Promotion Tournaments and Individual Performance Pay*

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Abstract

We analyze the optimal combination of promotion tournaments and individual performance pay in an employment relationship. An agent's effort is non-observable and he has private information about his suitability for promotion. Thus, promotion tournaments and individual performance pay need to be combined to serve both incentive and selection purposes. We find that, if it is sufficiently important to promote the more suitable candidate, the principal provides incentives only by using a promotion tournament. Thus, we give a possible explanation as to why, in practice, individual performance pay is less prevalent than promotion-based incentive systems.

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1 Introduction

Firms are confronted with essentially two challenges to maximize the productivity of their workforce. First, firms need to design appropriate incentive schemes in order to motivate their employees to implement effort (*motivation challenge*). Second, firms have to utilize viable mechanisms to facilitate the assignment of employees to jobs they are most suitable for (*selection challenge*). In the economic literature, it is well-understood that pay-for-performance can both motivate a firm's workforce and serve as a selection device.[1] However, as Baker et al. [1988] point out, most firms employ payment schemes that are largely independent of performance.[2] Moreover, arguing that "promotions are used as the primary incentive device in most organizations", Baker et al. [1988, pp. 600-1] pose the question why promotion-based incentive systems are more prevalent than explicit pay-for-performance schemes. We provide a possible answer to this puzzle by demonstrating that the optimal combination of promotion tournaments and linear individual performance pay may involve only low-powered individual incentives when motivation and selection issues arise simultaneously.

We consider a firm with two types of jobs: production and management. To fill vacancies in management with suitable candidates, a firm can pursue two different strategies. First, managers can be recruited from the external labor market. In this case, their past experience and performance may be used as signals about their individual abilities, which in turn facilitates an efficient selection process.[3] Clearly, recruiting from the external labor market can constitute the preferred hiring strategy when either external candidates are sufficiently more suitable for the relevant position than current employees [Tsoulouhas et al., 2007], or firm-specific human capital is of little importance for the specific management position.

Alternatively, the firm can use the internal labor market and promote some production workers to management positions. Recruiting managers from the pool of current employees can be advantageous for firms due to several reasons. Firstly, because of their employment history in the respective firm, employees generally acquired firm-specific human capital and adapted to the corporate culture, which is potentially crucial for being a successful manager.[4] Secondly,

[1] See, e.g., Salanié [2005]. Empirically, Lazear [2000] documents that the introduction of a simple piece rate scheme in a U.S. auto glass company increased output significantly and, at the same time, attracted more capable workers.

[2] See also Parent [2002] for empirical evidence.

[3] The effects of past performance on managerial incentives are the subject of the career concerns literature, starting with the seminal paper by Holmström [1999].

[4] For instance, Hatch and Dyer [2004] provide empirical evidence that the investment in firm-specific human

the prospect of promotion – and the associated benefits such as higher income, perks, status, and authority – can be a strong motivator for competing employees (e.g. Lazear and Rosen [1981], Nalebuff and Stiglitz [1983]). Thirdly, promotion tournaments can improve job assignments by facilitating the selection of more suitable employees for higher-level jobs (e.g., Rosen [1986], Clark and Riis [2001]).[5]

Several empirical studies suggest that the advantages of internal promotions dominate those of external recruitment, in particular with respect to positions in middle management (e.g., Turner [1994] and Fellman [2003]). Put differently, the promotion of employees to management jobs is a common phenomenon observable in firms. A prominent example is United Parcel Service (UPS) with an explicit commitment to "a promote-from-within approach to management development" [UPS, 2009].[6] According to UPS, striking 85 percent of its full-time management employees in 2006 were promoted from non-management positions.

While promotion tournaments clearly constitute a frequently utilized incentive and selection device in firms, surprisingly little is known about how they interact with other incentive schemes such as individual performance pay. This paper therefore aims at shedding light on the interaction of two commonly used incentive and selection devices: promotion tournaments and individual performance pay. More specifically, we investigate how firms can jointly employ individual performance pay and internal promotions to cope with the two previously emphasized challenges: motivating effort and facilitating the efficient assignment of employees to various jobs. This also allows us to explain some phenomena observable in business practice. In doing so, we focus on a situation where the firm prefers internal promotions to external recruitment because prospective managers need to acquire sufficient firm-specific human capital to conduct their future tasks effectively.

We analyze a principal-agent relationship between the owner of a firm (principal) and two employees (agents). Randomly recruited agents share the same abilities in production but may differ in their skills for the management task. Initially, there is symmetric uncertainty about an agent's management skills, i.e. no party can observe an agent's suitability for the management job. First, the agents are employed in production, allowing them to attain the level of firm-specific human capital required for the management position. Their respective effort as

capital significantly increases firm performance.

[5]Baker, Gibbs, and Holmström [1994] conclude from their analysis of personnel data from a medium-sized U.S. firm that the performance of employees at lower hierarchy levels is used to learn about their abilities, which in turn facilitates promotion decisions and thus more efficient job assignments.

[6]We thank an anonymous referee for pointing out this example.

production worker is non-observable, but the principal receives contractible individual performances measures. Therefore, the principal can provide the agents with a piece rate scheme based upon their individual performance in order to motivate effort.[7] Moreover, to fill the management position, the principal utilizes a typical promotion tournament: the better performing agent will be promoted and hence, becomes the new manager. While being employed as a production worker, each agent learns about his individual suitability for the management position in this particular firm. Consequently, agents become able to assess their individual valuation of being employed as a manager, which affects their incentives to compete for promotion.

A manager's effort is also non-observable. Moreover, since lower-level managers generally perform difficult-to-measure tasks such as supervising subordinates or organizing the workflow in production, contractible performance measures are not available.[8] A manager therefore receives a fixed salary and exerts some minimum required effort level. The management compensation constitutes the prize in the promotion tournament. Hence, the firm's compensation and promotion policy needs to serve two objectives: motivating production workers and, in case the recruited workers are heterogeneous, increasing the chances of promoting the better suited agent to the management level.

Our main result is that the introduction of a piece rate scheme may interfere with the selection of high-ability managers by means of a promotion tournament. The firm may therefore provide only low-powered individual incentives, or even refrain from using individual performance pay when promoting the more suitable candidate is sufficiently important. The rationale behind this result is as follows. Because workers and managers perform different tasks, production output cannot serve as a signal *per se* about a worker's suitability for the management job. However, workers who perceive themselves as capable future managers have a higher valuation for being promoted. Because of this higher valuation, more capable candidates work harder when the firm selects the best-performing worker for promotion. Consequently, by implementing a promotion tournament, the firm can use a worker's production output as a signal about his suitability for promotion. The provision of individual performance pay, however, can dilute the informativeness of this signal. If the recruited workers are heterogeneous, it becomes then less likely that the worker, who is more suitable for promotion, has also the higher output. The

[7] For example, at the auto glass company that Lazear [2000] investigates, installers receive a piece rate based on the number of glass units they installed.

[8] This assumption is not crucial for our results. We discuss a potential extension of our model with incentive contracts on the management level in Section 5.

reason is that the other worker, who is less suited for promotion, may respond more strongly to intensified individual effort incentives on the production stage.

Also pursuing the question of why promotion-based incentives are predominant in organizations, Fairburn and Malcomson [2001] focus on the impact of influence activities on the effectiveness of incentive schemes. In contrast to our framework, they analyze a situation where the performance of workers is non-verifiable, and managers allocate rewards according to their evaluations of workers' achievements. Fairburn and Malcomson [2001] demonstrate that the use of promotion tournaments diminishes the receptiveness of managers to potential influence activities, that would clearly render pay-for-performance schemes ineffective.[9]

There are alternative explanations as to why firms may be reluctant to adopt individual performance pay. Holmström and Milgrom [1991] show that it may be optimal for firms to refrain from providing individual performance pay if effort has multiple dimensions, where some dimension are more easily measured than others. Moreover, according to Bernheim and Whinston [1998], contracting parties might want to leave some verifiable aspects of performance unspecified as this allows to punish undesired behavior. Another possible explanation originates from psychology: monetary incentive payments may crowd out intrinsic motivation [Deci, 1971]. Frey and Oberholzer-Gee [1997], Benabou and Tirole [2003], and Sliwka [2007] provide economic explanations for the occurrence of crowding-out.

Our second result refers to how the employment contract, in balancing incentive and selection considerations, distorts agents' effort choices. If both agents are high-skilled and therefore suitable for the management position, they work too hard as compared to the first-best effort level. By contrast, if both agents are low-skilled and thus less suited for the management position, they exert too little effort. The reason is that, under any given contract, high-skilled agents are more motivated as they gain relatively more from promotion.

If agents are heterogeneous, inducing a large difference between the high-skilled and the low-skilled agent's effort levels improves selection. Taking this into account, the optimal combination of the piece rate scheme and the promotion tournament implies that the more able agent puts in too little effort, and the less able agent too much. Thus, the latter has an inefficiently high promotion probability. The principal is compelled to accept this inefficiency as a result

[9] Furthermore, starting with the seminal paper by Lazear and Rosen [1981], a large literature has identified conditions under which relative incentive schemes dominate individual performance pay or *vice versa*. See, e.g., Green and Stokey [1983] and Nalebuff and Stiglitz [1983]. However, none of these papers analyzes the combination of both incentive schemes.

of optimally trading off incentive and selection issues. This observation can be interpreted as a rationale for the occurrence of the Peter Principle, which states that employees are promoted to their level of incompetence [Peter and Hull, 1969]. Fairburn and Malcomson [2001] show that the conflicting goals of incentive provision and risk allocation may also cause the Peter Principle. In their framework, however, this occurs only if agents are risk-averse. In our model, agents are risk-neutral.[10]

Finally, our paper is also related to the literature on selection tournaments, which analyzes relative reward schemes with the primary objective to facilitate the assignment of employees to jobs they are most suitable for. Such tournaments have been analyzed by Rosen [1986], Meyer [1991], Clark and Riis [2001], Hvide and Kristiansen [2003], Tsoulouhas, Knoeber, and Agrawal [2007] and, in the context of sabotage, by Lazear [1989], Chen [2003], and Münster [2007].[11] In contrast to all of these authors, we focus on the selection effect of a promotion tournament in combination with a piece rate scheme. Furthermore, in our model, agents are heterogeneous in the tournament stage only because they differ in their respective valuation of the tournament prize. In the aforementioned papers, however, agents' heterogeneity is due to different abilities in the tournament stage.

