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On the Incentive Effects of Uncertainty in Monitoring Agents A Theoretical and Experimental Analysis

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Abstract

When two or more agents compete for a bonus and the agents' productivity in each of several possible occurrences depends stochastically on (constant) effort, the number of times that are checked to assign the bonus affects the level of uncertainty in the selection process. Uncertainty, in turn, is expected to increase the efforts made by competing agents (Cowen and Glazer (1996), Dubey and Haimanko (2003), Dubey and Wu (2001)). Theoretical predictions were derived and experimental evidence collected for the case of two competing agents, with the bonus awarded to that agent who outperforms the other. Levels of uncertainty (sampling occasions of productions, 1 or 3), cost of production (high or low), cost symmetry (asymmetric or symmetric), and piece-rate reward were manipulated factorially to test the robustness of the effects of uncertainty. For control, a single-agent case was also theoretically analyzed and empirically tested. The results indicate that, for tournaments, greater uncertainty does indeed lead to greater than expected effort and lower unit variable costs.

JEL: J33, M42, M52, M55

Keywords: Monitoring, Tournament, Incentives, Uncertainty, Stochastic Production Technology

1. Introduction

Many invest in sports, democratic elections, and the arts, although only a few can actually live on what they gain in return (see Leininger (1993)). While some of this behavior may be explained by the intrinsic value of actively competing, it is often the case that people compete for the prize offered to the most successful agent(s). Similarly to the “winner takes all” reward schemes in sports, employers also try to inspire extra effort by offering bonus schemes (Maloney and McCormick (2000)), awarding a substantial monetary amount to the best performing employee or work team.¹ To determine eligibility for the bonus, the performance of the competing individuals or teams must be assessed. However, any assessment of performance is prone to errors. First, performance itself is typically variable (e.g., day-to-day changes due to motivation, fatigue, or extreme conditions). Additionally, the measurement may be less than foolproof (due to unreliability in the assessment of quality, etc.). This proneness to error introduces uncertainty with respect to the outcome of the assessment. Our paper is concerned with the effect of such uncertainty on the performance of competing agents. How is the degree of uncertainty in the evaluation process related to effort and performance? Would a more reliable scrutiny result in better or worse performance? Would a principal instituting a monitoring scheme benefit more from an accurate or from a somewhat fallible assessment of performance? Our study provides a theoretical analysis and experimental evidence bearing on these issues.

A monitoring scheme has to specify the rules according to which the bonus is awarded and, in particular, the frequency with which the effort or output of the competing agents is monitored. Irrespective of the frequency with which it is applied, any monitoring scheme should ensure that the chances of winning are positively related to actual performance. Note, however, that the less frequent the

¹ See Beersma, et al. (2003) or, for a review on the effect of competition on performance, Miller and Hamblin (1963).

inspection, the weaker that relationship will be. In other words, less frequent monitoring introduces greater uncertainty regarding the correspondence between performance and outcome of the competition. This paper explores the effects of uncertainty on the efforts made by agents competing for a bonus.

An immediate implication of higher uncertainty regarding the eventual winner of a competition is that it improves the winning chances of the less able agents. A less obvious implication is that this may, in turn, motivate both less and more able agents to make a greater effort. This surprising effect of less scrutiny in monitoring has been theoretically demonstrated by Cowen and Glazer (1996), Dubey and Wu (2001), and Dubey and Haimanko (2003) and experimentally confirmed by Kareev and Avrahami (2007) for tournaments with two competitors. These studies considered m (≥ 2) production events from which the principal randomly selects n with $1 \leq n \leq m$ to identify the best performing agent. Such a setup, in which agents have to determine individual effort levels for each of the m production events, knowing n , but not which of the m events will be checked, together with a “winner takes all” reward scheme, renders the problem rather difficult and usually excludes pure strategy solutions.²

Our scenario induces deterministic choice behavior by assuming probabilistic production technologies. A given level of effort can result in more or less production in each of several production events. Higher effort results in higher probability of producing more – rather than less – in each event. More specifically, agents choose an effort level once which determines in an *iid*-fashion (via independent and identically distributed chance moves specifically for each agent) the odds for high production in each production event. Uncertainty is introduced by manipulating the number of times (1 or 3) random outcomes of the effort level (whether high or low) are determined. As this setup results in greater uncertainty, as the

² Mixed-strategy solutions are often viewed as questionable which, in game theory, has inspired the purification approach (see, for instance, Harsanyi (1973)).

number of production events declines accordingly. In turn, the effort level, together with the likelihood of being awarded a bonus, determines unit variable costs. For this setting we explore how the uncertainty in determining eligibility for the bonus affects the effort invested.

