Tournaments and Piece Rates Revisited: A Theoretical and Experimental Study of Output-Dependent Prize Tournaments

Werner Güth* René Levínský*§ Kerstin Pull† Ori Weisel‡¶

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Abstract

Tournaments represent an increasingly important component of organizational compensation systems. While prior research focused on fixed-prize tournaments where the prize to be awarded is set in advance, we introduce 'output-dependent prizes' where the tournament prize is endogenously determined by agents' output – it is high when the output is high and low when the output is low. We show that tournaments with output-dependent prizes outperform fixed-prize tournaments and piece rates. A multi-agent experiment supports the theoretical result.

Keywords: Tournaments, Relative performance, Experiment, Principal-agent

JEL Classifications: J3, L2

*Max Planck Institute of Economics, Kahlaische Strasse 10, 07745 Jena, Germany

†Eberhard Karls Universität Tübingen, Faculty of Economics and Social Sciences, Nauklerstrasse 47, 72074 Tübingen, Germany

‡University of Nottingham, Centre for Decision Research and Experimental Economics, NG7 2RD, Nottingham, United Kingdom

§Corresponding author. Email: levinsky@econ.mpg.de, Tel. +49-3641-686 642

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1 Introduction and Motivation

Tournament incentives, based on relative, rather than absolute, performance, have become an increasingly important component of organizational compensation systems (Orrison et al., 2004; Bothner et al., 2007). Starting with the seminal paper by Lazear and Rosen (1981), the incentive properties of (fixed prize) tournament compensation systems have repeatedly been analyzed (for an early review see McLaughlin, 1988; Kräkel, 2008, and Gürtler and Kräkel, 2010, are examples of recent studies). A general observation from this literature is that tournaments can, under certain circumstances (mainly the risk-neutrality of the agents), induce the same efforts from agents as piece rates, allowing principals to economize on measurement costs (as rank order is typically easier to measure than cardinal performance) and to allocate indivisible rewards without sacrificing production efficiency. In some situations tournaments can be even more efficient than piece rates, such that a firm employing a tournament compensation system can produce a higher output, or produce the same output at a lower cost, as compared to a firm employing a piece rate compensation system.

Empirical studies on tournament compensation systems often rely on sports data (e.g., Ehrenberg and Bognanno, 1990; Becker and Huselid, 1992; Bothner et al., 2007; Kaplan and Garstka, 2001) and increasingly on field studies from the organizational practice (Knoeber and Thurman, 1994; Bandiera et al., 2005; Matsumura and Shin, 2006; Casas-Arce and Martínez-Jerez, 2009; Backes-Gellner and Pull, 2013). The first experimental evidence on tournaments was provided by Bull et al. (1987), to be followed by a wide range of studies relying on laboratory data (e.g., Harbring and Irlenbusch, 2008, Freeman and Gelber, 2010 etc.) A recent, encompassing survey of experimental research on tournaments, contests and all-pay auctions is provided by Dechenaux et al. (forthcoming). Both the empirical and experimental studies mostly support the basic predictions of tournament theory. The literature, however, has mainly focused on 'fixed-prize' tournament incentives where the size of the prize (sum) to be awarded is set in advance and is not influenced by employee performance or firm success.

As long as firm performance can be assessed in advance with reasonable accuracy, a system of predefined tournament prizes that have to be paid out regardless of the firm's success may not pose a severe problem. However, if firm performance is difficult to assess in advance (e.g., due to an uncertain economic environment), a predetermined tournament prize may well exceed what the firm can actually afford to pay. In contrast, tournaments with prizes that are not fixed, but rather depend – or include a component which depends – on the organization's performance, eliminate or reduce the hazard of having to pay out a large prize when the organization is doing poorly.

An additional advantage of tournaments with output-dependent prizes is that they carry a smaller risk of horizontal collusion and sabotage. In fixed prize tournaments contestants can engage in collusive behavior by jointly reducing their effort, or in sabotage by taking actions to reduce each other's performance, knowing that the full prize will be paid out anyway (Harbring and Irlenbusch, 2003; Bandiera et al., 2005; Harbring et al., 2007). If the size of the prize (positively) depends on the agents' joint output, both collusion and sabotage are less attractive, because they lead to a smaller prize.

There are a few examples of tournaments with variable, rather than fixed, prizes. In so-called Japanese bonus tournaments, for instance, the bonus an agent receives is not set in advance, but rather depends on his or her relative performance (Kräkel, 2003; Endo, 1984). The bonus *sum* to be distributed to all of the agents, however, is set in advance, and does not depend on the agents' total absolute performance. Similarly, Cason et al. (2010), Cason et al. (2013) and Shupp et al. (2013) study 'proportional-prize' tournaments in which the prize sum is divided among the agents by their share of the total achievement. Again, however, the prize sum to be divided does not depend on agents' total achievement, but is fixed in advance. The same is true for the 'share contests' analysed by Falluchi et al. (2013) and for the compensation mechanism studied by Chowdhury et al. (2014). Chowdhury and Sheremeta (2011) and Baye et al. (2012) analyse contests where the prize to be awarded is fixed, but where additionally the own output and the rival's output enter the winning agent's payoff function. Hence, similarly to our model, agent payoff is influenced by (firm) performance. Contingent-prize R&D contests (Clark and Riis, 2007) where contestants can signal their ability by choosing a combination of winning and losing prizes from a prize menu provide yet another example of variable prize contests. However, since the prize to be awarded is to be paid in full even when the R&D enterprise is not successful, the situation is quite different from the type of output-dependent prize tournaments we study. Lastly, Cohen et al. (2008) analyze all-pay auctions with variable, effort-dependent rewards. However, while the reward at stake depends on the effort of the winning agent, it is not influenced by the output of the other agent.

In order to study the comparative advantages of output-dependent prize tournaments, we compare them with piece rates based on absolute performance and with fixed-prize tournaments (see Agranov and Tergiman, 2013, who compare piece rates, relative piece rates and fixed-prize tournaments for a similar approach). Specifically, we allow for employee compensation to be linearly dependent on (a) a *piece rate* based on absolute performance, (b) a pre-determined *fixed prize* awarded on the basis of relative performance, and (c) an *output-dependent prize* which is also awarded on the basis of relative performance, but whose size depends on firm success (interpreted as the joint production of agents). We refer to the latter as 'output-dependent prize tournaments'.

A possible real world example of output-dependent prizes is an appropriately designed profit sharing scheme where employees are rewarded according to the realized profit and where the share of the profit that goes to an individual employee is based on his or her relative performance. In our case of a 'winner-takes-all'-tournament, the best performing employee receives the full share; in practice, the share of the profit going to the employees might also be distributed among all employees according to their relative contributions (as is the case in Japanese bonus tournaments, see above).

Theoretically, we rely on a cost minimization approach when analyzing the optimal combination of the three incentive types. The focus is on optimal contract design from the perspective of the principal: whatever quantity is to be produced should be produced with the lowest possible cost. Our analysis shows that output-dependent prize tournaments are more cost-effective than piece rates and fixed-prize tournament incentives, the two most studied types of incentives in the literature.

