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Incentive systems for risky investment decisions under unknown preferences

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Our paper examines how to design incentive systems for managers making multi-period risky investment decisions. We show how compensation functions and performance measures must be designed to ensure that managers implement the expected value-maximizing set of projects. The Relative Benefit Cost Allocation (RBCA) Scheme[1] and its extensions revealed in literature on unknown time preferences generally fail to do so under unknown time and risk preferences. We illustrate that when coping with such unknown preferences in a risky setting, a specific state-dependent allocation rule is required. We introduce such an allocation scheme, which we refer to as the State-Contingent RBCA Scheme, and reveal that specific knowledge of the time and risk structure of the cash flows is needed to apply it.

1. Introduction

A frequently expressed concern in literature and practice is that managers make investment decisions in their own interest and not in the interest of the owners. Reasons for this behavior may be private interests of the manager (e.g. power, prestige, low exertion of effort) and/or a current compensation system giving financial incentives, which are not in line with the financial interests of the owners. Such poorly designed compensation systems have been blamed to incentivize too short-termed and too risky investments, especially in the context of the financial crisis (see e.g. Bebchuk et al., 2010; Samuelson and Stout, 2009). In order to avoid such value destroying decision-making, incentive systems should align the financial interests of both parties. However, the design of such incentive systems turns out to be challenging, especially if – as in practice – the preferences of the managers are unknown. In this paper, we show how to design incentive systems, which align the financial interests of both parties without knowledge of the time and risk preferences for multi-period risky investment decisions. The analysis reveals that in order to construct adequate performance measures, in addition to the specific inter-temporal cost allocation revealed in the literature (i.e. the Relative Benefit Cost Allocation (RBCA) Scheme), a state-dependent cost allocation is crucial under risk. We introduce such a new cost allocation scheme, which we refer to as the *State-Contingent (Robust) Relative Benefit Cost Allocation Scheme*. The proposed allocation scheme ensures time and statewise dominant performance measures and compensation for the desired investment strategy (i.e. the implementation of the value-maximizing set of projects). Furthermore, we analyze the information requirements to construct such performance measures.

We conduct our formal analysis within the following general theoretic framework: The owner of a firm delegates risky investment decisions to a manager who is better informed about all future project cash flows. The interest of the risk neutral owner is to maximize the expected firm value. The interest of the manager can be composed of financial and private interests. To ensure that the manager acts in the interest of the owner, an incentive system is established. This incentive system is composed of compensation functions and performance measures for each period.

In Literature, such principal agent relationships are analyzed within two main approaches, the *standard agency approach* and the *consistency approach*. The standard agency approach (Grossman and Hart, 1983; Holmström, 1979; Mirrlees, 1976; Shavell, 1979)

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[1] The Relative Benefit Cost Allocation (RBCA) Scheme has been introduced by Rogerson (1997). It ensures the performance measure of every single period to be a linear function of the net present value (NPV) of the project. All further literature on unknown time preferences is based on this approach.

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explicitly considers both private and financial interests of the manager and focuses on *optimal incentive system design*. To be able to derive such optimal incentive systems, it is necessary to assume well-specified scopes of action, corresponding probability distributions and (dis-)utility functions. The derived optimal incentive systems are not robust, i.e. the solution depends crucially on the specific assumptions of the model. If either the relationship between effort and the cash flow distribution or the utility function of the manager is unknown – as in most practical situations – this approach is very limited. The second approach, which is the basis of our analysis, aims to derive so-called *consistent incentive systems*. It assumes that the relationship between effort and the cash flow distribution is unknown and only focuses on explicitly aligning the *financial* interest of the manager and the owner with regard to any cash flow distribution. Consistent incentive systems ensure that if any investment decision has a financial advantage for the owner, it will also provide the manager with a financial advantage. Although non-financial interests are not considered explicitly, they can be addressed by exploiting the remaining degrees of freedom within the requirements for consistent incentive system design.

The *consistency approach* itself encompasses two incentive concepts: *Goal congruence* (GC) and *preference similarity* (PS) (Dutta and Reichelstein, 2005; Reichelstein, 1997; Rogerson, 1997; Solomons, 1965 resp. Pratt, 2000; Ross, 1974, 1973; Wilson, 1969, 1968). The difference relates to the concrete financial interest of the risk neutral owner: Whereas under GC it is to maximize the expected net present value (NPV) of the investments, under PS the NPV after managerial compensation is considered for maximization. Within both concepts, consistency can be achieved by designing appropriate performance measures and compensation functions. If the *utility function of the manager is known*, potential differences in financial preferences can be counterbalanced by adjusting the compensation functions. Then any complete performance measure, i.e. fulfilling NPV-identity,[2] will ensure consistent investment decisions (Pfeiffer and Velthuis, 2009). As such, any *residual income* measure is in general appropriate. However, if the utility function of the manager and as such his *time and/or risk preferences are unknown* to the owner, the only possibility to achieve consistent investment decisions persists in a specific design of the performance measures. For *unknown time preferences* prior analyses revealed that such performance measures can be constructed by means of the so-called *Relative Benefit Cost Allocation (RBCA) Scheme* (Reichelstein, 1997; Rogerson, 1997) and its extension (Mohnen and Bareket, 2007). These allocation schemes ensure that a specific portion of the NPV is reflected in the performance measure in each period. As such, NPV-maximizing investment decisions will result in *timewise dominant* performance measures and compensation for the manager.