For generality, we manipulated production cost: in certain experimental conditions it was higher for one agent than for another, and in others it was equal (and either high or low). Furthermore, since even in tournaments participants are often also rewarded according to their performance, and workers competing for a bonus may also be paid a piece rate, we introduced payment per unit of effort (ϵ), which assumed one of two values – either .1 or 10. The first value was chosen so as to mimic real-life situations, in which piece-rate payments to workers are typically small relative to the bonus (which was set at the value of $B=6$); the second value was chosen to test whether subjects would still react to uncertainty in a condition in which payment was so high that its motivating effect could eclipse that of the bonus.

The theoretical analyses and experimental tests of the effects of uncertainty on performance assumed a tournament with two or more participants. For generality, a single-agent case was also analyzed and tested. In section 2, we analyze the two-agents case. The experimental protocol is described in section 3, and the main experimental results are described in section 4. Section 5 presents the single-agent case, and section 6 concludes.

2. The tournament

Employees 1 and 2 can produce either a low amount L or a high amount H with $0 \leq L < H$. We denote for $i=1,2$ employee i 's probability that production is high by $p_i \in [0,1]$ and assume individual effort cost

$$C_i(p_i) = \frac{c_i}{2} p_i^2 \text{ with } c_i > B \text{ for } i=1,2,$$

where B is the positive bonus. We model production that takes place on several occasions, e.g. work days, and is monitored on a number of occasions, n . On each occasion, the probability that $i=1,2$ produces H is p_i , whereas the probability for L is $1-p_i$. Thus, for each competitor $i=1,2$, a sequence of independent and identical chance moves determines i 's productivity on each occasion according to constant probability p_i .

The agent receives a flat fee $F(\geq 0)$ and a positive piece-rate payment ε , depending (linearly) on p , in addition to his chance of gaining bonus $B(>0)$. The reward for the two employees $i=1,2$ is thus $F + \varepsilon p_i$ plus the possible positive bonus B which is awarded to the better performing employee³ minus the costs.

In our experiment, we compare $n=1$ with $n=3$. For $i=1,2$ and $i \neq j$ the probability that on a single occasion i produces more than j is $p_i(1-p_j)$. Thus, for $n=1$ agent i would receive bonus B with probability $p_i(1-p_j)$. For $n \geq 1$ the probability $P_i^n(p_i, p_j)$ of i winning the bonus is determined by combining two binominal distributions. Specifically,

$$P_i^n(p_i, p_j) = \sum_{k=1}^n \left[\binom{n}{k} p_i^k (1-p_i)^{n-k} \sum_{e=0}^{k-1} \binom{n}{e} p_j^e (1-p_j)^{n-e} \right],$$

is agent i 's probability of producing more than j on n occasions for any choice constellation (p_i, p_j) . For $i=1,2$ agent i 's expected payoff is thus

$$U_i(p_i, p_j) = F + \varepsilon p_i + B P_i^n(p_i, p_j) - C_i(p_i).$$

If ε is supposed to capture intrinsic work motivation (depending linearly on p_i), the setup can be justified as one where the principal wants to award the bonus to the agent with the highest p -level, but where the p -levels are only privately known

³ We exclude a bonus award when both agents are equally bad or good, i.e., achieve H equally often. In other words, we explore a tournament in which incentives are provided to an agent who outperforms the other(s).

(or at least not interpersonally verifiable). In our view, such an interpretation can be upheld for low ε but may be questionable for the (in the experiment 100 times) higher ε -value.

We therefore favor the interpretation of ε as a piece rate which can be justified by assuming that p -levels are verifiable between principal and agent but not across agents. Thus, a bonus tournament has to rely on actual production success and not on effort levels. Of course, principals might offer both incentives, piece rate ε and bonus B , for the better performing agents, although p -levels can be verified without restrictions. By a setup invoking both incentives, one could, for instance, explore which of the payoffs is the cheaper way of provoking a given increase of effort levels p_1 and p_2 , an increase of ε or B ?

Hence, agents maximize their utility $U_i(p_i, p_j)$ subject to $0 \leq p_{i,j} \leq 1$. In the simple case $n=1$, given $\varepsilon < c_j \left(\frac{c_i - B}{c_j - B} \right)$ and $\varepsilon < c_i \left(\frac{c_j - B}{c_i - B} \right)$ the second order conditions are granted, the first order derivatives determine an interior equilibrium (p_i^*, p_j^*) via solving the equation system

$$\frac{\varepsilon}{c_i} + \frac{B}{c_i}(1 - p_j) = p_i \text{ for } i, j=1, 2 \text{ and } i \neq j.$$

One obtains

$$p_i^* = \frac{(B + \varepsilon)(B - c_j)}{B^2 - c_i c_j} \text{ and } p_j^* = \frac{(B + \varepsilon)(B - c_i)}{B^2 - c_i c_j}.$$

However, there may be border equilibria. Without loss of generality we assume $c_i < c_j$.

$$\text{If } c_j \left(\frac{B - c_i}{B - c_j} \right) < \varepsilon < c_j \text{ and}$$

$$\frac{\partial}{\partial p_i} U_i(p_i^*, p_j^*) > 0 \text{ and } \frac{\partial}{\partial p_j} U_j(p_i^*, p_j^*) = 0 \text{ as well as } \frac{\partial^2}{\partial p_j^2} U_j(p_i^*, p_j^*) < 0,$$

then $p_i^* = 1$ and $p_j^* = \frac{\varepsilon}{c_j}$ establish a partial border equilibrium.