From the studies mentioned above, Tsoulouhas et al. [2007] is closest to our paper. They consider a tournament between employees (insiders) and external candidates (outsiders) who differ in their suitability for becoming the new CEO. They explicitly focus on the trade-off between providing employees with efficient effort incentives and selecting the most suitable candidate among all contestants. Central to their study is the question whether handicapping outsiders can be efficient in order to strengthen internal effort incentives while jeopardizing the selection effect of the tournament. They show that handicapping outsiders can be optimal whenever insiders are not much worse than the external contestants in terms of their suitability for becoming the new CEO. Put differently, firms might be willing to sacrifice the efficiency of selection in order to reinforce internal effort incentives. Our study differs in two main aspects: First, we focus on a tournament between internal contestants who vary in their suitability for promotion. Second, we identify the optimal combination of a promotion tournament and

[10] Alternative explanations for the occurrence of the Peter Principle are provided by, e.g., Bernhardt [1995], Faria [2000], Lazear [2004], and Koch and Nafziger [2007]. For empirical evidence on the Peter Principle refer to **?**.

[11] **?** and Gibbons and Waldman [2006] also investigate the optimal assignment of employees to different jobs, though in the absence of explicit tournament schemes in the usual fashion. In their framework, employees potentially differ in their respective abilities to perform tasks. Even though these abilities cannot directly be observed by firms, they can use the employees' respective output as biased signals about their individual abilities. This gradual learning process eventually facilities the optimal assignment of employees to jobs their are best suited for.

individual performance pay as a means to balance selection and incentive effects appropriately.

This paper is organized as follows. The model is introduced in Section 2. In Section 3, we derive agents' effort levels at the production stage given the tournament prize and individual performance pay. The optimal combination of the tournament prize and the individual incentive scheme is characterized in Section 4. Section 5 discusses the impact of some our assumptions on the results and considers some extensions. In Section 6, we elaborate on some empirical predictions which can be derived from our framework and conclude.

2 The Model

A risk-neutral principal owns a firm in which two types of tasks need to be performed: manufacturing tasks (*production stage*) and management tasks (*management stage*). The firm regularly recruits risk-neutral agents to carry out these tasks. There are more jobs in production than in management.

We focus on two representative periods in the firm's life. At the beginning of the first period, the firm needs to hire two production workers. At the beginning of the second period, there is a vacant management position. We assume that the prospective manager requires a sufficient level of firm-specific human capital to conduct the corresponding tasks effectively. Therefore, the manager will be recruited from the internal pool of agents, i.e., from the two production workers hired in the previous period.

There are two different types of agents in the labor market, denoted type A and type B. They are equally skilled in the manufacturing task,[12] but differ in their abilities for the management job. Agents of type A can conduct the management task more efficiently than agents of type B. Prior to the contracting stage, neither the principal nor the agents observe their respective types. It is, however, common knowledge that an agent is of type A with probability p, and of type B with probability $1 - p$, where $0 < p < 1$. After accepting the contract offered by the principal and entering into the employment relationship, an agent becomes familiar with the tasks of a manager in this particular firm, and can thus assess his own suitability for the management position. Put simply, an agent learns his own type. Moreover, each agent also observes the type of his coworker, whereas the principal never observes the agents' individual skills. This assumption reflects that employees who work closely together usually possess better

[12]This assumption is justified if the manufacturing task is simple and therefore does not require any particular skills, e.g. a job at an assembly line. For the case of different abilities in the production task, see Section 5.

information about one another's talents and ambitions than the principal.[13] For simplicity, we assume that an agent's reservation utility is independent of his type and equals zero throughout the game.

At the *production stage*, agent i, $i = 1, 2$, chooses a non-observable effort level $e_i \geq 0$, leading to the verifiable output

$$q_i = e_i + \mu_i, \tag{1}$$

where μ_1 and μ_2 are identically and independently distributed random variables with zero mean and $\mu_1, \mu_2 \in \mathbb{R}$.[14] Implementing effort e_i imposes strictly convex increasing costs $c(e_i)$. To ensure the existence of a pure-strategy equilibrium at the production stage, we further assume that $\inf_{e>0} c''(e) > 0$. Since effort is non-observable, the principal cannot specify a desired effort level in a court-enforceable contract. She can, however, offer an incentive contract based on the realized output q_i. We restrict our attention to linear incentive schemes, assuming that an agent's wage at the production stage consists of a piece rate r conditioned on q_i and a fixed payment w_1.[15]

At the *management stage*, for the reasons discussed in the Introduction, there are no contractible performance measures available. A manager therefore exerts only some minimum required effort level (i.e., he performs his task in a way that is acceptable to the principal so that he will not be dismissed) and receives a fixed wage w_2 in return. To ensure that one of the former production workers agrees to be employed as a manager, even if both workers are of type B, the principal needs to offer a non-negative management wage $w_2 \geq 0$. Since agents of type A have a higher ability for conducting the management task, their expected contribution to firm value is higher than that of type B agents. Letting Π_k, $k \in \{A, B\}$, denote type k's expected contribution to firm value on the management stage, it therefore holds that $\Pi_A > \Pi_B$. Moreover, we assume that – because of his higher talent – type A does not only perform the managerial task more effectively, but also needs less time to complete it. This implies that type A has also lower costs for implementing the minimum effort level as compared to type B.[16]

[13]Assuming that agents know one another's type also greatly simplifies the analysis. Nevertheless, the first-best job assignment may not be feasible, e.g. if communication between the principal and agents is prohibitively costly, or agents can collude [Laffont and Martimort, 2000]. We discuss this point in more detail in footnote 18.

[14]This output function is frequently used in the tournament literature. In particular, it is identical to the one in Lazear and Rosen [1981].

[15]Presumingly due to the high practical relevance and good tractability of linear payment schemes, many theoretical papers in labor economics focus on the analysis of linear incentive contracts. See Holmström and Milgrom [1987] for a discussion of the optimality of linear contracts.

[16]In general, talent will affect both the quality and the speed of finishing a task. For example, a better manager

Alternatively, type A could enjoy certain attributes of the management job more than type B (e.g. more interesting tasks, higher status), which lowers the former's disutility of effort. To reduce the notational burden, we normalize type B's effort costs for the management task to zero, while type A's costs are $-\delta$, where $\delta > 0$. Type A therefore obtains a higher utility from being employed as a manager.

Since $\Pi_A > \Pi_B$, the principal prefers to select a type A agent for the management position. With a management wage $w_2 \geq 0$, however, there will be no self-selection as both agents always prefer becoming a manager to leaving the firm.[17] Furthermore, we assume that, after the contracting stage, communication between the principal and the agents is prohibitively costly, e.g. due to time constraints on the side of the principal.[18] Therefore, the principal stipulates a compensation scheme and a promotion policy that will be offered to all potential production workers and does not allow for any form of ex-post communication. Consequently, employment rules are independent of an agent's type. In practice, establishing such simple employment rules facilitates recurrent recruitment and promotion procedures. For example, the owner of a large firm usually has to delegate the implementation of these procedures to a third party. Then, dictating employment rules that are not manipulable avoids agency problems such as influence activities or collusion, which may occur when payoff-relevant decisions are left to a third party's discretion (see e.g. Tirole [1986] or Fairburn and Malcomson [2001]).

To increase the chances of employing a type A agent as a manager, the principal can try to take advantage of the fact that type A agents have a higher valuation of being promoted to the management level. To do so, the principal designs the following promotion tournament: in the first period, both agents are assigned to the manufacturing task. At the end of this period, the

may find more effective solutions to organizational problems and also come up faster with a viable solution than a less able manager. Thus, being of a superior type implies to have a higher productivity *and* lower effort costs, as in our framework. Usually, only one of these assumptions is made to model different abilities of agents. However, we require both of them because we only allow for a fixed wage at the management stage. Refer to Section 5 for a more detailed discussion.

[17]Note that type B's weak preference for becoming a manager can easily be turned into a strong one by introducing costs for moving to a new firm after the first period.

[18]Such an assumption is not uncommon in the literature on incentive contracting (see e.g. Che and Yoo [2001], p. 528). It rules out the implementation of the first-best solution by asking both agents to report their types and punishing them if their reports do not coincide. In our model, this assumption has the consequence that wages are attached to jobs rather than to individual types, which is typically the case in practice (see e.g. Baker et al. [1988], Eriksson [1999]). Furthermore, the first-best solution is not implementable if communication is feasible but agents can collude and the principal might use information on agents' types opportunistically. To see this, let w_2^i, $i = A, B$, denote the wage of a type i manager. Offering a wage w_2^i that exceeds type i's effort costs may not be credible since the principal can use the information on the agent's type to lower his wage ex-post. Thus, $w_2^A = -\delta$ and $w_2^B = 0$. However, if at least one agent is of type A, agents obtain a positive expected rent from colluding to report that they both are of type B.

agent with the higher output is promoted to the management position. The tournament prize is the management wage w_2. Under this promotion rule, performance at the production stage serves as a signal about skills for the management job. As we will show in Section 3, whenever the randomly recruited agents are heterogeneous, type A exerts higher effort than type B. This is because type A's valuation of promotion is higher. Consequently, the better performing agent is more likely to be of type A.

Note that applying such a promotion tournament causes the following inefficiency: even though both types are equally skilled in production, they will exert different effort levels in the manufacturing task. This can be prevented only by a purely random assignment of agents to the management position, which clearly comes at the cost of completely neglecting selection issues. We henceforth assume that the principal prefers to design a promotion tournament – thereby improving her information about agents' types – to implementing efficient effort in the manufacturing task. Intuitively, this is the case whenever the promotion decision is sufficiently crucial for firm performance, i.e., $\Pi_A - \Pi_B$ is sufficiently high. We restrict attention to such a situation because we are interested in studying the optimal combination of piece rates schemes and promotion tournaments when both incentive provision and selection are important.

The timing of the game is as follows. First, the principal offers two randomly chosen agents a contract consisting of a piece rate scheme (r, w_1). After accepting the contract, each agent learns his type and that of his coworker. Then, both agents are assigned to the manufacturing task and choose their respective effort levels e_i.[19] Once output levels q_i are realized, both agents obtain their individual performance pay according the stipulated piece rate scheme. Furthermore, the agent with the higher output is promoted to the management level and obtains the management wage w_2. The other agent leaves the firm and receives his reservation utility.[20]

3 Effort in the Production Stage

In this section, we derive agents' effort choices in the production stage for a given employment contract. To do so, we need to account for three possible matches of agents: two homogeneous matches where both agents are either of type A or of type B; and a heterogeneous match with

[19] Agents thus observe their types *after* signing the contract but *before* choosing effort levels. In practice, this information might be acquired during a training period, where workers already exert some effort. However, we assume that this period is relatively short, and can therefore be neglected.

