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On the Selection of Measures to Quantify Organisational Performance

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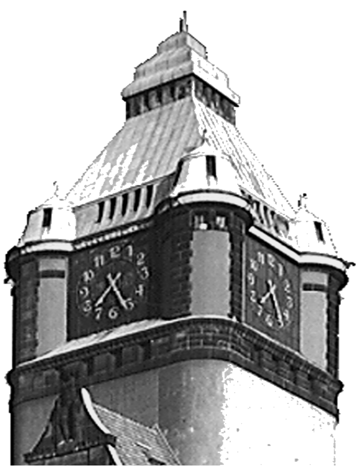

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On the Selection of Measures to Quantify Organisational Performance

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Abstract

In the last decade measuring a company's performance exclusively financially has been heavily criticised. Consequently, different performance measurement systems including the Balanced Scorecard, the Performance Pyramid, and the Quantum Performance were developed, discussed and implemented in industry. Besides the financial perspective, additional perspectives (e.g. customers, processes, employees, etc.) have been considered.

Organisational performance is assumed to be a multidimensional phenomenon today. Hence one important aspect of the discussion of several concepts of performance measurement has been the selection of the right measures.

Our paper focuses on the problem of measuring multidimensional organisational performance. Based on the multitask agency theory we enhanced the approaches of Holmstrom/Milgrom and Austin by introducing extrinsic and intrinsic motivation, cost of measurement and uncertainty of measurement into the model.

The resulting formal model suggests that it is important for the selection of measures whether the agent is motivated predominantly extrinsically or predominantly intrinsically. Again the selection of measures depends on cost of measurement as well as the uncertainty of the measures.

Our model suggests: it will be more easy to create a comprehensive performance measurement system to measure multidimensional organisational performance the more intrinsically the agent is motivated. Besides with lower (higher) cost of measurement and with lower (higher) uncertainty of measurement more (less) dimensions of organisational performance will be covered. Both effects mutually boost each other.

The paper concludes with two axioms of the selection of measures and a discussion of limitations.

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Table of Contents

1 Introduction

Today many firms as well as public institutions and governmental organisations are faced with the problem to measure their organisational performance. Organisational performance is defined as the ability of organisations to reach goals and hence fulfil expectations of stakeholders (Milgrom & Roberts 1992, p. 22). As these goals and expectations are complex, organisational performance is a multidimensional phenomenon. In this context several concepts of performance measurement, e. g. the Balanced Scorecard (Kaplan & Norton 1996) or the Performance Pyramid (Lynch & Cross 1995) were developed and particularly the Balanced Scorecard enjoys a wide practical acceptance (e. g. Frigo & Krumwiede 1999a, p. 1; Frigo & Krumwiede 1999b, p. 43; Towers Perrin (1996), pp. 1f.; Ittner & Larcker 1998a, p. 222).

Many authors have discussed the problem of selecting the right measures for organisational performance. The spectrum of comments ranges from “you measure the most important things” (Thor 1994, p. 8) to the demand that “the measures are easy to obtain” (Morgan 1998, p. 11).

This paper addresses the problem of selecting adequate measures to observe organisational performance from an analytical point of view. For this purpose a formal model based on the multitask principal-agent theory that covers several aspects of the selection of measures will be developed. Existing models are analysed and developed further as extrinsic and intrinsic motivation, cost of measurement and uncertainty of measurement are integrated. Conceptual and managerial implications of the resulting model which might support the improvement of performance measurement systems will be discussed.

2 Structure of the Problem

We will base our model on the multitask principal-agent theory, one of the most important enhancements of agency theory. In general, one principal (e. g. manager) and one agent (e. g. employee) act in multitask models. Karmann showed that under certain conditions multi-agent approaches could be reduced to single-agent multitask models (Karmann 1994). As opposed to other agency approaches, the agent performs several tasks (e. g. innovation to improve the product, service to make the product more convenient) on behalf of the principal that are all essential for the final product of the organisation.

The tasks are partially substitutable; hence production is useless if the agent provides no effort for one task at all. Finally the agent’s discomfort (work pain) is determined by his total effort for all tasks (Holmstrom & Milgrom 1991). A general overview on multitask agency problems is provided by Dewatripont et al. (Dewatripont et al. 2000).

The product is bought by a customer who pays the principal, whereas the price depends on the agent’s effort intensities for the tasks. Therefore, the principal tries to influence the agent’s effort by monitoring and rewarding him. For simplification the number of tasks is limited to two in any of the models discussed here.

3 Literature Review

Several models that mutually agree on these fundamentals can be found in the literature (e. g. Holmstrom & Milgrom 1991; Austin 1996; Bardsley 2001; Chambers & Quiggin 1996; Preyra & Pink 2001; Luporini & Parigi 1996; Lal & Srinivasan 1993; Gersbach 1998; Slade 1996). Two of them which correspond to our underlying problem of measuring organisational performance will be reviewed in detail as we create our own model on their basis.

3.1 Holmstrom & Milgrom

One of the first multitask principal-agent models was created by Holmstrom & Milgrom (e. g. Holmstrom & Milgrom 1991). They assumed that the agent can be motivated extrinsically only, hence the principal can increase the effort that the agent provides with a performance-based compensation. On the other hand the agent provides a basic effort even if he does not receive any performance based compensation.

Two cases have to be considered:

- The principal can measure the effort that the agent spends for both tasks.
- The principal can measure the agent's effort for one of the two tasks only.

If the principal monitors both tasks, any total effort combination can be realised. Hence the first-best optimum can be reached.

In the second case, the principal can provide an extrinsic incentive to the agent for one dimension at best. Holmstrom and Milgrom argue that the optimal effort mix cannot be realised, hence productivity declines and the principal deteriorates with partial supervision. Hence the principal reaches his second-best optimum if he refrains from any supervision at all.

Holmstrom and Milgrom recommended avoiding measuring and rewarding organisational performance if there is at least a single performance dimension where performance cannot be observed. This tends to be true for almost any real life situation. Hence the model leads to the suggestion to refrain from measuring organisational performance at all.

3.2 Austin

Further development was performed by Austin (Austin 1996) who introduced intrinsic motivation into his approach. He assumed an agent who is motivated both extrinsically and intrinsically, i. e. the agent is eager for money but also wants to make the customer happy.

As in the Holmstrom & Milgrom approach two cases have to be considered:

- The principal can measure the agent's effort for both tasks.
- The principal can measure the agent's effort for one of the two tasks only.

