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# On the fault (in)tolerance of coordination mechanisms for distributed investment decisions

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**Abstract** The efficient allocation of scarce financial resources lies at the core of financial management. Whenever humans are involved in the allocation process, it would be reasonable to consider abilities, in order to assure *efficiency*. For the context of coordinating investment decisions, the competitive hurdle rate (CHR) mechanism (Baldenius et al, 2007) is well established for allocating resources. This mechanism is derived from an agency model, which, as is the nature of agency models, assumes agents as being fully competent. We employ the agentization approach (Guerrero and Axtell, 2011) and transfer the logic behind the CHR mechanism into a simulation model, and account for individual incapabilities by adding errors in forecasting the initial cash outlay, the cash flow time series, and the departments' ability to operate projects. We show that increasing the number of project proposals, and decreasing the investment alternatives diversity (in terms of their profitability only), significantly decreases the fault tolerance of our CHR mechanism. For misforecasting cash outlays, this finding is independent from the error's dimension, while for larger errors in forecasting cash flows, and the departmental ability, the impact of diversity reverses. On the basis of our results, we provide decision support on how to increase the robustness of the CHR mechanism with respect to errors.

**Keywords** Robustness · Investment budget allocation · Simulation · Distributed decision-making · Competitive hurdle rate
JEL classification: C63, C44, G11, M21

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## 1 Introduction and research question

Capital budgeting is among the most important tasks of financial management (Ryan and Ryan, 2002). Among other reasons, this is because the level of efficiency of a euro spent on investment critically affects the long-term health of a business organization (Minton et al, 2002). Corporate capital budgeting is, at the same time, inherently difficult to handle as it entails the need to forecast payoffs over multiple future periods (Rogerson, 2008), making it prone to fault—and the methods for coordinating investment decisions are by no means set in stone: earlier research reveals a distinct preference for pay pack methods (Miller, 1960; Schall et al, 1978). From the 1970s onwards, methods that rely on the discounted cash flow paradigm, and methods that are based on the concept of the internal rate of return have, however, progressively gained attraction (Fremgen, 1973; Brigham, 1975; Ryan and Ryan, 2002).

The majority of the coordination mechanisms employed follow a purely 'centralized' approach, and their core part is to identify an efficient intra-organizational allocation of investment spending in the context of a single decision maker's optimization problem. For the case of multiple decision makers and distributed decision-making, little is known on how business organizations may succeed in optimally balancing interests on the departmental level and overall corporate interests, like, e.g., embodied in shareholder wealth maximization (Young and O'Byrne, 2002; Miller and O'Leary, 2005). With respect to this trade-off, the work of Baldenius et al (2007) is a remarkable exception (which is why our research work is significantly influenced by their ideas). These authors propose a (strongly incentive compatible) capital market-like mechanism for efficiently coordinating corporate investment decisions in the case of limited financial resources. In particular, Baldenius et al (2007) elaborate on a mode of determining capital costs, and integrating these costs into a system of corporate performance measurement. On the departmental level, the scarcity of the budget causes rivalry with respect to project funding, where a coordinating unit determines all costs of capital for the investment opportunities in consideration of the degree of intra-organizational competition (cf. Leitner and Behrens, 2013). Based on these capital costs announced to the departments, multiple decision makers independently decide whether they really want to operate the proposed investment opportunities, where incentives are shaped in a way that individual decisions go alongside a maximization of the shareholders' wealth.

Baldenius et al (2007) derive their so-called competitive hurdle rate (CHR) mechanism from an agency model, which incorporates restrictive assumptions about the individuals involved and the information accessible to the individuals. Axtell (2007) subsumes these assumptions as 'the neoclassical sweetspot': full rationality, perfect homogeneity of the agents, and non-interactiveness. In addition, neoclassical models assume that agents are fully competent in doing whatever it is they have decided to do (mostly to meet some predetermined objective) (Hendry, 2002). Another set of assumptions incorporated into neoclassical models postulates the availability of highly specific information for the individual. Summing up, we can claim that it is plausible to infer that changes in any of these assumptions pertaining to the agents' individual capabilities as well as to their access to information will both crucially affect the efficiency of the derived budget allocation mechanisms and cause a significant deviation from the commonly accepted (neoclassically oriented) literature. The latter already discusses that agency models are sometimes inappropriate for an application in the context of corporations, and, thus, most likely investigate research questions, which have a relatively low relevance for organizational practice (Eisenhardt, 1989; Fisher, 1989; Ghoshal and Moran, 1996; Hendry, 2002). While agency models are of immense merit when focusing on problems of adverse selection and moral hazard (i.e., the 'principal's problem', cf. Ross, 1973; Furubotn and Richter, 2000; Laffont and Martimort, 2002), the problem of limited competence remains unconsidered. Hendry (2002) takes note of this. He argues that such perfect competence does not exist in real world settings, and bluntly describes agents as being 'incompetent'. In other words, even if agents undertake relatively simple tasks, they are prone to making errors due to limitations in foresight, knowledge, and rational understanding. In addition, communication issues due to differences in language, culture, and cognition lead to agents slipping up (Martin, 1993; Simon, 1991; Hendry, 2002).

Within the context of corporate decision-making, Christensen and Knudsen (2007) discuss that, for future research, it is necessary to investigate the correlation between individual ability, the economic context in which organizations act, and the corporate decision-making structure. We take a first approach to come up to individual ability by analyzing the robustness of an implementation of a mechanism that rests upon the computation of the CHR augmented by the 'incompetence' of agents and the limitations in the accessibility of information. Moreover, we analyze variations in the extent of project heterogeneity with respect to the returns on investment, which can be regarded as a very rough proxy for the corporation's economic context. In addition, we focus on the organizational rather than on the decision-making structure of a business organization, i.e., we aim at exploring whether there is an impact of the level of intra-organizational competition for scarce financial resources on the fault tolerance of our CHR born mechanism.