[20] Alternatively, one could assume that the losing agent stays with the firm and competes in the next period with a newly hired agent. However, such an extension complicates the analysis without offering any additional insights.

a type A and a type B agent. For each match, we determine the combination of effort choices that constitutes a pure-strategy Nash-equilibrium.

By implementing effort in the production stage, agents do not only affect their incentive payments conditional on production output, but also their probability of being promoted to the management level. Agent i's promotion probability is

$$\mathrm{Prob}[q_i > q_j] = \mathrm{Prob}[e_i - e_j > \mu_j - \mu_i] \equiv G(e_i - e_j), \quad i, j \in \{1, 2\}, \ i \neq j, \tag{2}$$

where $G(\cdot)$ is the cumulative distribution function of the random variable $\mu_j - \mu_i$. Let $g(\cdot)$ denote the corresponding density function, which we assume to be differentiable and single-peaked at zero. Since μ_i and μ_j are identically distributed, $g(\cdot)$ is symmetric around zero.

We start by investigating the case of homogeneous agents. First, suppose that both randomly employed agents are of type A. Taking the effort of agent j as given, agent i chooses e_i to maximize his expected payment

$$w_1 + G(e_i - e_j)(w_2 + \delta) + re_i - c(e_i). \tag{3}$$

It is straightforward to verify that the Nash-equilibrium is unique and symmetric. The equilibrium effort, denoted e_{AA}, is implicitly defined by the first-order condition

$$g(0)(w_2 + \delta) + r = c'(e_{AA}). \tag{4}$$

Similarly, for the case where both agents are of type B, equilibrium effort e_{BB} is characterized by

$$g(0)w_2 + r = c'(e_{BB}). \tag{5}$$

To ensure that e_{AA} and e_{BB} indeed represent Nash-equilibria, it is sufficient to require that agents' objective functions are concave. This is the case if

$$g'(e_i - e_j)(w_2 + \delta) - c''(e_i) \ < \ 0 \quad \text{for all } e_i, e_j \geq 0, \tag{6}$$

$$\text{and} \qquad g'(e_i - e_j)w_2 - c''(e_i) \ < \ 0 \quad \text{for all } e_i, e_j \geq 0. \tag{7}$$

We assume that these conditions are satisfied for the highest w_2 that the principal is willing to offer the agents.[21] Since $\inf_{e>0} c'' > 0$, this is the case whenever random influences on output are significant enough, i.e., $g(\cdot)$ is sufficiently 'flat'.

Now we turn to the case of heterogeneous agents. Without loss of generality, assume that agent 1 is of type A and agent 2 is of type B. Type A's and type B's respective optimization problems are:

$$\max_{e_1} w_1 + G(e_1 - e_2)(w_2 + \delta) + re_1 - c(e_1), \tag{8}$$

$$\max_{e_2} w_1 + [1 - G(e_1 - e_2)]w_2 + re_2 - c(e_2). \tag{9}$$

Type A's and B's equilibrium effort levels e_A and e_B, respectively, are given by the following two first-order conditions:

$$g(e_A - e_B)(w_2 + \delta) + r \quad = \quad c'(e_A), \tag{10}$$

$$g(e_A - e_B)w_2 + r \quad = \quad c'(e_B). \tag{11}$$

The second-order conditions are identical to (6) and (7) and are thus satisfied.

From (10) and (11) it becomes clear that $\Delta e \equiv e_A - e_B > 0$. Because type A's benefit from being promoted is higher, he is motivated to work harder than type B under each given incentive scheme. Hence, type A has a higher probability of winning the promotion tournament, i.e. $G(\Delta e) > 0.5$.

We demonstrate in the Appendix (see Proof of Proposition 1) that e_A and e_B are increasing in r and w_2. Besides this *incentive effect*, increasing either r or w_2 has also a *selection effect*. The latter arises from the fact that modifying r or w_2 affects the effort difference Δe and thus, agents' promotion probabilities. The next Proposition characterizes this selection effect.

Proposition 1 *Suppose the randomly recruited agents are heterogeneous. If the harder working type A agent responds less strongly to intensified incentives than the type B agent (i.e. if $c''(e_A) > c''(e_B)$), type A's probability of winning the promotion tournament is decreasing in r and w_2. Otherwise, type A's winning probability increases in r and w_2.*

All proofs are given in the Appendix.

When the principal intensifies effort incentives by raising r or w_2, both types of agents are motivated to exert more effort. Whose effort level increases more rapidly depends upon the

[21] Recall that agents' effort costs are convex, whereas the principal's expected profit will be concave in effort. Since the principal needs to compensate both agents for their disutility of effort to guarantee their participation, it cannot be optimal to induce arbitrarily high effort levels. Thus, there exists an upper bound for w_2.

shape of the effort cost function. If marginal effort costs increase disproportionately ($c''(e_A) > c''(e_B)$), the harder working type A responds less strongly to intensified incentives than type B. In this case, providing higher effort incentives lowers type A's chances for promotion, and is therefore detrimental to selection. In contrast, if type A's effort is more responsive to intensified incentives ($c''(e_A) < c''(e_B)$), his winning probability increases in r and w_2.

Our main result, emphasized by Proposition 3, is derived under the presumption that $c''(e_A) > c''(e_B)$. This condition holds for all e_A and e_B if marginal cost of effort increases in e, i.e. $c'''(e) > 0$.[22] As discussed, this is equivalent to a situation where – under a tournament scheme – the effort choice of the harder working agent is less sensitive to intensified effort incentives. We believe that this is the more realistic case in a situation like ours, where two equally skilled production workers compete for promotion. A production worker who already puts in more effort than his co-worker should find it more difficult to enhance his performance as this would require to further increase his working pace or to work even longer hours. Naturally, a worker's physical capacity and potential working time per day is limited, and being closer to this limit means that exerting more effort is increasingly burdensome. This is in particular the case if one considers a situation where workers' effort levels are already significant. Such a situation seems to be realistic in the current production environment, where moderate performance may be ensured without explicit effort incentive schemes, e.g. by monitoring workers' behavior in the workplace or threatening to dismiss low performers. In our model, we can interpret $e = 0$ as such a moderate performance level. Anticipating that his hard-working co-worker has less scope for significantly improving his performance, the less hard-working employee has an additional incentive to increase his effort in order to improve his changes of winning the promotion tournament. Thus, we can conjecture that the effort difference between workers decreases, which is synonymous to assuming $c'''(e) > 0$ for all $e > 0$.

More generally, we presume that increasing effort incentives in a tournament context tends to even out performance differences. In a sports context, this conjecture finds support by an empirical study by Garicano and Palacios-Huerta [2006], who analyze the effects of increased effort incentives in professional soccer leagues. They find that the number of matches decided by two or more goals decreased by 5 percent, while ties decreased by only 4.2 percent. The

[22]The sign of c''' is also crucial for the results in Ederer [2008], who analyzes the optimal feedback policy in tournaments. However, in contrast to our framework, this is due to dynamic incentive effects in a two-period model.

number of matches finished with a 1-goal difference therefore increased significantly.[23]

4 The Principal's Problem

In this section, we characterize the principal's optimal choice of the individual performance pay and the management compensation as tournament price. To do so, we first focus on the principal's optimization problem and discuss some basic properties of the corresponding solution. Then, we will compare the induced (second-best) effort levels with the first-best solution. To further characterize the efficiency of the induced second-best effort levels for the heterogeneous tournament match, we contrast these effort levels to an additional benchmark. Finally, we derive our main result: we show how the principal adjusts the optimal piece rate scheme and the optimal management wage when selection becomes more important.

The principal's problem is to choose the contract elements w_1, w_2, and r which maximize her expected profit. The principal's optimization problem can be stated as follows:

$$\begin{aligned} \max_{w_1,w_2,r,e_A,e_B,e_{AA},e_{BB}} \; & 2p(1-p)[(1-r)(e_A+e_B)+G(\Delta e)\Pi_A+(1-G(\Delta e))\Pi_B] \\ & +p^2[2(1-r)e_{AA}+\Pi_A]+(1-p)^2[2(1-r)e_{BB}+\Pi_B]-2w_1-w_2 \end{aligned} \tag{12}$$

s.t. (4), (5), (10), (11), and

$$\begin{aligned} & w_1+p(1-p)[re_A+G(\Delta e)(w_2+\delta)-c(e_A)]+(1-p)p[re_B+(1-G(\Delta e))w_2-c(e_B)] \\ & +p^2[re_{AA}+0.5(w_2+\delta)-c(e_{AA})]+(1-p)^2[re_{BB}+0.5w_2-c(e_{BB})]\geq 0 \end{aligned} \tag{13}$$

Clearly, the principal's objective function (12) consists of the different expected profits from each possible tournament match, weighted by their respective probabilities of occurrence. For example, the first line in (12) refers to the case where agents are heterogeneous, which occurs with probability $2p(1-p)$. Then, at the production stage, the principal obtains the agents' output minus the piece rate, $(1-r)(e_A+e_B)$. At the management stage, the principal receives Π_A if the type A agent is promoted, which occurs with probability $G(\Delta e)$, and Π_B otherwise.

When maximizing her expected profit, the principal needs to account for the incentive com-

[23] Contrary to our approach, Garicano and Palacios-Huerta [2006] focus on the multi-dimensional aspect of effort. Their primary objective is to identify how intensified incentives affect productive effort (offensive play) and counterproductive effort (sabotage or "dirty play"). They find that soccer teams increased both types of effort, leaving the scoring unchanged. However, fewer matches were decided by a large number of goals.

patibility constraints for each potential tournament match as well as for the agents' participation constraint (13). The latter implies that an agent's expected utility from the employment relationship must be at least as high as his reservation utility, which is normalized to zero. In (13), the first term in square brackets refers to the case where the agent is of type A while his co-worker is of type B. The second term in square brackets relates to the opposite case. The last two terms are associated with the homogeneous matches, where both agents implement identical effort levels in production and therefore, have the same promotion probability of 0.5.

Next, observe that cost minimization requires the principal to choose w_1 such that (13) binds. Consequently, we can eliminate w_1 from the principal's optimization problem and hence, obtain the simplified problem:

$$\max_{r,w_2,e_A,e_B,e_{AA},e_{BB}} \Pi := \pi_{AB} + \pi_{AA} + \pi_{BB} \qquad \text{s.t. } (4),(5),(10),(11). \tag{14}$$

The term π_{kl}, where $k, l \in \{A, B\}$, denotes the expected profit from a tournament match where one agent is of type k and the other agent of type l, weighted by its probability of occurrence, i.e.,

$$\pi_{AB} \equiv 2p(1-p)\left[e_A + e_B + G(\Delta e)(\Pi_A + \delta) + (1 - G(\Delta e))\Pi_B - c(e_A) - c(e_B)\right], \tag{15}$$

$$\pi_{AA} \equiv p^2\left[2e_{AA} + \Pi_A + \delta - 2c(e_{AA})\right], \tag{16}$$

$$\pi_{BB} \equiv (1-p)^2\left[2e_{BB} + \Pi_B - 2c(e_{BB})\right]. \tag{17}$$

From a closer inspection of (15)-(17) it becomes clear that – in each tournament match – the principal extracts the entire surplus from the employment relationship. For instance, in the heterogeneous match reflected by equation (15), the principal obtains the expected surplus from the management stage, in addition to the entire expected output from the production stage, $e_A + e_B$, net of agents' effort costs. This can be observed because agents do not possess private information prior to the contracting stage, and the principal can adjust the fixed wage w_1 such that both agents are just compensated for their expected costs of effort.