In the first case the first-best optimum can be realised by full supervision. This result is congruent to the Holmstrom & Milgrom model.

A completely different finding is derived from the second case. If the principal offers an incentive for an effort in the measurable dimension, under certain conditions the agent will not reduce his effort for the immeasurable task by the same amount. Hence the agent's total effort supply increases and, contrary to the Holmstrom & Milgrom model, the principal might improve with partial supervision. This is the second best solution.

In contrast to Holmstrom & Milgrom's conclusions Austin suggested to measure and reward organisational performance even if there is a performance dimension where performance cannot be observed. Hence Austin's model supports the practical use of multidimensional performance measurement systems (e. g. the Balanced Scorecard).

4 The Model

The models of Holmstrom & Milgrom as well as Austin will be advanced by formally introducing cost and uncertainty of measurements. We will develop our model using a step-by-step procedure whereas we restrict ourselves to two tasks to apply illustrative figures. First the basics of the model will be discussed.

4.1 Basic Model

Setup

An agent, a principal, and a customer act in our model's economy.

The agent provides effort for dimension x_1 and x_2 (e. g. innovation and service) by allocating his total effort x to x_1 and x_2, hence $x = x_1 + x_2$. Furthermore the agent's total effort capacity is limited to $\bar{x}$. The agent dislikes work, but if the principal hires him (and pays a fixed wage) the agent will provide a basic effort "just not to be bored". We will use a continuous and continuously differentiable cost function $c(X) \geq 0$ to express the agent's resentment to work. The agent is indifferent concerning the allocation of his effort, hence $\underset{x_1+x_2=x_1'+x_2'}{\forall} c(x_1, x_2) = c(x_1', x_2')$.

Hence, the agent does not strive for diversified work where he avoids exclusive effort for one task. For a certain total effort $\breve{x}$ the cost function vanishes: $c(X = (x_1, x_2)) = 0 : x_1 + x_2 = \breve{x}$. In addition the only local and global minimum of the agent's cost function is at $\breve{x}$ and the cost function is convex $\left(\frac{d^2c}{dx^2} > 0\right)$. Hence the function covers the increase of the agent's utility with an increase of effort to a certain level as discussed by Kreps (Kreps 1997, p. 361). Beyond $\breve{x}$ an effort increase can be induced by supplying compensation to the agent.

The customer evaluates the usefulness of the agent's effort mix. This will be considered by a convex and monotonous set of preferences $z(X = (x_1, x_2))$. Hence the customer prefers equal effort combinations (e. g. $X = (½ \cdot x, ½ \cdot x)$) compared to extreme combinations, e. g. $X = (0, x)$.

The principal obtains payment $g(z)$ from the customer that depends on customer satisfaction. Therefore, the principal's income finally depends on the agent's effort. The principal pays the agent to induce him to work.

Both principal and agent can observe the customer's preferences.

Behaviour

From the principal's point of view an optimal allocation $(\ddot{x}_1, \ddot{x}_2)$ of a certain total effort level x results, with $(\ddot{x}_1, \ddot{x}_2): \max_{x_1, x_2} g(z(x_1, x_2))$ s.t. $x_1 + x_2 = x$.

Based on the optimal allocation of a certain total effort a best-mix path can be calculated, that includes the optimal allocation of any level of total effort:

(1) $$\dddot{X} = (x_1, x_2): \forall_x \max_{x_1, x_2} g(z(x_1, x_2)) \text{ s.t. } x_1 + x_2 = x .$$

Within a graphical solution (see Fig. 1) the best-mix path is determined as a set of tangent points for any total effort level and the customer's indifference curves.

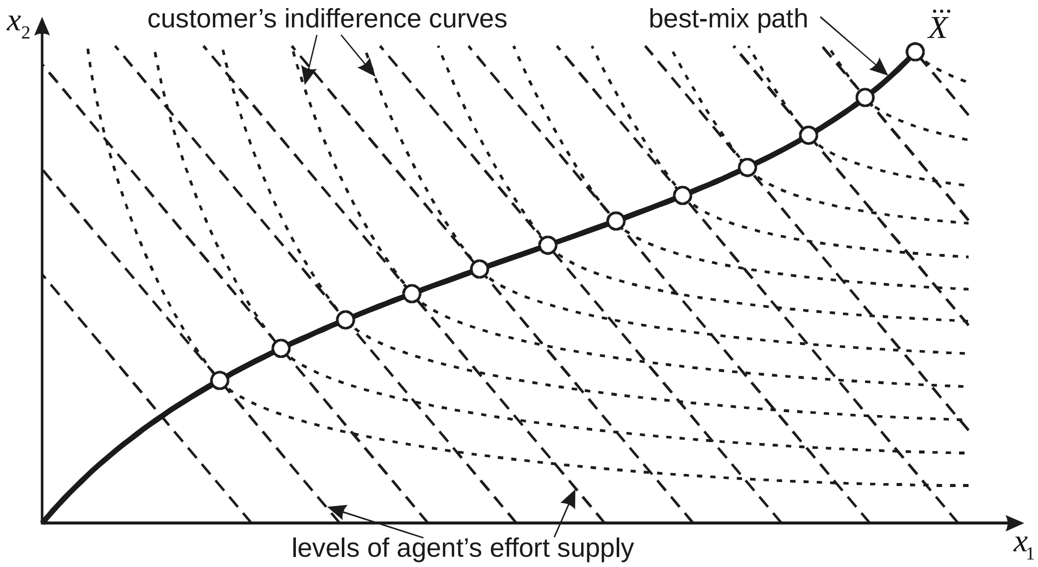

Fig. 1: Example of a best-mix path

If the principal pays no performance-based salary the agent will supply a basic effort only. As in the basic model the agent is extrinsically motivated only, hence, the cost function covers any source of motivation. Therefore, the agent will provide a total basic effort $\hat{x}$ that is at the agent's cost minimum: $\hat{x} = \breve{x}$. We will refer to this case as *non-supervision* as the principal does not observe and reward the agent's effort.

The principal can induce the agent to increase his effort by offering a performance based monetary compensation. To this end, instead of a fixed salary the principal uses an "all-or-nothing” contract that offers a salary if and only if the agent realises a certain effort level $\tilde{X} = (\tilde{x}_1, \tilde{x}_2)$. The agent will comply, as otherwise he would have no income. We will refer to this as *supervision*.