We test the theoretical predictions with data from a laboratory experiment with both agent- and principal-participants. Our data qualitatively support the theoretical propositions: despite the fact that agent-participants systematically deviated from their theoretically predicted effort level, output-dependent prizes prove to be the most profitable in our experimental sessions (relative to the conventional alternatives). Principal-participants seemed to realize this, as they displayed a strong tendency in favor of output-dependent prizes when designing incentive systems. In sum, our results suggest to foster the use of output-dependent prizes in the organizational practice.

2 Theoretical Analysis

We analyze the cost minimization problem (CMP) of a principal who employs a group of agents, assuming that the principal is free to determine the quantity she wished to produce and the incentive scheme by which the agents are paid. The general optimization problem of the principal is

$$\pi(x) = R(x) - C_{\alpha,\beta,\omega}(x) \tag{1}$$

where x is the production quantity, $\pi(x)$ denotes the principal's profit, $R(x)$ denotes the revenue, and $C_{\alpha,\beta,\omega}(x)$ denotes the principal's cost of producing x with incentive parameters α, β and ω, which correspond to the three types of incentives we consider (respectively a fixed prize, an output-dependent prize, and a piece rate). Our aim is to provide the principal with optimal values of the incentive parameters $\alpha^*, \beta^*, \omega^*$ that will minimize the cost function $C(x) \equiv C_{\alpha^*,\beta^*,\omega^*}(x)$, such that

$$C_{\alpha^*,\beta^*,\omega^*}(x) \leq C_{\alpha,\beta,\omega}(x) \; \forall \alpha, \beta, \omega, x.$$

The CMP is formulated in the tradition of the standard microeconomic theory where the principal is interested in the cheapest bundle of inputs that results in the production of a given output x. The only additional assumption in our analysis is that the efforts of the agents are mutually best replies. In other words, we solve the market interaction by backward induction, starting with the (final) subgame between the competing agents, and then considering the decisions of the principals.

It is important to note that the cost minimizing incentive scheme does not depend on the structure of the market, and is not affected by (profit reducing) competition with other principals (as in Lazear and Rosen, 1981). The principal will use the same incentive scheme as a monopolist, oligopolist or even as a competitor in a market where she cannot influence the market price at all. The market structure will be reflected by the revenue function $R(x)$ in (1) and consequently, of course, by the optimal quantity to be produced.

The motivation of our theoretical analysis can be summarized by the following question: which incentive scheme (i.e., combination of α, β and ω) is optimal in the sense of providing a given (expected) production amount at minimal cost?

We consider two competing agents, 1 and 2, who may represent individual employees or teams in the same firm. Both agents $i \in \{1,2\}$ must choose an effort level $x_i \geq \underline{x}$ (with $\underline{x} \geq 0$). Each effort x_i generates an output of $x_i + \varepsilon_i$, where $\varepsilon_i \in [\underline{\varepsilon}, \bar{\varepsilon}]$ is a noise term with $\underline{\varepsilon} < \bar{\varepsilon}$, $\underline{x} + \underline{\varepsilon} \geq 0$ and density $\varphi(\cdot)$ with all probability mass in the interval $[\underline{\varepsilon}, \bar{\varepsilon}]$. According to such an iid-case, the noise levels ε_1 and ε_2 are stochastically independent and identically distributed. These restrictions ensure the nonnegativity of the agents' output. The payoff of agent i with competitor $j \neq i$ can now be defined as

$$u_i(x_i, x_j, \varepsilon_i, \varepsilon_j) = \begin{cases} \omega(x_i + \varepsilon_i) - c_i(x_i) & \text{if} \quad x_i + \varepsilon_i \leq x_j + \varepsilon_j \\ \omega(x_i + \varepsilon_i) + \alpha + \beta(x_i + \varepsilon_i + x_j + \varepsilon_j) - c(x_i) & \text{otherwise.} \end{cases} \tag{2}$$

Here, $\omega \in \mathbb{R}_+$ is a piece rate, $\alpha \in \mathbb{R}_+$ is a fixed prize, $\beta(x_i + \varepsilon_i + x_j + \varepsilon_j)$ is an output-dependent prize ($\beta \in \mathbb{R}_+$ determines to which degree the output-dependant prize depends on firm performance, and $c_i(x_i)$ denotes the cost of investing effort x_i.[1] After agents independently choose x_1 and x_2 (their effort levels) and nature selects ε_1 and ε_2 (according to $\varphi(\cdot)$), the ranking of the individual (observable) output levels $x_1 + \varepsilon_1$ and $x_2 + \varepsilon_2$ determines which agent receives the fixed and output-dependent prizes ($\alpha + \beta(x_i + \varepsilon_i + x_j + \varepsilon_j)$). Both agents receive the piece rate ($\omega(x_i + \varepsilon_i)$).

To test the model experimentally we restrict ourselves to a specific form of $\varphi(\cdot)$ and $c_i(\cdot)$. In particular, we assume the noise terms ε_i to be uniformly distributed[2] on $[0, \varepsilon]$ and the effort costs to be quadratic ($c_i(x_i) = \frac{\gamma}{2} x_i^2$, with $\gamma > 0$ for $i = 1, 2$). Finally, we assume

[1] Firm performance is simply the sum of the output levels of the two agents ($x_i + \varepsilon_i + x_j + \varepsilon_j$).

[2] Some tournament models (e.g., Lazear and Rosen, 1981) rely on normally distributed noise for the sake of mathematical convenience. While this violation of economic nonnegativity constraints is easily sustainable in theory, it is not possible to implement a true (non-truncated) normal distribution in an experiment.

that the participants encounter the tournament repeatedly. Therefore, it is reasonable to assume common(ly known) risk neutrality. The expected payoffs of agents $i \in \{1, 2\}$ are

$$Eu_i = \omega(x_i + \tfrac{\varepsilon}{2}) + \tfrac{1}{\varepsilon} \int_0^{\varepsilon} h(x_i, x_j, \varepsilon_j)\, d\varepsilon_j - \frac{\gamma}{2} x_i^2 \,, \tag{3}$$

where the fist term reflects the expected piece-rate profit of the agent, the second term the expected profit from winning the tournament, the third term corresponds to the effort cost, and

$$h(x_i, x_j, \varepsilon_j) = \begin{cases} 0 & \text{if} \quad x_i \leq x_j + \varepsilon_j - \varepsilon \,, \\ \frac{1}{\varepsilon} \int_0^{\varepsilon} [\alpha + \beta(x_i + \varepsilon_i + x_j + \varepsilon_j)]\, d\varepsilon_i & \text{if} \quad x_i \geq x_j + \varepsilon_j \,, \\ \frac{1}{\varepsilon} \int_{x_j+\varepsilon_j-x_i}^{\varepsilon} [\alpha + \beta(x_i + \varepsilon_i + x_j + \varepsilon_j)]\, d\varepsilon_i & \text{otherwise.} \end{cases}$$

The function h distinguishes between three cases: agent i loses for any value of ε_i (even $\varepsilon_i = \varepsilon$); agent i wins for any value of ε_i (even $\varepsilon = 0$); the winner depends on ε_i.