Let e_A^*, e_B^*, e_{AA}^*, and e_{BB}^* denote the effort levels that solve the principal's optimization problem (14). To evaluate the efficiency of these effort levels, we now analyze how they compare to the first-best effort level,

$$e^{FB} = \text{argmax}_e e - c(e). \tag{18}$$

Clearly, the principal would induce the first-best effort level e^{FB} if types and effort were publicly observable. The incentive compatibility constraints (4) and (5) imply that effort in an AA-match always exceeds effort in a BB-match, i.e., $e^*_{AA} > e^*_{BB}$. Furthermore, from the incentive-compatibility constraints for the heterogeneous tournament, (10) and (11), we know that $e^*_A > e^*_B$. Hence, it is clear that the induced effort levels for the different tournament matches cannot all be identical to the first-best effort level e^{FB}. The next proposition further characterizes the implemented effort levels e^*_A, e^*_B, e^*_{AA}, and e^*_{BB}.

Proposition 2 *Suppose the employment contract comprises $r^*, w_2^* > 0$. Then, agents in a BB-match exert too little, and agents in an AA-match exert too much effort as compared to the first-best effort level, i.e., $e^*_{BB} < e^{FB} < e^*_{AA}$. In an AB-match, type B's effort is inefficiently low, i.e., $e^*_B < e^*_{BB} < e^{FB}$. Moreover, type A implements less effort in the heterogenous than in the homogenous tournament match, i.e., $e^*_A < e^*_{AA}$. This implies that type A's effort can be either too high or too low relative to the first-best effort level e^{FB}.*

To understand the intuition for the result in Proposition 2 with respect to the homogeneous matches, recall that the piece rate r and the management wage w_2 are substitutes with respect to the provision of incentives at the production stage. Accordingly, there exists an infinite number of combinations of r and w_2 that induce the desired effort levels in the AB-match at the same costs for the principal. Among these combinations, the principal selects the one that provides appropriate effort incentives in the homogeneous tournaments. If agents worked too little (too hard) in both homogeneous tournament matches compared to the first-best solution, the principal's marginal benefit from increasing (decreasing) effort incentives would be positive. Consequently, under the optimal combination of a piece rate scheme and a promotion tournament, agents implement inefficiently high effort in AA-matches and inefficiently low effort in BB-matches.

Furthermore, for any arbitrary compensation scheme, an agent works harder if he faces an opponent with the same valuation for promotion, i.e., $e^*_B < e^*_{BB}$ and $e^*_A < e^*_{AA}$. Intuitively, different valuations for the management job implies different effort levels, which in turn gives the harder working agent an advantage in the competition for promotion. As a result, increasing effort is less beneficial for both types of agents in an AB-match. This implies that type B's effort is even further below the first-best effort level when he competes with a type A agent for promotion. By contrast, whether type A's effort level in the heterogenous tournament, e^*_A, is closer to or further from the first-best effort level than his effort in the homogenous tournament, e^*_{AA}, depends on the specific functional forms.

It is also interesting to have a closer look at the promotion probability of a type B worker in an AB-match, which is characterized by $1 - G(e^*_A - e^*_B)$ and hence, positive. However, if the first-best solution was feasible, the principal would never select a type B agent for the management position. Therefore, type B's promotion probability is inefficiently high under the contract solving the optimization problem (14). To quantify this inefficiency, we now consider an additional benchmark. Let $\hat{e}_A$ and $\hat{e}_B$ denote the effort levels that maximize π_{AB} as given in (15). For this benchmark, we already take into account that implementing a higher effort for type A than for type B in an AB-match improves selection and his therefore beneficial to the principal. The benchmark effort levels $\hat{e}_A$ and $\hat{e}_B$ are implicitly characterized by

$$c'(\hat{e}_A) = 1 + g(\Delta\hat{e})(\Pi_A - \Pi_B + \delta), \tag{19}$$

$$c'(\hat{e}_B) = 1 - g(\Delta\hat{e})(\Pi_A - \Pi_B + \delta). \tag{20}$$

Hence, to maximize π_{AB}, the principal prefers type A to work harder than type B, i.e., $\hat{e}_A > \hat{e}_B$. Moreover, this implies $\hat{e}_A > e^{FB} > \hat{e}_B$. Corollary 1 now points out that type B's promotion probability is not only too high relative to the first-best solution, but also compared to the previously defined benchmark.

Corollary 1 *Compared to the benchmark effort levels $\hat{e}_A$ and $\hat{e}_B$, type A works too little while type B works too hard in an AB-match, i.e.,*

$$e^*_A < \hat{e}_A \text{ and } \hat{e}_B < e^*_B.$$

Thus, agent B's promotion probability is inefficiently high relative to the benchmark promotion probability, i.e., $1 - G(\hat{e}_A - \hat{e}_B) < 1 - G(e^*_A - e^*_B)$.

There are two driving forces behind this result. First, the principal is simply not able to induce the benchmark effort levels $\hat{e}_A$ and $\hat{e}_B$ because she cannot contract upon effort and is not able to observe the agent's respective types. Thus, any incentive contract cannot induce the efficient effort levels, and at the same time, ensure an efficient job assignment.[24]

[24]Formally, the incentive compatibility constraints for the heterogeneous match, (10) and (11), imply that $c'(e^*_A) - c'(e^*_B) = g(\Delta e^*)\delta$. It then follows from (19) and (20) that $c'(e^*_A) - c'(e^*_B) \neq c'(\hat{e}_A) - c'(\hat{e}_B)$.

Nevertheless, it would still be possible to induce the benchmark promotion probability, which is characterized by the effort difference $\Delta\hat{e} = \hat{e}_A - \hat{e}_B$. Here, the second driving force comes into play: the conflict between incentive provision and selection. To induce the benchmark effort difference $\Delta\hat{e}$, both agents' effort levels would have to be either higher or lower than $\hat{e}_A$ and $\hat{e}_B$, respectively. Clearly, this is not optimal from an incentive perspective. The principal therefore compromises on selection and induces a lower effort difference by making the type A agent working less, and the type B agent working harder than in the benchmark case. This in turn implies that type B is promoted too frequently as compared to the benchmark. The principal deliberately accepts this inefficiency as a necessary consequence of balancing incentive and selection effects appropriately.

The following proposition emphasizes how the contract elements change when it becomes more important for the principal to promote a type A agent.

Proposition 3 *Suppose that $c''(e_A^*) > c''(e_B^*)$ and $\Pi_A - \Pi_B$ increases, i.e., assigning a type A agent to the management position becomes more desirable. The principal then offers a lower piece rate r^* and a higher management wage w_2^*, i.e.,*

$$\frac{\partial r^*}{\partial(\Pi_A - \Pi_B)} < 0 \text{ and } \frac{\partial w_2^*}{\partial(\Pi_A - \Pi_B)} > 0.$$

Overall, the induced effort levels e_A^* and e_B^* decrease, while the induced effort difference $\Delta e^* = e_A^* - e_B^*$ increases. As a consequence, in a heterogeneous tournament match, type A's promotion probability increases. The effort levels in the homogeneous tournaments, e_{AA}^* and e_{BB}^*, remain unchanged.

Recall from Proposition 1 that both lowering the piece rate r and the management wage w_2 improves selection if the harder working type A agent responds less strongly to intensified effort incentives than type B (i.e., $c''(e_A^*) > c''(e_B^*)$). Why, then, does the principal decrease r and increase w_2 when promoting a type A agent becomes more important? The answer can be found in the optimal incentive structure for the homogeneous tournaments. Since selection is irrelevant in these matches, the implemented effort should be independent of $\Pi_A - \Pi_B$. Indeed, the adjustments of r^* and w_2^* are such that e_{AA}^* and e_{BB}^* remain constant. This can only be achieved if any change in effort incentives caused by a higher piece rate is offset by appropriately adjusting the management wage. According to the incentive compatibility constraints for the homogeneous tournament matches, (4) and (5), an agent's marginal benefit from raising effort increases by 1 under a marginally higher piece rate r. By contrast, the marginal gain from implementing more effort under a marginally higher management wage w_2 increases by $g(0)$. Thus, the incentive effects from adopting the piece rate and the management wage just cancel out if

$$\frac{\partial r^*}{\partial(\Pi_A - \Pi_B)} + g(0)\frac{\partial w_2^*}{\partial(\Pi_A - \Pi_B)} = 0. \tag{21}$$

An increase in r^* must therefore be accompanied by a lower w_2^* and vice versa.

In the heterogeneous tournament match, a reduction of the effort difference – which aims at improving the selection effect – is achieved when overall effort incentives decrease. We can infer from the respective incentive compatibility constraints, (10) and (11), that this is the case if

$$\frac{\partial r^*}{\partial(\Pi_A - \Pi_B)} + g(\Delta e^*)\frac{\partial w_2^*}{\partial(\Pi_A - \Pi_B)} < 0. \tag{22}$$

Since $g(\cdot)$ is single-peaked at zero, we have $g(\Delta e^*) < g(0)$. This implies that agents in an AB-match respond less strongly to adjustments of the management wage w_2 than agents in a homogeneous match. Intuitively, since heterogeneous agents exert different effort levels, their promotion probabilities are less sensitive to changes in effort than those of homogeneous agents. As a consequence, a higher management wage has a weaker incentive effect when agents differ in their skills. Thus, given that r^* and w_2^* are adopted such that (21) holds, the impact on effort levels in a heterogeneous match is determined by the sign of the change in r rather than w_2. As a result, a reduction in e_A^* and e_B^* – while holding e_{AA}^* and e_{BB}^* constant – can only be achieved by *lowering* the piece rate and *raising* the management wage.

The driving force behind this result is the tension between incentive and selection considerations, which can be summarized as follows: The principal knows that selection is not always important. Sometimes, the principal hires production workers who would be equally good managers (AA- or BB-match), but sometimes production workers differ substantially in their management skills (AB-match). In the latter case, the compensation scheme should support the selection of good managers. However, at the same time, effort incentives for homogeneous workers should not be too heavily distorted. This objective can be achieved by offering both workers a higher piece rate scheme and a lower management wage whenever selection becomes more important (i.e., $\Pi_A - \Pi_B$ increases).