The extent of the principal’s budget used for compensating the agent (by a fixed or a performance-based salary) is β. Consistent to Holmstrom/Milgrom and Austin we consider the budget to be exogenously fixed. Hence the principal’s budget for compensating the agent does not depend on the agent’s effort. As our paper deals with the selection of measures within a performance measurement system the motivational effects of an increase or decrease of the overall compensation are not relevant.

4.2 Introducing Permanent Extrinsic and Intrinsic Motivation

In the Austin model the agent is intrinsically motivated by customer satisfaction when providing an effort above the basic effort while he is not intrinsically motivated when selecting his basic effort. To create a consistent model we will assume that the agent is intrinsically motivated in both cases.

To include intrinsic motivation, a monotonous function $f(z)$ will be used to describe how the agent is motivated by customer satisfaction. Hence the *agent’s general calculus* considering the extrinsic motivation through the compensation β is

(2) $$X : \max_X \; f(z(X)) - c(X) + \beta \text{ s.t. } x_1 + x_2 \leq \bar{x}.$$

It will be used in the non-supervision case to determine the level of the agent’s basic effort $\hat{x}$ as well as in the supervision case.

Now the agent is not indifferent concerning the effort allocation *in general* as he prefers equal effort for both dimensions compared to extreme (e. g. no effort for service). Note that the agent is *personally* still indifferent concerning the performance of the two tasks. The result of intrinsic motivation is that he gives additional consideration to the customer’s needs. Therefore, the agent prefers equal effort combinations compared to extreme combinations in congruence with the customer’s preferences. If the agent is not intrinsically motivated at all, as in the Holmstrom & Milgrom-model, then $f(z) = 0$.

According to (2), the necessary condition for the *optimal basic effort* (i. e. non-supervision, hence a fixed salary is paid) results:

(3) $$\underset{i=1,2}{\forall} \frac{\partial\left(f(z(X) - c(X)) + \beta\right)}{\partial x_i} = 0.$$

We will not examine the sufficient condition in detail here. Because of their specification the cost and utility functions possess maxima only.

4.3 Cost of Measurement

Until now information is free in the model. After the preceding discussion that resulted in a consistent basic model cost of measurement will be introduced.

The principal has to measure the agent's performance to provide a performance-based compensation to the agent. The Holmstrom & Milgrom model does not consider the principal's cost to measure the agent's effort of a particular effort dimension at all. Austin postulates that a non-observable effort dimension be characterised by high cost of measurement (Austin 1996, pp. 66ff.). On the other hand, his model does not explicitly consider cost of measurement. Baker (Baker 2000) investigated how much an organisation should pay to develop better performance measures.

Subsequently we will take nonrecurring cost m_{x_1} (resp. m_{x_2}) into account that is incurred when the principal measures effort for task x_1 (resp. x_2). Hence a completely non-observable measure is characterised by cost of measurement that approaches infinity.

Integrating cost of measurement the principal's general calculus is:

(4) $$\max_X \; g(z(X)) - m_{x_1} - m_{x_2} - \beta .$$

As opposed to the Austin model were one effort dimension was assumed to be not observable at all (infinite cost of measurement for that dimension) in our model the principal can potentially observe any effort dimension. If he exercises this privilege and observes the effort dimension x_1 (resp. x_2) the corresponding cost of measurement m_{x_1} (resp. m_{x_2}) has to be included in his calculus.

Full supervision

Full supervision occurs when the principal observes and rewards both effort dimensions. By using an "all-or-nothing" contract the principal demands $\tilde{X}$ and, therefore, has to include both m_{x_1} and m_{x_2} in his calculus. As stated in section 4.1, the principal will not increase his budget for compensation but no longer offers a fixed compensation and spends the entire budget β for the "all-or-nothing" contract. Hence the principal can improve his income with the bonus if

(5) $$g(z(\tilde{X})) - m_{x_1} - m_{x_2} - \beta > g\left(z\left(\dddot{\hat{X}}\right)\right) - \beta .$$

To maximise his income that directly results from customer satisfaction the principal will demand effort combinations on the best-mix path described by (1). Additionally (5) shows that, if cost of measurement of at least one effort dimension is too high the principal cannot improve with full supervision compared to the non-supervision case.

Partial supervision

If the principal has to refrain from fully supervising the agent he still may increase his income by an "all-or-nothing" contract for one selected effort dimension, even if the agent's effort combination will not be on the best-mix path.

For a more comprehensive presentation we will assume the principal to offer an "all-or-nothing" bonus for the effort dimension x_1. Hence there will be no performance-based compensation for x_2. Now the agent can only optimise his effort for the "free" effort dimension x_2. The agent's calculus (2) applies, while the level of x_1 is predetermined:

(6) $$X : \max_{x_2} \ f(z(X)) - c(X) + \beta \ \text{ s.t. } \ x_1 + x_2 \le \bar{x}$$

The necessary condition for the optimal effort from the agent's point of view according to (6) is

(7) $$\frac{\partial f(z(X))}{\partial x_2} - \frac{\partial c(X)}{\partial x_2} = 0 \, .$$

Again the sufficient condition will not be examined in detail.

If the principal will apply partial supervision by offering an "all-or-nothing" contract for effort dimension x_1 (demanding $\tilde{x}_1$), cost of measurement m_{x_1} are incurred. The principal will improve by partial supervision compared to non-supervision if

(8) $$g\left(z\left(\tilde{X}\right)\right) - m_{x_1} - \beta > g\left(z\left(\ddot{\hat{X}}\right)\right) - \beta \, .$$

4.4 Uncertainty of Measurement

So far we assumed the values measured by the principal for x_1 and x_2 to be certain. Now inaccuracy of measurement will be integrated into the model by random variables $\boldsymbol{x}_1$ and $\boldsymbol{x}_2$, respectively, that represent the measured values of x_1 and x_2, respectively. $\boldsymbol{x}_1$ and $\boldsymbol{x}_2$ are independent, normally distributed with mean x_1 and x_2, respectively, and variance $\sigma_{x_1}{}^2$ and $\sigma_{x_2}{}^2$, respectively.

The stochastic element of our model is different from that of the Holmstrom & Milgrom model. While Holmstrom & Milgrom regarded the product that is generated by the agent to be determined by the agent's effort and a random influence simultaneously, we will assume that the product depends on the agent's effort only, but the perceived values of the agent's effort to be a random variable. Hence the values of the agent's effort that the principal observes are random variables. Consequently, other variables like the customer satisfaction z that results from the customer's perception of the agent's effort and the principal's return g become random variables, too. Principal and agent also differ in their risk attitude as will be discussed in detail now.

