p_{11})-p_{10}(1-p_{01})(1+g)}{p_{11}^2-p_{01}p_{10}(1+g)}w_{FS} \\ + \frac{(1-p_{11})^2-(1-p_{10})(1-p_{01})(1+g)}{p_{11}^2-p_{01}p_{10}(1+g)}w_{FF} > \frac{\psi}{p_{11}^2-p_{01}p_{10}(1+g)} \end{aligned}$$

That is,

$$\begin{aligned} p_{11}^2 w_{SS} + p_{11}^2 \frac{p_{11}(1-p_{11})-p_{01}(1-p_{10})(1+g)}{p_{11}^2-p_{01}p_{10}(1+g)}w_{SF} \\ + p_{11}^2 \frac{p_{11}(1-p_{11})-p_{10}(1-p_{01})(1+g)}{p_{11}^2-p_{01}p_{10}(1+g)}w_{FS} \\ + \frac{(1-p_{11})^2-(1-p_{10})(1-p_{01})(1+g)}{p_{11}^2-p_{01}p_{10}(1+g)}w_{FF} > \frac{p_{11}^2\psi}{p_{11}^2-p_{01}p_{10}(1+g)} \end{aligned}$$

Notice that,

$$\begin{aligned}
& p_{11}^2 w_{SS} + p_{11}(1-p_{11})w_{SF} + p_{11}(1-p_{11})w_{FS} + (1-p_{11})^2 w_{FF} \\
&= p_{11}^2 w_{SS} + \frac{p_{11}(1-p_{11})(p_{11}-p_{01}(1+g))}{p_{11}-p_{01}(1+g)} w_{SF} \\
&+ \frac{p_{11}(1-p_{11})(p_{11}-p_{10}(1+g))}{p_{11}-p_{10}(1+g)} w_{FS} + \frac{(1-p_{11})^2(p_{11}-p_{10}(1+g))}{p_{11}-p_{10}(1+g)} w_{FF} \\
&= p_{11}^2 w_{SS} + p_{11}^2 \frac{p_{11}(1-p_{11})-p_{01}(1-p_{11}(1+g))}{p_{11}(p_{11}-p_{01}(1+g))} w_{SF} \\
&+ p_{11}^2 \frac{p_{11}(1-p_{11})-p_{10}(1-p_{11}(1+g))}{p_{11}(p_{11}-p_{10}(1+g))} w_{FS} \\
&+ p_{11}^2 \frac{(1-p_{11})^2 - [(1-p_{11})^2 p_{10}(1+g)]/p_{11}}{p_{11}-p_{10}(1+g)} w_{FF} \\
&> p_{11}^2 w_{SS} + p_{11}^2 \frac{p_{11}(1-p_{11})-p_{01}(1-p_{10})(1+g)}{p_{11}^2 - p_{01}p_{10}(1+g)} w_{SF} \\
&+ p_{11}^2 \frac{p_{11}(1-p_{11})-p_{10}(1-p_{10})(1+g)}{p_{11}^2 - p_{01}p_{10}(1+g)} w_{FS} \\
&+ \frac{(1-p_{11})^2 - (1-p_{10})(1-p_{01})(1+g)}{p_{11}^2 - p_{01}p_{10}(1+g)} w_{FF} \\
&> \frac{p_{11}^2 \psi}{p_{11}^2 - p_{01}p_{10}(1+g)}
\end{aligned}$$

The left-hand side of above inequality is the expected wage payment in this case,  $\mathbb{E}w(4)$ . The right-hand side is  $\mathbb{E}w(1)$ . Thus,  $\mathbb{E}w(4) > \mathbb{E}w(1)$ . Thus, a wage schedule  $\omega = (w_{SS}, w_{SF}, w_{FS}, w_{FF})$  with  $w_{SS}, w_{SF}, w_{FS}, w_{FF} > 0$  cannot be minimizing the expected wage payment. ■

