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Worker Compensation Schemes and Product Market Competition

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Abstract

We analyze product market competition between firm owners where the risk-neutral workers decide on their efforts and, thereby, on the output levels. Various worker compensation schemes are compared: a piece-rate compensation scheme as a benchmark when workers' output performance is verifiable, and a contest-based as well as a tournament-based compensation scheme when it is only verifiable who the best performing worker is. According to optimal designs, all the considered compensation contracts lead to an equal market outcome. Therefore, it depends decisively on the relative costs of organizing a monitoring device, a contest, or a tournament whether the one or the other compensation scheme should be implemented.

Keywords: Worker compensation schemes, piece rates, contests, tournaments, product market competition

JEL Classification: C72, L22, M52

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1 Introduction

Standard principal-agent models, as discussed in business economics, usually concentrate on a firm's internal organization and analyze compensation contracts between a single principal, a firm owner or a manager, and one or more agents, the workers. In industrial economics, compensation contracts are studied in terms of strategic delegation and competition. However, in contrast to the standard principal-agent models, the agents are usually managers not workers. Güth, Pull and Stadler (2011, 2015) and Stadler and Pull (2015) combined these two strands of literature and analyzed the design of piece-rate and contest-based compensation contracts for workers when the firms compete in a heterogeneous product market. This enabled the authors to extend the business economics models on the one hand and to enrich the industrial economics models on the other hand.

The present paper follows this approach and considers competing firms, each consisting of one owner and several workers who decide on effort levels anticipating how these decisions affect their effort costs. We simplify the setting by assuming a homogeneous product market but complement the former analyses by also studying tournament-based compensation schemes. While piece rates are based on workers' verifiable output performance, contest-based and tournament-based compensation schemes can be implemented even if worker output is not verifiable. In order to implement such compensation schemes, owners only need information on the workers' relative performance. Our study shows that, in case of risk-neutral agents, the market outcome of piece-rate compensation can be reproduced by contest-based as well as by tournament-based compensation schemes. Therefore, it depends decisively on the relative costs of organizing a monitoring device, a contest, or a tournament whether the one or the other compensation scheme should be implemented.

The paper is organized as follows: In Section 2 we analyze piece-rate compensation schemes as a benchmark. In Section 3, we consider contest-based compensation schemes, in Section 4 tournament-based compensation schemes. Section 5 concludes the paper.

2 Piece-Rate Compensation

We adopt a simplified setting of Stadler and Pull (2015) and consider a homogeneous product market with two firms $i = 1, 2$. The inverse market demand function reads[1]

$$p = 1 - q_i - q_j \ , \quad i, j = 1, 2, \ i \neq j \ .$$

The single input factor of production is the effort $e_{i,k}$ of workers $k = 1, ..., n_i$ in firms $i = 1, 2$, where the effort-cost function is assumed to be quadratic, $c(e_{i,k}) = e_{i,k}^2/2$. The output of firm i is a linear aggregation of the worker effort levels and amounts to $q_i = \sum_{k=1}^{n_i} e_{i,k}$.

Each firm consists of one owner and n_i workers. The piece-rate compensation game (P) has two stages. In the first stage, owners $i = 1, 2$ simultaneously offer observable and irreversible piece-rate contracts $\Gamma_i = f_i + w_i e_{i,k}$ to their workers, specifying the fixed (positive or negative) salaries f_i and the piece rates w_i per output unit. Workers are awarded according to these contracts and suffer from the effort costs of production. They realize the net utilities

$$U_{i,k}(e_{i,k}) = f_i + w_i e_{i,k} - e_{i,k}^2/2 \ , \quad i = 1, 2, \ k = 1, ..., n_i \ . \tag{1}$$

In the second stage of the game, workers maximize their net utilities (1) with respect to their efforts $e_{i,k}$. The first-order conditions imply

$$e_{i,k}^* = e_i^* = w_i \tag{2}$$

for all workers $k = 1, ..., n_i$ employed by firms $i = 1, 2$. This gives the net utilities $U_{i,k}(e_i^*) = f_i + w_i^2/2$. When the reservation utilities, resulting from compensation-contract offers in other markets or from unemployment benefits, are given by $\overline{U}$, owners will pay the lowest feasible salaries $f_i = \overline{U} - w_i^2/2$.

[1] The inverse market demand function can be derived from the consumers' quasi-linear quadratic utility function $W(q_0, q_1, q_2) = q_0 + q_1 + q_2 - (q_1^2 + q_2^2)^2/2$, where the quantities q_1 and q_2 are offered by the firms $i = 1, 2$, respectively, and q_0 is the quantity of the numéraire good.