Setup

Here we assume the customer as well as the agent to be risk neutral. The customer's utility function is defined by $u_K(y) = y$, and that of the agent by $u_A(y) = y$. Both functions have an Arrow-Pratt value of absolute risk aversion $r_K = r_A = 0$ (Arrow 1970, pp. 90). The principal is risk averse. His utility function can be described by a Bernoulli utility function with $u_P(y) = 1 - e^{-y}$ where $r_P = -\frac{\frac{d^2 u_P(y)}{dy^2}}{\frac{du_P(y)}{dy}} = 1$.

Behaviour

The principal no longer optimises his income but the utility that derives from his income. Hence the principal's general calculus is

$$\max_{x_1, x_2} u_P\left(g(z(\boldsymbol{x}_1, \boldsymbol{x}_2)) - m_{x_1} - m_{x_2} - \beta\right).$$

According to the Bernoulli principal the expected utility $E\left(u_P\left(g(z(\boldsymbol{x}_1, \boldsymbol{x}_2)) - m_{x_1} - m_{x_2} - \beta\right)\right)$ and not the expected value $E\left(g(z(\boldsymbol{x}_1, \boldsymbol{x}_2)) - m_{x_1} - m_{x_2} - \beta\right)$ is the decision variable.

This expected utility criterion can be transformed into an equivalent μ-σ-criterion with the following μ-σ-objective function:

(9) $$v = E(\boldsymbol{y}) - \frac{1}{2} \cdot \sigma_{\boldsymbol{y}}^{\ 2} \text{ where } \boldsymbol{y} = g(z(\boldsymbol{x}_1, \boldsymbol{x}_2)) - m_{x_1} - m_{x_2} - \beta .$$

Hence the principal's general calculus is

(10) $$\max_{x_1, x_2} \ E\left(g(z(\boldsymbol{x}_1, \boldsymbol{x}_2)) - m_{x_1} - m_{x_2} - \beta\right) - \frac{1}{2} \cdot \operatorname{var}\left(g(z(\boldsymbol{x}_1, \boldsymbol{x}_2)) - m_{x_1} - m_{x_2} - \beta\right).$$

The customer's and the agent's calculi do not change as terms until equation (3) are still valid. Hence the non-supervision case is not affected by the stochastic component.

Similar to (5) the principal can improve by full supervision if

(11) $$E\left(g(z(\boldsymbol{x}_1, \boldsymbol{x}_2)) - m_{x_1} - m_{x_2} - \beta\right) - \frac{1}{2} \cdot \operatorname{var}\left(g(z(\boldsymbol{x}_1, \boldsymbol{x}_2)) - m_{x_1} - m_{x_2} - \beta\right) > g\left(z\left(\dddot{\hat{X}}\right)\right) - \beta .$$

The condition for partial supervision corresponding to (8) is

(12) $$E\left(g(z(\boldsymbol{x}_1, x_2)) - m_{x_1} - \beta\right) - \frac{1}{2} \cdot \operatorname{var}\left(g(z(\boldsymbol{x}_1, x_2)) - m_{x_1} - \beta\right) > g\left(z\left(\dddot{\hat{X}}\right)\right) - \beta .$$

4.5 Calibration

Until now our model has not been specified in great detail. Hence the results of the discussion are not very specific. We will now assume more explicit functions to derive a more detailed understanding of the selection of measures to quantify organisational performance. The calibration is necessary, as otherwise there would be no explicit solution of several equations. It will also be helpful to provide a graphical interpretation of the selection of measures.

4.5.1 Functional Assumptions and Basic Model

Customer satisfaction will be represented by $z(X) = x_1 \cdot x_2$. Using a Lagrange function the best-mix path $\ddot{X} : \underset{x}{\forall} \max z(X)$ s.t. $x_1 + x_2 = x$ can be calculated accordingly: $x_1 = x_2$.

To consider the agent's intrinsic motivation here we will use $f(z) = a \cdot z$, where a describes how strong the agent's decisions are influenced by customer satisfaction. The agent should not dislike customer satisfaction and he should not be overly philanthropic either, hence $0 \le a \le 1$. In addition the agent is characterised by a polynomial cost function $c(X) = (x_1 + x_2 - d)^2$. We assume there should be a certain $\breve{x}$ with $c(\breve{x}) = 0$, hence $d \ge 0$. The level of effort the agent will provide by any means is described by d.

A linear function $g(z)$ will be used to describe how much of the customer's benefit the principal skims. Subsequently we assume $g(z) = b \cdot z$ with $0 \le b \le 1$. Therefore b describes the price level for the product that principal and agent produce.

4.5.2 Introducing Permanent Extrinsic and Intrinsic Motivation

Considering the calibration (3) can be substantiated:

$$\underset{i=1,2}{\forall} \frac{\partial\left(\left(a \cdot x_1 \cdot x_2 - (x_1 + x_2 - d)^2\right) + \beta\right)}{\partial x_i} = 0 \text{, thus}$$

(3a) $$\frac{\partial\left(\left(a \cdot x_1 \cdot x_2 - (x_1 + x_2 - d)^2\right) + \beta\right)}{\partial x_1} = a \cdot x_2 - 2 \cdot (x_1 + x_2 - d) = 0 \text{, and}$$

(3b) $$\frac{\partial\left(\left(a \cdot x_1 \cdot x_2 - (x_1 + x_2 - d)^2\right) + \beta\right)}{\partial x_2} = a \cdot x_1 - 2 \cdot (x_1 + x_2 - d) = 0.$$

By equating (3a) and (3b) we obtain $x_1 = x_2$. From utilising this identity in (3a) or (3b) $x_1 = x_2 = -\frac{2 \cdot d}{a - 4}$ results. As the cost minimal effort that results from the cost function $c(X)$ is $\breve{x} = x_1 + x_2 = d$, the agent's basic effort $\hat{X} = \left(-\frac{2 \cdot d}{a-4}, -\frac{2 \cdot d}{a-4}\right)$ exceeds his cost minimal effort for $0 \le a \le 1$. Hence an additional intrinsic motivation results in a higher basic effort while the budget β the principal spends for extrinsically motivating the agent does not influence the basic effort level.

4.5.3 Cost of Measurement

Following the structure of chapter 4.3 we will discuss the specification of our model in the *full* and *partial supervised case* separately.