For $\beta \geq \frac{\gamma\varepsilon}{2}$ the best reply of agent j to x_i is $x_j > x_i$. Consequently, both agents invest the maximal possible effort. For $\beta < \frac{\gamma\varepsilon}{2}$ the unique equilibrium effort $\hat{x}$ (in the sense of mutually best replies) is

$$\hat{x} = \frac{2\alpha + \varepsilon(3\beta + 2\omega)}{2\gamma\varepsilon - 4\beta} \qquad \text{for } i \in \{1, 2\}, \tag{4}$$

and the expected joint output is $2\hat{x} + \varepsilon$. See Appendix A.1 for a detailed derivation of this result.

The principal's (expected) cost function is composed of the fixed bonus α, which is to be paid in full regardless of the agents' production levels; and of the output-dependent prize β and the piece rate ω, which linearly depend on the production levels:

$$C_{\alpha,\beta,\omega}(x_1 + x_2 + \varepsilon) = \alpha + (\beta + \omega)(x_1 + x_2 + \varepsilon) \tag{5}$$

Since the principal can implement a three-dimensional incentive scheme (α, β, ω), the goal is to find a combination of these three values that yields the expected output of $2\hat{x} + \varepsilon$ at a minimal (expected) cost. Formally, this is equivalent to finding a combination (α, β, ω) that minimizes the costs of the principal on the non-negative part of the plane defined by equation 4 (graphically illustrated in Figure 1).

Assuming that agents invest effort according to equation 4, we can express α as

$$\alpha = \gamma\hat{x}\varepsilon - (2\hat{x} - \frac{3}{2}\varepsilon)\beta - \varepsilon\omega \tag{6}$$

and substitute it in equation 5 to get

$$C_{\alpha,\beta,\omega}(2\hat{x} + \varepsilon) = \gamma\varepsilon\hat{x} + 2\hat{x}\omega - \frac{\varepsilon}{2}\beta. \tag{7}$$

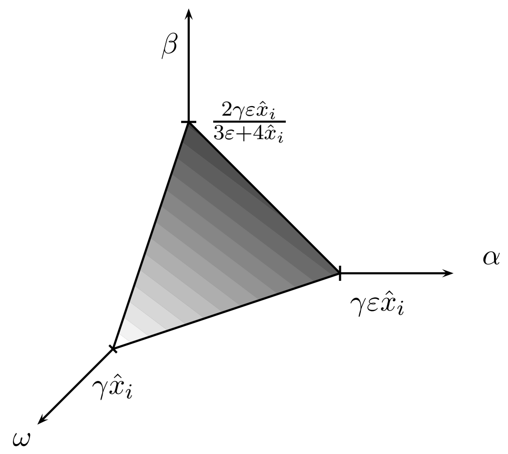

Figure 1: Contracts with an expected output of $2\hat{x}+\varepsilon$. All contracts (combinations of α, β, ω) lie on the triangle which is the non-negative part of the plane defined by (4). The gradual shading of the triangle corresponds to the expected profit of the principal. The darker the shade, the more profitable the contract is. The most attractive contract from the principal's perspective is located at the intersection of the plane with the β axis, where only the output-dependent prize is used. The least attractive contract is at the intersection of the plane with the ω axis, where only a piece rate is paid.

It is easy to see that the (expected) cost function is increasing in ω and decreasing in β. Thus, the optimal incentive scheme should have the lowest possible value of ω and the highest possible value of β, which are 0 and $\frac{2\gamma\varepsilon\hat{x}}{3\varepsilon+4\hat{x}}$, respectively. Since it directly follows (from equation 4) that $\alpha = 0$, the optimal incentive scheme is

$$(\alpha, \beta, \omega) = \left(0, \frac{2\gamma\varepsilon\hat{x}}{3\varepsilon+4\hat{x}}, 0\right)$$

and the corresponding cost is $C(2\hat{x}+\varepsilon) = \frac{(2\hat{x}_i+\varepsilon)2\gamma\varepsilon\hat{x}}{3\varepsilon+4\hat{x}}$, or, denoting the expected output $2\hat{x}+\varepsilon$ as ξ,

$$C(\xi) = \frac{\gamma\varepsilon\xi(\xi-\varepsilon)}{\varepsilon+2\xi}.$$

From the principal's point of view, it is best to use the output-dependent prize (β) exclusively, and not include a fixed prize α or piece rate ω in the incentive scheme.

Proposition The output-dependent prize β is more cost-effective than the fixed prize α which, in turn, is more cost-effective than the piece rate ω.

Our theoretical analysis neglects possible drawbacks (from the principal's point of view) of tournament competitions, which may play a role in real organizational, or even experimental, settings, such as collusive behavior, sabotage, and negative effects of competition on corporate identity. In our view it is obvious that tournaments with output-dependent prizes are - in comparison to fixed-prize incentives - relatively immune to collusion, and to a lesser degree also to sabotage, because if agents reduce their efforts or the output of others the prize will be smaller. The concern regarding corporate identity is that competition between agents will reduce their feeling of corporate identity, which in return will reduce their willingness to invest high efforts. Piece rate incentives, as they are not competitive at all, seem to be the least problematic when considering possible negative effects on corporate identity, while fixed and output-dependent prizes seem to be similar in this respect, as they are both competitive.

3 Experimental Design

The experiment was designed with two main questions in mind: Will the theoretically cost minimizing incentive component (i.e., the output-dependent prize) also be behaviorally the most cost effective, i.e., will it deliver the same (or similar) output levels at lower labor costs? Will it be predominantly employed by principals? These two empirical questions reflect the two stages of our (modified) CMP problem: the first one examines the behavior of agents in the final subgame, and the second examines the behavior of principals in the entire CMP.

The experiment was run at the computer laboratory of the Max Planck Institute of Economics in Jena, Germany, and included 112 participants, mostly undergraduates of the University of Jena, enrolled in different fields. Each of the four computerized experimental sessions (28 participants per session) lasted about 100 minutes. Earnings, including a show-up fee of €2.50, ranged from €4.60 to €17.44. Upon arrival, each participant was seated in a visually isolated cubicle. Detailed written and oral instructions (to establish common knowledge) explained the rules and payoffs of the game and were followed by a control questionnaire. After the experiment, participants were paid individually and left the laboratory separately.

In each session, the 28 participants were randomly partitioned into four 7-person groups. In each group, one participant was assigned the role of 'principal' and 6 were assigned to be 'agents'. The 7-person groups remained constant throughout the experiment, and this was made known to the participants. Participants did not know which of the other participants were in their group. Each session was divided into three 10-round phases, and each phases began with principals selecting one of fifteen available contracts, defined by combinations of α, β, and ω. In each round the six agents were randomly split up into three pairs.