This leads to the firm owners' profits

$$\begin{aligned}\pi_i(w_i, w_j, n_i, n_j) &= (1 - q_i - q_j - w_i)q_i - n_i f_i \\ &= (1 - n_i e_i^* - n_j e_j^* - w_i)n_i e_i^* - n_i f_i \\ &= [1 - (n_i + 1/2)w_i - n_j w_j]n_i w_i - n_i \overline{U} \ , \quad i, j = 1, 2, \ i \neq j \ . \qquad (3)\end{aligned}$$

In the first stage of the game, owner principals maximize their profits by offering optimal compensation contracts to their workers, specifying the fixed salaries f_i, the piece rates w_i, and - in the long run - the number of employed workers n_i.

We distinguish two cases, one with an exogenously given number of worker agents (as usual in standard principal-agent settings) and one with an endogenous long-run equilibrium number of employed workers.

The piece-rate compensation game in the case of an exogenously given number of workers

Principals maximize their profits (3) with respect to the piece rates w_i. The first-order conditions are

$$[1 - (2n_i + 1)w_i - n_j w_j]n_i = 0 \ . \qquad (4)$$

Given the symmetric number $n_1 = n_2 = n$ of workers per firm, the equilibrium piece rates and workers' efforts amount to

$$w^P = e^P = \frac{1}{3n + 1} \ , \qquad (5)$$

leading to the market price

$$p^P = 1 - 2ne^P = \frac{n + 1}{3n + 1}$$

and the firm profits

$$\pi^P = \frac{(2n + 1)n}{2(3n + 1)^2} - n\overline{U} \ . \qquad (6)$$

While worker efforts do not depend on the reservation utility $\overline{U}$, the firm profits are decreasing in $\overline{U}$. Some numerical calculations for $n_1 = n_2 = n$ workers per firm and a common worker reservation utility of $\overline{U} = 0$ are presented in Table 1.

Table 1: Results for the piece-rate compensation game (P) with a given number n of workers per firm and the reservation utility $\overline{U} = 0$

n	w^P	e^P	p^P	π^P
2	0.143	0.143	0.429	0.102
3	0.100	0.100	0.400	0.105
4	0.077	0.077	0.385	0.106
5	0.063	0.063	0.375	0.107
6	0.053	0.053	0.368	0.108
...	...	...	...	...
∞	0.000	0.000	0.333	0.111

The piece-rate compensation scheme reproduces the market performance of unitary firms. This can be seen from the profit equation (3) which is strategically equivalent to the profit equation of unitary firms being able to decide directly on worker efforts via enforceable contracts. This equivalence holds since there is no strategic effect of the piece rates offered by one firm on the efforts of the rival firm's workers.

The piece-rate compensation game in the case of endogenously determined employment levels

When firms are not constrained by a given number of workers, they additionally maximize their profits with respect to the number n_i of employed workers. The corresponding first-order conditions are

$$[1 - (2n_i + 1/2)w_i - n_j w_j]w_i - \overline{U} = 0\ . \tag{7}$$

Taking into account the first-order conditions (4) for the piece rates w_i, we obtain the equilibrium number of employed workers

$$n^P = \frac{1 - \sqrt{2\overline{U}}}{3\sqrt{2\overline{U}}} \tag{8}$$

and hence the equilibrium piece rates and efforts

$$w^P = e^P = \sqrt{2\overline{U}} \tag{9}$$

in terms of the workers' reservation utility only. Given the worker efforts, it is straightforward to derive the market price

$$p^P = \frac{1 + 2\sqrt{2\overline{U}}}{3}$$

and the firm profits

$$\pi^P = \frac{(1 - \sqrt{2\overline{U}})^2}{9} \ . \tag{10}$$

These solutions are well-known from the standard Cournot duopoly model (see, e.g., Belleflamme and Peitz 2015, chapter 3), when the firms' unit production costs are given by $w = \sqrt{2\overline{U}}$. Table 2 shows the numerical calculations for an endogenous number of workers per firm. In order to ensure intra-firm interaction, i.e. $n \geq 2$, we assume that $\overline{U} \in [0, 1/98]$.

The fixed salaries prove to be $f^P = 0$ such that the compensation contracts offered by both of the firm owners to each of their workers are specified as $\Gamma_i = \sqrt{2\overline{U}}\ e_i$. A comparison with Table 1 shows that worker efforts coincide. However, the firm profits are reduced for all positive reservation levels $\overline{U} > 0$ enforcing higher worker compensations.