We expand existing accounting research by focusing on *unknown time and risk preferences*. By analyzing the implications of unknown risk and time preference in a setting with risky investment projects, we relax the most restricting assumption of the prevalent models on GC and PS (i.e. risk neutrality of the manager or certainty). Within this setting, prevalent allocation schemes derived under unknown time preferences fail to induce consistency. The reason for this deficit is that whereas risk-neutral decision makers only consider expected values in their decision process, risk-averse decision makers also care about the distribution across different states in each period. As such, consistent performance measures must portray stronger properties to induce the desired investment decisions regardless of managers' risk preferences. Our findings are based on the preliminary work of Wollscheid (2013) and contribute to existing literature by introducing an allocation scheme, which we refer to as *State-Contingent (Robust) RBCA Scheme*. It ensures both *GC and PS* for *risky investment decisions* despite *unknown time and risk preferences* of the manager. Our *State-Contingent (Robust) RBCA Scheme* leads to *state- and timewise dominant* performance measures, distributing a specific portion of the expected NPV in every state in each period. As such, *dominant compensation pay-offs* for the desired investment decisions are ensured, while using positive marginal compensation for all states, periods and projects.

This paper is organized as follows: The next section introduces the formal model. In Section 3, consistent incentive systems for risky investment decisions under unknown time and risk preferences are derived. We first focus on a single-project setting (3.1) and then analyze the multi-project case (3.2). Section 4 finally discusses the implications of our findings.

2. The basic model

In line with prior investigations (e.g. Mohnen and Bareket, 2007; Pfeiffer and Velthuis, 2009; Reichelstein, 1997; Rogerson, 1997), we analyze a principal agent relationship, in which a firm owner (principal P) delegates investment decisions to a better-informed manager (agent A). These investment decisions accrue at time $t = 0$. If the manager decides to invest, the investment requires an initial investment expenditure I in $t = 0$ and subsequently generates risky cash flows c_{ts} (or riskless cash flows c_t) in state s at times $1 \leq t \leq T$. The probability of state s at time t is denoted by p_{ts} with $\sum_{s=1}^{S} p_{ts} = 1 \ \forall t$. The initial investment expenditure as well as the cash flows in each state s at each point in time t may contain cash flow components (I_i resp.c_{its}) from one or several projects i, i.e. $I = \sum_{i=1}^{n} I_i$ resp. $c_{ts} = \sum_{i=1}^{n} c_{its}$.

To capture the risk and time structure of cash flows we further assume, without loss of generality, that the state specific cash flows (resp. their components) can be represented as:

$$c_{ts}(I) = \psi_{ts} \cdot E(c_t(I)) = \psi_{ts} \cdot x_t \cdot y(I) \quad \text{with} \quad E\left(\psi_t\right) = 1. \tag{1}$$

The *variation factor* ψ_{ts} depicts the state specific variation of cash flows with respect to its expected value. The expected periodic cash flow $E(c_t(I))$ is the product of a *temporal growth factor* x_t and a *profitability factor* $y(I)$.

Only the manager has complete information of possible investment projects, i.e. only he knows the investment expenditures, possible future periodic cash flows c_{ts} in the different states and the probability of each environmental state p_{ts}. The realized initial investment expenditure I, and all realized cash flows c_{ts} are observable by the owner.

To align their financial interests, the owner establishes an *incentive system* by designing *performance measures* π_{ts} and by specifying the *functional relationship* between the performance measures and the variable compensation of the manager ω_t at each point in time $1 \leq t \leq T$:

$$\omega_t = \omega_t(\pi_{ts}). \tag{2}$$

We focus on incentive systems ensuring $\omega_t(\pi_{ts}) = 0 \, \forall t, s$ for cases in which the manager does not invest at all.[3] The performance measures considered in this analysis are accrual accounting measures,

[2] NPV-identity states that the present value of the performance measures equals the present value of the cash flows.

[3] As such, we do not consider a fixed compensation component resp. a base performance level in the performance measures. Furthermore, the compensation at time t is solely a function of the performance measure π_{ts}. Hence, the function $\omega_t(\pi_{ts})$ is neither state nor project dependent.

which are based on the investment expenditure and the realized cash flows:

$$\pi_{ts} = \pi_{ts}(I, c_{1s}, \ldots, c_{ts}). \quad (3)$$

Such performance measures are calculated technically by allocating investment expenditures and cash flows over time. In our setting we will focus on performance measures with both time- and state-wise allocation rules.

The manager evaluates given compensation payments in the light of his individual utility function $V = V(\omega_1, \omega_2, \ldots, \omega_T)$. The time and risk preferences of the manager $\left(\gamma_A^t \text{ resp.} \eta_{At}\right)$ are determined by his utility function and can be derived as $\gamma_A^t = V'_0/V'_t$ resp. $\eta_{At} = -V''_t/V'_t$. In our setting, the utility function, hence the time and risk preferences of the manager, is his private information. However, the owner knows that the utility of the manager is monotonically increasing in his compensation of all periods and states $\partial V/\partial\omega_t \geq 0\,\forall t\,\exists t > 0: \partial V/\partial\omega_t > 0$. As such, we include extreme preferences in our analysis, in which e.g. the manager does not value his compensation at some points in time at all. As such, our analysis does not only encompass the situation in which the manager stays in the firm during all periods, but can also be conveyed to situations in which the manager may leave the firm at any time t, $1 < t < T$ and therefore forgo compensation.