If $\varepsilon > \max\{c_i, c_j\}$, due to

$$\frac{\partial}{\partial p_i} U_i(p_i^*, p_j^*) > 0 \quad \text{and} \quad \frac{\partial}{\partial p_j} U_j(p_i^*, p_j^*) > 0,$$

one obtains $p_i^* = 1 = p_j^*$. Thus, border equilibria occur when personal costs (c_i and c_j) are very low or ε is large so that the piece-rate payment becomes the driving force of effort choices.

For $n > 2$ one has to solve quite complex polynomial equations to derive the interior equilibria. In Table 1, we list the (local⁴) equilibria (p_1^*, p_2^*) for the parameter constellations employed in the study.

Individual unit variable costs (for $p_i > 0$) are given by

$$\frac{\varepsilon p_i + P_i^n(p_i, p_j)B}{p_i}.$$

We use a bonus of $B=6$ and compare both low ($c_1=11=c_2$) and high ($c_1=22=c_2$) symmetric cost parameters with asymmetric ones ($c_1=11$, $c_2=22$ and $c_1=22$, $c_2=11$); note that $B < c_i$ for $i=1,2$ always holds. To save parameters, we use $H=1$, $L=0$, and vary only the number of monitoring occasions ($n=1$ and $n=3$), the production costs, and $\varepsilon \in \{.1, 10\}$.

Equilibria were computed numerically by first solving the system of two first order

conditions $\left(\frac{\partial}{\partial p_i} U_i(p_i, p_j) = 0 \text{ for } i, j = 1, 2 \text{ and } i \neq j \right)$ and then checking the two

second order conditions $\left(\frac{\partial^2}{\partial p_i^2} U_i(p_i, p_j) < 0 \text{ for } i, j = 1, 2 \text{ and } i \neq j \right)$ locally for this

interior solution candidate. In the asymmetric cost condition of $\varepsilon=10$, where the conditions for interior solutions do not hold, optimal choices imply reactions to p_i^* or $p_j^*=1$.

⁴ For $n=3$ we check the second order condition only locally at (p_i^*, p_j^*) .

As can be seen from Table 1, the rise in n from 1 to 3 increases equilibrium effort choices in the tournament. But will only boundedly rational agents, engaged in a tournament, act accordingly? Since greater certainty might crowd in shirking incentives⁵ (Cowen and Glazer (1996)), the behavioral effects of greater certainty appear at least worth studying.

For $n=1$ two of four possible production outcomes would lead to a bonus payment, whereas for $n=3$, 44 out of 64 outcomes imply a bonus award where, of course, the probabilities of the different outcomes depend on the equilibrium (p_1^*, p_2^*) . This suggests that the likelihood of winning the bonus increases with the level of scrutiny. Actually, for $\varepsilon=10$ and asymmetric costs this is only a (negative) effect of more scrutiny since the equilibrium efforts are the same for $n=1$ and $n=3$. Otherwise, this always boosts total equilibrium effort but inflicts higher bonus costs to the principal (see the last columns in Table 1 for the overall effect on unit variable costs).

Tournament a) $\varepsilon = 0.1, F=10, B=6$				
Costs	Equilibrium effort		Equilibrium unit variable costs	
	n = 1	n = 3	n=1	n=3
$c_i=c_j=11$	0.358	0.515	3.946	4.104
$c_i=c_j=22$	0.218	0.307	4.792	6.494
$c_i=11$	0.474	0.525	5.212	8.520
$c_j=22$	0.148	0.145	3.256	2.650
Tournament b) $\varepsilon =10, F=10, B=6$				
Costs	Equilibrium effort		Equilibrium unit variable costs	
	n = 1	n = 3	n=1	n=3
$c_i=c_j=11$	0.941	0.984	10.353	10.275
$c_i=c_j=22$	0.571	0.701	12.571	12.786
$c_i=11$	1.00	1.00	13.273	15.437
$c_j=22$	0.455	0.455	10.00	10.00

Table 1: Equilibrium choices and unit variable costs for all tournament settings

⁵ Such crowding-in effects are usually observed only by comparing no monitoring with monitoring, though hardly ever by comparing less with more monitoring.