Table 2: Results for the piece-rate compensation game (P) with endogenously determined employment levels

$\bar{U}$	n^P	w^P	e^P	p^P	π^P
1/98	2	0.143	0.143	0.429	0.082
1/200	3	0.100	0.100	0.400	0.090
1/338	4	0.077	0.077	0.385	0.095
1/512	5	0.063	0.063	0.375	0.098
1/722	6	0.053	0.053	0.368	0.100
...	...	...	...	...	...
0	∞	0.000	0.000	0.333	0.111

Piece-rate compensation schemes can only be implemented when the workers' absolute performance is verifiable. In practice, an appropriate monitoring device is often not available at a sufficiently low cost. Rather, owners may only be able to measure relative worker performance, e.g. through a contest or a tournament.

3 Contest-Based Compensation

As an alternative to piece-rate compensation we now consider contest-based compensation schemes. As is well-known, there are several institutional set-ups appropriate to convert agents' efforts into winning probabilities in contests (see, e.g., Konrad 2009). These approaches make a strong case for the contest-success function $\mu_{i,k} = e_{i,k}/(\sum_{k=1}^{n_i} e_{i,k}) = e_{i,k}/q_i$, where $\mu_{i,k}$ denotes the probability of worker k to win the contest of firm i.[2]

[2]This is a special case of the more general Tullock contest-success function $\mu_{i,k} = e_{i,k}^r/(\sum_{k=1}^{n_i} e_{i,k}^r)$, where the ranking-precision parameter is normalized to $r = 1$.

As a dynamic justification, assume the winning worker is the one who is observed to be the first to reach a certain amount of production in the contest race. Then it is plausible to specify the probability of winning as $e_{i,k}/(\sum_{k=1}^{n_i} e_{i,k})$, which simplifies to $1/n_i$ in a symmetric equilibrium.

Stadler and Pull (2015), inter alia, have considered a contract design with fixed firm-specific contest prizes V_i where the winners take all. This contest-based compensation game (C) has again two stages: in the first stage, owners $i = 1, 2$ simultaneously offer compensation contracts to their workers, specifying the fixed (positive or negative) salaries f_i and fixed contest prizes V_i. Workers are awarded according to the contracts $\Gamma_i = f_i + V_i$ when winning the contest and $\Gamma_i = f_i$ when losing. All workers participating in the contest expect the net utilities

$$EU_{i,k}(e_{i,k}) = f_i + (e_{i,k}/q_i)V_i - e_{i,k}^2/2 \ , \qquad i = 1, 2, \ k = 1, ..., n_i \ . \tag{11}$$

In the second stage of the compensation game, the risk-neutral workers maximize their expected net utilities with respect to their efforts $e_{i,k}$. From the first-order conditions, we obtain the efforts

$$e_{i,k}^* = e_i^* = \sqrt{(n_i - 1)V_i}/n_i \tag{12}$$

for all workers $k = 1, ..., n_i$ employed by firms $i = 1, 2$. The efforts depend positively on the firm-specific contest prizes V_i and, in contrast to the piece-rate compensation game, negatively on the number of workers n_i. This implies the expected net utilities $EU_{i,k}(e_i^*) = f_i + [(n_i + 1)/(2n_i^2)]V_i$.

When the reservation utility is again given by $\overline{U} \in [0, 1/98]$, workers receive the fixed salaries $f_i = \overline{U} - [(n_i + 1)/(2n_i^2)]V_i$ such that the profit functions of the firms can be written as

$$\begin{aligned} \pi_i(V_i, V_j, n_i, n_j) &= (1 - n_i e_i^* - n_j e_j^*) n_i e_i^* - n_i f_i - V_i \\ &= (1 - n_i e_i^* - n_j e_j^*) n_i e_i^* - n_i \overline{U} - [(n_i - 1)/(2n_i)]V_i \ , \ i, j = 1, 2, \ i \neq j \ . \end{aligned} \tag{13}$$

In the first stage of the game, owner principals maximize their profits (13) by offering an optimal compensation contract to their workers, specifying the fixed salaries f_i, the contest prices V_i, and - in the long run - the number of employed workers n_i.