Regarding the evaluation of the owner, which is determined on the basis of his utility function, – as stated above – two different approaches in literature exist: On the one hand, the *goal congruence (GC)* concept, which implicitly assumes that the utility of the owner depends solely on (gross) cash flows, i.e. $U = U(I, c_1, \ldots, c_T)$ (Dutta and Reichelstein, 2005; Mohnen and Bareket, 2007; Pfeiffer and Velthuis, 2009; Reichelstein, 1997; Rogerson, 1997; Solomons, 1965); and on the other hand, the *preference similarity (PS)* concept in which his utility is a function of net cash flows, defined as (gross) cash flows less compensation costs, i.e. $U = U(I, c_1 - \omega_1, \ldots, c_T - \omega_T)$ (Pfeiffer and Velthuis, 2009; Pratt, 2000; Ross, 1974, 1973; Wilson, 1969, 1968). To simplify the analysis, the owner is assumed to be risk neutral, i.e. $U''_t = 0\,\forall t$ implying $\eta_{Pt} = 0\,\forall t$. His time preference can be derived as $\gamma_P^t = U'_0/U'_t$ with $U'_t = \partial U_t/\partial c_t$ under GC resp. $U'_t = \partial U_t/\partial(c_t - \omega_t)$ under PS. As such, he evaluates expected utility on the basis of *expected net present value (before and after compensation respectively).*

In both concepts, the focus of the owner's problem is to design an incentive system $\omega_t = \omega_t(\pi_{ts})\,\forall t, s$ which ensures that the manager, while maximizing his own individual expected financial utility, chooses an investment strategy d which simultaneously maximizes the expected utility of the owner for arbitrary projects (from the set of available projects D) (Pfeiffer and Velthuis, 2009):

$$\begin{aligned} &\text{GC}: \arg\max_{d\in D}\left\{E\left[V(\omega_1, \ldots, \omega_T)\right]\right\} = \arg\max_{d\in D}\left\{E\left[U(I, c_1, \ldots, c_T)\right]\right\} \text{ resp.} \\ &\text{PS}: \arg\max_{d\in D}\left\{E\left[V(\omega_1, \ldots, \omega_T)\right]\right\} = \arg\max_{d\in D}\left\{E\left[U(I, c_1 - \omega_1, \ldots, c_T - \omega_T)\right]\right\} \end{aligned} \quad (4)$$

We refer to incentive systems and their components, which ensure GC resp. PS as *consistent*.

3. Consistent incentive systems for unknown time and risk preferences

3.1. Consistent incentive system design for the single-project case

We first analyze the case of a single risky multi-period normal project, i.e. $c_{ts} > 0\,\forall t, s$. We assume a general accounting measure of the form

$$\pi_{ts} = c_{ts}(I) - a_{ts}(I), \quad (5)$$

in which only the investment expenditure I is allocated, namely via a cost allocation function $a_{ts}(I)$. If $a_{ts}(I)$ is linear we represent the allocated cost as $a_{ts}(I) = A_{ts} \cdot I$ with A_{ts} referred to as allocation scheme.

According to (4), incentives systems are consistent in the *single-project* setting if the manager has a financial incentive to implement [not to implement] the project if and only if its expected NPV (resp. after compensation) is positive [negative].

Proposition 1. *Under unknown time and risk preferences of the manager, consistent incentives for single risky normal investment decisions are induced by*

i) *residual income* performance measures with *linear* cost allocation functions: $\pi_{ts} = c_{ts}(I) - A_{ts} \cdot I$,
ii) investment costs allocated by the *State-Contingent Relative Benefit Cost Allocation (State-Contingent RBCA) Scheme*, i.e. $A_{ts} = \psi_{ts} \cdot x_t / \sum_{\tau=1}^{T} x_\tau \cdot \gamma_P^\tau$ and
iii) *positive marginal compensation*, i.e. $\omega_t'(\pi_{ts}) > 0$ for goal congruence resp. *positive marginal compensation smaller than one*, i.e. $0 < \omega_t'(\pi_{ts}) < 1$ for preference similarity.

Proof. To prove that the cost allocation scheme is *necessary*, we first consider a project with $E(NPV) = \sum_{\tau=1}^{T} E(c_{\tau s}(I)) \cdot \gamma_P^\tau - I = 0$. If in some states at some points of time the performance measures were strictly positive [negative], the manager could strictly prefer [not prefer] the project. If in some states at some points of time the performance measures were strictly positive and in others strictly negative, the manager could accept or reject the project. His decision would depend on his preferences, which are unknown. As such for a project with $E(NPV) = 0$ the performance measure must *necessarily* equal zero at every point in time $1 \leq t \leq T$ in every state to ensure goal congruence resp. preference similarity. For the considered project with $E(NPV) = 0$ the profitability factor amounts to $y(I) = I/\sum_{\tau=1}^{T} x_\tau \cdot \gamma_P^\tau$. Inserting this profitability factor into $\pi_{ts} = c_{ts}(I) - a_{ts}(I) = 0$ reveals the *necessary* condition for the cost allocation scheme:

$$\pi_{ts} = \psi_{ts} \cdot x_t \cdot \frac{I}{\sum_{\tau=1}^{T} x_\tau \cdot \gamma_P^\tau} - a_{ts}(I) \overset{!}{=} 0 \Leftrightarrow a_{ts}(I) \overset{!}{=} \underbrace{\psi_{ts} \cdot \frac{x_t}{\sum_{\tau=1}^{T} x_\tau \cdot \gamma_P^\tau}}_{=A_{ts}} \cdot I. \quad (6)$$

To show that the State-Contingent RBCA Scheme is *sufficient* we consider an arbitrary project. We can represent the performance measure as follows:

$$\begin{aligned} \pi_{ts} &= c_{ts}(I) - a_{ts}(I) = \psi_{ts} \cdot x_t \cdot \left[y(I) - \frac{I}{\sum_{\tau=1}^{T} x_\tau \cdot \gamma_P^\tau}\right] \\ &= \underbrace{\psi_{ts} \cdot \frac{x_t}{\sum_{\tau=1}^{T} x_\tau \cdot \gamma_P^\tau}}_{=A_{ts}} \cdot E(NPV(I)). \end{aligned} \quad (7)$$