In the parametrization of the experiment we assumed uniformly distributed noise ($\varepsilon \in [0, 40]$) and that the cost parameter equals 1 ($\gamma = 1$). The 15 contracts (i.e., combinations of α, β, and ω) that principals could choose from at the beginning of each phase all yielded the same subgame perfect equilibrium effort of 20 by the agents ($\hat{x} = 20$). From (4) it follows that all of these contracts satisfied

$$20 = \frac{2\alpha + 40(3\beta + 2\omega)}{80 - 4\beta} \quad \Rightarrow \quad \alpha = 800 - 100\beta - 40\omega\,. \tag{8}$$

To make the model as simple as possible we decided to abstract from any kind of competition between firms, and assumed that principals can sell whatever 'their' agents produce at a constant price of 20 per unit.[3] Thus, the revenue of principals is

$$R(x_1, x_2, \varepsilon_1, \varepsilon_2) = 20(x_1 + \varepsilon_1 + x_2 + \varepsilon_2), \tag{9}$$

and from $\hat{x}_i = 20$, $\varepsilon = 40$, and (5), (8), and (9) it follows that their expected profit is

$$\begin{aligned} Eu_p(\alpha, \beta, \omega, x_1, x_2, \varepsilon_1, \varepsilon_2) &= R(x_1, x_2, \varepsilon_1, \varepsilon_2) - C_{\alpha,\beta,\omega}(x_1, x_2, \varepsilon) \\ &= 20(2\hat{x}_i + \varepsilon) - (\alpha + (\beta + \omega)(2\hat{x} + \varepsilon)) \\ &= (20 - \beta - \omega)80 - (800 - 100\beta - 40\omega) \\ &= 800 + 20\beta - 40\omega. \end{aligned} \tag{10}$$

As shown in the theoretical section, the principal's expected profit (10) increases with β and decreases with ω.

Figure 2 illustrates the 15 available incentive schemes in the plane satisfying (8). The principal's choice of one of these contracts set the stage for the interactions of her six agents in the following ten rounds (i.e., phase). After learning which contract (α, β, ω) had been implemented by the principal, each agent was randomly paired, in each round, with one of the other five agents in the same group. Agents were not identifiable, and thus did not know with whom they were randomly paired in each round

Agent $i \in \{1, 2\}$ could choose an effort level $x_i \in [0, 30]$, knowing that the random variable ε_i is uniformly distributed in $\varepsilon_i \in [0, 40]$ and that both cost functions $c_i(x_i)$, $i \in \{1, 2\}$ are given by $\frac{x_i^2}{2}$ (i.e., $\gamma = 1$). At the end of each round agents were informed about their own production level, the production level of their partner in that round, and their earnings, divided into the fixed prize, output-dependent prize, and piece rate components. Then they were randomly rematched with another agent from the same group and the next round began.

In line with the fact that organizational incentive schemes are rarely re-designed, and changes are typically made after a long time of experience with a certain structure, principals in the experiment were only allowed to change the incentive scheme between phases, after ten rounds in which the previous incentive scheme has been in effect. Since the six

[3] This value of 20 is not to be confused with the equilibrium effort of 20 which agents should invest according to our parametrization. While the use of the same value may be slightly confusing for the reader, is was not confusing for the participants, as they were not explicitly told that the equilibrium effort is 20.

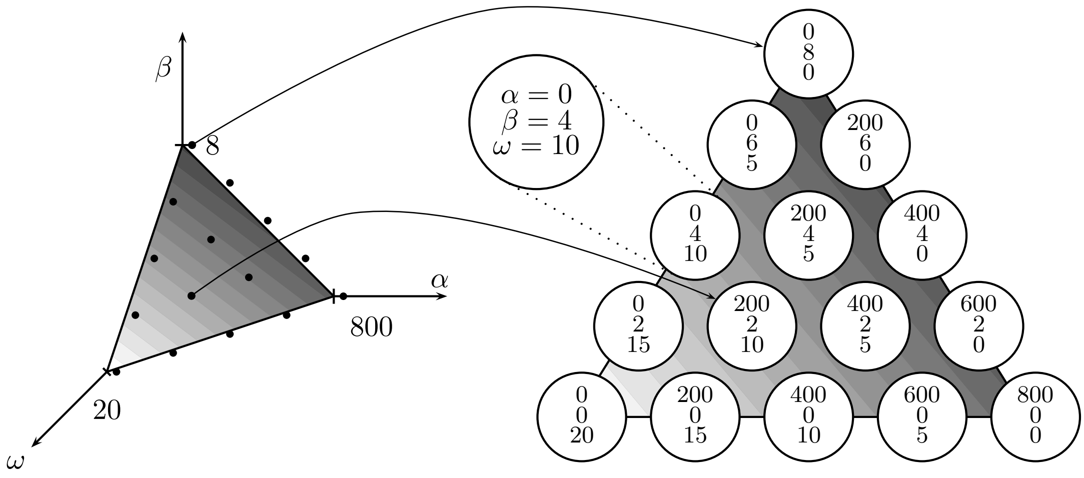

Figure 2: Available contracts. The triangular plane on the left is a specific case of the one in 1, with the parameters used in the experiment. The triangle on the right corresponds to the plane on the left, and details the value of each incentive component for each of the 15 contracts that were available to principals. The three numbers in each circle, from top to bottom, are the values of α, β, and ω.

agents were matched into three pairs in each round, principals could see the results of thirty (ten rounds, three tournaments in each round) tournaments before deciding on a new incentive scheme.

Following each round, principals were informed about the production of each agent, the joint revenue, their cost, and their profit.[4] This information remained on the principal's screen, and information from the next round was appended to it. Thus, at the end of each ten-round phase, the principal had on-screen information about all thirty tournaments which took place in the phase. Additionally, after each of the three phases, principals received feedback which included the average production, revenues, costs, and profits across all the tournaments that took place in the phase.

4 Results

4.1 Agents' Choice of Effort

Since the equilibrium effort is 20 for all of the possible contracts available to principals, we first check whether agents' efforts were indeed identical (and equal to 20) across all contracts. Figure 3 displays the average effort invested by agents for each specific contract. It is clear that the average effort levels under the different contracts differ from each other and deviate from the equilibrium effort choice of 20: Average efforts vary from 16.05 in

[4] production $= x_i + \varepsilon_i$; joint revenue $= 20(x_1 + \varepsilon_1 + x_2 + \varepsilon_2)$; cost $= (\omega + \beta)(x_1 + \varepsilon_1 + x_2 + \varepsilon_2) + \alpha$; profit $= u_p$

the lower right-hand corner ($\alpha = 800, \beta = 0, \omega = 0$) up to 23.35 in the contract with $\alpha = 0, \beta = 2$ and $\omega = 15$. Apparently, agents choose lower (higher) effort levels under contracts that are theoretically more (less) profitable for the principal.[5]

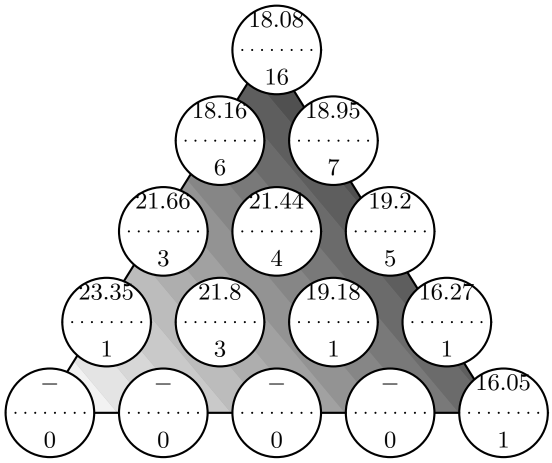

Figure 3: Average efforts and frequency by contract. The average effort invested by agents under each contract (top) and the number of times the contract was chosen by principals (bottom) (see Figure 2 for a mapping of contracts to points on the triangle).