To do so, we employ a so-called agentization approach[1] (Guerrero and Axtell, 2011) and conceptually transfer the logic behind Baldenius et al (2007)'s CHR mechanism, which is derived from an agency model, into a simulation model (see section 2). Please notice that agency models and agentized simulation models are two distinct research paradigms which hardly have anything in common. Agency models are concerned with problems between parties of a contract (e.g., employer and employee) that arise when there are conflicting objectives, information asymmetries, or when it is difficult for the principal to observe the agent's actions (Ross, 1973; Eisenhardt, 1989; Leitner, 2013). Agentized models, such as the one presented here, do, however, not aim at analyzing such contractual relationships, but investigate the impact of agents' decisions and actions on the micro-level, i.e., the departmental level, on the macro-level, i.e., the overall outcome in terms of efficient project selection and implementation (cf. also Ma and Nakamori, 2005; Tesfatsion, 2006). Since we are

[1] Agentization is the exercise of rendering neoclassical models into computational ones. In our case, it allows us to get rid of a neoclassical core assumption: agents are no more homogenous (corresponding to the representative agent assumption, see, e.g., Kirman (1992)). Moreover, we drop the assumption of agents being fully informed, presume that agents are not fully capable to execute their plans, and perceive agents to be able to interact (in spite of the fact that interaction is excluded between department managers, while the coordinating unit of a business organization interacts with all of its departments).

particularly interested in the impact of distorted forecasts on the efficiency of the investment selection rules in the case of distributed decision-making, we will model department managers as being incapable of correctly forecasting (all) measures related to the investment alternatives for which they apply for funding (like the initial cash outlay, the intertemporal distribution of cash flows, and their abilities or efficiencies of operating an investment alternative). With respect to the availability of information, Baldenius et al (2007) assume that some main measures related to investment alternatives are common knowledge. Since accumulating knowledge about project measures is usually costly and gained through expert knowledge and sophisticated forecasting, here we reject this 'common knowledge assumption'. Rather, we endow the decision makers involved with limited information bases, i.e., with 'private knowledge', but compensate by introducing additional communication channels between the coordinating unit and the department managers.

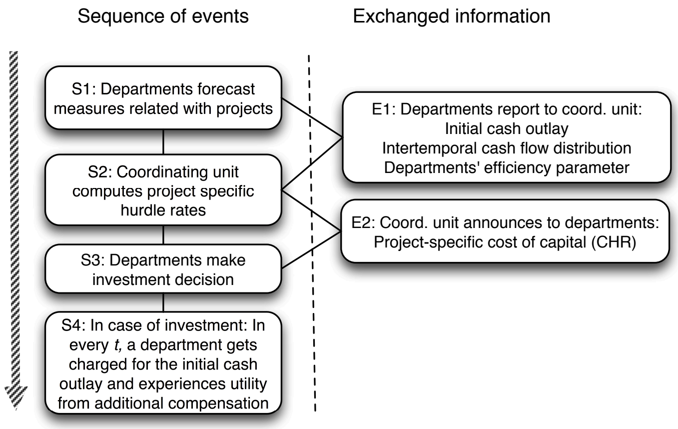
Utilizing our model to investigate several scenarios (which are described in section 3), section 4 will show that a higher degree of organizational sophistication, reflected by a higher number of serious project proposals, makes the CHR born mechanism presented here more vulnerable with respect to the occurrence of forecasting errors. Moreover, we will learn that whenever project alternatives hardly differ with respect to their returns on investment parameters, forecasting errors also severely challenge robustness. On the contrary, we find that—as far as forecasts in cash flow series, initial capital outlays, and the departments' abilities of carrying out projects are considered—a higher degree of 'investment heterogeneity' (where, for a real world organization's management, this degree could be subject to choice in the short-run) allows for admission to the realm of increased fault tolerance. For errors in forecasting cash flow time series, and the departmental ability of operating projects, this finding reverses, as the dimension of the according error increases.

## 2 The simulation model

Let a business organization consist of $n \geq 2$ departments and a coordinating unit. Departments are in charge of setting up and carrying out investment projects, where all $n$ departments viz. department managers are endowed with decision-making authority with respect to whether or not to implement investment opportunities. As we assume that acquiring financial resources from outside the organization is not feasible for them, department managers have to rely on funding from within the corporation, where the business organization aims at allocating scarce financial resources such that its shareholders' wealth is maximized (Young and O'Byrne, 2002; Meier et al, 2001). If a department manager decides to operate an investment opportunity[2], it is funded by the corporation but, at the same time, it is charged for the provision of the initial cash outlay based on a CHR born rule. In our model, we do not establish any communication between departments, and assume that the investment opportunities implemented do not cause any spillover effects.

[2] Note that we do not refer to *all* investment opportunities within a cooperation, but only to those that compete for the same pot of funding.

**Fig. 1** Coordinating investment decisions: Course of actions and information exchanged




We implement the 'CHR mechanism' in the following way (cf. also Fig. 1)[3]: We model decision makers on the departmental level or for short *departments*, as referring to risk-neutral 'agents', and the 'principal' as referring to a *coordinating unit* which is in charge of coordinative tasks, and the allocation of the scarce financial budget. At time period $t = 0$, each department $i$ $(i = 1, ..., n)$ proposes to the coordinating unit exactly one investment alternative of durableness $T$, to be implemented in the following period, $t = 1$. Note that, for the rest of the paper, the index $i$ indicates both a department and the project intended to be carried out by that department. After receiving all project proposals, the coordinating unit computes all project-specific costs of capital and individually communicates this information to the respective proposing department. Whenever a department decides to put its project proposal into action, in every time period $t$ $(t = 1, ..., T)$, it will be charged according to the project-specific capital cost announced. Then, each department will have to decide on the basis of expected future utility whether or not to operate the proposed project. In this regard, like Baldenius et al (2007), without loss of generality, we impute that due to a scarcity of financial resources the corporation can provide funding for at most one project. We account for this by defining a binary variable $I_i \in \{0, 1\}$ that indicates whether the project proposed by department $i$ is put into action $(I_i = 1)$ or not $(I_i = 0)$. Then, considering the restriction that at most one project can be funded, a feasible corporate investment strategy fulfills

$$\sum_{i=1}^{n} I_i \leq 1 \; . \tag{1}$$

Consequently, all project-specific capital costs have to be computed in a way so that the autonomously deciding departments are provided with appropriate incentives to put into action only the most profitable project proposal (cf. Eq. 1), i.e., the project