This representation shows the performance measures not only equal zero in any state at each point in time $1 \leq t \leq T$ for expected zero-NPV projects, but they are also always positive [negative] for any normal project ($x_t > 0 \wedge \psi_{ts} > 0\,\forall t, s$) with positive [negative] expected NPV. In connection with $\omega_t'(\pi_{ts}) > 0$ this guarantees that the manager will always accept [reject] projects with positive [negative] expected NPV. This is *sufficient* to ensure goal congruence. In the concept of preference similarity the use of these performance measures while using a positive marginal compensation only ensures consistency if, in addition, an upper bound on marginal compensation of $\omega_t'(\pi_{ts}) < 1$ holds. This upper bound guarantees $\omega_t(\pi_{ts}) < \pi_{ts}$ and as such that the expected present value of compensation costs never exceeds the expected net present value of the project:

$$E\left[U\left(I, c_1 - \omega_1, \ldots, c_T - \omega_T\right)\right] = E\left(NPV\right) - PV\left(E\left(\omega_t\right)\right) = \sum_{t=1}^{T} \gamma_P^t \cdot \sum_{s=1}^{S} p_{ts} \cdot \pi_{ts} - \sum_{t=1}^{T} \gamma_P^t \cdot \sum_{s=1}^{S} p_{ts} \cdot \omega_t\left(\pi_{ts}\right) > 0. \quad (8)$$

If marginal compensation is bigger than 1 in a certain state at any point in time, $\omega_t'(\pi_{ts}) > 1$, then for a project which renders nearly all its value in this state at this point in time, the present value of compensation could be bigger than its expected NPV.[4]

Proposition one states that within the class of considered accounting measures only a specific form of residual income ensures consistency. The cost allocation of the investment expenditure I has to be linear, i.e. $a_{ts}(I) = A_{ts} \cdot I$. The cost allocation scheme A_{ts} – referred to as the *State-Contingent RBCA Scheme* – corresponds to the product of the realized state specific variation factor and the normalized temporal growth parameter. As such, the allocation of the investment expenditure has to be proportional to the time and risk structure of the investment cash flows c_{ts}. A characteristic of the resulting performance measures is that according to (7) they equal the product of the allocation scheme A_{ts} and the expected NPV. Therefore a project with $E(NPV) > 0$ will generate positive performance measures and positive compensation, in any state at every point in time. As such, the *State-Contingent RBCA Scheme* guarantees a time- and statewise dominant distribution of compensation for the desired investment decision. This implies that the concrete preferences of the manager are not crucial for his evaluation and the corresponding investment decision. Insofar the owner as assumed in the setting does not need the knowledge of the manager's preferences. However to construct a State-Contingent RBCA performance measure, the owner needs specific *knowledge* of the time and risk structure, i.e. he must know the *temporal growth parameters* of all expected project cash flows and the specific *variation factor* of the *realized state.*

For a riskless project, the State-Contingent RBCA Scheme degenerates to the *original RBCA Scheme* (Rogerson, 1997), i.e. $A_t^{RBCA} = x_t / \sum_{\tau=1}^{T} x_\tau \cdot \gamma_P^\tau$, which only takes account of the time structure, but does not ensure the desired investment decisions in the risky setting.[5] The State-Contingent RBCA rule differs from the allocation rule in the original RBCA Scheme by the variation factor. This has two implications: First, the *State-Contingent RBCA* is not only period specific, but also *state specific*. Second, whereas the RBCA Scheme is complete, the State-Contingent RBCA Scheme only ensures the *expected allocated costs* to be *complete*.[6]

3.2. Consistent incentive system design for the multi-project case

We now consider the case that the manager can invest in more than one normal project. In this *multi-project case* consistency requires that the manager invests in the *set of projects*, which *maximizes overall expected NPV* (before and after compensation respectively).[7]

If projects are *not exclusive* overall expected NPV is maximized if all projects with positive [negative] expected NPV are accepted [rejected]. As such the *State-Contingent RBCA Scheme* can be applied to each project directly rendering an individual project performance measure (π_{tsi}) as in the single project case. The overall performance measure amounts to:

$$\pi_{ts} = \sum_{i=1}^{n} \pi_{tsi}^{\text{State-Contingent RBCA}} = \sum_{i=1}^{n} \underbrace{\psi_{tsi} \cdot \frac{x_{ti}}{\sum_{\tau=1}^{T} x_{\tau i} \cdot \gamma_P^\tau}}_{=A_{tsi}} \cdot E\left(NPV_i\left(I_i\right)\right).$$

However, if projects are *exclusive,* not all projects with a positive expected NPV can be implemented. If additionally the projects have *different* time and risk structures, then the *State-Contingent RBCA Scheme, if applied directly,* is not adequate to induce consistency. If the State-Contingent RBCA Scheme is applied directly to each project, then the portion of the expected NPV of the individual project (i.e. NPV_i) reflected in the individual project performance measures in the different periods and states is *project specific* (i.e. $\pi_{tsi} = A_{tsi} \cdot E(NPV_i(I_i))$). Due to this, a project with a higher expected NPV ($E(NPV_i(I_i)) > E(NPV_j(I_j))$ could render a lower project performance measure ($\pi_{tsi} < \pi_{tsj}$) in some state at some point in time, if its value of the allocation scheme is lower ($A_{tsi} < A_{tsj}$). As the investments exclude each other, the manager generally has to trade-off between compensation contributed by individual projects. This trade-off would rely on his risk and time preferences, which are unknown.