Full supervision

Using the optimal basic effort $\ddot{\hat{X}} = \left(-\frac{2 \cdot d}{a-4}, -\frac{2 \cdot d}{a-4}\right)$ that resulted from the calibrated model, equation (5) can be specified as the principal's general calculus with full supervision. Accordingly, the principal can improve by granting a performance based bonus to the agent, if

$$\text{(5a)} \qquad b \cdot \tilde{x}_1 \cdot \tilde{x}_2 - m_{x_1} - m_{x_2} - \beta > b \cdot \frac{4 \cdot d^2}{(a-4)^2} - \beta .$$

Because $x_1 = x_2$ applies for the best-mix path

$$\tilde{x}_i^{\,2} - 1/b \cdot \left(m_{x_1} + m_{x_2}\right) > \frac{4 \cdot d^2}{(a-4)^2} \text{, and}$$

$$\text{(5b)} \qquad \tilde{x}_i > \sqrt{\frac{4 \cdot d^2}{(a-4)^2} + 1/b \cdot \left(m_{x_1} + m_{x_2}\right)}$$

result. If cost of measurement disappear for both effort dimensions, the principal can improve with every $\tilde{X} = (\tilde{x}_1, \tilde{x}_2)$ at the best-mix path beyond the basic effort $\hat{x}$. As the principal's income raises with increasing effort, the effort capacity is the limiting factor and the principal demands $\tilde{X} = \left(\frac{\overline{x}}{2}, \frac{\overline{x}}{2}\right)$ from the agent.

(5b) also shows that if cost of measurement are too high, a performance based bonus could only improve the principal's income if he demands effort that is beyond the agent's effort capacity. As the agent will not supply this effort, the principal has to refrain from full supervision if

$$\tilde{x}_1 + \tilde{x}_2 > \overline{x}$$

$$2 \cdot \sqrt{\frac{4 \cdot d^2}{(a-4)^2} + 1/b \cdot \left(m_{x_1} + m_{x_2}\right)} > \overline{x}$$

$$\left(m_{x_1} + m_{x_2}\right) > b \cdot \left(\frac{\overline{x}^2}{4} - \frac{4d^2}{(a-4)^2}\right).$$

Hence high cost of measurement will force the principal to refrain from full supervision. This is also true if cost of measurement of even one dimension only is too high.

Partial supervision

The condition for optimal effort from the agent's point of view (7) can be substantiated in the calibrated model:

$$\frac{\partial a \cdot x_1 \cdot x_2}{\partial x_2} - \frac{\partial c(x_1 + x_2 - d)}{\partial x_2} = 0$$

$$a \cdot x_1 - 2 \cdot (x_1 + x_2 - d) = 0$$

(7a) $$x_2 = d + \frac{a-2}{2} \cdot x_1 .$$

The scope of (7a) is bounded by the optimally allocated basic effort $\dddot{\hat{x}}_1 = -\frac{2 \cdot d}{a-4}$, i. e. the agent's non-supervision optimum, and the non-negativity of x_i. Hence $-\frac{2 \cdot d}{a-4} \leq \tilde{x}_1 \leq -\frac{2 \cdot d}{a-2}$. The lower border of the interval results in $\dddot{\hat{X}}$ while the upper border leads to point E in Fig. 2. For smaller x_1, equation (7a) is not reasonably defined because the basic effort is not met, for larger x_1 the agent supplies $x_2 = 0$.

If the agent's intrinsic motivation enhances, a increases. According to (7a) the agent will then provide more effort for x_2 when x_1 is determined by the "all-or-nothing" contract. Hence the overall organisational performance can improve with an increasing intrinsic motivation of the agent. In Fig. 2 this results in a rotation of $\hat{X}$ around the intersection of $\breve{X}$ and the x_2-axis. Consequently $\dddot{\hat{X}}$ as well as points B and C will result in better organisational performance.

The principal's opportunities for improvement by partial supervision described by (8) can be substantiated where $\tilde{x}_1$ is determined by the "all-or-nothing" bonus and x_2 is not observed by the principal:

$$b \cdot \tilde{x}_1 \cdot \left(d + \frac{a-2}{2} \cdot \tilde{x}_1 \right) - m_{x_1} - \beta > b \cdot \frac{4 \cdot d^2}{(a-4)^2} - \beta$$

(8a) $$\left(\tilde{x}_1 + \frac{d}{a-2} \right)^2 < \frac{a^2 \cdot d^2}{(a-4)^2 \cdot (a-2)^2} + \frac{2}{b \cdot (a-2)} \cdot m_{x_1} .$$

The solution of (8a) is:

(8b) $$-\frac{d}{a-2} - \sqrt{\frac{a^2 \cdot d^2}{(a-4)^2 \cdot (a-2)^2} + \frac{2}{b \cdot (a-2)} \cdot m_{x_1}} < \tilde{x}_1 < -\frac{d}{a-2} + \sqrt{\frac{a^2 \cdot d^2}{(a-4)^2 \cdot (a-2)^2} + \frac{2}{b \cdot (a-2)} \cdot m_{x_1}}$$

Eventually it has to be checked if the scope of (7a) covers the entire solution area of (8b) that is true here.

Cost of measurement of $m_{x_1} = 0$ can be regarded as a special case because the area of valid $\tilde{x}_1$ is extremely large with $\frac{-2 \cdot d}{(a-4)} < \tilde{x}_1 < \frac{4 \cdot d}{(a-2) \cdot (a-4)}$. The lower border of the interval results in $\dddot{\hat{X}}$ while the upper corresponds to point C in Fig. 2.

As the interval is open in the case with no cost of measurement m_{x_1} the principal can improve his income with some $\tilde{x}_1$ that are marginally larger than the optimally allocated basic effort $\dddot{\hat{X}}$. (8b) also shows that the principal can be worse off in the case with cost of measurement m_{x_1} if he chooses $\tilde{x}_1$ too close to the optimally allocated basic effort. If $m_{x_1} > \frac{-a^2 \cdot d^2 \cdot b}{2 \cdot (a-2) \cdot (a-4)^2}$ so that the solution set of (8b) is empty, it is impossible for the principal to improve his income by measuring and rewarding the x_1 effort. The principal's maximum income with $m_{x_1} = \frac{-a^2 \cdot d^2 \cdot b}{2 \cdot (a-2) \cdot (a-4)^2}$ and usage of the "all-or-nothing" bonus equals his income at the optimal allocated basic effort.