[3] The simulation model was implemented using *Visual Basic for Applications*.

yielding the maximum gain in net present value (NPV). This sequence of events and the associated exchanges of information between departments and the coordinating unit are summarized in Fig. 1.

Without loss of generality, at $t = 0$, we normalize all *status quo* cash flows to zero. The departments' initial selection of project proposals is modeled 'by drawing $n$ investment projects out of $n$ randomly generated investment landscapes' (see, e.g., Leitner and Wall, 2011a,b). Let the drawn investment alternatives be characterized by the following three main parameters (where the true values of these parameters are not *known* with certainty by any of the departments before a realization of the corresponding project): (i) an initial cash outlay, $\kappa_i$, which is drawn from the uniformly distributed interval $K = [\underline{\kappa}, \overline{\kappa}] \subset \mathbb{R}^+$, and (ii) a parameter $\eta_i$, which covers project $i$'s return on investment as a fraction of the initial cash outlay, $\kappa_i$. For all departments, the parameters $\eta_i$ are drawn from the uniformly distributed interval $H = [\underline{\eta}, \overline{\eta}] \subset \mathbb{R}^+ \cup \{0\}$. Finally, let projects be characterized by (iii) an intertemporal distribution of cash flows, where project $i$'s cash flow share for time period $t$ is denoted by $\gamma_{it}$. Notice that $\sum_{t=1}^{T} \gamma_{it} = 1$. The cash flow shares are generated according to the rule

$$\gamma_{it} = \frac{c_{it}}{\sum_{\tau=1}^{T} c_{i\tau}} , \tag{2}$$

where the proportions $c_{it}$ are randomly drawn from the unit interval. We assume the lower and the upper bounds of the intervals $K$ and $H$ to be *ex ante* fixed (e.g., by the coordinating unit). Thereby, the departmental freedom of action is limited. This assumption captures managerial control in real world situations. Widening the intervals favors projects that are potentially more heterogenous with respect to initial cash outlay and return on investment. Also randomly generating the intertemporal cash flow distributions implies a considerable degree of heterogeneity among project proposals.

In addition, we assume that the departments are non-homogenous with respect to their abilities of operating investment projects. To model this, let each department $i$ be characterized by an ability parameter, $\rho_i$, which is drawn from the uniformly distributed interval $P = [\underline{\rho}, \overline{\rho}] \subseteq [0, 1]$, and which is not known with accuracy by department $i$ before realization of the project propsed by it. Given the projects' and the departments' characteristics, in time period $t$, the operative cash flow of the project carried out by department $i$ results in $\chi_{it} \cdot \rho_i$, where

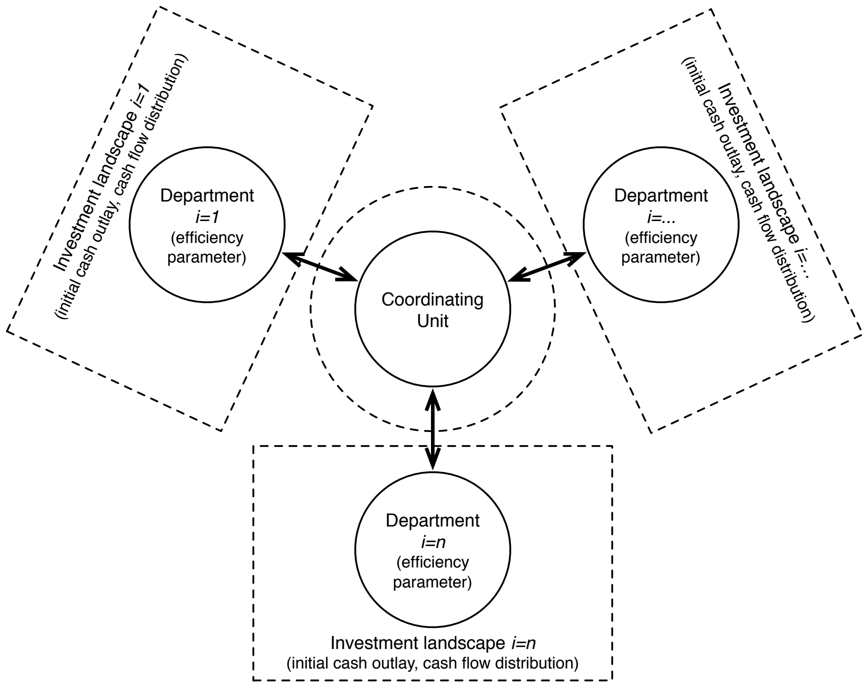
$$\chi_{it} := \kappa_i \cdot \eta_i \cdot \gamma_{it} \; . \tag{3}$$

Let project $i$'s intertemporal distribution of cash flows be then represented by the $T$-dimensional row vector

$$\mathbf{x}_i = [\chi_{i1} \; \chi_{i2} \; \cdots \; \chi_{iT}] \, . \tag{4}$$

Contrary to Baldenius et al (2007), we assume information about $\mathbf{x}_i$ *not* to be com-

**Fig. 2** Model structure




monly available, but make it department *i*'s very private task to accumulate information about $\mathbf{x}_i$, which is gained through forecasting only. Notice that this is a result of non establishing communication among departments.