Now we impose the additional (and certainly realistic) restriction that piece rates should be nonnegative. We then obtain the following result.

Corollary 2 *Suppose that the principal prefers to restrict the piece rate scheme r to nonnegative values. If $c''(e_A) > c''(e_B)$ for all effort levels e_A and e_B that satisfy $e_A > e_B$, and $\Pi_A - \Pi_B$ is sufficiently large, then the principal does not provide individual performance pay, i.e., $r^* = 0$.*

Corollary 2 implies that the principal refrains from offering the agent individual performance pay if selecting high-ability managers is sufficiently important, and the effort choice of these already harder working high-ability types is less sensitive to intensified incentives. In this case, putting more emphasis on individual performance pay would encourage low-ability types to catch up and thus, increase their chances of promotion.

The potential difference of workers with respect to their abilities, quantified by $\Pi_A - \Pi_B$, is likely to be large in environments where the principal finds it difficult to screen agents before offering them an employment contract. This can be due to two reasons. First, a worker's performance in his former occupations is not publicly observable. Second, a worker's former performance constitutes only a poor proxy for his performance in higher-level jobs. Both aspects fit our framework. First, a production worker's performance is commonly not publicly observable. In particular, if previous employers also paid only fixed wages, individual performance has not been rewarded before and hence, the ability of production workers cannot be deduced from their wages earned in former jobs. Second, production tasks require substantially different skills than management tasks. Accordingly, even if a worker has good references, this may not facilitate efficient promotion decisions as well-performing production workers are not necessarily successful managers. Therefore, our results help to explain the absence of performance pay in lower hierarchy levels in firms when ex-ante evaluations of employees' characteristics are hardly possible. More specifically, screening can be expected to be more difficult for workers with a low education level due to the lack of degrees signalling their individual skills. Indeed, several empirical studies suggest that individual performance pay is more prevalent in firms with a highly-educated workforce (e.g. **?**, **?**, Barth et al. [2008]). Finally, our conclusion that promotion tournaments constitute the primary incentive device when selection is important, is in line with two observations. First, employees with a low education level earn in most cases only minimum wages. Second, internal compensation structures are generally characterized by significant wage differentials across different hierarchy levels.

5 Extensions and Discussion

In this section, we discuss the impact of some of our assumptions on the results stated above.

So far, we have analyzed a situation where both types of agents have identical skills in production. Now suppose instead that type A has effort costs $\alpha c(e_i)$, $\alpha > 0$, at the production stage, whereas type B's effort costs are still $c(e_j)$. If $\alpha = 1$, we are clearly in the case of equally skilled agents as analyzed above. If $\alpha > 1$, type A is a better manager but a worse production worker than type B. This reflects a situation where agents have different abilities and/or preferences for different tasks. For example, type B might be satisfied with a job in production because he prefers simple tasks, but would dislike a more responsible and demanding occupation. By contrast, type A may be more ambitious and perceives simple tasks as stultifying. He therefore has higher marginal cost of effort for the production task than type B.[25] If, on the other hand, $\alpha < 1$, type A is not only the better manager, but also the more efficient production worker. This corresponds to a situation where good types are characterized by higher a productivity in each of the two jobs. In our framework, we consider the case $\alpha \geq 1$ to be more relevant since then the incentive and selection aspect of the promotion tournament is crucial. The reason is that – without employing a promotion tournament – type A would have only low effort incentives at the production stage. We proceed by showing that all our results continue to hold for the case with $\alpha \geq 1$. For $\alpha < 1$, however, our results remain satisfied if α is not too small.

For a heterogenous tournament match, it is straightforward to verify that type A's effort is decreasing, and type B's effort is increasing in α. Thus, ceteris paribus, a higher value of α deteriorates selection. However, the principal can counteract this effect by adjusting the incentive instruments w_2 and r appropriately. Analogous to the condition emphasized by Proposition 1, type A's promotion probability is decreasing in w_2 and r if and only if[26]

$$\alpha c''(e_A) > c''(e_B). \tag{23}$$

Consequently, if this condition holds for the optimal effort levels $e_A = e_A^*$ and $e_B = e_B^*$, the principal still decreases r and increases w_2 when selecting a type A agent for the management position becomes more important. Thus, the results of Propositions 1 and 3 immediately extend

[25] For our framework to remain meaningful, we assume that B's cost advantage in production is not too strong such that, in equilibrium, type A still chooses a higher effort level. Otherwise, the principal would always want to promote the agent with the lower output, who is then more likely to be of type A.

[26] The derivation of this condition is equivalent to the derivation of equation (28) in the Appendix.

if we replace the condition $c''(e_A) > c''(e_B)$ with condition (23).[27] Clearly, condition (23) is more likely to hold if α is large. The reason is that, the higher A's marginal effort costs compared to B's, the less sensitive is A's effort to intensified incentives relative to B's effort. In particular, provided that (23) holds for identical skills in production as we assumed above (i.e., if $c''(e_A) > c''(e_B)$), it will continue to hold for $\alpha > 1$. Therefore, if agents are *either* good managers *or* good production workers, our results are reinforced. Intuitively, since type A is a worse production worker as compared to type B, enhancing incentives leads to an even stronger deterioration of the selection effect than for identical abilities in production.

Now consider the case $\alpha < 1$ and assume that (23) holds for $\alpha = 1$. A lower α then has two opposite effects. On the one hand, the effort difference $e_A - e_B$ increases. Then, type A works much harder than type B, which may even further decrease the former's relative responsiveness to intensified effort incentives. On the other hand, A has lower marginal cost, which counteracts the first effect. Overall, our results will continue to hold if α is sufficiently close to one. For small enough values of α, however, (23) will be violated. In this case, our results from Propositions 1 and 3 are reversed. Intensifying incentives then increases $e_A - e_B$ and thus, improves selection. As a consequence, r^* is then increasing and w_2^* decreasing in $\Pi_A - \Pi_B$. Intuitively, if α is small, type A already enjoys a significantly higher ability at the production stage. The incentive and selection effect of the promotion tournament, which stems from A's higher ability at the management job, then becomes less important. The principal therefore puts more emphasis on individual incentives at the production stage. The same is true when we return to the case of identical agents in production ($\alpha = 1$), but now assume that the harder working agent's effort is more responsive to enhanced incentives (i.e., $c''(e_A) < c''(e_B)$).

Finally, in our model, being of a superior type with respect to the management task means having a higher productivity *and* lower effort costs. Typically, only one of these assumptions is made to differentiate between types of agents. However, to ensure that the principal prefers to promote a type A agent *and* that a type A agent has a higher valuation for promotion than a type B agent, we need to impose both assumptions. This is because we only allow for a fixed management wage. However, in a richer framework where incentive contracts for managers are feasible, it would be sufficient that type A has either a higher marginal productivity or lower marginal effort costs. Then, at the end of the first period, the principal offers the promoted agent

[27] The findings summarized by Proposition 2 continue to hold for all values of α, and are independent of whether condition (23) is satisfied or not. The only exception is, if agents differ in their skills for the manufacturing task, that $\hat{e}_{AA} \neq \hat{e}_{BB}$.

a menu of contracts as in a standard adverse selection model. Regardless of being more productive or more cost efficient, a high-skilled type earns a higher rent than a low-skilled type under their respective preferred contracts. Therefore, type A still benefits more from being employed as a manager. Furthermore, despite extracting a higher rent, type A contributes relatively more to firm value. The principal therefore benefits from utilizing a promotion tournament which increases the likelihood of selecting a type A agent for the management position. If selection is sufficiently important, it should still be the case that the principal refrains from offering a piece rate scheme for the manufacturing task.

6 Conclusion

We investigate the optimal combination of individual performance pay and promotion tournaments which is aimed at motivating high effort (*motivation challenge*) and, concurrently, facilitating efficient job assignments (*selection challenge*). We find that individual performance pay and promotion tournaments are substitutes in the provision of effort incentives. The specific intensity of individual performance pay, however, is determined by the relative importance of the selection effect of promotion tournaments for firm performance. We focus on a situation where harder working employees are relatively less responsive to intensified effort incentives. Then, the more important it is to promote the most suitable worker to the management position, the higher is the management wage and the lower-powered are individual effort incentives. Moreover, although contractible performance measures are available at the production stage, we find that it can be even optimal for a firm to refrain from providing individual performance pay if the efficient job assignment is sufficiently crucial for firm performance. This can be observed because individual rewards dilute the selection effect of promotion tournaments.

In our analysis, we have focused on firms which utilize internal promotion tournaments to fill vacancies in management, rather than hiring potential candidates from the external labor market. As emphasized in the Introduction, firms predominantly use their internal labor markets when the acquisition of firm-specific human capital is a crucial factor of managerial performance. For these firms, our model predicts a negative relationship between individual performance pay and wage differentials across hierarchy levels. As revealed by our analysis, the specific design of incentive schemes in these firms is determined by the importance of individual skills of employees for their performance as managers. More precisely, higher wage differentials – which constitute the prizes for internal promotion tournaments – are accompanied by low-powered individual performance pay at lower-level jobs if individual skills have a significant effect on managerial performance.

Our prediction of a negative relationship between individual performance pay and wage differentials is in line with several empirical studies (see e.g. Baker et al. [1988] and further references therein) which find that promotion-based incentive schemes are predominant in most firms. For these firms, our analysis suggests that individual skills – and therefore efficient job assignments – are particulary important for managerial performance. This can be predicted because individual performance pay – according to our analysis – is detrimental for the selection effect of internal promotion tournaments.

On the contrary, if firms frequently recruit their managers from the external labor market, the selection effect of promotion tournaments clearly plays a minor role in the design of internal incentive schemes. Since then the provision of individual performance pay has a less severe impact on the efficiency of job assignments, we would expect that these firms utilize high-powered individual incentive pay as predicted by standard contract theory literature.[28] However, according to Baker et al. [1988] and Parent [2002], the use of high-powered incentives can only rarely be observed in practice. In light of these observations, our model indicates that in most firms individual skills have a significant contribution to managerial performance, which in turn accentuates the importance of efficient job assignments.

Finally, we note that while our framework provides clear empirical predictions, a careful econometric testing faces a non-trivial measurement problem. Although it is easy to measure wage differentials and individual performance pay in firms, differences in skills of employees – and thus their respective suitability for management positions – can not directly be quantified. However, to test for our predicted causality between the importance of individual skills for managerial performance and the specific combination of promotion-based incentives and individual performance pay, one needs to identify appropriate proxies for these skills. We belief that the most promising identification strategy would be to use panel data and compare the variation of performance of lower and middle management in firms within the same industries.