3. Experimental protocol

The computerized experiments were conducted in the laboratory of the Max Planck Institute in Jena, using z-Tree (Fischbacher (2007)). Three hundred and eighty-four undergraduate students of Jena University, with a background in natural and social sciences, took part in the experiments; they were recruited by use of ORSEE (Greiner (2004)). Sessions were run in groups of 32, with pairing conducted randomly on each round within groups of 8. Subjects were randomly assigned to groups by letting them choose a number. The instructions were made commonly known; whether they were understood was tested by a questionnaire.

The software provided a calculator to help subjects understand how choices affect the probability of winning the bonus. Having chosen p , subjects received feedback about their costs, whether they won the bonus, their profits, and overall earnings. An average session lasted approximately 2 hours 15 minutes, and the subjects earned *€17.17 on average*.⁶

Piece-rate payment (ε) assumed one of two values – either .1 or 10. This variable was manipulated between subjects, with 192 of them participating in each condition. The number of production events ($n=1$ and $n=3$), cost (high=22 or low=11), and cost symmetry (same cost for both competitors or one low and one high cost competitor) were factorially manipulated within subjects. Within each number of production events, the symmetric cost situations preceded the asymmetric ones, with half the participants first experiencing high and the other half first experiencing low costs. The order of the number of production events was counterbalanced between participants (see Table 2). Six observations were con-

⁶ Note: the average hourly payment of a student amounts to €6.15.

ducted within each combination of conditions, resulting in a total of 48 observations per subject.

Instructions were carefully explained, such as using tables, how the overall probability to win the bonus depended on the effort choices of the subject, and the person she was paired with on that round. Table 2 provides a summary of the experimental conditions.

Evaluated production events	Costs to start with	Symmetric cost conditions		Asymmetric cost conditions	
		low (high) $c_i = c_j$	high (low) $c_i = c_j$	low (high) $c_i < c_j$	high (low) $c_i > c_j$
n=1	low (high)	11,11 ; (22,22)	22,22 ; (11,11)	11,22 ; (22,11)	22,11 ; (11,22)
n=3	low (high)	11,11 ; (22,22)	22,22 ; (11,11)	11,22 ; (22,11)	22,11 ; (11,22)
Bonus: $B = 6$, flat fee: $F = 10$ setting a) $\varepsilon = 0.1$ setting b) $\varepsilon = 10$					

Table 2: Parameter setting for $n=1$ and $n=3$ production events

4. Results

The equilibrium value indicates the level of effort under which agents' profits are maximized, given the specific combination of conditions. Therefore, the first analysis (section 4.1) tested to what extent subjects were sensitive to that level and to the different variables determining it. Only after establishing a close correspondence between behavior and optimal level and sensitivity to the variables manipulated in the study, can the notion of extra effort, namely, effort invested beyond the optimal level, be addressed and its correspondence to uncertainty tested. The latter analysis was conducted separately for the low (section 4.2) and high (section 4.3) piece-rate payment. Within each of these sections we report the results for two dependent variables: the deviation of effort level from the equilibrium benchmark, and the unit variable cost.

4.1 Sensitivity to equilibrium

The data show that subjects were highly sensitive to the equilibrium: all variables that determined this – level of uncertainty, cost combination (both cost to self and partner), and piece-rate payment (ϵ) - significantly affected the effort level chosen: uncertainty ($F(1,18416)=43.025$, $MSE=0.058$, $p<0.001$), costs ($F(1,18416)=7176.751$, $MSE=0.058$, $p<0.001$), symmetry ($F(1,18416)=225.795$, $MSE=0.058$, $p<0.001$), and piece-rate payment ($F(1,18416)=9005.098$, $MSE=0.058$, $p<0.001$). There were also significant interaction effects of uncertainty and symmetry ($F(1,18416)=10.921$, $MSE=0.058$, $p=0.001$), costs and symmetry ($F(1,18416)=787.882$, $MSE=0.058$, $p<0.001$), uncertainty and piece-rate payment ($F(1,18416)=25.098$, $MSE=0.058$, $p<0.001$), costs and piece-rate payment ($F(1,18416)=12.917$, $MSE=0.058$, $p<0.001$), and symmetry and piece-rate payment ($F(1,18416)=13.348$, $MSE=0.058$, $p<0.001$). Furthermore, uncertainty, costs, and piece-rate payment interacted significantly ($F(1,18416)=18.324$, $MSE=0.058$, $p<0.001$), similar to costs, symmetry, and piece-rate payment ($F(1,18416)=48.6$, $MSE=0.058$, $p<0.001$) as well as uncertainty, symmetry, and piece-rate payment ($F(1,18416)=4.566$, $MSE=0.058$, $p=0.033$). With all main effects being in the expected direction, the correlation between chosen and optimal effort is very high indeed (*Spearman's rho* = .675, $p=0.01$). Although the effort invested was highly correlated to the optimal effort, we were still interested in the effect of uncertainty on the effort made relative to equilibrium. In particular, we wanted to find out whether the tournament caused subjects to invest above what is optimal for them, and whether the difference between actual and optimal effort was sensitive to the level of uncertainty. We performed these analyses separately for the low and high piece-rate payment.