Following the above observation, we check whether the contract, characterized either by the principals' equilibrium profit, or by the *level* of each contract component (α, β, ω) associated with it, is a good predictor of the effort invested by agents.[6] Figure 6 graphically displays how agents' efforts depend on the different characteristics of the incentive scheme. We use Tobit regressions, taking into account that only observations across groups are independent (by clustering errors at the group level), with the agents' efforts as a dependent censored variable.[7] The explanatory variables (in four separate regressions) are the principals' equilibrium profit, and the level of the α, β, and ω contract components. As adding the period as an additional explanatory variable in these regressions has a neg-

[5]This pattern suggests reciprocal behavior on the side of the agents. Since agents are paid less for the same effort under contracts that maximize the expected profit of the principal, they may be negatively reciprocating these contract choices by investing less effort (than the equilibrium level). Similarly, agents may be positively reciprocating choices of contracts that yield less profit to the principal, and higher wages to themselves, by investing more effort.

[6]For the purpose of this and the following analyses we use the *level* of each contract component rather than its absolute value. For example, while the possible values of the α component are 0, 200, 400, 600, and 800, the variable included in the analyses has corresponding values of 0, 1, 2, 3, and 4. The same holds for the β and ω components.

[7]Each of these Tobit regressions uses only one explanatory variable (the principal's equilibrium profit, the level of the α component, the level of the β component, or the level of the ω component). It is not possible to include all of these as explanatory variables in the same regression model because they are not independent from one another; the level of each contract component can be determined by the other two, and the principals' equilibrium profit can also be determined by the levels of any pair of components.

ligible effect on the results (and $p > 0.34$ for the period coefficient in all four cases), we proceed to consider the basic regressions (without the period).

The general result from these regressions is that agents systematically deviate from their equilibrium effort of 20. When we use the principals' equilibrium profit as the (only) predictor, the coefficient is -0.00744 ($t = -4.05$, $p < 0.0005$). The interpretation of the coefficient is straightforward; the more profitable a contract is for the principal, the lower the effort invested by agents. Specifically, an increase of 100 points in the principal's equilibrium profit results in a decrease of 0.744 in the agents' effort.[8]

Using the level of each of the contract components, rather than the principal's equilibrium profit, as the explanatory variable in the Tobit regressions, reveals that agents react differently to each component.[9] The coefficient for the ω component is 1.78 ($t = 3.83$, $p < 0.0005$), indicating a rather strong and positive relation between the level of ω and the agents' efforts. For the β component the coefficient is -0.78 and only marginally significant ($t = -1.57$, $p = 0.116$), indicating that agents possibly exert less effort the higher the level of the β component. Most strikingly, agents are not sensitive at all to the α component of the contracts (coefficient: -0.18, $t = -0.30$, $p = 0.763$), the main incentive component in the incentive literature.

As mentioned above, adding the period number as an explanatory variable does not change these results, and does not suggest that agents adjust there efforts during the ten rounds of each phase. To exclude effects of experience from previous phases we ran the same regressions for first-phase decisions only, and the result was also not significant ($p > 0.93$ for all four regressions), leading us to conclude that effort choices did not systematically change during the course of each phase.

Given the negative relation between the principal's equilibrium profit and the agents' effort, principals' (empirical) profits must be relatively higher than the equilibrium profit for the theoretically inferior contracts and lower for the superior contracts. Such a pattern could possibly reverse the hierarchy of contracts, such that theoretically superior contracts are (empirically) less profitable (to the principals) than theoretically inferior ones. However, as can be seen in the right of Figure 4, agents' deviations from the optimal effort only marginally alter the profitability ranking from the principal's perspective. With one exception (the 5th and 7th theoretically ranked contracts switch positions in the empirical ranking), the empirical ranking of profits corresponds to the theoretical one.

[8] The small value of the coefficient is somewhat misleading and results from the difference in scales between the equilibrium profits (0 to 960) and the effort level interval from which agents could choose (0 to 30). Considering the full ranges of possible payoffs and effort levels, an increase of 10.4% (of the full range) in payoffs is accompanied by an increase of 2.5% in effort.

[9] Figure 6 in the Appendix visualizes the dependency of agents' effort on the level of α, β, and ω, and the equilibrium profit of the principal, depending on contract choice.

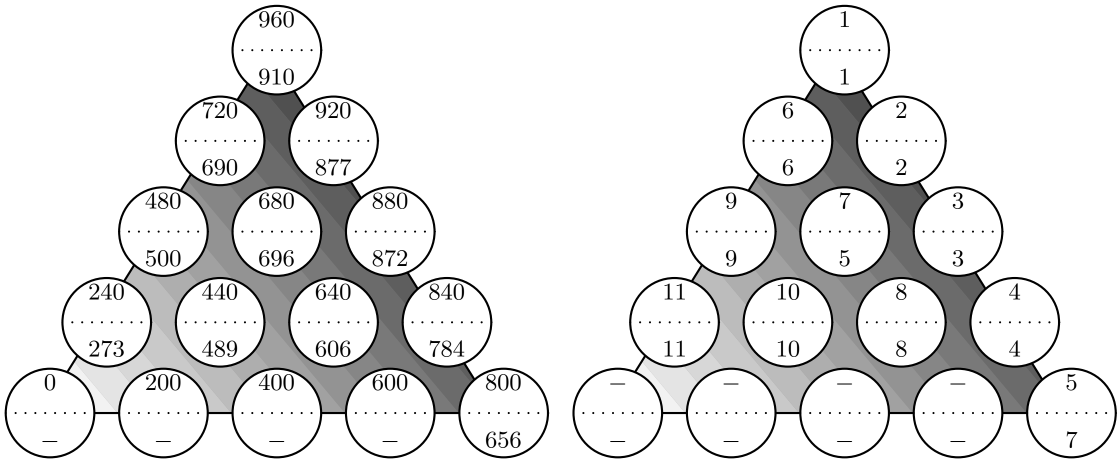

Figure 4: Principal profits by contract. The numbers on the left are the theoretical (top; assuming that agents choose equilibrium efforts) and empirical (bottom) profits of the principals for each available contract. The numbers on the right are rankings of the theoretical and empirical principal profits which appear on the left (see Figure 2 for a mapping of contracts to points on the triangles).

Accordingly, using principals' equilibrium profit to predict their actual profit in a linear regression (taking into account that only observations across groups are independent) reveals a very strong and positive relation. The coefficient of the equilibrium profit is 0.67 ($t = 5.47, p < 0.0005$), indicating that an increase of 1 point in the theoretical profit was accompanied by an increase of 0.67 points in the actual profit.

Results – Agents Agents systematically deviated from the equilibrium effort level; the better a contract was for the principal (in equilibrium), the less effort was invested by agents. Efforts were positively related to ω, (marginally) negatively to β, and were not related to α. Despite these deviations, the empirical and theoretical rankings of contracts from the principal's point of view were highly correlated. Effort choices were stable within each (ten-period) phase.

4.2 Principals' Choice of Incentive Scheme

The second part of our analysis examines the choices of contracts made by principals. Figure 3 describes how often each incentive scheme was chosen. As can be clearly seen in the figure, the (theoretically and empirically) most attractive contract from the principals' perspective ($\alpha = 0, \beta = 8, \omega = 0$) is also the one chosen most frequently, and particularly unattractive schemes are not chosen at all. However, there are also theoretically attractive incentive schemes (e.g., in the lower right-hand corner of the triangle) that were hardly ever chosen by the principals – who apparently anticipated agents' suboptimal efforts in these particular incentive schemes.