However, as we will now show, the State-Contingent RBCA Scheme can be adequately applied to ensure consistency, if the cash flows from the various projects are previously *transformed* into the same risk and time structure. As such, we now focus on performance measures of the form $\pi_{ts} = \hat{c}_{ts}(I) - \hat{A}_{ts} \cdot I$, in which $\hat{c}_{ts}(I)$ refers to the transformed cash flows and $\hat{A}_{ts}$ to the *State-Contingent Robust RBCA Scheme.*

To *unify the risk and time structures* we introduce the time and state specific transformation factor α_{tsi} to transform cash flows of individual projects. As such, the project cash flows are allocated over time and within the state space. Without loss of generality, the transformation factor α_{tsi} can be written as:

$$\alpha_{tsi} = \delta_{tsi} \cdot \alpha_{ti}. \quad (9)$$

Factor α_{ti} describes the temporal transformation of the cash flows in time, whereas factor δ_{tsi} depicts the transformation of the cash flows across the different states. The transformed cash flows can

[4] This result is due to our assumption of *project unspecific* compensation functions. However, if the time and risk structure of cash flows and as such the respective structure of performance measures were known, it would be possible under preference similarity to choose a *project specific* compensation function with $\omega_t'(\pi_{ts}) > 1$ in some states/periods, as long as this was counterbalanced in other states/periods. This higher degree of freedom would arise in this case as preference similarity only requires that the expected variable compensation does not exceed the expected net present value of the realized investment project.

[5] This is due to the fact that the original RBCA Scheme does not guarantee $\pi_{ts} > 0$ statewise for $E(NPV) > 0$ in the risky setting.

[6] Calculating its expected present value directly shows that the expected cost allocation scheme is complete with respect to the time preferences of the owner, i.e. $\sum_{t=1}^{T} E(A_{ts}) \cdot \gamma_P^t = 1$.

[7] Overall expected NPV results as the sum of the individual projects expected NPVs of all implemented projects i.e. $E(NPV) = \sum_{i=1}^{n} E(NPV_i)$.

also be represented as follows:

$$\hat{c}_{ts}(I) = \sum_{i=1}^{n} \alpha_{tsi} \cdot c_{tsi}(I_i) = \sum_{i=1}^{n} \left(\delta_{tsi} \cdot \alpha_{ti}\right) \cdot \left(\psi_{tsi} \cdot x_{ti} \cdot y_i(I_i)\right)$$

$$= \sum_{i=1}^{n} \underbrace{\left(\delta_{tsi} \cdot \psi_{tsi}\right)}_{\equiv \hat{\psi}_{tsi}} \cdot \underbrace{\left(\alpha_{ti} \cdot x_{ti}\right)}_{\equiv \hat{x}_{ti}} \cdot y_i(I_i). \quad (10)$$

As δ_{tsi} must be set to induce the *identical variation factors* $\hat{\psi}_{tsi} = \hat{\psi}_{ts}$ and α_{ti} to induce *identical temporal growth factors* $\hat{x}_{ti} = \hat{x}_t$ for all projects, i.e. $\delta_{tsi} = \hat{\psi}_{ts}/\psi_{tsi} \wedge \alpha_{ti} = \hat{x}_t/x_{ti} \forall i$, the transformed cash flows can be stated as:

$$\hat{c}_{ts}(I) = \sum_{i=1}^{n} \hat{\psi}_{ts} \cdot \hat{x}_t \cdot y_i(I_i) = \hat{\psi}_{ts} \cdot \hat{x}_t \cdot \sum_{i=1}^{n} y_i(I_i). \quad (11)$$

Now the State-Contingent RBCA Scheme can be applied on the basis of the transformed risk and time structure. If the transformation of the cash flows is value-conserving with regard to the time preference of the owner,[8] i.e.

$$E\left(\hat{\psi}_{ts}\right) = E\left(\psi_{tsi}\right) = 1 \quad \text{and} \quad \sum_{\tau=1}^{T} \hat{x}_\tau \cdot \gamma_P^\tau = \sum_{\tau=1}^{T} x_\tau \cdot \gamma_P^\tau, \quad (12)$$

then the performance measures amount to[9]:

$$\pi_{ts} = \hat{\psi}_{ts} \cdot \hat{x}_t \cdot \sum_{i=1}^{n} y_i(I_i) - \hat{A}_{ts} \cdot \sum_{i=1}^{n} I_i$$

$$= \hat{A}_{ts} \cdot \sum_{i=1}^{n} \left(\sum_{\tau=1}^{T} \hat{x}_\tau \cdot \gamma_P^\tau \cdot y_i(I) - I_i \right) = \hat{A}_{ts} \cdot E(NPV). \quad (13)$$

These performance measures incentivize the implementation of the set of investment projects, which maximizes the overall expected NPV, if compensation functions are designed as in the single project setting.

Our results are summarized in the following proposition.