4.2 Low piece-rate payment

Deviation from Equilibrium

The mean deviation of actual effort from the equilibrium (see Table 3, middle column) was calculated for the six rounds of (exactly) the same condition and subjected to an analysis of variance with level of uncertainty and cost combination as

within-subjects variables. The data indicate that, in spite of the high correlation between uncertainty level and effort, the latter is higher than optimal, and particularly so in the more uncertain case of a single production evaluation.

The mean deviation from equilibrium is 0.091 ($F(1,191)=58.668$, $MSE=$, $p<0.001$). Importantly, we found significantly more over-performance for high ($n=1$) rather than for low ($n=3$) uncertainty ($F(1,191)=7.744$, $MSE=0.051$, $p=0.006$). The level of uncertainty explains 3.9%⁷ of the overall variance of the data, showing a small but important impact on the behavior of subjects. In cost symmetry subjects over-performed significantly more than in asymmetric cost conditions ($F(1,191)=22.19$, $MSE=0.028$, $p<0.001$). The symmetry explains about 10.4% of the variance. Although cost also affected over-performance ($F(1,191)=4.505$, $MSE=0.057$, $p=0.035$), it explains only 2.3% of the overall variance. We also observed the following, significant interaction effects:

Uncertainty interacted with the symmetry of cost conditions. The over-performance observed with higher uncertainty is reduced in the asymmetric cost condition ($F(1,191)=10.924$, $MSE=0.031$, $p=0.001$).

Uncertainty interacted with the cost level. High over-performance was observed in the low cost but not in the high cost conditions ($F(1,191)=23.408$, $MSE=0.026$, $p<0.001$).

Cost level also interacted with symmetry. Over-performance was insensitive to cost in the symmetric conditions but considerably lower for the high cost position in the asymmetric condition ($F(1,191)=19.656$, $MSE=0.025$, $p<0.001$).

Costs	Equilibrium		Mean effort minus equilibrium				Average unit variable costs			
	n = 1	n = 3	n=1	SD	n=3	SD	n=1	SD	n=3	SD
$c_i=c_j=11$	0.359	0.515	0.157	0.249	0.055	0.263	3.114	0.876	4.043	1.455
$c_i=c_j=22$	0.217	0.307	0.126	0.242	0.105	0.247	4.028	0.916	5.840	1.948
$c_i=11$	0.474	0.525	0.122	0.232	0.081	0.219	5.055	0.705	7.648	2.058
$c_j=22$	0.148	0.145	0.022	0.215	0.058	0.226	2.526	1.080	3.116	1.566

Table 3: Descriptive statistics for Tournament $\varepsilon=0.1$

⁷ All percentages of variances accounted for are partial eta squared (see Young (1993)).

Unit Variable Cost

Another way to appreciate the effect of the level of uncertainty is to consider the situation from the perspective of an employer who implemented this bonus scheme and would like to know what level of uncertainty to use. To that end, we calculated the average unit variable cost in each of the conditions and subjected it to an analysis of variance. Note that this value is undefined for cases in which subjects invested on average zero effort. Out of 768 observed average effort choices in $n=1$, 88 did not exceed zero, as compared to 73 in $n=3$. Eliminating these cases from further analyses, we observe significantly lower average unit variable costs for $n=1$ than for $n=3$ ($F(1,112)=184.859$, $MSE=2.683$, $p<0.001$). Increasing uncertainty by setting $n=1$ rather than $n=3$, decreases the average unit variable costs from 5.162 ($SD=1.756$) to 3.681 ($SD=0.89$), a decline of 28.69%. The level of uncertainty explains 62.3% of the overall variance of this variable. For each effort unit principals pay on average less in $n=1$ than in $n=3$. In symmetric rather than asymmetric cost conditions, employers bear significantly less unit variable costs ($F(1,112)=12.236$, $MSE=2.009$, $p=0.001$), which explains 9.8% of the overall variance. Not surprisingly, when agents keep personnel costs high instead of holding them low, they reduce effort levels and, subsequently, their chances to win the bonus. Hence, unit variable costs are significantly smaller ($F(1,112)=182.758$, $MSE=1.462$, $p<0.001$). This effect accounts for 62% of the overall variance.

Uncertainty interacted with costs such that the overall effect of uncertainty was more pronounced in the low than in the high cost conditions ($F(1,112)=13.391$, $MSE=1.323$, $p<0.001$).