In line with Baldenius et al (2007), we model department *i*'s ability of operating project proposals, $\rho_i$, as unknown by all departments other than *i*. As indicated by the dashed boxes in Fig. 2, this leads to disjointed departmental information spaces. The coordinating unit's information space, which is indicated by the dashed circle, is filled with the projects' forecasted measures reported by the departments. Figure 2 indicates the existing communication channels by solid arrows, where information is exchanged as illustrated by Fig. 1.

In contrast to Baldenius et al (2007), we reject the departments' perfect foresight assumption with respect to the main measures related to their intended investment projects. Rather, we model departments to make forecasting errors and declare that these non-systematical errors occur due to 'the principal's other problems', as elaborated by Hendry (2002). We assume all errors to be normally distributed with mean zero and variance $\sigma^2$, and model them as adjoined to the undistorted values of the projects' measures.[4] Regarding the sequence of the departmental actions, the forecasting procedure is captured by Fig. 1, step S1. We denote the forecasts of the three

[4] In order to avoid negative forecasts, we limit the error terms to $\pm 3\sigma$.

measures associated with projects as follows: (i) the distorted forecast of project $i$'s initial cash-outlay is represented by

$$\hat{\kappa}_i := \kappa_i(1+\varepsilon_{i\kappa}), \tag{5}$$

with $\varepsilon_{i\kappa} \in \mathcal{N}(0, \sigma_\kappa^2)$. Correspondingly, (ii) department $i$'s error in forecasting the achievable cash flow for period $t$ is included in

$$\hat{\chi}_{it} := \chi_{it}(1+\varepsilon_{it\chi}), \tag{6}$$

with $\varepsilon_{it\chi} \in \mathcal{N}(0, \sigma_\chi^2)$. We denote project $i$'s forecast of future cash flow streams by the $T$-dimensional row vector $\hat{\mathbf{x}}_i = [\hat{\chi}_{i1} \ldots \hat{\chi}_{iT}]$ (cf. also Eq. 4). Finally, (iii) the erroneous forecast of department $i$'s ability of operating project proposals results in

$$\hat{\rho}_i := \rho_i(1+\varepsilon_{i\rho}), \tag{7}$$

with $\varepsilon_{i\rho} \in \mathcal{N}(0, \sigma_\rho^2)$.[5]

When all project measures are forecasted according to Eqs. 5-7, they are next reported to the coordinating unit (cf. Fig. 1, step E1).[6] The coordinating unit, then, calculates project specific capital costs and announces them to the departments (cf. Fig. 1, steps S2 and E2). As the coordinating unit's information space is restricted to the values estimated and reported by the departments (cf. the dashed circle in Fig. 2), the project specific capital costs are computed on the basis of the departments' distorted forecasts.

For the calculation of project-specific capital costs (cf. Fig. 1, step S2), the coordinating unit starts with calculating all projects' NPVs. Let the discount factors, which are needed to come up with the NPVs, be defined by the $T$-dimensional column vector

$$\mathbf{r}(r) = \begin{bmatrix} (1+r)^{-1} \\ \vdots \\ (1+r)^{-T} \end{bmatrix}, \tag{8}$$

where $r$ stands for the cost of capital. Then, project $i$'s NPV results in

$$\Lambda_i(r, \rho_i) := PV_i(\mathbf{r}(r), \mathbf{x}_i, \rho_i) - \kappa_i = \mathbf{r}(r) \circ \mathbf{x}_i \cdot \rho_i - \kappa_i. \tag{9}$$

Recall that the coordinating unit's information is restricted to values reported by the departments (cf. Fig. 2). Let, then, Eq. 9 be augmented by the corporation's cost of

[5] Please notice that the introduced types of errors are independent of each other. I.e., to build up a simulator, we first generate the investment alternatives with all their associated measures upon realization. Then, second, the agents have to forecast these (unknown) measures whereby the forecasts are always based on the error-free case. Thus, errors are independent so that, for example, an erroneous foreacst of the initial cash-outlay (cf. Eq. 5) does not affect the basis for forecasting the cash flow time series, $\chi_{it}$, in Eq. 6.

[6] Note that agency problems are excluded in the approach presented here. Thus, any deliberate misreporting from the departmental side can be ignored. Agents are 'incompetent' but not dishonest.

capital $r_c \geq 0$ and the project $i$'s NPV computed on the basis of the departments' estimates (cf. Eq. 5 to 7) by $\hat{\Lambda}_i(r_c,\hat{\rho}_i) := PV_i(\mathbf{r}(r_c), \hat{\mathbf{x}}_i, \hat{\rho}_i) - \hat{\kappa}_i$. This implies that the NPVs for the proposed projects $1,...,n$ are given by $\hat{\Lambda}_1(r_c,\hat{\rho}_1),...,\hat{\Lambda}_n(r_c,\hat{\rho}_n)$, respectively.

Next, for each project proposal a critical NPV, $\hat{\Lambda}_i^*$, is computed. This critical level of the NPV corresponds to the highest NPV of all projects other than $i$. Let the critical NPV be formalized by

$$\hat{\Lambda}_i^* := max\{\hat{\Lambda}_1(r_c,\hat{\rho}_1),\ ...,\ \hat{\Lambda}_{i-1}(r_c,\hat{\rho}_{i-1}),\ \hat{\Lambda}_{i+1}(r_c,\hat{\rho}_{i+1}),\ ...,\ \hat{\Lambda}_n(r_c,\hat{\rho}_n)\}. \quad (10)$$

$\hat{\Lambda}_i^*$ is computed utilizing the organization's cost of capital, $r_c$. Next, for each department $i$ the coordinating unit calculates a critical level of the ability parameter for which $\hat{\Lambda}_i^*$ constitutes the basis, i.e.,

$$\hat{\rho}_i^* := \hat{\rho}_i^*(r_c) = \hat{\rho}_i \cdot \frac{\hat{\Lambda}_i^*}{\hat{\Lambda}_i(r_c,\hat{\rho}_i)}. \quad (11)$$