[28]In our framework, if firm-specific human capital played no role and hence, internal promotion is not important, the firm would induce first-best effort on the production stage by setting $r = 1$ and $w_2 = -\delta$. Such a management wage implies, however, that only a type A worker is willing to work as a manager. In case of a BB-match, no worker is willing to fill the management position, and the firm needs to recruit a manager from the external labor market by offering the wage $-p\delta$ to an arbitrarily chosen candidate.

7 Appendix

Proof of Proposition 1. From (10) and (11) we obtain

$$H \begin{pmatrix} \frac{\partial e_A}{\partial r} \\ \frac{\partial e_B}{\partial r} \end{pmatrix} = \begin{pmatrix} -1 \\ -1 \end{pmatrix}, \tag{24}$$

where

$$H := \begin{pmatrix} g'(\Delta e)(w_2+\delta) - c''(e_A) & -g'(\Delta e)(w_2+\delta) \\ g'(\Delta e)w_2 & -g'(\Delta e)w_2 - c''(e_B) \end{pmatrix}. \tag{25}$$

Since $\Delta e > 0$, we have $g'(\Delta e) < 0$. Together with (6), (7), and $-g'(\Delta e) = g'(-\Delta e)$ it follows that $\det(H) > 0$. Applying Cramer's Rule to (24) yields

$$\frac{\partial e_A}{\partial r} = \frac{-g'(\Delta e)\delta + c''(e_B)}{\det(H)} > 0, \tag{26}$$

$$\frac{\partial e_B}{\partial r} = \frac{-g'(\Delta e)\delta + c''(e_A)}{\det(H)} > 0. \tag{27}$$

Consequently,

$$\frac{\partial \Delta e}{\partial r} = \frac{c''(e_B) - c''(e_A)}{\det(H)}. \tag{28}$$

If $c''(e_B) < c''(e_A)$, Δe is decreasing in r. Otherwise, Δe is increasing in r.

Applying the same procedure with respect to w_2, we obtain

$$\frac{\partial e_A}{\partial w_2} = g(\Delta e)\frac{\partial e_A}{\partial r}, \tag{29}$$

$$\frac{\partial e_B}{\partial w_2} = g(\Delta e)\frac{\partial e_B}{\partial r}, \tag{30}$$

and, thus, Proposition 1 follows. □

Proof of Proposition 2. Let $\mathcal{L}$ denote the Lagrangian of problem (14), and $\lambda_1, \ldots, \lambda_4$ the Lagrange multipliers for the constraints (4), (5), (10), and (11), respectively. The corresponding first-order conditions are

$$
\begin{aligned}
\frac{\partial \mathcal{L}}{\partial r} &= \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 = 0, && (31)\\
\frac{\partial \mathcal{L}}{\partial w_2} &= [\lambda_1 + \lambda_2]\, g(0) + [\lambda_3 + \lambda_4]\, g(\Delta e^*) = 0, && (32)\\
\frac{\partial \mathcal{L}}{\partial e_A^*} &= 2p(1-p)\,[1 + g(\Delta e^*)(\Pi_A - \Pi_B + \delta) - c'(e_A^*)] \\
&\qquad + \lambda_3\,[g'(\Delta e^*)(w_2 + \delta) - c''(e_A^*)] + \lambda_4 g(\Delta e^*) w_2 = 0, && (33)\\
\frac{\partial \mathcal{L}}{\partial e_B^*} &= 2p(1-p)\,[1 - g(\Delta e^*)(\Pi_A - \Pi_B + \delta) - c'(e_B^*)] \\
&\qquad - \lambda_3 g'(\Delta e^*)(w_2 + \delta) - \lambda_4\,[g'(\Delta e^*) w_2 + c''(e_B^*)] = 0, && (34)\\
\frac{\partial \mathcal{L}}{\partial e_{AA}^*} &= 2p^2\,[1 - c'(e_{AA}^*)] - \lambda_1 c''(e_{AA}^*) = 0, && (35)\\
\frac{\partial \mathcal{L}}{\partial e_{BB}^*} &= 2(1-p)^2\,[1 - c'(e_{BB}^*)] - \lambda_2 c''(e_{BB}^*) = 0. && (36)
\end{aligned}
$$

Since $g(\Delta e^*) < g(0)$, it follows from (31) and (32) that $\lambda_1 + \lambda_2 = \lambda_3 + \lambda_4 = 0$. Suppose for a moment that $\lambda_1 = \lambda_2 = 0$. In this case, (35) and (36) imply that $c'(e_{AA}^*) = c'(e_{BB}^*)$, which is a contradiction to (4) and (5). Thus, $\lambda_1 = -\lambda_2 \neq 0$. Consequently, by (35) and (36), $1 - c'(e_{AA}^*)$ and $1 - c'(e_{BB}^*)$ must have opposite signs. Moreover, (4) and (5) entail $c'(e_{AA}^*) > c'(e_{BB}^*)$. Therefore, $1 - c'(e_{AA}^*) < 0$ and $0 < 1 - c'(e_{BB}^*)$. Since $c'(e^{FB}) = 1$, this implies that $e^{FB} < e_{AA}^*$ and $e_{BB}^* < e^{FB}$. By comparing the incentive compatibility constraints for the BB-match and the AB-match, (5) and (11) respectively, we see that, $e_B^* < e_{BB}^*$. Hence, $e_B^* < e^{FB}$. Similarly, from (4) and (10), we have $e_A^* < e_{AA}^*$. However, depending on the specific functional forms, e_A^* might be smaller or greater than e^{FB}. □

Proof of Corollary 1. Consider again the first-order conditions for the principal's problem (14), equations (31)-(36). Suppose for a moment that $\lambda_3 = \lambda_4 = 0$. Then, (33) and (34) in conjunction with (4) and (5) imply

$$
\begin{aligned}
1 + g(\Delta e^*)(\Pi_A - \Pi_B + \delta) &= g(\Delta e^*)(w_2 + \delta) + r, && (37)\\
1 - g(\Delta e^*)(\Pi_A - \Pi_B + \delta) &= g(\Delta e^*) w_2 + r. && (38)
\end{aligned}
$$

Subtracting the second from the first equation yields $2(\Pi_A - \Pi_B) + \delta = 0$, which is a contradiction to $\Pi_A > \Pi_B$ and $\delta > 0$. Thus, $\lambda_3 = -\lambda_4 \neq 0$. Using this observation, (33) and (34) can be transformed to

$$2p(1-p)\underbrace{\left[1+g(\Delta e^*)(\Pi_A-\Pi_B+\delta)-c'(e_A^*)\right]}_{\equiv F_1}\underbrace{+\lambda_3\left[g'(\Delta e^*)\delta-c''(e_A^*)\right]}_{\equiv F_2}=0, \tag{39}$$

$$2p(1-p)\underbrace{\left[1-g(\Delta e^*)(\Pi_A-\Pi_B+\delta)-c'(e_B^*)\right]}_{\equiv G_1}\underbrace{-\lambda_3[g'(\Delta e^*)\delta-c''(e_B^*)]}_{\equiv G_2}=0. \tag{40}$$

Applying (10) and (11) yields

$$F_1 = 1+g(\Delta e^*)(\Pi_A-\Pi_B-w_2)-r, \tag{41}$$

$$G_1 = 1-g(\Delta e^*)(\Pi_A-\Pi_B+w_2+\delta)-r. \tag{42}$$

Hence, $F_1>G_1$. Furthermore, by (6) and (7), F_2 and G_2 have opposite signs, so that the same must be true for F_1 and G_1. As a result, $F_1>0>G_1$, implying $e_A^*<\hat{e}_A$ and $\hat{e}_B<e_B^*$. $\square$

Proof of Proposition 3. The principal's problem (14) can be further simplified to

$$\max_{r,w_2}\ \left[\Pi(r,w_2)\equiv\pi_{AB}(r,w_2)+\pi_{AA}(r,w_2)+\pi_{BB}(r,w_2)\right], \tag{43}$$

where $\pi_{AB}(r,w_2)$, $\pi_{AA}(r,w_2)$, and $\pi_{BB}(r,w_2)$ are defined as in (15)-(17). The only difference is that e_{AA}, e_{BB}, e_A, and e_B are now expressed as functions of r and w_2, which are implicitly given by (4), (5), (10), and (11), respectively. We assume that the functional forms are such that $\Pi(r,w_2)$ is concave for all $p\in(0,1)$. Provided that $r^*, w_2^*>0$, the optimal piece rate and management wage are characterized by the first-order conditions

$$\frac{\partial\Pi}{\partial r} = \frac{\partial\pi_{AB}}{\partial r}+\frac{\partial\pi_{AA}}{\partial r}+\frac{\partial\pi_{BB}}{\partial r}=0, \tag{44}$$

$$\frac{\partial\Pi}{\partial w_2} = \frac{\partial\pi_{AB}}{\partial w_2}+\frac{\partial\pi_{AA}}{\partial w_2}+\frac{\partial\pi_{BB}}{\partial w_2}=0. \tag{45}$$

For $y \in \{r, w_2\}$ we obtain

$$\begin{aligned}\frac{\partial \pi_{AB}}{\partial y} &= 2p(1-p)\left[(1-c'(e_A^*))\frac{\partial e_A^*}{\partial y} + (1-c'(e_B^*))\frac{\partial e_B^*}{\partial y}\right.\\ &\qquad \left. + g(\Delta e^*)\frac{\partial(\Delta e^*)}{\partial y}(\Pi_A - \Pi_B + \delta)\right], \qquad (46)\\ \frac{\partial \pi_{AA}}{\partial y} &= 2p^2[1-c'(e_{AA}^*)]\frac{\partial e_{AA}^*}{\partial y}, \qquad (47)\\ \frac{\partial \pi_{BB}}{\partial y} &= 2(1-p)^2[1-c'(e_{BB}^*)]\frac{\partial e_{BB}^*}{\partial y}. \qquad (48)\end{aligned}$$

Then, (44) and (45) imply

$$K\begin{pmatrix} \frac{\partial r^*}{\partial(\Pi_A-\Pi_B)} \\ \frac{\partial w_2^*}{\partial(\Pi_A-\Pi_B)} \end{pmatrix} = \begin{pmatrix} -2p(1-p)g(\Delta e^*)\frac{\partial(\Delta e^*)}{\partial r} \\ -2p(1-p)g(\Delta e^*)\frac{\partial(\Delta e^*)}{\partial w_2} \end{pmatrix}, \qquad (49)$$

where

$$K := \begin{pmatrix} \frac{\partial^2 \Pi}{\partial r^2} & \frac{\partial^2 \Pi}{\partial r \partial w_2} \\ \frac{\partial^2 \Pi}{\partial r \partial w_2} & \frac{\partial^2 \Pi}{\partial w_2^2} \end{pmatrix}. \qquad (50)$$