Proposition 2. *Under unknown time and risk preferences of the manager, consistent incentives for multiple risky normal investment decisions are induced by*

i) *residual income* performance measures with *allocated cash flows* and *linear* cost allocation functions: $\pi_{ts} = \hat{c}_{ts}(I) - \hat{A}_{ts} \cdot I$,
ii) cash flows allocated by means of the *transformation factors* α_{tsi}:

$$\hat{c}_{ts}(I) = \sum_{i}^{n} \alpha_{tsi} \cdot c_{tsi}(I_i) \text{ with } \alpha_{tsi} = \frac{\hat{\psi}_{ts} \cdot \hat{x}_t}{\psi_{tsi} \cdot x_{ti}},$$

$$\hat{\psi}_{ts}, \hat{x}_t > 0 \ \ \forall t, s, \ \ E\left(\hat{\psi}_{ts}\right) = E\left(\psi_{tsi}\right) = 1$$

$$\text{and} \qquad \sum_{\tau=1}^{T} \hat{x}_\tau \cdot \gamma_P^\tau = \sum_{\tau=1}^{T} x_\tau \cdot \gamma_P^\tau,$$

iii) investment costs allocated by the *State-Contingent Robust Relative Benefit Cost Allocation Scheme (State-Contingent Robust RBCA)*, i.e.

$$\hat{A}_{ts} = \hat{\psi}_{ts} \cdot \frac{\hat{x}_t}{\sum_{\tau=1}^{T} \hat{x}_\tau \cdot \gamma_P^\tau} \quad \text{and}$$

iv) *positive marginal compensation*, i.e. $\omega_t{}'(\pi_{ts}) > 0$ for goal congruence resp. *positive marginal compensation smaller than one*, i.e. $0 < \omega_t{}'(\pi_{ts}) < 1$ for preference similarity.

In the multi-project setting the *State-Contingent Robust RBCA Scheme* in connection with a value-conserving *transformation* of all projects into the *same time and risk structure* guarantees that a *project-unspecific portion* of the expected NPV is reflected in the performance measures in all states at every point in time. This ensures a time- and statewise dominant distribution of the performance measures and hence compensation for decisions, which maximize overall expected NPV. The information requirements to construct the State-Contingent Robust RBCA performance measures are identical to those for the construction of the State-Contingent RBCA Scheme in the single project setting. There are no additional information requirements for the previous transformation of the cash flows.[10]

For *riskless projects*, the State-Contingent Robust RBCA Scheme degenerates to the *Robust RBCA Scheme* by Mohnen and Bareket (2007), i.e. $\pi_t = \hat{c}_t - \hat{A}_t \cdot I$ with $\hat{A}_t = \hat{x}_t / \sum_{\tau=1}^{T} \hat{x}_\tau \cdot \gamma_P^\tau$, $\alpha_{ti} = \hat{x}_t / x_{ti}$, $\hat{x}_t > 0 \ \wedge \ \sum_{\tau=1}^{T} \hat{x}_\tau \cdot \gamma_P^\tau = \sum_{\tau=1}^{T} x_\tau \cdot \gamma_P^\tau$. Our State-Contingent Robust RBCA performance measures differ from those of Mohnen and Bareket (2007) in two aspects: First, our cash flow allocation rules allow a cash flow *transformation within the state space*, and not only over time. As such, the State-Contingent RBCA Scheme enables the transformation of all projects into the *same risk class*. Second, after the cash flow transformation, the State-Contingent RBCA Scheme is applied instead of the original RBCA Scheme by Rogerson (1997).[11]

In analogy to the findings of Mohnen and Bareket (2007) the State-Contingent Robust RBCA Scheme does not only ensure consistency for regular, but also for *irregular projects* (e.g. multi-year construction contracts or leases) as they are transformed into normal projects.

4. Discussion

4.1. Conclusions

We will now briefly discuss some important practical implications of our findings. The formal analysis provided in this paper gives justification for the use of *residual income* as a performance measure for managerial incentive systems. In practice, residual

[8] In literature the conservation property appears in various models (e.g. Feltham and Ohlson, 1996, 1995; Ohlson, 1995; Preinreich, 1938).

[9] If the transformation of the cash flow is not value neutral then the performance measure will not amount to a portion of the expected NPV.

[10] The owner can ensure $E(\hat{\psi}_{ts}) = E(\psi_{tsi}) = 1$ without knowledge of the probabilities of the environmental states, by either transforming all projects into the (observed) risk structure of any realized project, i.e. $\hat{\psi}_{ts} = \psi_{tsi}$, or by transforming all projects into riskless ones, i.e. $\hat{\psi}_{ts} = \hat{\psi} = 1 \, \forall \, t, \, s$.

[11] In analogy to our findings in the single project setting, in contrast to the *original* Robust RBCA Scheme our *State-Contingent* Robust RBCA Scheme is *only complete in expected values*.

income measures (e.g. EVA) are widespread. However, it is important to note the concrete *allocation scheme* is *crucial* and has to be *state-specific* in a risky setting if the preferences of the manager are unknown. In practice, allocation schemes, consisting of depreciation schedules and capital charges, are in general not state specific as required. Furthermore, it is often stated in theory and practice that allocation rules should be complete. Our analysis shows that the consistent allocation rule is only complete in expected values and not in realized values. If – as in practice – investment expenditures are written off totally and capital charges are based on remaining book values, then capital costs must be state specific. Otherwise a state specific depreciation rule is needed, which will generally not be ex post complete. As such, depending on the environmental development more or less than the initial investment expenditure will be written off. This is, however, not in accordance with common accounting principles.

Due to the high information requirements, the concrete design of the allocation scheme will be challenging in practice. To *construct* the State-Contingent (Robust) RBCA-Scheme *specific knowledge* of the precise *time and risk structure* of the respective cash flows is required: As such, the owner not only has to know the complete temporal growth structure of the cash flows (as discussed in the literature concerning unknown time preferences), but additionally for every realized state, the ratio of the state-contingent cash flow to the expected value at each point in time (variation factor). Only the described precise knowledge and the flexibility of the performance measure enable the solution in which the concrete time and risk preferences of the manager play no crucial role as a time- and statewise dominant distribution of compensation for the desired investment decision is achieved. As such the practical implementation is severely limited.