The expression $\hat{\rho}_i^*$, as defined in Eq. 11, constitutes the lowest level of ability, for which department $i$ would operate project $i$ at least as profitable as all other $n-1$ projects. Moreover, $\hat{\rho}_i^*$ constitutes the basis for determining the *hurdle rates*, i.e., the project-specific costs of capital. We denote these hurdle rates, which are computed by exponential interpolation, by $r_1^*,...,r_i^*,...,r_n^*$. The project-specific costs of capital are implicitly defined by

$$\hat{\Lambda}_i(r_i^*,\hat{\rho}_i^*) = 0\ . \quad (12)$$

Next, the coordinating unit announces the hurdle rates, $r_i^*$, to the submitting departments, which have to decide whether or not they put into action their proposed investment project (cf. Fig. 1, steps E2 and S3). In particular, they decide to implement the project if the corresponding NPV is positive, which yields the following decision-making rule:

$$I_i = \begin{cases} 1, & \text{if } \hat{\Lambda}_i(r_i^*,\hat{\rho}_i) > 0\ , \\ 0, & \text{otherwise.} \end{cases} \quad (13)$$

Whenever a department decides to operate the proposed project (i.e., $I_i = 1$), it is charged according to the relative benefit depreciation schedule (cf. Rogerson, 1997), using the hurdle rate, $r_i^*$, as a discount factor. Then, department $i$'s capital charge rate in time period $t$ can be computed by

$$\kappa_i \cdot \frac{\hat{\chi}_{it}}{\mathbf{r}(r_i^*) \circ \hat{\mathbf{x}}_i}. \quad (14)$$

In every time period $t$, departments get rewarded a variable compensation, which is computed as a function of residual income, i.e., as $f(\upsilon_{it})$, where department $i$'s residual income in period $t$ is given by operative cash flow, $\chi_{it} \cdot \rho_i$ (cf. Eq. 3) minus the capital charge rates (cf. Eq. 14), i.e.,

$$\upsilon_{it} = \left( \chi_{it} \cdot \rho_i\ -\ \kappa_i \cdot \frac{\hat{\chi}_{it}}{\mathbf{r}(r_i^*) \circ \hat{\mathbf{x}}_i} \right) \cdot I_i. \quad (15)$$

Let, then, department $i$'s future variable compensation components be denoted by the $T$-dimensional row vector

$$\mathbf{v}_i = [f(\upsilon_{i1}) \ \dots \ f(\upsilon_{iT})] \,. \tag{16}$$

We assume departments to aim at maximizing their individual utilities, which are set up as functions of the variable compensation component based on residual income, and refer to department $i$'s utility function as

$$U_i(\mathbf{r}(r_c) \circ \mathbf{v}_i) \,, \tag{17}$$

where, for simplicity, we assume departments to discount their future variable compensation components at the corporation's cost of capital, $r_c$. Rule 13 implies that putting into action the proposed project is attractive only for one department. The CHR born mechanism aims at maximizing the corporations utility, which we denote by

$$U_c(\Lambda_i\,(r_c, \rho_i) - \mathbf{r}(r_c) \circ \mathbf{v}_i) \,, \tag{18}$$

subject to Eq. 1. Notice, however, that the investment budget allocation mechanism is based on data forecasted by the departments, which are potentially erroneous, and not on the data observed upon realization. Thus, the project eventually realized will not necessarily maximize Eq. 18, which is caused by the departments' 'incompetence' in forecasting investment indicators (cf. Eq. 5 to 7), and the limitation in the corporation's information space (cf. Fig. 2).

## 3 On the simulation setup and measuring robustness

To investigate our research question and diagnose indications for fault tolerance of the allocation procedure presented in section 2, we will simulate variations in model parameters sketching the following four attributes: (i) the agents' incompetence in forecasting, (ii) the level of project heterogeneity, (iii) the investment alternatives' useful life span, and (iv) the level of organizational sophistication.

The set of forecasting distortions to be studied is implemented according to Eqs. 5 to 7, where the agents' 'incompetence' is modeled by adjoining normally distributed errors with mean 0 and variance $\sigma^2$ to the true values. In order to investigate different levels of the agents' incapability in forecasting, we run simulations for $\sigma = 0.05$ up to $\sigma = 0.3$, where we increase $\sigma$ in steps of 0.05. We define the (ii) level of project heterogeneity to correspond to the length of the interval $H = [\underline{\eta}, \overline{\eta}]$, i.e., as the diversity in the projects' return on investment parameters. In order to express and measure project heterogeneity, we introduce $\mathscr{H} := \overline{\eta} - \underline{\eta}$.[7] As $\mathscr{H}$ increases, also the level of 'project heterogeneity' increases, and *vice versa*. In particular, we regard $\mathscr{H}$ to be a proxy for the corporation's economic context from the supply-side perspective on investments, i.e., a higher $\mathscr{H}$ indicates a more diverse structure of offers for investment alternatives. A high level of heterogeneity, here, might be caused by intense competition on the supply-side market. A low $\mathscr{H}$, on the contrary, represents a rather

[7] Notice that changes $H = [\underline{\eta}, \overline{\eta}]$ affect each and every project.

narrow supply-side market for investment projects. Very customized investments and very specialized suppliers might be the case for this scenario. We run simulations for the parameter $\mathscr{H} = 0.5$ to 2.5 by fixing $\underline{\eta}$ at 1.5 and altering $\overline{\eta}$ from 2.0 to 4.0 in steps of 0.5. For (iii) the assets' useful life, $T$, we take account of the term structure and simulate scenarios for $T = 3,\ 5$, and 7. Finally, for (iv) the level of organizational sophistication we simulate variations in the number of departments, and thus, in the number of proposed project alternatives. In particular, we investigate our research question for $n = 2,\ 4$, and 6.