	Equilibrium profit		Empirical profit	
Comparison	S	p	S	p
Phase one – phase two	-14.5	0.2622	-5	0.8209
Phase one – phase three	-6.0	0.6338	-11	0.5966
Phase two – phase three	10.5	0.4033	5	0.8209

Table 1: Principals' contract dynamics. S – Wilcoxon signed rank sum test statistic; p – significance level

Figure 7 in the Appendix visualizes the frequency of contract choices as a function of the level of α, β, and ω, and of the principal's equilibrium profit. Since the contracts are clearly ranked in terms of the equilibrium profit of the principal, and especially since the empirical profits closely preserve this ranking, we checked whether principals indeed chose contracts that were more profitable to them, namely, contracts with a high β (and α) component and a low ω component. Figure 3 shows that this is mostly the case. Both the contracts' theoretical and empirical profits are highly correlated with the frequency with which they were chosen ($r = 0.61$, $p = 0.0161$; $r = 0.60$, $p = 0.049$; respectively). Principals display a very strong tendency to choose contracts with high β levels ($r = 0.90$, $p < 0.0001$), and a weaker tendency to rely on contracts with low ω levels ($r = -0.50$, $p = 0.0594$). The correlation between the level of the α component and the contracts' frequency is negative, but not significant ($r = -0.4056$, $p = 0.1337$).

Do principals change their contract choices in a systematic way during the experiment? Principals have only two opportunities to adapt the contract – once after the first phase and once after the second – but they receive a lot of feedback information (thirty tournaments per phase). Thus, one can reasonably expect that they will choose more favorable contracts as the experiment progresses, e.g., due to the 'law of effect', as propagated by reinforcement learning (Roth and Erev, 1995; Erev and Roth, 1998).

To check for systematic changes in principals' contract choices across phases, we compared, for each principal, the equilibrium profits of the contracts she chose in the first and second phase. Similarly, we compared the first phase to the third phase and the second phase to the third phase. We also conducted equivalent comparisons for the empirical profits. Wilcoxon signed rank sum tests, however, do not reveal any systematic differences (Table 1).[10]

Results – Principals Principals tended to choose the (theoretically and empirically) superior contracts, and were primarily sensitive to the β component. Contract choices did not change systematically from phase to phase.

[10]The lack of noticeable dynamics in principals' contract choices may be partly due to the fact that in many cases principals already started out by relying heavily on output-dependent prize incentives (β) in the first phase and therefore had little room for improvement in subsequent phases.

5 Discussion

Tournaments are often used by firms and organizations as supplements to more standard reward schemes, like salaries or piece rates. Here we introduced *output-dependent prize tournaments*, where the size of the prize depends on firm performance, which in turn depends on the effort of the competing agents, and showed both theoretically and experimentally that output-dependant prize tournaments outperform two other well studied compensation schemes, namely piece rates and fixed prize tournaments.

The main goal of our theoretical analysis was to find an incentive scheme (based on a combination of a piece-rate, a fixed prize and an output-dependent prize) that minimizes the principal's (or firm's) cost of producing a pre-determined output. We based our theoretical approach on a classical cost minimizing problem (CMP) to prove its independence of the market environment.[11] According to our modified CMP, the firm chooses its best incentive scheme, assuming (by backward induction) that agents exert the equilibrium efforts in the resulting subgames. We show that the equilibrium of this game (which constitutes a proper subgame of the entire market game) is largely independent of the parameters of the model (e.g., cost function, noise distribution), and that it simply requires that the firm incentivizes the agents solely on the basis of an output-dependent prize, and avoids piece-rate and the fixed prize incentives.

By restricting our analysis to the (modified) CMP, and abstracting from the particular structure of the market in which the firm operates, we show that our result is rather general and robust. The solution of the CMP - to use only an output-dependent prize as an incentive - can be applied in *any* market situation, such as Cournot or Stackelberg (both if the firm is leader or follower) markets, and even when the firm is a monopoly.

The lower expected cost of exerting a given amount of effort from the agents is not the only advantage of output-dependent prizes over fixed prizes; they also bear less potential for collusion and sabotage, since both reduce firm performance and hence lower the tournament prize. All together, output-dependent prize tournaments seem to be a very attractive compensation system from the point of view of firms.

There are also possible negative aspects associated with the use of output-dependent prizes. An obvious one is the negative externality on agents – if firms can pay less for the same effort by using output-dependent prizes, it is necessarily at the agents' expense. Another negative aspect of output-dependent prizes, from the point of view of (risk averse) agents, is that both the size of the prize and the probability of winning it are affected by their own idiosyncratic uncertainty (captured by ε in our model) and by the idiosyncratic uncertainty of the other agents. In comparison, in fixed prize tournaments idiosyncratic

[11] See Güth et al. (2015) on the potential interaction effects between the choice of compensation and inter-firm competition.

uncertainty (both one's own and that of the other agents) affects only the probability of winning (but not the size of the prize), and when piece rates are used idiosyncratic uncertainty affects only the size of the prize (but not the probability of winning). This increased uncertainty might lead risk averse agents to perceive the already unfriendly output-dependent prizes (in terms of expected profits) as even less friendly.

Such negative perceptions by the agents can adversely affect firms' profits. Agents may (negatively) reciprocate the instalment of what they perceive as an unfriendly compensation system – in the case of output-dependant prizes, due to low expected profits and increased uncertainty – by decreasing their efforts below the equilibrium level, as suggested by various reciprocity theories. This pattern is indeed suggested by our data, although in our case agents' deviations from the equilibrium effort level did not suffice to render output-dependent prizes unattractive for principals.

We are aware that of the many possible market structures (e.g., Cournot, Stackelberg, monopolistic) we experimentally explore a particular case where the principals (firms) are price takers (as in a perfectly competitive market). In such an experimental market, all of the strategic considerations of the principal-participants are devoted to choosing the optimal incentive scheme for paying their agents, and (horizontal) between-firm competition is disregarded, such that our principal-participants did not have to deal with the added complexity of operating in a competitive market. Experimental work on more complex market constellations can shed more light on the practical advantages and shortcomings of output-dependent prizes.