Costs also interacted with symmetry. In the symmetric case, unit variable costs were higher for the high cost condition, but in the asymmetric case they were much lower for the high cost position ($F(1,112)=722.267$, $MSE=1.868$, $p<0.001$).

There was also a three-way interaction between all three variables: whereas in the symmetric case the advantage of uncertainty was more pronounced in the high cost condition, it was more pronounced in the low cost position of the asymmetric case ($F(1,112)=82.456$, $MSE=1.426$, $p<0.001$).

4.3 High piece-rate payment

Deviation from Equilibrium

In the high piece-rate payment, the optimal effort is close to or even at the upper bound. Setting $\varepsilon=10$ provides agents with a larger, additional marginal payoff from working than the bonus itself. This implies that, when cost is low, over-performance is either impossible (in the asymmetric case) or difficult to achieve (in the symmetric case). Since our focus is on the effect of uncertainty, we proceed with the analyses as before, but it should be remembered that effects and interactions involving cost should be interpreted with caution.

Similar to the previous treatment, effort choices are sensitive to variations in the level of uncertainty and costs (see Table 4). Results show that the overall deviation from the equilibria of 0.003 is insignificant ($F(1,191)=.214$, $MSE=0.055$, $p=0.644$). However, the level of uncertainty significantly affects these deviations ($F(1,191)=37.686$, $MSE=0.013$, $p<0.001$), explaining 16.5% of the total variance. The data indicate slightly higher than optimal effort (0.02, $SD=0.189$) in the more uncertain case of $n=1$ as compared to lower than optimal effort choices (-0.015, $SD=0.193$) with $n=3$. We observe under-performance in cost symmetry but over-performance in asymmetry ($F(1,191)=30.498$, $MSE=0.013$, $p<0.001$): almost 13.8% of the overall variance is explained by the effect of symmetry. Again, costs affect the deviations from equilibria significantly ($F(1,191)=165.13$, $MSE=0.034$, $p<0.001$), where low (high) cost agents under (over)-perform. This variable explains 46.4% of the variance. There were also a number of interactions between variables:

Uncertainty interacted with symmetry. Over-performance with higher uncertainty was only observed in the symmetric case ($F(1,191)=61.870$, $MSE=0.009$, $p<0.001$).

Uncertainty also interacted with cost levels. The effect of uncertainty was more pronounced in the high than in the low cost conditions ($F(1,191)=12.469$, $MSE=0.009$, $p=0.001$).

Cost interacted with symmetry. The effect of cost was more pronounced in the asymmetric than in the symmetric conditions ($F(1,191)=47.454$, $MSE=0.009$, $p<0.001$). Note that, due to boundary equilibria and equilibria close to 1, under-performance is a natural, e.g., an effect of noisy decision making, consequence for low cost agents.

There was also a three-way interaction between all three variables: whereas in the symmetric case the advantage of uncertainty was very pronounced in the high cost condition and only slightly so in the low cost condition, there was hardly any effect of uncertainty in the asymmetric case, irrespective of costs ($F(1,191)=32.49$, $MSE=0.006$, $p<0.001$).

Costs	Equilibrium		Mean effort minus equilibrium				Average unit variable costs			
	n = 1	n = 3	n=1	SD	n=3	SD	n=1	SD	n=3	SD
$c_i=c_j=11$	0.941	0.984	-0.040	0.120	-0.073	0.114	10.591	0.354	11.023	0.668
$c_i=c_j=22$	0.571	0.701	0.086	0.166	-0.026	0.177	12.049	0.545	12.948	0.899
$c_i=11$	1.000	1.000	-0.057	0.086	-0.061	0.102	12.720	0.512	14.456	0.918
$c_j=22$	0.455	0.455	0.092	0.139	0.100	0.155	10.340	0.286	10.474	0.581

Table 4: Descriptive statistics for Tournament $\varepsilon=10$

Unit Variable Costs

There was no need to correct unit variable costs since no zero average effort choices occurred. We observe significantly lower average unit variable costs in $n=1$ than in $n=3$. ($F(1,191)=673.612$, $MSE=0.365$, $p<0.001$). This difference in uncertainty explains 77.9% of the overall variance. Increasing uncertainty decreases average unit variable costs by 6.55% from 12.226 ($SD=2.297$) in $n=3$ to 11.425 ($SD=1.450$) in $n=1$. Unit variable costs are significantly higher when agents compete in asymmetric cost conditions ($F(1,191)=123.742$, $MSE=0.369$, $p<0.001$). This effect of symmetry accounts for 39.3% of the overall variance, while the costs explain 81.6%. With low cost agents, employers bear significantly higher unit variable costs as with high cost agents ($F(1,191)=844.698$, $MSE=0.252$, $p<0.001$).