All other model parameters are kept constant throughout the simulation experiments: the corporation's cost of capital, $r_c$, is fixed at 0.1, and project $i$'s initial cash outlay (for $i = 1,...,n$) is drawn from $\mathscr{U}\,[100{,}000, 110{,}000]$. Moreover, department $i$'s ability to operate project $i$ is drawn from from $\mathscr{U}\,[0.8, 0.85]$. Thus, for all three types of forecasting error (cf. Eqs. 5 to 7), we investigate $6 \times 5 \times 3 \times 3$ scenarios, each by performing $80,000$ simulation runs (which last from $t = 1$ till $t = T$). Thus, we run $3 \times 270 \times 80,000$ simulations in total.

In order to evaluate the robustness of the competitive hurdle rate born mechanism presented here, we report two measures: the probability for carrying out suboptimal projects, and the average foregone NPV when doing so. Let the project with the highest NPV be, therefore, indicated by $i^* := \{i | max_i(\Lambda(r_c, \rho_i))\}$, and the project finally realized by $i^{(*)} := \{i | \hat{\Lambda}_i(r_i^*, \hat{\rho}_i) > 0\}$. Then, we denote the probability for carrying out suboptimal projects by

$$\tilde{P} := \mathbb{P}[i^{(*)} \neq i^*]. \tag{19}$$

Above, we have already mentioned that we perform $S = 80,000$ simulations per scenario. For all of these we store the NPVs, $\Lambda_{i^*}^s(r_c, \rho_{i^*})$, and the NPVs of the projects finally carried out, $\Lambda_{i^{(*)}}^s\left(r_c, \rho_{i^{(*)}}\right)$, where the superscript $s$ $(s = 1,...,S)$ indicates the simulation run. Then, for each of the 270 scenarios (which cover all possible combinations of the parameters $\sigma$, $\mathscr{H}$, $T$, and $n$), the average foregone NPVs are calculated according to

$$\tilde{\Lambda} := \frac{1}{S} \sum_{s=1}^{S} \Lambda_{i^{(*)}}^s\left(r_c, \rho_{i^{(*)}}\right) - \Lambda_{i^*}^s(r_c, \rho_{i^*}). \tag{20}$$

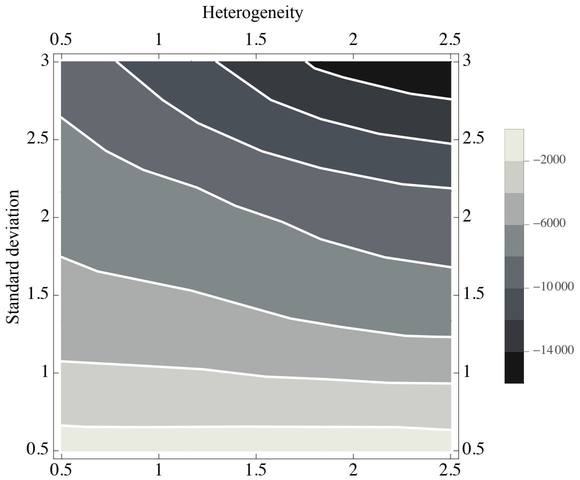
Equations 19 and 20 give valuable information about the fault (in)tolerance of a CHR born way of investment coordination. We regard this as important (additional) knowledge to accompany what we know about Baldenius et al (2007)'s mechanism, which is claimed to be '*the only satisfactory capital budgeting mechanism that achieves both strong incentive compatibility and efficient project selection*' (Baldenius et al, 2007, p. 839), since decision makers are held accountable for announcements of future investment plans.

## 4 Results and discussion

We find that, in the case of misforecasting any of the project-related measures, rather homogeneous investment landscapes imply a high probability of carrying out suboptimal projects (see Appendix, Tabs. A1 to A9)—and, if the degree of misforecasting is relatively small, this has an immediate impact on the average foregone NPV. In other words, if projects hardly differ with respect to their return on investment parameters (which is interprestd as a low level of heterogeneity, $\mathscr{H}$), picking a suboptimal project directly translates into loosing a substantial amount of potential shareholder wealth. As shown by Tabs. A1 to A3 and Tabs. A7 to A9 for future cash flows and departmental abilities of operating a project, respectively, for a high degree of misforecasting the result from above is reversed: the expected forgone NPV declines with projects becoming more and more alike (i.e., $\mathscr{H}$ declines). For large values of $\sigma$, this inverse relationship between $\tilde{\Lambda}$ and $\tilde{P}$ (cf. Eqs. 19 and 20, respectively) comes from the fact that the degree of fault (in)tolerance is driven by two potentially antagonistic forces: on the one hand, an increased heterogeneity of the investment landscape reduces the likelihood of implementing a suboptimal project, since this implies that NPVs are very dissimilar. On the other hand, an increase in the standard deviation of forecasting errors makes it more likely that projects are ranked in a suboptimal order, with respect to maximizing shareholder wealth. Note that this pattern is observed for forecasting errors in cash flows and departmental abilities independently from $T$. What does, however, change with $T$ is the location of the 'point of inflexion', abbreviated as $\mathscr{P}$, which can be defined as the level of $\sigma$ for which the direct relationship between $\tilde{\Lambda}$ and $\tilde{P}$ turns into an indirect one.