From (29) and (30) it follows that $\frac{\partial(\Delta e^*)}{\partial w_2} = g(\Delta e^*)\frac{\partial(\Delta e^*)}{\partial r}$. Using this relationship and applying Cramer's Rule to (49) yields

$$\begin{aligned}\frac{\partial r^*}{\partial(\Pi_A - \Pi_B)}\det(K) &= 2p(1-p)g(\Delta e^*)\frac{\partial(\Delta e^*)}{\partial r}\left[g(\Delta e^*)\frac{\partial^2 \Pi}{\partial r \partial w_2} - \frac{\partial^2 \Pi}{\partial w_2^2}\right], \qquad (51)\\ \frac{\partial w_2^*}{\partial(\Pi_A - \Pi_B)}\det(K) &= 2p(1-p)g(\Delta e^*)\frac{\partial(\Delta e^*)}{\partial r}\left[\frac{\partial^2 \Pi}{\partial r \partial w_2} - g(\Delta e^*)\frac{\partial^2 \Pi}{\partial r^2}\right]. \qquad (52)\end{aligned}$$

These expressions can be transformed to[29]

$$\begin{aligned}&\frac{\partial r^*}{\partial(\Pi_A - \Pi_B)}\det(K) = \\ &\qquad -2p(1-p)g(\Delta e^*)\frac{\partial(\Delta e^*)}{\partial r}g(0)[g(0) - g(\Delta e^*)]\left[\frac{\partial^2 \pi_{AA}}{\partial r^2} + \frac{\partial^2 \pi_{BB}}{\partial r^2}\right], \qquad (53)\end{aligned}$$

[29]A proof is available from the authors upon request.

$$\frac{\partial w_2^*}{\partial(\Pi_A - \Pi_B)} \det(K) =$$

$$2p(1-p)g(\Delta e^*)\frac{\partial(\Delta e^*)}{\partial r}[g(0) - g(\Delta e^*)]\left[\frac{\partial^2 \pi_{AA}}{\partial r^2} + \frac{\partial^2 \pi_{BB}}{\partial r^2}\right]. \quad (54)$$

Since Π is concave, K must be negative definite. Thus, $\det(K) > 0$. Since $c''(e_A^*) > c''(e_B^*)$, according to Proposition 1, $\frac{\partial \Delta e^*}{\partial r} < 0$. Furthermore, since $\Pi = \pi_{AA}$ for $p = 1$ and $\Pi = \pi_{BB}$ for $p = 0$, concavity of Π for all $p \in (0,1)$ implies concavity of π_{AA} and π_{BB}. Thus, $\frac{\partial^2 \pi_{ii}}{\partial r^2} < 0$ for $i = A, B$. Overall, we therefore obtain

$$\frac{\partial r^*}{\partial(\Pi_A - \Pi_B)} < 0, \ \frac{\partial w_2^*}{\partial(\Pi_A - \Pi_B)} > 0. \quad (55)$$

From the equations (53) and (54) it follows immediately that

$$\frac{\partial r^*}{\partial(\Pi_A - \Pi_B)} = -g(0)\frac{\partial w_2^*}{\partial(\Pi_A - \Pi_B)}. \quad (56)$$

Using (56) in a comparative statics analysis applied to (10) and (11), it is easily verified that $\frac{\partial e_A^*}{\partial(\Pi_A - \Pi_B)}, \frac{\partial e_B^*}{\partial(\Pi_A - \Pi_B)} < 0$, and $\frac{\partial(\Delta e^*)}{\partial(\Pi_A - \Pi_B)} > 0$. Moreover, using (56) in conjunction with (4) and (5), it is straightforward to verify that $\frac{\partial e_{AA}^*}{\partial(\Pi_A - \Pi_B)} = \frac{\partial e_{BB}^*}{\partial(\Pi_A - \Pi_B)} = 0$. □

Proof of Corollary 2. First recall that $\frac{\partial \Delta e^*}{\partial r} < 0$. Then, from (44) and (46)-(48), we can see that there is a pair $\bar{\Pi}_A, \bar{\Pi}_B$ such that $\max_{w_2} \frac{\partial \Pi}{\partial r}\Big|_{r=0} < 0$ for all $\Pi_A - \Pi_B > \bar{\Pi}_A - \bar{\Pi}_B$. Since Π is concave, $\frac{\partial \Pi}{\partial r}$ is decreasing in r for all w_2. Thus, $\frac{\partial \Pi}{\partial r} < 0$ for all $r > 0$ and $\Pi_A - \Pi_B > \bar{\Pi}_A - \bar{\Pi}_B$. Hence, $r^* = 0$ for all $\Pi_A - \Pi_B > \bar{\Pi}_A - \bar{\Pi}_B$. □

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Appendix for Referees (not to be published)

Derivation of (53). To derive (53), we transform the term in square brackets in equation (51). To do so, we use the relationships

$$\begin{aligned}\frac{\partial e_i^*}{\partial w_2} &= g(\Delta e^*)\frac{\partial e_i^*}{\partial r}, &(57)\\ \frac{\partial e_{ii}^*}{\partial w_2} &= g(0)\frac{\partial e_{ii}^*}{\partial r}, &(58)\\ \frac{\partial^2 e_{ii}^*}{\partial r \partial w_2} &= g(0)\frac{\partial^2 e_{ii}^*}{\partial r^2} = \frac{1}{g(0)}\frac{\partial^2 e_{ii}^*}{\partial w_2^2}, &(59)\end{aligned}$$

where $i = A, B$. Equation (57) is identical to (29) and (30), respectively. Equation (58) is easily verified by applying the implicit function theorem to (4) and (5), respectively. The last equation can be proved as follows. From (4) and (5) we obtain $\frac{\partial e_{ii}^*}{\partial r} = \frac{1}{c''(e_{ii}^*)}$ and thus

$$\frac{\partial^2 e_{ii}^*}{\partial r^2} = -\frac{c'''(e_{ii}^*)}{[c''(e_{ii}^*)]^2}\frac{\partial e_{ii}^*}{\partial r}. \tag{60}$$

Therefore,

$$\frac{\partial^2 e_{ii}^*}{\partial r \partial w_2} = -\frac{c'''(e_{ii}^*)}{[c''(e_{ii}^*)]^2}\frac{\partial e_{ii}^*}{\partial w_2} = -\frac{c'''(e_{ii}^*)}{[c''(e_{ii}^*)]^2}g(0)\frac{\partial e_{ii}^*}{\partial r} = g(0)\frac{\partial^2 e_{ii}^*}{\partial r^2}. \tag{61}$$

Analogously, $\frac{\partial e_{ii}^*}{\partial w_2} = \frac{g(0)}{c''(e_{ii}^*)}$ and hence

$$\frac{\partial^2 e_{ii}^*}{\partial w_2^2} = -g(0)\frac{c'''(e_{ii}^*)}{[c''(e_{ii}^*)]^2}\frac{\partial e_{ii}^*}{\partial w_2}. \tag{62}$$

Consequently,

$$\frac{\partial^2 e_{ii}^*}{\partial r \partial w_2} = -\frac{c'''(e_{ii}^*)}{[c''(e_{ii}^*)]^2}\frac{\partial e_{ii}^*}{\partial w_2} = \frac{1}{g(0)}\frac{\partial^2 e_{ii}^*}{\partial w_2^2}. \tag{63}$$

We are now able to make the following transformations:

$$
\begin{aligned}
& g(\Delta e^*)\frac{\partial^2 \Pi}{\partial r \partial w_2} - \frac{\partial^2 \Pi}{\partial w_2^2} && (64)\\
= \; & g(\Delta e^*)\left(\frac{\partial^2 \pi_{AB}}{\partial r \partial w_2} + \frac{\partial^2 \pi_{AA}}{\partial r \partial w_2} + \frac{\partial^2 \pi_{BB}}{\partial r \partial w_2}\right) - \left(\frac{\partial^2 \pi_{AB}}{\partial w_2^2} + \frac{\partial^2 \pi_{AA}}{\partial w_2^2} + \frac{\partial^2 \pi_{BB}}{\partial w_2^2}\right) && (65)\\
= \; & g(\Delta e^*)\frac{\partial^2 \pi_{AB}}{\partial r \partial w_2} - \frac{\partial^2 \pi_{AB}}{\partial w_2^2} + \left(\frac{g(\Delta e^*)}{g(0)} - 1\right)\left(\frac{\partial^2 \pi_{AA}}{\partial w_2^2} + \frac{\partial^2 \pi_{BB}}{\partial w_2^2}\right) && (66)\\
= \; & g(\Delta e^*)\frac{\partial^2 \pi_{AB}}{\partial r \partial w_2} - \frac{\partial^2 \pi_{AB}}{\partial w_2^2} - g(0)\left(g(0) - g(\Delta e^*)\right)\left(\frac{\partial^2 \pi_{AA}}{\partial r^2} + \frac{\partial^2 \pi_{BB}}{\partial r^2}\right) && (67)
\end{aligned}
$$

For the second and third equation, we used that

$$
\frac{\partial^2 \pi_{AA}}{\partial r \partial w_2} + \frac{\partial^2 \pi_{BB}}{\partial r \partial w_2} = \frac{1}{g(0)}\left[\frac{\partial^2 \pi_{AA}}{\partial w_2^2} + \frac{\partial^2 \pi_{BB}}{\partial w_2^2}\right] = g(0)\left[\frac{\partial^2 \pi_{AA}}{\partial r^2} + \frac{\partial^2 \pi_{BB}}{\partial r^2}\right], \tag{68}
$$

which is straightforward to verify by applying (58) and (59) to the derivatives of π_{AA} and π_{BB}, respectively. The derivatives of π_{AA} are

$$
\begin{aligned}
\frac{\partial^2 \pi_{AA}}{\partial r \partial w_2} &= 2p^2\left[(1 - c'(e^*_{AA}))\frac{\partial^2 e^*_{AA}}{\partial r \partial w_2} - c''(e^*_{AA})\frac{\partial e^*_{AA}}{\partial w_2}\frac{\partial e^*_{AA}}{\partial r}\right] && (69)\\
\frac{\partial^2 \pi_{AA}}{\partial r^2} &= 2p^2\left[(1 - c'(e^*_{AA}))\frac{\partial^2 e^*_{AA}}{\partial r^2} - c''(e^*_{AA})\frac{\partial e^*_{AA}}{\partial r}\frac{\partial e^*_{AA}}{\partial r}\right] && (70)\\
\frac{\partial^2 \pi_{AA}}{\partial w_2^2} &= 2p^2\left[(1 - c'(e^*_{AA}))\frac{\partial^2 e^*_{AA}}{\partial w_2^2} - c''(e^*_{AA})\frac{\partial e^*_{AA}}{\partial w_2}\frac{\partial e^*_{AA}}{\partial w_2}\right]. && (71)
\end{aligned}
$$

Similarly, we can compute the derivatives for π_{BB}.