However, an alternative approach to attain consistent performance measures can be found in applying the concept of benchmarking. To illustrate this possibility we now consider the *allocated investment costs* $a_{ts}(I)$ in (5) as *benchmark* cash flows, which are subtracted from the periodic cash flows to evaluate performance. Our findings imply that an *adequate* benchmark must belong to the *same risk class* and have the *same time structure* as the investment projects. Furthermore the benchmark must have an expected NPV equal to zero.[12] We suggest for practical implementation that such benchmarks may be found in cash flows from other internal or external projects, divisions, firms or branches. It is important to note that our findings suggest that in practice, risky benchmarks that do *not create value* should be chosen or the cash flows of the benchmarks must be *normalized* to a value added of zero. If benchmark cash flows are not normalized, the hurdles are too high (low) in the case of value enhancing (destroying) benchmarks. Furthermore, the awareness of the crucial role of identical risk classes for performance evaluation could be useful with regard to the question of how to *structure business units*. It implies that for performance measurement reasons, it would be desirable if managers were only responsible for investments within one risk class.

However, the exact implementation of this benchmark solution initially appears also very limited in practice, as a benchmark with perfectly identical time and risk structures will rarely exist.[13] But even if the solution cannot be applied exactly, an approximation may be implemented on the basis of a similar project, division, firm or branch with more or less the same time and risk structure. In this case the unknown preferences of the manager would still play a role, but their role should not be so crucial due to the resulting smoothing of the performance measures over time and across states.

With regard to compensation functions our findings show that there is only a slight restriction, as the marginal compensation must be strictly positive and smaller than one under preference similarity. As such, *linear, concave and convex compensation functions* are all adequate. Compensation in practice is often restricted by caps and/or floors. However, it is important to note that this can lead to wrong incentives. In our setting it is crucial that marginal compensation is always *strictly* positive to guarantee the appropriate incentive.

4.2. *Efficient allocation of compensation and further agency problems*

The conditions for a consistent incentive system, ensuring the desired investment decisions, derived in our analysis leave a high degree of freedom, which can be exploited to *allocate compensation efficiently* and to address *further agency problems*.[14]

In our multi-period risky setting costs of the incentive scheme can be reduced by implementing *efficient risk sharing* and an *efficient allocation of compensation over time.*

As the owner is risk neutral and the manager risk averse *efficient risk sharing* implies that the owner bears all risk (Ross, 1974). This can be easily achieved by a fixed payment in each period, which violates consistency. However, risk-free compensation can be attained, while ensuring consistency: In the one project case, this is achieved by applying the State-Contingent RBCA Scheme and (in extension to our prior analysis) the following state-contingent bonus coefficient $\omega'_{ts} = \bar{w}_t/\psi_{ts}$ in each period. This state-contingent bonus coefficient varies around its expected value $\bar{w}_t$ inversely proportional to the variation factor.[15] In the multi-project case our analysis showed how cash flows from the various projects can be transformed into the same arbitrary risk and time structure before applying the State-Contingent Robust RBCA Scheme. Thus a risk-free performance measure can be induced, and, in connection with state independent bonus coefficients, risk-free compensation.[16]

An *efficient allocation of compensation over time* is determined according to the time preference of the manger relative to the time preference of the owner. If the manager has an expected higher (lower) time preference than the owner, i.e. $\gamma_A^\tau < \gamma_P^\tau$ ($\gamma_A^\tau > \gamma_P^\tau$), it is efficient to allocate compensation as early (late) as possible. However, in our setting the time preferences of the manager are not known to the owner and as such the owner may only consider more or less exact expectations. As time preferences are in general endogenous, the (re-)allocation across periods mentioned above would then result in an alignment of expected induced time preferences.[17]

The only source of agency conflict, which was explicitly addressed in our formal analysis was that the manager may not make investment decisions in the interest of the owner, if their financial interests are not properly aligned via the incentive

[12] This becomes obvious as our State-Contingent RBCA Scheme revealed that the profitability factor of the benchmark cash flows has to equal the *break-even profitability factor* of this particular project (i.e. the profitability factor leading to an expected NPV of zero).

[13] We thank anonymous reviewer for this comment.

[14] Recall that in contrast to the standard agency setting an *optimal* incentive scheme cannot be derived in our setting as the utility function of the manager and i. a. the relationship between effort and profits are unknown to the owner.

[15] In connection with (7) this leads to: $\omega_{ts} = \bar{w}_t \cdot \left(x_t / \sum_{\tau=1}^{T} x_\tau \cdot \gamma_P^\tau\right) \cdot E(NPV(I))$ and $\sum_{t=1}^{T} \omega_t \cdot \gamma_A^t = \sum_{t=1}^{T} \bar{w}_t \cdot \left(x_t \cdot \gamma_A^t / \sum_{\tau=1}^{T} x_\tau \cdot \gamma_P^\tau\right) \cdot E(NPV(I))$.

[16] This solution can also be obtained in the single project case if performance measures on the basis of transformed cash flows are considered.

[17] If time preferences were exogenous and unequal a reallocation of cash flows over time could be used to create unlimited utility for both parties.

scheme. However *other sources of agency conflict* which typically stem from private interests of the manager will exist in association with the investment decisions.[18] In the backdrop of our setting the manager may among other things experience disutility resulting from his information-collection effort before making his investment decisions (pre-decision effort problem). Moreover investment projects may be connected with a specific fixed positive or negative private value for the manager (decision inherent private interest problem). As such the manager might particularly favor some specific investment projects due to power or prestige and/or dislike other projects, which cause fixed effort in order to be realized. Furthermore the manager may exert (variable) value-enhancing effort after investing in a project, which increases the expected cash flows but is privately costly (post-decision effort problem).