Tables A7 to A9 tell us that the position of the $\mathscr{P}$ is quite robust for increasing $T$, as far as misforecasts in departmental abilities are concerned. If we observe, however, misforecasts of the cash flow time series (cf. Tabs. A1 to A3), an increased durableness of the projects shifts $\mathscr{P}$ into the direction of higher $\sigma$-values. This directly translates into the conclusion that higher $\mathscr{H}$-values are to be preferred over a lower $\mathscr{H}$, as long as the $\sigma$-value is lower than the location of the 'point of inflexion', $\mathscr{P}$ (cf. also the pattern in Fig. 3). The same observation is made, if the number of departments and, thus, project proposals, $n$, decreases. A higher degree of organizational sophistication, thus, turns out to make the CHR born mechanism more vulnerable with respect to forecasting errors. This results in higher foregone NPVs, and a higher probability of putting suboptimal investments into action. A final interesting observation concerning anticipated cash flows is that $\tilde{P}$ increases with $\sigma$, but the magnitude of the change, $\Delta\tilde{P}$, declines with $\sigma$: Table A1 shows, for example, that by incrementing $\sigma$ from 0.05 to 0.1 for $\mathscr{H} = 0.5$, $\tilde{P}$ increases from 0.11 to 0.199 by 0.089 percent points, while by increasing $\sigma$ from 0.1 to 0.15, $\tilde{P}$ increases from 0.199 to 0.264 by 0.065 percent points. For larger $\mathscr{H}$-values, the probability for operating a suboptimal project becomes significantly smaller. For $\mathscr{H} = 2.5$ the following can be observed: incrementing $\sigma$ from 0.05 to 0.1 leads to $\tilde{P}$ increases from 0.039 to 0.074 by 0.035 percent points, while by increasing $\sigma$ from 0.1 to 0.15, $\tilde{P}$ similarly increases 0.033 percent points. This allows us to infer that the rates of changes become more homogenous with increasing $\mathscr{H}$. As far as the elasticity, $\%\Delta\tilde{P}/\%\Delta\sigma$, is concerned, we find that the relative rate of change is constant, even though the slope of the elasticity function decreases with increasing $\mathscr{H}$. Altogether, this stresses the result that for errors in forecasting cash flow time series which are below $\mathscr{P}$, our implementation of the CHR mechanism is most robust for larger degrees of heterogeneity, $\mathscr{H}$, and a lower number of project proposals, $n$. This finding is also supported by the expected values of foregone cash flows, i.e. $\tilde{\Lambda} \cdot \tilde{P}$. Utilizing the expected foregone

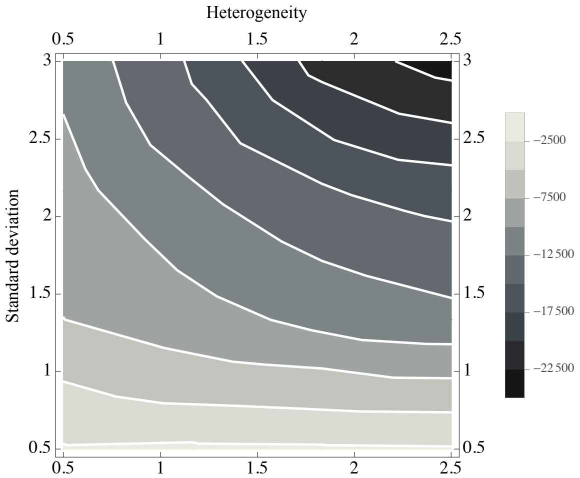
**Fig. 3** Forecasting error cash flow series ($T = 3$, $n = 6$)




NPVs shows comparable patterns to $\tilde{\Lambda}$, with the only difference that $\mathscr{P}$ shifts into the direction of larger $\sigma$-values. The pattern which can be observed for $\tilde{\Lambda}$ in Tabs. A1 to A3 is also depicted in Fig. 3.

The effects, which can be observed for errors in forecasting the departments' ability to operate projects (cf. Tabs. A7 to A9), are quite similar to the effects of misforecasted cash flows (cf. Tabs. A1 to A3). This is traceable since both errors directly affect the projects' NPVs. One substantial distinction is that significantly higher values for foregone shareholder wealth can be observed for the former type of error. However, as for errors in forecasting cash flow time series, the probability to operate a suboptimal investment project decreases with an increasing number of serious project proposals, $n$, while the corresponding average foregone NPV increases (cf. Tabs. A7 to A9). Thus, a higher level of organizational granularity again leads to our CHR born mechanism being more robust, with respect to $\tilde{P}$. In addition, we can observe that the probabilities, $\tilde{P}$, are relatively robust against changes in $T$, which is not the case for errors in forecasting cash flow time series (where $\tilde{P}$ slightly decreases with $T$). Thus, for errors in forecasting the departmental ability, $T$ increases the robustness of our CHR mechanism. For errors in forecasting cash flow time series, no correlation between the asset's useful life, $T$, and our coordination mechanism's robustness can be substantiated on the basis of our results. With respect to the 'point of inflexion', $\mathscr{P}$, we can observe the trend that a larger number of project proposals, $n$, leads to $\mathscr{P}$ occurring for smaller values of $\sigma$. The results in Tabs. A7 to A9 allow us to deduce that the elasticity function, $\%\Delta\tilde{P}/\%\Delta\sigma$, is similar to a linear function, where, as in the case of forecasting errors in cash flow time series, the function's slope decreases with increasing heterogeneity, $\mathscr{H}$. Thus, also for errors in forecasting the departmental ability, we can conclude that our CHR born mechanism is most robust for larger levels of heterogeneity, $\mathscr{H}$. This result reverses as $\sigma$ surpasses $\mathscr{P}$ (cf. the pattern in Fig. 4). With respect to the probability to make errors, $\tilde{P}$, we find that a