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Appendix

A.1 Derivation

In this section we derive the equilibrium effort level of the agents, starting with their expected payoff, as given in Equation 3:

$$Eu_i = \omega(x_i + \tfrac{\varepsilon}{2}) + \tfrac{1}{\varepsilon}\int_0^{\varepsilon} h(x_i, x_j, \varepsilon_j)\, d\varepsilon_j - \frac{\gamma}{2} x_i^2\,, \tag{3 revisited}$$

with

$$h(x_i, x_j, \varepsilon_j) = \begin{cases} 0 & \text{if} \quad x_i \le x_j + \varepsilon_j - \varepsilon\,, \\ \frac{1}{\varepsilon}\int_0^{\varepsilon} [\alpha + \beta(x_i + \varepsilon_i + x_j + \varepsilon_j)]\, d\varepsilon_i & \text{if} \quad x_i \ge x_j + \varepsilon_j\,, \\ \frac{1}{\varepsilon}\int_{x_j+\varepsilon_j-x_i}^{\varepsilon} [\alpha + \beta(x_i + \varepsilon_i + x_j + \varepsilon_j)]\, d\varepsilon_i & \text{otherwise.} \end{cases}$$

Expressing the definite integrals in the definition of the function $h(x_i, x_j, \varepsilon_j)$ we get

$$h(x_i, x_j, \varepsilon_j) = \begin{cases} 0 & \text{if} \quad x_i \le x_j + \varepsilon_j - \varepsilon\,, \\ \alpha + \beta(x_i + \frac{\varepsilon}{2} + x_j + \varepsilon_j)] & \text{if} \quad x_i \ge x_j + \varepsilon_j\,, \\ \frac{1}{2\varepsilon}(x_i + \varepsilon - x_j - \varepsilon_j)[2\alpha + \beta(x_i + \varepsilon + 3x_j + 3\varepsilon_j)] & \text{otherwise.} \end{cases}$$

Substituting $h(x_i, x_j, \varepsilon_j)$ in Equation (3) and differentiating the expected profit with respect to x_i we get

$$\frac{\partial Eu_i}{\partial x_i} = \begin{cases} \omega - \gamma x_i & \text{if} \quad x_i \le x_j + \varepsilon_j - \varepsilon\,, \\ \omega + \beta - \gamma x_i & \text{if} \quad x_i \ge x_j + \varepsilon_j\,, \\ \frac{1}{2\varepsilon}[2\omega\varepsilon + 2\alpha + \beta(2x_i + 2x_j + 3\varepsilon) - 2\varepsilon\gamma x_i] & \text{otherwise,} \end{cases}$$

and the best reply of i to j, assuming a symmetric equilibrium, is

$$x_i = \frac{\beta}{\varepsilon\gamma - \beta} x_j + \frac{2\omega\varepsilon + 2\alpha + 3\varepsilon\beta}{2(\varepsilon\gamma - \beta)}.$$

When $\frac{\beta}{\varepsilon\gamma-\beta} \ge 1$ (rewritten as $\beta \ge \frac{\gamma\varepsilon}{2}$) i's best reply to any x_j is $x_i > x_j$. From the symmetry between i and j it follows that when $\beta \ge \frac{\gamma\varepsilon}{2}$ both agents invest the maximal effort. When $\beta < \frac{\gamma\varepsilon}{2}$, and again considering the symmetry between i and j, the unique equilibrium effort $\hat{x}$ (in the sense of mutually best replies) must satisfy the first order condition

$$2\omega\varepsilon + 2\alpha + \beta(4\hat{x} + 3\varepsilon) - 2\varepsilon\gamma\hat{x} = 0,$$

resulting in

$$\hat{x} = \frac{2\alpha + \varepsilon(3\beta + 2\omega)}{2\gamma\varepsilon - 4\beta} \quad \text{for } i \in \{1, 2\}. \tag{4 revisited}$$

A.2 Instructions

The situation

This experiment consists of multiple rounds. Before the first round, we will randomly assign you to one of two possible roles, namely the A-role and the P-role, which you will keep throughout the entire experiment. There will be groups of one P-participant and six A-participants that stay together over 10 rounds (=1 phase). In each round, the six A-participants in a group will be split up randomly in three pairs. Thus, each A-participant faces the same P-participant in all the 10 rounds of one phase, but is very likely to be paired with a different A-participant in each round.

The decision process

At the beginning of each phase, the P-participant determines a reward scheme for his/her group. The components of these reward schemes are explained below. After that, and knowing the reward scheme, the A-participants choose their action: each of the two A-participants in a pair independently chooses a number between 0 and 30.

Suppose that one A-participant chooses x and the other $\hat{x}$. These choices are linked to costs of $\frac{1}{2}x^2$ and $\frac{1}{2}\hat{x}^2$, respectively. The choice of x is linked to an output of $y = x + \varepsilon$, and the choice of $\hat{x}$ is linked to an output of $\hat{y} = \hat{x} + \hat{\varepsilon}$. ε and $\hat{\varepsilon}$ are independently and evenly distributed random variables in the intervals $0 \leq \varepsilon \leq 40$ and $0 \leq \hat{\varepsilon} \leq 40$. In other words, any possible value of ε and $\hat{\varepsilon}$ is equally likely to occur, and both random variables are drawn independently from each other.

If the output of the A-participant who chose x is larger or equal to the output of the A-participant who chose $\hat{x}$, i.e., $y \geq \hat{y}$, the A-participant who chose x earns $cy + a + b(y + \hat{y}) - \frac{x^2}{2}$, and the A-participant who chose $\hat{x}$ only earns $cy - \frac{\hat{x}^2}{2}$. In other words, only the A-participant whose output is <u>not smaller</u> than the output of the other A-participant in the pair, receives the extra payment $a + b(y + \hat{y})$.

The first part of the extra payment, a, does not depend on the total output $y + \hat{y}$ of a pair, while the second part of the payment, $b(y + \hat{y})$, increases linearly with the total output $y + \hat{y}$ - if and when b is larger than zero.

The payment of cy and $c\hat{y}$ is independent of whether $y \geq \hat{y}$. Thus, when c is larger than zero, the payment of cy and $c\hat{y}$ ensures that A-participants receive a payment that increases in their individual output.

The P-participant earns a constant amount of 20 ECU for each unit of output, minus the payments to the six A-participants. For each pair of A-participants, the P-participant earns $(20 - c - b)(y + \hat{y}) - a$.

The P-participant is not free to choose any possible reward system (a, b, c), but must choose one of the following 15 rewards systems, where the first, second and third numbers in each cell stand for a, b, and c:

$0, 0, 20$	$0, 2, 15$	$0, 4, 10$	$0, 6, 5$	$0, 8, 0$
$200, 0, 15$	$200, 2, 10$	$200, 4, 5$	$200, 6, 0$	
$400, 0, 10$	$400, 2, 5$	$400, 4, 0$		
$600, 0, 5$	$600, 2, 0$			
$800, 0, 0$				

The experiment ends after 3 phases (30 rounds). Your payment is the sum of all your earnings in all periods. This sum is converted to Euro with the following conversion rate: 1 Euro = 4000 ECU.

You will be paid privately in cash at the end of the experiment.