From comparing (51), (53), and (67), it remains to show that

$$
g(\Delta e^*)\frac{\partial^2 \pi_{AB}}{\partial r \partial w_2} - \frac{\partial^2 \pi_{AB}}{\partial w_2^2} = 0. \tag{72}
$$

The derivatives of π_{AB} are

$$\begin{aligned}
\frac{\partial^2 \pi_{AB}}{\partial r \partial w_2} &= 2p(1-p)\left\{[1-c'(e_A^*)]\frac{\partial^2 e_A^*}{\partial r \partial w_2} - \underline{c''(e_A^*)\frac{\partial e_A^*}{\partial w_2}\frac{\partial e_A^*}{\partial r}}\right. &(73)\\
&\quad +[1-c'(e_B^*)]\frac{\partial^2 e_B^*}{\partial r \partial w_2} - \underline{c''(e_B^*)\frac{\partial e_B^*}{\partial w_2}\frac{\partial e_B^*}{\partial r}} &(74)\\
&\quad \left.+(\Pi_A - \Pi_B + \delta)\left[g'(\Delta e^*)\frac{\partial \Delta e^*}{\partial w_2}\frac{\partial \Delta e^*}{\partial r} + g(\Delta e^*)\frac{\partial^2 \Delta e^*}{\partial r \partial w_2}\right]\right\} &(75)\\
\frac{\partial^2 \pi_{AB}}{\partial w_2^2} &= 2p(1-p)\left\{[1-c'(e_A^*)]\frac{\partial^2 e_A^*}{\partial w_2^2} - \underline{c''(e_A^*)\left(\frac{\partial e_A^*}{\partial w_2}\right)^2}\right. &(76)\\
&\quad +[1-c'(e_B^*)]\frac{\partial^2 e_B^*}{\partial w_2^2} - \underline{c''(e_B^*)\left(\frac{\partial e_B^*}{\partial w_2}\right)^2} &(77)\\
&\quad \left.+(\Pi_A - \Pi_B + \delta)\left[g'(\Delta e^*)\left(\frac{\partial \Delta e^*}{\partial w_2}\right)^2 + g(\Delta e^*)\frac{\partial^2 \Delta e^*}{\partial w_2^2}\right]\right\}. &(78)
\end{aligned}$$

Applying that $\frac{\partial e_i^*}{\partial w_2} = g(\Delta e^*)\frac{\partial e_i^*}{\partial r}$, all underlined terms cancel out in $g(\Delta e^*)\frac{\partial^2 \pi_{AB}}{\partial r \partial w_2} - \frac{\partial^2 \pi_{AB}}{\partial w_2^2}$. Finally, applying that

$$\begin{aligned}
\frac{\partial^2 \Delta e^*}{\partial w_2 \partial r} &= \frac{\partial^2 e_A^*}{\partial w_2 \partial r} - \frac{\partial^2 e_B^*}{\partial w_2 \partial r}, &(79)\\
\frac{\partial^2 \Delta e^*}{\partial w_2^2} &= \frac{\partial^2 e_A^*}{\partial w_2^2} - \frac{\partial^2 e_B^*}{\partial w_2^2}, &(80)
\end{aligned}$$

yields

$$\begin{aligned}
g(\Delta e^*)\frac{\partial^2 \pi_{AB}}{\partial r \partial w_2} - \frac{\partial^2 \pi_{AB}}{\partial w_2^2} &= 2p(1-p)\left\{[1-c'(e_A^*) + g(\Delta e^*)(\Pi_A - \Pi_B + \delta)]\left[g(\Delta e^*)\frac{\partial^2 e_A^*}{\partial r \partial w_2} - \frac{\partial^2 e_A^*}{\partial w_2^2}\right]\right.\\
&\quad \left.+ [1-c'(e_B^*) - g(\Delta e^*)(\Pi_A - \Pi_B + \delta)]\left[g(\Delta e^*)\frac{\partial^2 e_B^*}{\partial r \partial w_2} - \frac{\partial^2 e_B^*}{\partial w_2^2}\right]\right\}. &(81)
\end{aligned}$$

Furthermore, by taking the derivative of (57) for $i = w_2$ w.r.t. w_2, we obtain

$$\frac{\partial^2 e_i^*}{\partial w_2^2} = g'(\Delta e^*)\frac{\partial (\Delta e^*)}{\partial w_2}\frac{\partial e_i^*}{\partial r} + g(\Delta e^*)\frac{\partial^2 e_i^*}{\partial r \partial w_2}. \tag{82}$$

It follows that (81) can be rewritten as

$$
\begin{aligned}
g(\Delta e^*)\frac{\partial^2 \pi_{AB}}{\partial r \partial w_2} - \frac{\partial^2 \pi_{AB}}{\partial w_2^2} &= 2p(1-p)g'(\Delta e^*)\frac{\partial(\Delta e^*)}{\partial w_2}\left\{[1-c'(e_A^*) + g(\Delta e^*)(\Pi_A - \Pi_B + \delta)]\frac{\partial e_A^*}{\partial r}\right. \\
&\qquad \left. + [1-c'(e_B^*) - g(\Delta e^*)(\Pi_A - \Pi_B + \delta)]\frac{\partial e_B^*}{\partial r}\right\} \qquad (83) \\
&= 2p(1-p)g'(\Delta e^*)\frac{\partial(\Delta e^*)}{\partial w_2}\frac{\partial \pi_{AB}}{\partial r}. \qquad (84)
\end{aligned}
$$

Using (57) and (58), the first-order conditions (44) and (45) can be transformed to

$$
\begin{aligned}
\frac{\partial \Pi}{\partial r} &= \frac{\partial \pi_{AB}}{\partial r} + \frac{\partial \pi_{AA}}{\partial r} + \frac{\partial \pi_{BB}}{\partial r} = 0, \qquad (85) \\
\frac{\partial \Pi}{\partial w_2} &= g(\Delta e^*)\frac{\partial \pi_{AB}}{\partial r} + g(0)\left(\frac{\partial \pi_{AA}}{\partial r} + \frac{\partial \pi_{BB}}{\partial r}\right) = 0. \qquad (86)
\end{aligned}
$$

Thus, since $g(\Delta e^*) < g(0)$, we must have $\frac{\partial \pi_{AB}}{\partial r} = 0$ and $\frac{\partial \pi_{AA}}{\partial r} + \frac{\partial \pi_{BB}}{\partial r} = 0$ at any interior solution. Together with (84) it follows that

$$
g(\Delta e^*)\frac{\partial^2 \pi_{AB}}{\partial r \partial w_2} - \frac{\partial^2 \pi_{AB}}{\partial w_2^2} = 0. \qquad (87)
$$

Very similarly, to derive (54), we can compute

$$
\begin{aligned}
&\frac{\partial^2 \Pi}{\partial r \partial w_2} - g(\Delta e^*)\frac{\partial^2 \Pi}{\partial r^2} \qquad (88) \\
=\ &\frac{\partial^2 \pi_{AB}}{\partial r \partial w_2} - g(\Delta e^*)\frac{\partial^2 \pi_{AB}}{\partial r^2} + (g(0) - g(\Delta e^*))\left\{\frac{\partial^2 \pi_{AA}}{\partial r^2} + \frac{\partial^2 \pi_{BB}}{\partial r^2}\right\} \qquad (89) \\
=\ &(g(0) - g(\Delta e^*))\left\{\frac{\partial^2 \pi_{AA}}{\partial r^2} + \frac{\partial^2 \pi_{BB}}{\partial r^2}\right\}, \qquad (90)
\end{aligned}
$$

where the second equation follows since one can show that $\frac{\partial^2 \pi_{AB}}{\partial r \partial w_2} - g(\Delta e^*)\frac{\partial^2 \pi_{AB}}{\partial r^2} = 0$. □

Comparative statics of e_A^*, e_B^*, and $e_A^* - e_B^*$ w.r.t. $\Pi_A - \Pi_B$**.** Applying Cramer's rule yields

$$\frac{\partial e_A^*}{\partial(\Pi_A - \Pi_B)} \det(H) \tag{91}$$

$$= \det \begin{pmatrix} -\left(g(e_A^* - e_B^*)\frac{\partial w_2}{\partial(\Pi_A - \Pi_B)} + \frac{\partial r}{\partial(\Pi_A - \Pi_B)}\right) & -g'(e_A^* - e_B^*)(w_2 + \delta) \\ -\left(g(e_A^* - e_B^*)\frac{\partial w_2}{\partial(\Pi_A - \Pi_B)} + \frac{\partial r}{\partial(\Pi_A - \Pi_B)}\right) & -g'(e_A^* - e_B^*)w_2 - c''(e_B^*) \end{pmatrix} \tag{92}$$

$$= -(g'(e_A^* - e_B^*)\delta - c''(e_B^*)) \left[g(e_A^* - e_B^*)\frac{\partial w_2}{\partial(\Pi_A - \Pi_B)} + \frac{\partial r}{\partial(\Pi_A - \Pi_B)}\right]. \tag{93}$$

By (21), the term in square brackets is negative. This observation and the fact that $\det(H) > 0$ lead to $\frac{\partial e_A^*}{\partial(\Pi_A - \Pi_B)} < 0$. Similarly, we obtain

$$\frac{\partial e_B^*}{\partial(\Pi_A - \Pi_B)} \det(H) = -(g'(e_A^* - e_B^*)\delta - c''(e_A^*)) \left[g(e_A^* - e_B^*)\frac{\partial w_2}{\partial(\Pi_A - \Pi_B)} + \frac{\partial r}{\partial(\Pi_A - \Pi_B)}\right], \tag{94}$$

which is strictly negative. Finally,

$$\frac{\partial(e_A^* - e_B^*)}{\partial(\Pi_A - \Pi_B)} \det(H) = -(c''(e_A^*) - c''(e_B^*)) \left[g(e_A^* - e_B^*)\frac{\partial w_2}{\partial(\Pi_A - \Pi_B)} + \frac{\partial r}{\partial(\Pi_A - \Pi_B)}\right], \tag{95}$$

which is strictly positive since $c''(e_A^*) > c''(e_B^*)$. □