The contest-based compensation game in the case of an exogenously given number of workers

Given the fixed number $n_1 = n_2 = n$ of workers per firm, the first-order conditions with respect to the contest prizes V_i imply

$$V^* = \frac{n^2}{(n-1)(3n+1)^2} \ . \tag{14}$$

Substituting $V_i = V^*$ and $n_i = n$ into (12) leads to the workers' effort

$$e^C = \frac{1}{3n+1} \ , \tag{15}$$

which coincides with e^P as derived in equation (5) for the piece-rate compensation scheme. The market performance with piece-rate contracts is therefore reproduced by this contest-based contract with a fixed contest prize for the winning worker.

The contest-based compensation game in the case of an endogenously determined employment level

This result continues to hold when we endogenize the equilibrium number of workers per firm. By maximizing the profits (13) with respect to the number of employed workers and taking into account (14), we obtain the equilibrium employment levels

$$n^C = \frac{1-\sqrt{2\overline{U}}}{3\sqrt{2\overline{U}}} \tag{16}$$

and hence the equilibrium contest prizes

$$V^C = \frac{2(1-\sqrt{2\overline{U}})^2\overline{U}}{3(\sqrt{2\overline{U}}-8\overline{U})} \ . \tag{17}$$

Substitute (16) into (15) to obtain the equilibrium effort

$$e^C = \sqrt{2\overline{U}}\ ,$$

which coincides with the equilibrium worker effort (9) as resulting in the case of piece-rate compensation. Table 3 shows the numerical calculations for an endogenous number of workers per firm.

Table 3: Results for the contest-based compensation game (C) with endogenously determined employment levels

$\overline{U}$	n^C	V^C	e^C	p^C	π^C
1/98	2	0.082	0.143	0.429	0.082
1/200	3	0.045	0.100	0.400	0.090
1/338	4	0.032	0.077	0.385	0.095
1/512	5	0.024	0.063	0.375	0.098
1/722	6	0.020	0.053	0.368	0.100
...	...	...	...	...	...
0	∞	0.000	0.000	0.333	0.111

The fixed salaries prove to be

$$f^C = -\frac{12\overline{U}^2}{\sqrt{2\overline{U}} - 8\overline{U}}\ .$$

$V^C > 0$ implies that $\sqrt{2\overline{U}} - 8\overline{U} > 0$ and therefore $f^C < 0$. This negative fixed salary is the price workers have to pay in order to participate in the contest.

4 Tournament-Based Compensation

As a further compensation scheme, we now consider tournament-based contracts. Similar to a contest, a tournament is a competition between the firms' workers who show effort to gain a prize. To explain the difference between contests and tournaments, Taylor (1995, p. 874) refers to the example of motor-car races: A contest is like 'Indianapolis 500' (try to be the first to go the allotted distance of 500 miles), while a tournament is like 'Le Mans' (try to be the farthest in the allotted time of 24 hours).

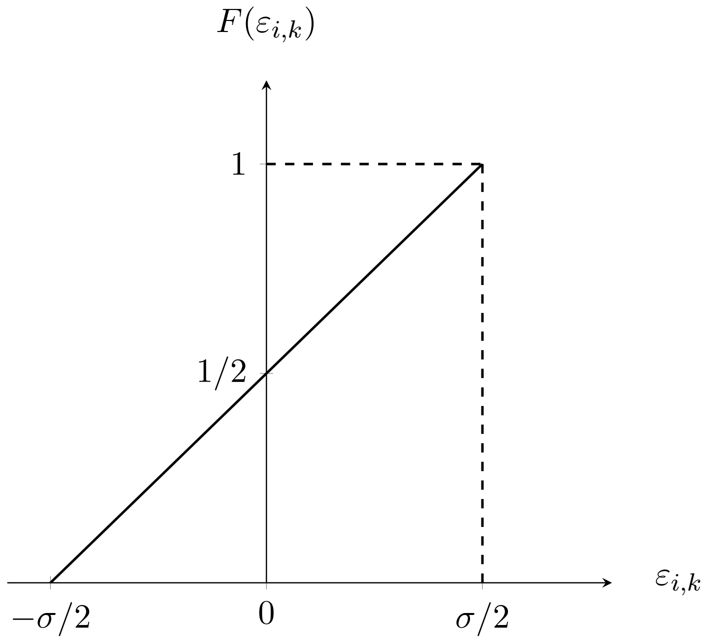
The tournament-based compensation game (T) has two stages: in the first stage, owners $i = 1, 2$ simultaneously offer compensation contracts to their workers, specifying the fixed (positive or negative) salaries f_i and fixed tournament prizes V_i for the winners of the tournaments. Workers are awarded according to the contracts $\Gamma_i = f_i + V_i$ when winning the tournament and $\Gamma_i = f_i$ when losing. All workers participating in the tournaments expect the net utilities