All interactions are significant. The interaction of uncertainty and symmetry was such that the advantage of uncertainty was more distinct in asymmetry ($F(1,191)=21.629$, $MSE=0.321$, $p<0.001$).

Uncertainty interacted with costs. The effect of uncertainty was more pronounced with low rather than high cost conditions ($F(1,191)=133.153$, $MSE=0.232$, $p<0.001$).

Cost interacted with symmetry as well. In symmetry the unit variable costs were higher for the high cost condition, whereas in asymmetry they were lower for this position ($F(1,191)=3826.126$, $MSE=0.596$, $p<0.001$).

Again, there was a three-way interaction between all variables. While in symmetry the advantage of uncertainty was more pronounced in high cost conditions, in asymmetry it was more distinct for the low cost position ($F(1,191)=335.622$, $MSE=0.307$, $p<0.001$).

We found rather similar interaction effects of influential variables on subjects' choice behavior in $\varepsilon=10$ as in $\varepsilon=0.1$, confirming the robustness of our findings. Again, principals, having to bear in mind both, average variable costs and relative performance, benefit from lower costs per effort unit and over-performance rather than under-performance with high rather than low uncertainty.

5. Single agent

To find out whether the effects of uncertainty on over- and under-performance and unit variable costs observed in the tournaments (described above) are related to the tournament situation, the case of a single agent was analyzed and tested. The single agent can produce either a high (H) or a low (L) output level on each of several occasions where $0 \leq L < H$. The cost $C(p)$ of producing H with probability p in each instance is determined by

$$C(p) = \frac{c}{2} p^2 \text{ with } c > 0.$$

Assume that the agent receives a flat fee $F(\geq 0)$ and a positive piece-rate reward ε with $\varepsilon + nB < c$, depending (linearly) on p , in addition to his chance of gaining bonus $B(> 0)$. For sample size $(n=)1$, we model a situation in which the principal only checks once whether the agent's output level is H or L . Since observing H represents a flawless performance, the agent's payoff is

$$U = F + \varepsilon p + pB - \frac{c}{2} p^2.$$

From

$$U'(p) = \varepsilon + B - cp \text{ and } U''(p) = -c < 0$$

one derives

$$p^* = (\varepsilon + B) / c.$$

For $n \geq 2$ a flawless performance requires to observe n times H so that the payoff is

$$U(p) = F + \varepsilon p + p^n B - \frac{c}{2} p^2.$$

Because of $U'(0) = \varepsilon > 0$ and $U'(1) = \varepsilon + nB - c < 0$, neither $p = 0$ nor $p = 1$ is a solution. The solution $p(n)$ for $n \geq 2$ is thus determined by

$$\varepsilon + nB(p(n))^{n-1} - cp(n) = 0 \text{ with } U''(p(n)) = n(n-1)B(p(n))^{n-2} - c < 0.$$

For larger n the first (second) order conditions may have to be solved (checked) numerically.⁸

For the experimental numerical parameters (shown in Table 5) the equilibrium effort levels, the deviations of effort choices from optimality, and unit variable costs are shown in Table 6, where unit variable costs are defined by

$$\varepsilon + p^{n-1} B.$$

We ran two sessions without any interactions between subjects. The 64 invited subjects were similarly instructed, used the same software but a slightly different parameter setting than in the tournament settings.

⁸ For $n=3$, the case studied experimentally in addition to $n=1$, the first (second) derivative of $U(p)$ is quadratic (linear) in p , allowing an analytic derivation.

Evaluated production events	Cost condition 1 low (high)	Cost condition 2 high (low)
$n = 1$	20 (30)	30 (20)
$n = 3$	20 (30)	30 (20)
$\varepsilon=0.9, F=10, B=6$		

Table 5: Parameter setting for each sample size in “single agent”

After subjects had repeatedly chosen effort p (six times for each cost situation) for a given level of uncertainty, all *six* choices for two cost and two scrutiny levels were repeated once, resulting in 48 choices per subject. The sessions lasted for approximately 2.5 hours, and average earnings amounted to €17.56.

In the single-agent case, high performance was required in every production event to receive the bonus. Hence, the uncertainty for $n=1$ was again higher than that for $n=3$.