The principal will improve compared to non-supervision with any effort demand $\tilde{x}_1$ within the interval of (8b). The best solution can be determined by maximising the left term of (8) subject to (7). Hence the following criterion can be formulated:

$$\max_{\tilde{x}_1} g\left(z\left(\tilde{X}\right)\right) - m_{x_1} - \beta \text{ s.t. } \frac{\partial f\left(z(X)\right)}{\partial x_2} = \frac{\partial c(X)}{\partial x_2}.$$

With the calibration

$$\max_{\tilde{x}_1} b \cdot \tilde{x}_1 \cdot \left(d + \frac{a-2}{2} \cdot \tilde{x}_1\right) - m_{x_1} - \beta$$

results. The necessary condition is

$$b \cdot \left(d + \frac{a-2}{2} \cdot \tilde{x}_1\right) - b \cdot \frac{a-2}{2} \cdot \tilde{x}_1 = 0$$

$$\tilde{x}_1 = -\frac{d}{a-2}$$

represented by point B in Fig. 2.

The optimal $\tilde{x}_1$ is situated at the centre of the interval (8b) and is independent of the level of cost of measurement m_{x_1}. According to (7a) the agent will choose $x_2 = \frac{d}{2}$ if the principal's "all-or-nothing" contract sets $\tilde{x}_1 = -\frac{d}{a-2}$.

Fig. 2 is intended to illustrate some exemplary situations. The effort capacity $\bar{x} = 10$ is represented by $\bar{X}$. The parameters are set to $d = 4$, $a = 0.5$, and $b = 0.8$. The agent's least cost combinations are situated at $\breve{X}$. The basic effort is described by $\dddot{\hat{X}}$.

Fig. 2 includes two different situations:

1. With cost of measurement $\left(m_{x_1}, m_{x_2}\right) = (0{,}5)$, the principal can increase his income compared to non-supervision if he observes and rewards both effort dimensions, i. e. implementing full supervision. With every effort between D and $\dddot{\bar{X}}$ on the best-mix path $\dddot{X}$ the principal improves. From the principal's point of view the optimum will be reached at $\dddot{\bar{X}} = (5{,}5)$.

2. If cost of measurement are $\left(m_{x_1}, m_{x_2}\right) = (0{,}100)$ the principal cannot improve at the best-mix path within the effort capacity as cost of measurement of dimension x_2 are too high. Therefore, the principal will observe only one dimension and offers a performance-based bonus for this dimension. Because of lower cost of measurement this will certainly be x_1. Every effort dimension that might be realised is situated at $\hat{X}$. Although effort combinations beyond the intersection of $\hat{X}$ and the x_1-axis (point E in Fig. 2) can be reached, the principal will not choose these as customer satisfaction is zero and the principal's utility is negative. With any effort combination between $\dddot{\hat{X}}$ and C the principal can improve his income compared to the non-supervision case. The principal obtains his maximal income with $(x_1, x_2) = \left(\frac{8}{3}, 2\right)$ at B.

Starting from cost of measurement $\left(m_{x_1}, m_{x_2}\right) = (0{,}5)$ with increasing m_{x_1} or m_{x_2}, D approaches $\dddot{\bar{X}}$ and more agent effort is necessary for the principal to improve. If the sum of m_{x_1} and m_{x_2} exceeds $\frac{3{,}876}{245} \approx 15.82$, D relocates behind $\dddot{\bar{X}}$ at the best-mix path and the principal cannot improve his income by fully supervising the agent at all.

When partial supervision occurs, with an increase of m_{x_1}, the spread where the principal improves compared to non-supervision reduces. Here the optimum B does not shift.

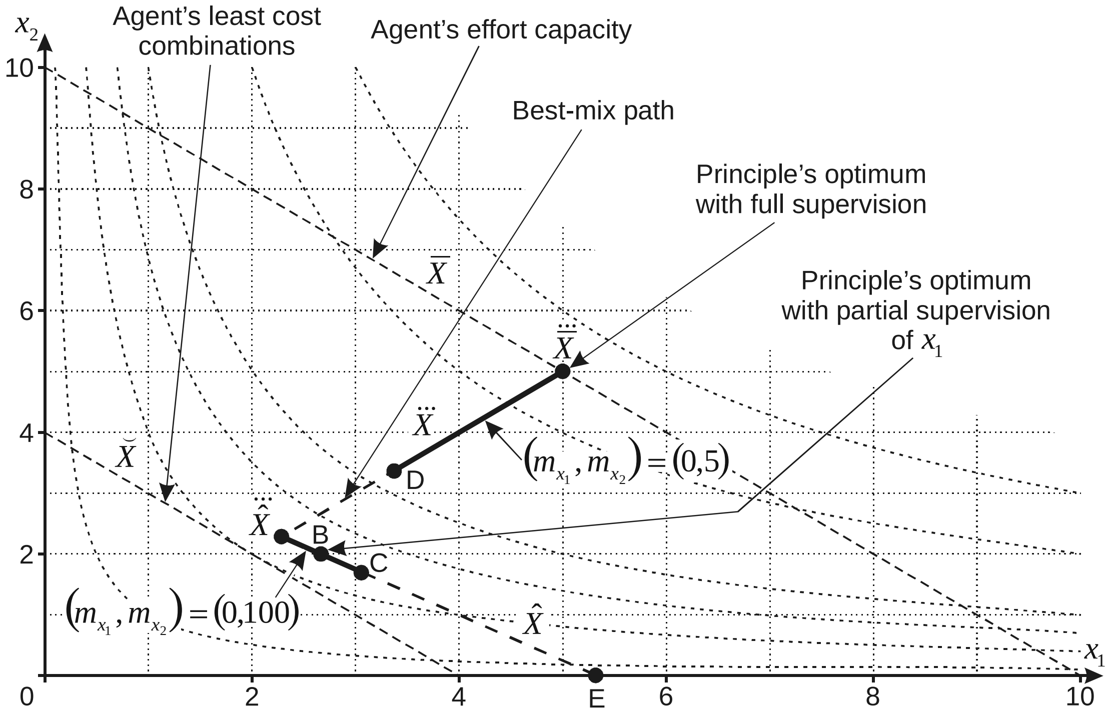

Fig. 2: Exemplary summarisation of the model with cost of measurement

4.5.4 Uncertainty of Measurement

For the expected value in the principal's general calculus considering the uncertainty of measurement (9), (10), and (11) apply:

$$E(\boldsymbol{y}) = E\left(g(\boldsymbol{x}_1, \boldsymbol{x}_2) - m_{x_1} - m_{x_2} - \beta\right)$$

$$E(\boldsymbol{y}) = E\left(b \cdot \boldsymbol{x}_1 \cdot \boldsymbol{x}_2 - m_{x_1} - m_{x_2} - \beta\right)$$

$$E(\boldsymbol{y}) = b \cdot E(\boldsymbol{x}_1 \cdot \boldsymbol{x}_2) - m_{x_1} - m_{x_2} - \beta$$

$$E(\boldsymbol{y}) = b \cdot E(\boldsymbol{x}_1) \cdot E(\boldsymbol{x}_2) + b \cdot \mathrm{cov}(\boldsymbol{x}_1, \boldsymbol{x}_2) - m_{x_1} - m_{x_2} - \beta,$$

and as $\mathrm{cov}(\boldsymbol{x}_1, \boldsymbol{x}_2) = 0$ because of the independence of $\boldsymbol{x}_1$ and $\boldsymbol{x}_2$:

$$E(\boldsymbol{y}) = b \cdot E(\boldsymbol{x}_1) \cdot E(\boldsymbol{x}_2) - m_{x_1} - m_{x_2} - \beta$$

$$E(\boldsymbol{y}) = b \cdot x_1 \cdot x_2 - m_{x_1} - m_{x_2} - \beta.$$

The variance $\sigma_y{}^2 = \mathrm{var}(\boldsymbol{y})$ can be calculated as follows:

$$\mathrm{var}(\boldsymbol{y}) = \mathrm{var}\left(g(\boldsymbol{x}_1, \boldsymbol{x}_2) - m_{x_1} - m_{x_2} - \beta\right)$$

$$\mathrm{var}(\boldsymbol{y}) = \mathrm{var}\left(b \cdot \boldsymbol{x}_1 \cdot \boldsymbol{x}_2 - m_{x_1} - m_{x_2} - \beta\right)$$

$$\mathrm{var}(\boldsymbol{y}) = b^2 \cdot \mathrm{var}(\boldsymbol{x}_1 \cdot \boldsymbol{x}_2)$$

and because of the independence of $\boldsymbol{x}_1$ and $\boldsymbol{x}_2$:

$$\mathrm{var}(\boldsymbol{y}) = b^2 \cdot \left(E(\boldsymbol{x}_2)^2 \cdot \mathrm{var}(\boldsymbol{x}_1) + E(\boldsymbol{x}_1)^2 \cdot \mathrm{var}(\boldsymbol{x}_2) + \mathrm{var}(\boldsymbol{x}_1) \cdot \mathrm{var}(\boldsymbol{x}_2)\right)$$

$$\mathrm{var}(\boldsymbol{y}) = b^2 \cdot \left(x_2{}^2 \cdot \sigma_{\boldsymbol{x}_1}{}^2 + x_1{}^2 \cdot \sigma_{\boldsymbol{x}_2}{}^2 + \sigma_{\boldsymbol{x}_1}{}^2 \cdot \sigma_{\boldsymbol{x}_2}{}^2\right).$$

Hence the principal's μ-σ-objective function is

(9a) $$v = b \cdot x_1 \cdot x_2 - m_{x_1} - m_{x_2} - \beta - \frac{1}{2} \cdot b^2 \cdot \left({x_2}^2 \cdot {\sigma_{x_1}}^2 + {x_1}^2 \cdot {\sigma_{x_2}}^2 + {\sigma_{x_1}}^2 \cdot {\sigma_{x_2}}^2 \right).$$

Using the calibration, the criterion (11) when the principal improves with full supervision compared to non-supervision can be substantiated:

(11a) $$g\left(z\left(\tilde{X}\right)\right) - m_{x_1} - m_{x_2} - \beta - \frac{1}{2} \cdot b^2 \cdot \left({x_2}^2 \cdot {\sigma_{x_1}}^2 + {x_1}^2 \cdot {\sigma_{x_2}}^2 + {\sigma_{x_1}}^2 \cdot {\sigma_{x_2}}^2 \right) > g\left(z\left(\dddot{\hat{X}} \right)\right) - \beta .$$

When non-supervision occurs, the agent's basic effort $\dddot{\hat{x}}_1 = \dddot{\hat{x}}_2 = -\frac{2 \cdot d}{a-4}$ is not affected by a variance. Hence the level of the μ-σ-objective function is $v = b \cdot \frac{4 \cdot d^2}{(a-4)^2} - \beta$.

The solution of (11a) is

(11b) $$\tilde{x}_i > \sqrt{\frac{\frac{4 \cdot b \cdot d^2}{(a-4)^2} + m_{x_1} + m_{x_2} + \frac{1}{2} \cdot b^2 \cdot {\sigma_{x_1}}^2 \cdot {\sigma_{x_2}}^2}{b - \frac{1}{2} \cdot b^2 \cdot \left({\sigma_{x_1}}^2 + {\sigma_{x_2}}^2 \right)}} .$$

If the variance of the measured values increases so that the denominator of the root gets negative the principal cannot improve by full supervision. The same applies if the root of (11b) exceeds half of the total effort capacity, i. e. if the cost of measurement of at least one effort dimension or the variance of both dimensions get too large.

The calculus of the risk neutral agent is not influenced by the stochastic component. Hence the terms from (6) up to and including (7a) hold true.

As a specification of (12) the principal can improve his income by partial supervision compared to non-supervision if

(12a) $$g\left(z\left(\tilde{X}\right)\right) - m_{x_1} - \beta - \frac{1}{2} \cdot b^2 \cdot {x_2}^2 \cdot {\sigma_{x_1}}^2 > g\left(z\left(\dddot{\hat{X}} \right)\right) - \beta .$$

Using the functional assumptions

$$b \cdot x_1 \cdot \left(d + \frac{a-2}{2} \cdot x_1 \right) - m_{x_1} - \beta - \frac{1}{2} \cdot b^2 \cdot \left(d + \frac{a-2}{2} \cdot x_1 \right)^2 \cdot {\sigma_{x_1}}^2 > b \cdot \frac{4 \cdot d^2}{(a-4)^2} - \beta$$

results. The solution corresponding to (8a) is

(12b) $$\left(x_1 - \frac{4 \cdot d - 2 \cdot b \cdot d \cdot (a-2) \cdot {\sigma_{x_1}}^2}{-4 \cdot (a-2) + b \cdot (a-2)^2 \cdot {\sigma_{x_1}}^2} \right)^2 < \frac{\begin{array}{l} 16 \cdot b \cdot d^2 \cdot \left(8 \cdot (a-2) + (a-4)^2 \right) \\ - m \cdot 8 \cdot (a-2) \cdot (a-4)^2 \cdot \left(-4 + b \cdot (a-2) {\sigma_{x_1}}^2 \right) \\ -32 \cdot b^2 \cdot d^2 \cdot (a-2)^2 \cdot {\sigma_{x_1}}^2 \end{array}}{b \cdot (a-2)^2 \cdot (a-4)^2 \cdot \left(-4 + b \cdot (a-2) \cdot {\sigma_{x_1}}^2 \right)^2} .$$

Because of the complexity of (12b) we forego to transform it into an equation corresponding to (8b). The transformation can be performed equivalent to the solution of $(x-a)^2 < b$ in x.