To additionally cope with these *other sources of agency conflict* an overall high marginal compensation can be chosen, as the incentive effects increase in marginal compensation.

In the case of the *pre-decision effort problem* a high marginal compensation will induce high effort in the pre-decision phase. The consistent allocation scheme will ensure that, for every possible information level, the manager will implement the expected value-maximizing set of projects. However in our setting risk-free compensation can only be achieved in the post effort phase as the information process is risky and therefore will be associated with a risk premium for the manager (Christensen et al., 2002).

Positive or negative *decision inherent private interests* can be taken into account by considering a positive or negative monetary equivalent in the respective periods. If the owner could manage to align the time preferences, then first-best incentive effects with regard to such decision inherent private interests can be induced with state-independent marginal compensation $\omega_t{}'(\pi_{ts}) = 1$ resp. an expected state-contingent bonus coefficient $\bar{w}_t = 1$.[19] Besides, if risk free compensation is achieved as described above, then no risk premium will have to be paid in this case.

If induced time preferences are aligned, such described high marginal compensation $\omega_t{}'(\pi_{ts}) = 1$ resp. $\bar{w}_t = 1$ will also portray first-best incentive effects with regard to the *post-decision effort problem*. It should be noted that in order to be consistent with our setting effort may not influence the risk class.[20]

However, as time preferences are not known in our basic model, only expected preferences can be aligned. As such the solution $\omega_t{}'(\pi_{ts}) = 1$ resp. $\bar{w}_t = 1$ would imply over- or under motivation in the case of *decision inherent private interests* and in the *post-decision effort problem*. Furthermore, we must recall that the aim of the incentive scheme on which we focus is to induce *consistent investment decisions*. As such the restriction $\omega_t{}'(\pi_{ts}) < 1$ resp. $\bar{w}_t < 1$ must be observed under preference similarity.

In the light of our model, powerful incentives with regard to other sources of agency conflict appear less costly when the allocation of compensation over time and across states is more efficient. Our analysis especially emphasizes how risk can be filtered out while designing a favorable consistent incentive scheme.

4.3. *Future research*

Although we analyzed consistent incentive system design in a relatively general model, we made some restricting assumptions. We assumed the owner to be risk neutral. However, for practical purposes it could be interesting to explore the implications of a risk averse owner. Furthermore, we only considered one manager. It would be of interest to analyze the multi-manager case. In this context the possibility of interpersonal cost allocations or benchmarking would arise. Moreover, an investigation of inter-company coordination problems (e.g. concerning risk issues) could be of interest.

4.4. *Summary*

The main intent of our analysis was to show how to design incentives systems for value- maximizing investment decision-making in a challenging but realistic *multi-period risky setting with unknown time and risk preferences* of the manager. Future expected cash flows were assumed to be privately known by the manager. We pointed out the crucial role of the *performance measures* within this setting and revealed that appropriate performance measures necessarily have to be *state-dependent*. For the concrete design of such performance measures in the single-project case, we derived a new, state-dependent allocation scheme, which we referred to as the *State-Contingent Relative Benefit Cost Allocation (RBCA) Scheme*. It allocates the investment costs relative to the time and risk structure of the periodic cash flows while taking their time value into account. In the multi-project setting, however, our research revealed that if projects can be exclusive, to ensure consistency, a specific transformation of the individual project cash flows is needed before applying the *State-Contingent RBCA Scheme*. The specific transformation rules of the cash flows were derived so as to induce the *same risk and time structure* for all projects. Within both settings, we showed how our findings are related to the existing literature, which focuses on the case of unknown *time* preferences and ensures the desired incentives (only) under *risk neutrality or certainty* (esp. Rogerson, 1997 resp. Mohnen and Bareket, 2007). Furthermore, we pointed out implications for practical use, especially the importance of benchmarking for practical performance evaluation. Our findings imply that for this purpose benchmark cash flows (e.g. of other firms, divisions or projects) should have the same time and risk structure as the realized projects and exhibit an expected NPV of zero.

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[18] However, if no other source of goal conflict exists, there is a trivial solution to the incentive problem: A manager who is provided only with a fixed compensation payment would have no incentive to deviate from the preferred investment strategy of the owner. We thank an anonymous reviewer for making this point.

[19] For a brief formal analysis we first consider the ideal situation of pareto-efficiency, i.e. fully aligned induced time preferences $\gamma_A^\tau = \gamma_P^\tau = \gamma^\tau$ and the single project case with state-contingent bonus coefficients, which induce riskless compensation. Furthermore we assume a cooperation constraint, which is expected to be binding. In this case the first-best solution would be to make decisions, which maximize $E(NPV(I)) + \sum_{t=0}^{T} v_t \cdot \gamma^t$ with v_t representing the monetary equivalents for the *decision inherent private interests*. Using the incentive scheme described the manager would maximize $\sum_{t=1}^{T} \bar{w}_t \cdot \left(x_t \cdot \gamma^t / \sum_{\tau=1}^{T} x_\tau \cdot \gamma^\tau \right) \cdot E\left(NPV\left(I\right)\right) + \sum_{t=0}^{T} v_t \cdot \gamma^t$. The first-best solution is thus induced for $\sum_{t=1}^{T} \bar{w}_t \cdot x_t \cdot \gamma^t = \sum_{t=1}^{T} x_t \cdot \gamma^t$. This condition holds i. a. for $\bar{w}_t = 1$, which implies an expected bonus coefficient of one for each period.

[20] This would hold if directly after the investment decision, the manager could exert an effort, e, which only influences the profitability factor y. This would be the case for $y(I, e) = y(e \cdot I)$ *or* $y(I, e) = y(I + e)$.

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