This finishes the proof of Proposition 3 ■

*Desert Preferences with Risk Aversion:*

*Principal's Problem*

$$\begin{aligned}
 & \max_{\{w_{SS}, w_{SF}, w_{FS}, w_{FF}\}} && -(p_1^2 w_{SS} + p_1(1-p_1)(w_{SF} + w_{FS}) + (1-p_1)^2 w_{FF}) \\
 & \text{subject to} && \\
 & \text{(IR)} && p_1^2 \varphi(w_{SS}) + p_1(1-p_1)(\varphi(w_{SF}) + \varphi(w_{FS})) + (1-p_1)^2 \varphi(w_{FF}) \\
 & && + p_1(1-p_1) \left[ D \left( \varphi(w_{SF}) - \varphi \left( \frac{w_{SF} + w_{FS}}{2} \right) \right) \right] \\
 & && + p_1(1-p_1) \left[ D \left( \varphi(w_{FS}) - \varphi \left( \frac{w_{SF} + w_{FS}}{2} \right) \right) \right] \geq \psi \\
 & \text{(IC)} && p_1(p_1 - p_0)\varphi(w_{SS}) + (1-p_1)(p_1 - p_0)\varphi(w_{SF}) - p_1(p_1 - p_0)\varphi(w_{FS}) \\
 & && - (1-p_1)(p_1 - p_0)\varphi(w_{FF}) - p_1 p_0 D(\varphi(w_{SS})) - (1-p_1)p_0 D(\varphi(w_{SF})) \\
 & && - p_1(1-p_0)D(\varphi(w_{FS})) - (1-p_1)(1-p_0)D(\varphi(w_{FF})) - \psi \\
 & && + p_1(1-p_1) \left[ D \left( \varphi(w_{SF}) - \varphi \left( \frac{w_{SF} + w_{FS}}{2} \right) \right) \right] \\
 & && + p_1(1-p_1) \left[ D \left( \varphi(w_{FS}) - \varphi \left( \frac{w_{SF} + w_{FS}}{2} \right) \right) \right] \geq 0
 \end{aligned}$$

*The Lagrangian and the First-Order Conditions*

$$\begin{aligned}
 \mathcal{L} &= -(p_1^2 w_{SS} + p_1(1-p_1)(w_{SF} + w_{FS}) + (1-p_1)^2 w_{FF}) \\
 &+ \lambda_{IR} (p_1^2 \varphi(w_{SS}) + p_1(1-p_1)(\varphi(w_{SF}) + \varphi(w_{FS})) + (1-p_1)^2 \varphi(w_{FF}) \\
 &+ p_1(1-p_1) \left[ D \left( \varphi(w_{SF}) - \varphi \left( \frac{w_{SF} + w_{FS}}{2} \right) \right) + D \left( \varphi(w_{FS}) - \varphi \left( \frac{w_{SF} + w_{FS}}{2} \right) \right) \right] - \psi) \\
 &+ \lambda_{IC} \left( p_1(p_1 - p_0)\varphi(w_{SS}) + (1-p_1)(p_1 - p_0)\varphi(w_{SF}) - p_1(p_1 - p_0)\varphi(w_{FS}) \right. \\
 &- (1-p_1)(p_1 - p_0)\varphi(w_{FF}) - p_1 p_0 D(\varphi(w_{SS})) - (1-p_1)p_0 D(\varphi(w_{SF})) \\
 &- p_1(1-p_0)D(\varphi(w_{FS})) - (1-p_1)(1-p_0)D(\varphi(w_{FF})) - \psi \\
 &+ p_1(1-p_1) \left[ D \left( \varphi(w_{SF}) - \varphi \left( \frac{w_{SF} + w_{FS}}{2} \right) \right) + D \left( \varphi(w_{FS}) - \varphi \left( \frac{w_{SF} + w_{FS}}{2} \right) \right) \right] \left. \right)
 \end{aligned}$$

F.O.C. w.r.t.  $w_{SS}$

$$\begin{aligned}
& -p_1^2 + \lambda_{IC} \left[ p_1(p_1 - p_0)\varphi'(w_{SS}) - p_1p_0D'(\varphi(w_{SS}))\varphi'(w_{SS}) \right] + \lambda_{IR}p_1^2\varphi'(w_{SS}) = 0 \\
\Rightarrow \varphi'(w_{SS}) &= \frac{p_1}{-p_0(1 + D'(\varphi(w_{SS})))\lambda_{IC} + p_1(\lambda_{IC} + \lambda_{IR})}
\end{aligned}$$