A.3. Figures

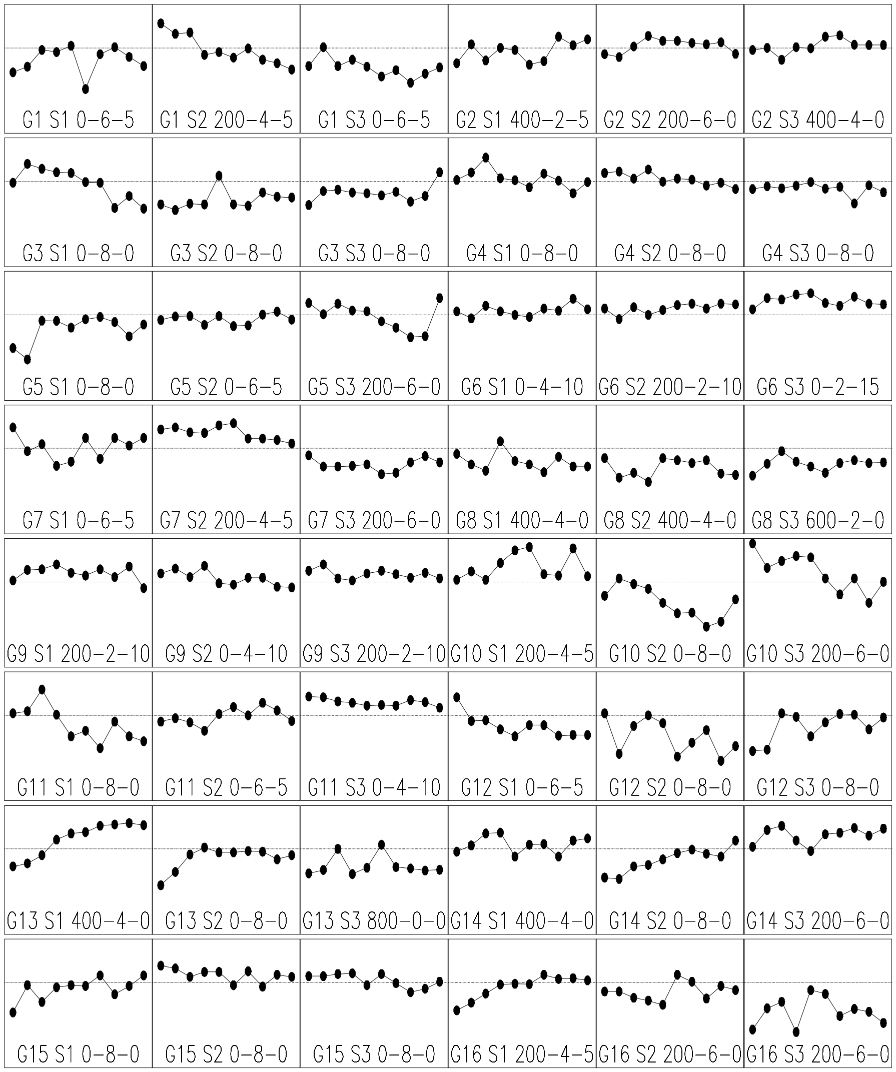

Figure 5: **Mean group efforts – all observations.** Each of the 48 (16 groups × 3 phases) plots describes average efforts for a specific group in one (10-round) phase. The horizontal axis in each plot is the 'round' axis, going from 1 (left) to 10 (right), and the vertical axis is the effort axis, going from 0 (bottom) to 30 (top). The horizontal line in each plot marks the equilibrium effort of 20. Each plot is labeled with information regarding the group, phase, and the contract that was in effect. The group number (1-16) is prefixed by 'G'; the phase number (1-3) by 'S'; and the 3 numbers separated by dashes pertain to the α, β, and ω components of the contract that was chosen by the principal for the phase. For example, the top left plot is labeled 'G1 P1 0-6-5'. This means that the data pertains to average efforts of group number one during the first phase, and that the principal chose $\alpha = 0$, $\beta = 6$, and $\omega = 5$.

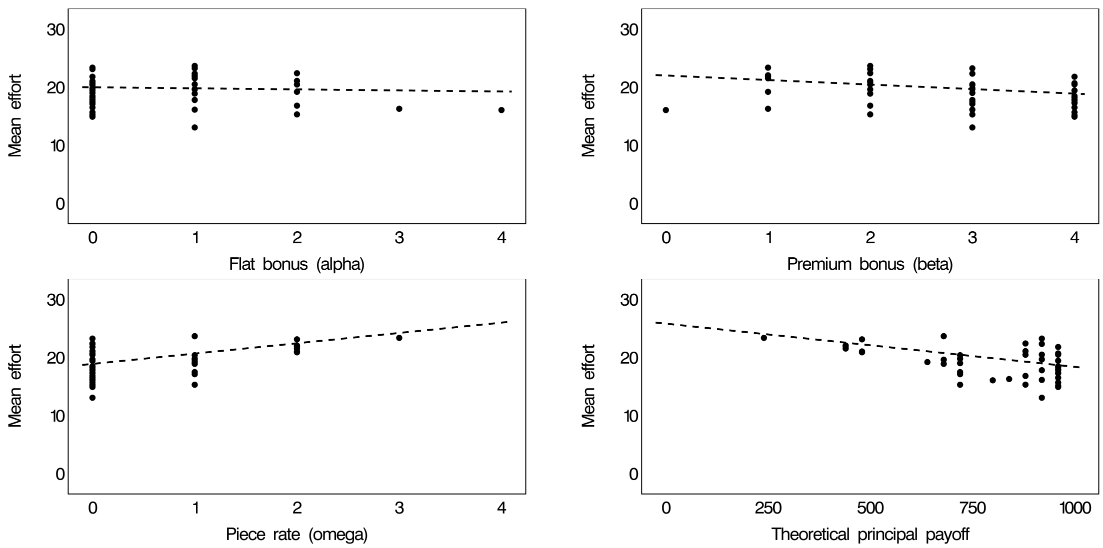

Figure 6: Mean efforts of agents as a function of the level of each contract component and of the theoretical principal payoff, with Tobit regression lines. Each dot represents the average efforts of members of a single group in one phase.

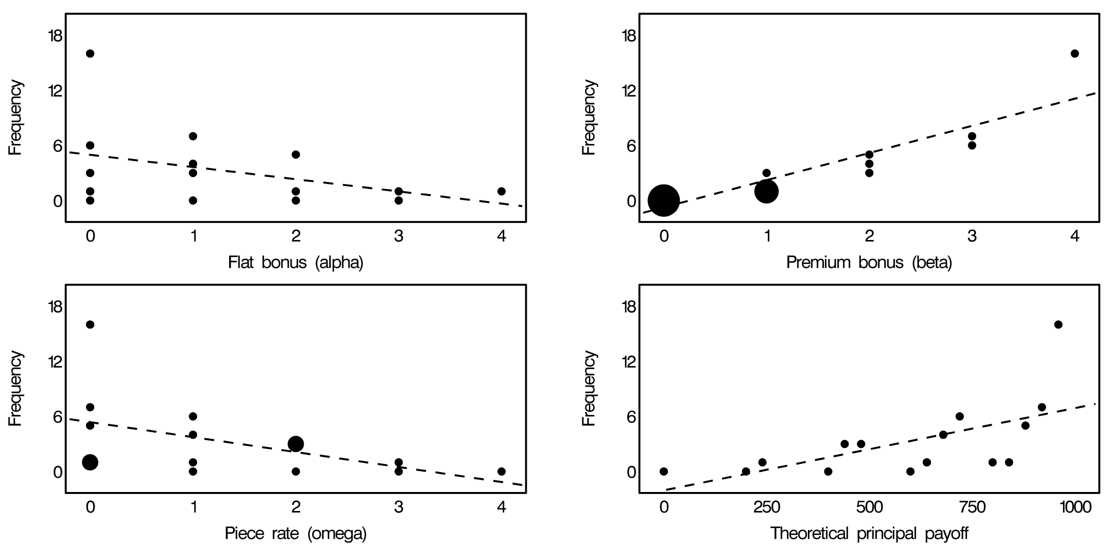

Figure 7: Frequency of contract choices as a function of the level of each contract component and of the theoretical principal payoff, with linear regression lines. Each small dot represents one of the 15 available contracts. Larger dots indicate that multiple contracts share the same frequency and horizontal-axis value.