Results show that costs and the level of uncertainty influence the effort choices in a similar way as they did the equilibria (the Spearman’s correlation between actual effort and the equilibrium being $\rho = .436$, $p=0.01$). Deviations from the equilibria are significant but small (0.033 , $F(1,63)=4.691$, $MSE=0.061$, $p=0.034$), revealing an effort level quite close to optimality. We found significant differences between the uncertainty levels ($F(1,63)=36.807$, $MSE=0.016$, $p<0.001$), with almost 36.9% of the overall variance explained by that variable. In contrast to the tournament, significant over-performance⁹ was only evident in low (0.081 , $SD=0.196$) uncertainty, while we found under-performance under high uncertainty (-0.015 , $SD=0.206$). Subjects were insensitive to variations in costs, with low and high cost agents hardly over-performing ($F(1,63)=2.309$, $MSE=0.007$, $p<0.134$). However, we found uncertainty interacting with costs, where an advan-

⁹ Significant at $p<0.01$, asymptotic Wilcoxon rank sum test.

tage of low uncertainty was more pronounced with low cost agents ($F(1,63)=8.761$, $MSE=0.006$, $p=0.004$)

Cost	Equilibrium effort		Mean effort minus equilibria			Equilibrium unit variable costs		Average unit variable costs ¹⁰	
	n=1	n=3	n=1	SD	n=3	SD	n=1	n=3	SD
20	0.345	0.047	-0.021	0.170	0.104	0.158	6.900	0.913	1.407
30	0.23	0.031	-0.008	0.151	0.059	0.115	6.900	0.906	1.156

Table 6: Descriptive statistics for the single-agent case

Note that for $n=1$ unit variable costs are a constant, independent of effort level p . As such, the effect of uncertainty on performance does not affect unit variable costs. We nevertheless report the analyses for completeness. Zero average effort choices were observed in 3 (8) out of 128 cases for high (low) uncertainty; these cases were eliminated in further analyses. We found a highly significant impact of the level of uncertainty ($F(1,58)=3410.468$, $MSE=0.546$, $p<0.001$). This effect explains 98.3% of the overall variance. Clearly, choosing low uncertainty ($n=3$) saves 81.53% of the average unit variable costs. Even though these costs are also affected by costs ($F(1,58)=19.721$, $MSE=0.047$, $p<0.001$), this variable explains 25.4% of the overall variance. We found uncertainty significantly interacting with costs, where the effect of uncertainty was slightly more intense with high cost ($F(1,58)=19.721$, $MSE=0.047$, $p<0.001$).

The latter results are in line with those reported by Kareev and Avrahami (2007) who also observed that the motivating effect of uncertainty prevailed in the competitive but not in the single-agent case.

6. Discussion

For some firms competition among agents promotes their performance (Beersma et al. (2003), Campbell and Furrer (1995), Deutsch (1949)). Introducing (bonus) tournaments, for instance, might inspire extra effort (Maloney and McCormick (2000)) and give incentives for principals to install adequate evaluation mechanisms. These mechanisms may not work since production outcomes of agents

¹⁰ For $n=1$ the unit variable costs do not depend on the choice of p and thus are 6.900 by definition.

are variable due to their effort choice reactions to the environment and the measurement of the production outcome is error-prone.

In order to construct an adequate model, we purified agents' performance in a probabilistic production setting, where constant effort determined the probability to produce either a high or low production outcome. The monitoring scheme we employed, which varied the frequency of production outcome inspections, awarded the bonus to the clearly better performing agent. The scheme implies that the more evaluation occasions there are, the fewer errors are made in determining the better performing agent. However, theoretical considerations indicate that decreasing uncertainty might discourage agents from making much effort, and our theoretical benchmark solution indeed shows a decreasing effort in uncertainty.

In the suitable experimental environment set up by us, we saw that the effort level of subjects was very sensitive to both variations in uncertainty and cost conditions. From this we reason that deviations of the chosen efforts from the optimal effort level, as indicated by the theoretical benchmarks, are a sensitive measure of the quality of subjects' reactions to such variations. With high uncertainty ($n=1$) we observed significant over-performance compared to optimality. When decreasing the level of uncertainty ($n=3$), we observed less over-performance with the low piece-rate payment ($\varepsilon=.1$), and even under-performance with the high piece-rate payment ($\varepsilon=10$). Hence, we find that subjects choose an effort level closer to optimality the more certain they are about the outcome of the competition.

As a consequence, the effort unit becomes less costly with higher uncertainty (i.e., with fewer evaluation occasions). Furthermore, if the act of assessing performance is in itself costly, the benefit of fewer evaluation events to the principal is further increased.

In other words, since greater uncertainty leads to an excess of actual over-optimal effort choices, benefiting the principal who pays less for each effort unit in

$n=1$. Moreover, if assessing the performance is costly, principals may benefit even further from few rather than many evaluation occasions.

To summarize, we find that agents are prone to compensate their lack of certainty in estimating their winning probability with a kind of tournament fever, leading to higher than optimal performance, while at the same time greater uncertainty saves average unit variable costs (since the bonus is awarded less often). Furthermore, less monitoring does not only save monitoring costs, but can also be perceived as increasing organizational justice, positively affecting employees' work motivation due to reciprocity and other social relations (Aryee et al. (2002)).

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