$$EU_{i,k}(e_{i,k}) = f_i + \mu_{i,k} V_i - e_{i,k}^2/2 \ , \qquad i = 1, 2, \ k = 1, ..., n_i \ , \tag{18}$$

where $\mu_{i,k}$ denotes the probability of worker k to win the tournament of firm i. Again, there is a stochastic component in tournaments which determines the best performing worker even if the equilibrium efforts of all workers are equal. When a worker exerts effort $e_{i,k}$, his tournament performance as perceived by the owner is assumed to be $e_{i,k} + \varepsilon_{i,k}$, where $\varepsilon_{i,k}$ are identically and independently distributed random variables with mean zero. In contrast to the standard rank-order tournament as introduced by Lazear and Rosen (1981), we assume that the observation of the tournament result is disturbed by the stochastic noise term, but not the workers' production process itself.

To keep the model tractable, we assume the uniform distribution $F(\varepsilon_{i,k}) = \varepsilon_{i,k}/\sigma + 1/2$ on the support $\varepsilon_{i,k} \in [-\sigma/2, \sigma/2]$ such that the density $\partial F(\varepsilon_{i,k})/\partial \varepsilon_{i,k} = 1/\sigma$ is constant. The variable $\sigma > 0$ is a measure of observation noise (see the illustration in Figure 1). In the limit case where σ approaches zero, this noise is negligible such that worker effort is verifiable and piece-rate or even enforcement contracts are feasible. Increasing values of σ indicate increasing observation noise with respect to the workers' output performance.

Figure 1: The distribution function of the observation-noise variable $\varepsilon_{i,k}$



A worker who exerts effort $e_{i,k}$, while all other workers in firm i exert the equilibrium effort e_i^*, wins the tournament with probability[3]

$$\mu_{i,k} = \int_{-\sigma/2}^{\sigma/2} F(e_{i,k} - e_i^* + \varepsilon_{i,k})^{(n_i-1)}(1/\sigma)d\varepsilon_{i,k}\ , \qquad i = 1, 2,\ k = 1, ..., n_i\ .$$

The derivative with respect to the effort $e_{i,k}$ is

$$\partial\mu_{i,k}/\partial e_{i,k} = \int_{-\sigma/2}^{\sigma/2} (n_i - 1)F(e_{i,k} - e_i^* + \varepsilon_{i,k})^{(n_i-2)}(1/\sigma)^2 d\varepsilon_{i,k}\ .$$

[3]The general probabilities for the different ranks in the tournaments depending on the distribution functions of the error term are presented in Akerlof and Holden (2012).

In the symmetric equilibrium ($e_{i,k} = e_i^*$), this derivative simplifies to

$$\begin{aligned}\partial \mu_{i,k}/\partial e_{i,k} =& \int_{-\sigma/2}^{\sigma/2} (n_i - 1) F(\varepsilon_{i,k})^{(n_i-2)} (1/\sigma)^2 d\varepsilon_{i,k} \\ =& F(\varepsilon_{i,k})^{n_i-1}(1/\sigma)|_{-\sigma/2}^{\sigma/2} \ = \ 1/\sigma \ ,\end{aligned}$$

which depends proportionally on the density $1/\sigma$ of the uniform distribution, but not on the number n_i of employed workers per firm.

Taking into account this derivative, it is straightforward to show that the first-order conditions of maximizing the expected net utilities (18) are

$$e_{i,k}^* = e_i^* = V_i/\sigma \tag{19}$$

for all risk-neutral workers $k = 1, ..., n_i$ employed by firms $i = 1, 2$. This implies the expected net utilities $EU_{i,k}(e_i^*) = f_i + (1/n_i)V_i - [1/(2\sigma^2)]V_i^2$.

When the reservation utility is again given by $\overline{U} \in [0, 1/98]$, workers receive the fixed salaries $f_i = \overline{U} - (1/n_i)V_i + [1/(2\sigma^2)]V_i^2$ such that the profit functions of the firms can be written as

$$\begin{aligned}\pi_i(V_i, V_j, n_i, n_j) &= (1 - n_i e_i^* - n_j e_j^*) n_i e_i^* - n_i f_i - V_i \\ &= (1 - n_i e_i^* - n_j e_j^*) n_i e_i^* - n_i \overline{U} - [n_i/(2\sigma^2)]V_i^2 \ , \quad i, j = 1, 2, \ i \neq j \ .\end{aligned} \tag{20}$$

In the first stage, owner principals maximize their profits (20) by offering an optimal compensation contract to their workers, specifying the fixed salaries f_i, the tournament prizes V_i, and - in the long-run - the number of employed workers n_i.