F.O.C. w.r.t.  $w_{SF}$

$$\begin{aligned}
& -p_1(1 - p_1) + \lambda_{IC} \left[ (1 - p_1)(p_1 - p_0)\varphi'(w_{SF}) - p_0(1 - p_1)D'(\varphi(w_{SF}))\varphi'(w_{SF}) \right] \\
& + \lambda_{IR} \left[ p_1(1 - p_1)\varphi'(w_{SF}) \right. \\
& \quad \left. + p_1(1 - p_1)D' \left( \varphi(w_{SF}) - \varphi \left( \frac{w_{SF} + w_{FS}}{2} \right) \right) \left[ \varphi'(w_{SF}) - \frac{1}{2}\varphi' \left( \frac{w_{SF} + w_{FS}}{2} \right) \right] \right. \\
& \quad \left. - p_1(1 - p_1)D' \left( \varphi(w_{FS}) - \varphi \left( \frac{w_{SF} + w_{FS}}{2} \right) \right) \frac{1}{2}\varphi' \left( \frac{w_{SF} + w_{FS}}{2} \right) \right] = 0 \\
\Rightarrow \varphi'(w_{SF}) &= \\
& \frac{p_1 \left[ 1 + (\lambda_{IC} + \lambda_{IR})\frac{1}{2}\varphi' \left( \frac{w_{SF} + w_{FS}}{2} \right) (d + g) \right]}{-\lambda_{IC}p_0(1 + D'(\varphi(w_{SF}))) + (\lambda_{IC} + \lambda_{IR})p_1 \left[ 1 + D'(\varphi(w_{SF}) - \varphi \left( \frac{w_{SF} + w_{FS}}{2} \right)) \right]}
\end{aligned}$$

F.O.C. w.r.t.  $w_{FS}$

$$\begin{aligned}
& -p_1(1 - p_1) - \lambda_{IC} \left[ p_1(p_1 - p_0)\varphi'(w_{FS}) + p_1(1 - p_0)D'(\varphi(w_{FS}))\varphi'(w_{FS}) \right] \\
& + \lambda_{IR} \left[ p_1(1 - p_1)\varphi'(w_{FS}) \right. \\
& \quad \left. + p_1(1 - p_1)D' \left( \varphi(w_{FS}) - \varphi \left( \frac{w_{SF} + w_{FS}}{2} \right) \right) \left[ \varphi'(w_{FS}) - \frac{1}{2}\varphi' \left( \frac{w_{SF} + w_{FS}}{2} \right) \right] \right. \\
& \quad \left. - p_1(1 - p_1)D' \left( \varphi(w_{SF}) - \varphi \left( \frac{w_{SF} + w_{FS}}{2} \right) \right) \frac{1}{2}\varphi' \left( \frac{w_{SF} + w_{FS}}{2} \right) \right] = 0 \\
\Rightarrow \varphi'(w_{FS}) &= \\
& \frac{(1 - p_1) \left[ 1 + (\lambda_{IC} + \lambda_{IR})\frac{1}{2}\varphi' \left( \frac{w_{SF} + w_{FS}}{2} \right) (d + g) \right]}{-\lambda_{IC}(1 - p_0)(1 + D'(\varphi(w_{FS}))) + (\lambda_{IC} + \lambda_{IR})(1 - p_1)(1 + D'(\varphi(w_{FS}) - \varphi \left( \frac{w_{SF} + w_{FS}}{2} \right)))}
\end{aligned}$$

F.O.C. w.r.t.  $w_{FF}$

$$\begin{aligned} & -(1-p_1)^2 - \lambda_{IC} \left[ (1-p_1)(p_1-p_0)\varphi'(w_{FF}) + (1-p_1)(1-p_0)D'(\varphi(w_{FF}))\varphi'(w_{FF}) \right] \\ & + \lambda_{IR}(1-p_1)^2\varphi'(w_{FF}) = 0 \\ \Rightarrow \varphi'(w_{FF}) &= \frac{1-p_1}{-\lambda_{IC}(1-p_0)(1+D'(\varphi(w_{FF}))) + (\lambda_{IC} + \lambda_{IR})(1-p_1)} \end{aligned}$$

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