If the right term of (12b) gets negative the principal cannot increase his income by partial supervision. The improvement may fail because of a high variance of $\boldsymbol{x}_1$ as well as of high cost of measurement m_{x_1}. Both effects mutually boost each other: with high cost of measurement the critical level of the variance decreases and a high variance reduces the critical level of measurement cost. This means that higher cost of measurement is justified if the variances of the measured efforts are smaller and vice versa. The variances can be regarded as a measure for the reliability of a performance measure that may be part of the quality of the performance measurement system in general.

5 Conclusions

There are several models that make suggestions on the selection of measures to quantify organisational performance. Based on the work of Holmstrom & Milgrom and Austin we developed a formal model based on multitask principal-agent-theory that considers an extrinsically and intrinsically motivated agent, cost of measurement and the uncertainty of measurement.

If there are reliable measures for every performance dimension available that can be obtained at reasonable cost, the first best solution can be realised. This is the intersection of the optimal allocated effort (best-mix path) and the agent's effort capacity. Hence we can formulate the first axiom on the selection of measures to quantify organisational performance:

1. If every relevant effort dimension can be measured within an organisation at reasonable cost and if high quality measures are available for every effort dimension, the organisation's performance measurement system should observe and reward all effort dimensions.

On the other hand the second best solution is more interesting and more relevant to real life. The second best applies if the first best optimum is out of range because of high cost of measurement or a high variance of measures of at least one performance dimension. Depending on the level of measurement cost, measure reliability and the agent's motivation, organisational performance can be improved by partial supervision (i. e. observing only one performance dimension). If these conditions are not true the second best is non-supervision (i. e. offering no performance based compensation and leave the agent alone). Based on the quantitative analysis in section 4.5.4 the corresponding axiom is:

2. If at least one relevant effort dimension can be measured within an organisation at reasonable cost and if high quality measures are available for that effort dimension, the organisation's performance measurement system should observe and reward that effort dimension.

As already noted in the introduction, the selection of measures for organisational performance is widely discussed with suggestions to use relevant measures only or proposals to choose measures that are easy to obtain. Our model suggests that both postulates

- measure what is important for an organisation’s long-term success, and
- measure what is easily measurable

are not as diametrical than previously thought, but have to be used simultaneously to select measures. Kiefer & Novack, 1999, p. 26 held a different view (use axiom 1 only), as did Feltham & Xie, 1994, pp. 431ff.

The demand to use a balanced set of measurements to measure organisational performance is widespread in the literature (Vitale & Mavrinac & Hauser 1994, p. 13; Kaplan & Atkinson 1998, p. 375 and others). While it is compatible to the first axiom, there is at least partial disagreement with the second axiom. Axson’s 1999, p. 8 opinion that it is unrealistic to strive for a balanced set of measures but to strive for tailored measures that meet an organisation’s needs confirms the second axiom.

We found that the agent’s motivation is very important when choosing measures to quantify organisational performance.

If the agent corresponds to the average human being of McGregor’s “theory X” (McGregor 1960) that dislikes work, the manager should refrain from measuring organisational performance at all if there is at least one relevant performance dimension that cannot be measured at reasonable cost or with reliable measures. As there will always be a performance dimension in real life organisations that is difficult to measure, performance measurement systems such as the Balanced Scorecard would become counter-productive.

If the agent represents an average human being that corresponds to McGregors “theory Y” i. e. that regards work as a source of satisfaction as well as of pain to be avoided, a completely different suggestion on the selection of performance measures will be derived. Now managers should not be afraid of declining overall performance if they do not have reliable measures that are easy to obtain for every performance dimension. Even if some relevant information is not available organisational performance might improve by using a performance measurement system.

The model also showed that if the agent’s intrinsic motivation can be increased, organisational performance will improve. This holds true for partial supervision as well as for non-supervision while for full supervision the agent’s intrinsic or extrinsic motivation is irrelevant.

Limitations

Baiman 1990, pp. 344ff. formulated three criticisms of the principal-agent theory in general:

- realism of the assumptions of principal-agent models,
- simplicity of the models analysed, and
- complexity of the results.

In the following we will analyse each of these points further.

Most of the functional assumptions we used during the development of the model are arbitrary. Partly these assumptions simplify, e. g. specific functions for customer satisfaction $z(X)$ or agent motivation $f(z)$. Partly these assumptions affect the type of the model's implications extensively, e. g. the principal's, agent's, and customer's risk behaviour. The irrelevance of the total amount of rewards is another assumption that is not very close to reality.

Similar to the Austin model, our model contains cases where the agent provides effort although his total utility is negative. To eliminate this shortcoming, the cost of inducing an increase in effort has to be integrated into the model. Even under full supervision the principal might not strive to achieve the agent's effort capacity, as it will be too expensive. Integrating cost of inducing effort increase do affect the total amount of effort spend, but do not affect the model's implications concerning the selection of measures. Hence we assumed the total amount of rewards to be constant.

Our model is a simplifying image of reality. For instance, we do not consider interactions on labour, commodity and financial markets. Likewise we neglect several aspects of behavioural theories such as trust and fairness (see similar Baiman 1990, pp. 344ff.).

Baiman's criticism on the complexity of results of agency analysis focuses on the type of contracts between principal and agent that cannot be observed in reality. Our focus was not so much on contracts but on measures of a performance measurement system. We conclude with two normative axioms how measures to quantify organisational performance should be selected by demonstrating the effect of measurement cost, intrinsic and extrinsic motivation and the uncertainty of measurement.

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