The tournament-based compensation game in the case of an exogenously given number of workers

Given the fixed number $n_1 = n_2 = n$ of workers per firm, the maximization of the profit functions (20) with respect to the tournament prizes V_i leads to the first-order conditions

$$V^* = \frac{\sigma}{3n+1} \; . \tag{21}$$

Substituting $V_i = V^*$ into (19) leads to the workers' effort

$$e^T = \frac{1}{3n+1} \; , \tag{22}$$

which coincides with e^P and e^C as derived in equations (5) and (15) for the previous compensation games. The market performance with piece-rate contracts can therefore also be reproduced by this tournament-based contract with a fixed prize for the winning worker.

The tournament-based compensation game in the case of an endogenously determined employment level

This result continues to hold when we endogenize the equilibrium number of workers per firm. By maximizing the profits (20) with respect to the number of employed workers and taking into account (21) and (22), we obtain the endogenous number of employed workers per firm

$$n^T = \frac{1-\sqrt{2\overline{U}}}{3\sqrt{2\overline{U}}} \; , \tag{23}$$

which coincides with the employment levels n^P in (10) and n^C in (16). Substitution into (21) gives the equilibrium tournament prizes

$$V^T = \sqrt{2\overline{U}}\; \sigma \; , \tag{24}$$

which are monotonically decreasing in the density $1/\sigma$ of the noise parameter. Substituting (23) into (22) gives the worker effort

$$e^T = \sqrt{2\overline{U}} \; ,$$

which coincides with the worker effort in the previous compensation games. As a consequence it holds that $p^T = p^C = p^P$ and $\pi^T = \pi^C = \pi^P$. Table 4 shows the numerical calculations for an endogenous number of workers per firm for the intermediate noise parameter $\sigma = 1$.

Table 4: Results for the tournament-based compensation game (T) with endogenously determined employment levels ($\sigma = 1$)

$\bar{U}$	n^T	V^T	e^T	p^T	π^T
1/98	2	0.143	0.143	0.439	0.082
1/200	3	0.100	0.100	0.400	0.090
1/338	4	0.077	0.077	0.385	0.095
1/512	5	0.063	0.063	0.375	0.098
1/722	6	0.053	0.053	0.368	0.100
...	...	...	...	...	...
0	∞	0.000	0.000	0.333	0.111

The fixed salaries prove to be

$$f^T = -\frac{2(3\sigma - 1 + \sqrt{2\overline{U}})\overline{U}}{1 - \sqrt{2\overline{U}}}$$

and are monotonically increasing in the density $1/\sigma$. In the extreme case of the density approaching zero (i.e., $\sigma \to \infty$), extremely high tournament prizes are necessary to encourage worker effort. In the opposite extreme case of an infinitely high density around mean zero so that uncertainty becomes negligible (i.e., $\sigma = 0$), no further incentive from tournament prizes is necessary. It is clear from the workers' participation constraints that high tournament prizes go along with low (and possibly negative) fixed salaries and vice versa.

Regardless of the type of the compensation scheme, the optimal designs (f^P and w^P in the case of piece-rate compensation, f^C and V^C in the case of a contest, and f^T

and V^T in the case of a tournament) induce the same number of employed workers, the same worker effort and, hence, the same market performance. Therefore, the adequate compensation scheme depends decisively on its relative implementation costs.

5 Summary and Conclusion

This paper studied product market competition between firms where owners decide on the number of employed workers and implement a compensation scheme to which worker agents react by choosing efforts and, thereby, output levels. Depending on the verifiability of workers' absolute or relative performance, firm owners can offer a piece-rate, a contest-based, or a tournament-based compensation scheme in order to maximize their profits.

In practice, a verification of workers' absolute output performance is often not possible so that piece-rate contracts are not feasible. However, a contest-based compensation scheme that only relies on the verifiability of contest performance or a tournament-based compensation scheme that only relies on the verifiability of tournament performance can be implemented. Under the assumed risk-neutrality of workers, the different compensation schemes lead to the same performance of the owner principals and the same expected payments for the worker agents.

Therefore, whether a monitoring device, a contest, or a tournament should be implemented, is a question of the relative differences in the organization costs. Since a perfect monitoring device usually proves to be very expensive, this might explain the attractiveness of contests and tournaments in theory and practice.

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