**Fig. 4** Forecasting error departmental efficiency ($T = 3$, $n = 6$)

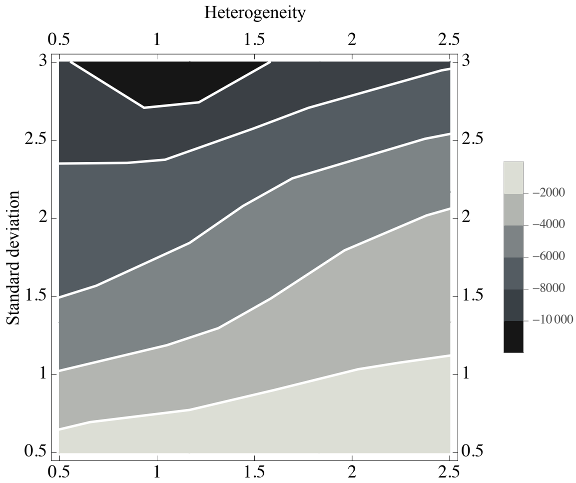



higher number of $n$ leads to our mechanism being more robust. Notice, this finding is only significant for lower $\mathscr{H}$-values. If we compute the expected value of foregone NPVs (i.e., $\tilde{\Lambda} \cdot \tilde{P}$), we get clear evidence that our mechanism is most robust for larger $\mathscr{H}$- and lower $n$-values.

For errors in forecasting the initial cash outlay, which is needed to launch a project, results are different (cf. Tabs. A4 to A6). We can observe that the magnitude of foregone NPV is lower than $\tilde{\Lambda}$ is for errors in forecasting the departmental ability to operate projects (cf. Tabs. A7 to A9), but higher than the foregone NPV in the case of errors in forecasting cash flow time series (cf. Tabs. A1 to A3). The probability to choose a suboptimal project, $\tilde{P}$, is on a similar level as for the case of misforecasting cash flows, and below the probability in the case of misforecasting abilities. The results given in Tabs. A4 to A6 unambiguously indicate that an increase in the level of heterogeneity, $\mathscr{H}$, leads to the foregone NPVs decreasing (the corresponding pattern is also displayed in Fig. 5), while an increase in the number of departments, or, in other words, serious project proposals, $n$, causes the foregone NPVs to increase. With respect to $\tilde{P}$, we observe that the probability to operate suboptimal projects is relatively constant for the investigated $T$. Moreover, we can observe the trend that $\tilde{P}$ decreases with increases in $n$. The extent of increases in $\tilde{P}$ for increases in $\sigma$, decreases with $n$, i.e., the function $\Delta\tilde{P}/\Delta\sigma$ is shaped as a convex function, while the elasticity function, $\%\Delta\tilde{P}/\%\Delta\sigma$, comes close to being a linear function. As for the prior types of errors, an increase in the level of heterogeneity, $\mathscr{H}$, significantly decreases the elasticity function's slope.

To put our results in a nutshell: projects that are very much alike in terms of their returns on investment do not easily tolerate faults. For misforecasts of the initial cash outlay this is independent from the level of $\sigma$, while for errors in forecasting cash flow time series and departmental ability of carrying out projects, this finding holds for small $\sigma$ only. For the two latter types of errors, in the case of larger errors (i.e.,

**Fig. 5** Forecasting error initial cash outlay ($T = 3$, $n = 6$)




$\sigma > \mathscr{P}$), decreasing the level of heterogeneity, however, increases the mechanism's fault-tolerance. Moreover, for increases in the number of departments, $n$, we find that the average foregone NPV increases. For errors in forecasting the initial cash-outlay and the departmental ability, a higher number of project proposals leads to a decrease in the probability of making errors, while for errors in estimating cash flow time series the opposite can be observed.

This implies important policy advice, since project heterogeneity (with respect to the projects' estimated returns on investment) is subject to choice in the short-run, and selected by the business organizations's coordinating unit before the procedure starts.[8] In business organizations, heterogeneity can, for example, be narrowed down by increasing the minimum payoff an investment project has to achieve which would lead to the proposed investment projects being more alike (and probably to less projects being proposed). Note that, if more details are known about the degree of departmental incapability to forecast measures related to projects, contour plots 3 to 5 can be used to support decision-making. Here, for each level of $\sigma$, a business corporation can read off which levels of heterogeneity to choose, in order to minimize the undesired effect of errors. However, the information gained from the policy chart needs to be used with caution. E.g., under certain circumstances a low level of heterogeneity, $\mathscr{H}$, indeed decreases an error's unwanted effect on the corporation's shareholder wealth, but one has to keep in mind that it is bought at the price of a reduced future development potential for the organization (Leitner and Behrens, 2013, 2014). Regarding the prioritization of error avoidance: it is plausible to assume that individuals will tend to pay particular attention to avoiding false estimations of the initial cash outlay, as they constitute financial resources, which have to be ac-

8 Please notice that Figs. 3 to 5 plot the observed contours for $T = 3$ and $n = 6$. Very similar patterns can be observed for all investigated characterizations of the assets' useful life, $T$, and the number of departments, $n$.

tually spent (Kahneman and Tversky, 1979). On the contrary, errors in forecasting cash flow series and the departmental ability represent foregone profits. Our results do, thus, suggest that misforcasting the ability to operate projects is the key to reduce losses in shareholder value.

## 5 Concluding remarks and future work

This paper presents the implementation of the competitive hurdle rate (CHR) mechanism (cf. Baldenius et al, 2007) into a computational model. The robustness of the CHR born budget allocation mechanism within our computational model critically hinges on how much projects, competing for the same pot of funding, are allowed to vary with respect their returns on investment, but also on the number of project proposals submitted to the coordinating unit. Within the context of our model, in particular if the number of feasible project proposals is small, a higher degree of 'project diversity' dampens down the negative effects of misforecasting measures associated with investment projects. If the number of proposals increases, 'project heterogeneity' still is to be preferred over 'project homogeneity'[9], while the prevented loss in SHV decreases. Moreover, we find that this result reverses if the standard deviations associated with the managers' forecasting errors surpass some critical levels. Counterintuitively, in this case a higher probability of funding a suboptimal project proposal goes hand in hand with a smaller loss in SHV. I.e., above the critical level of misforecasting the expected loss in SHV is always smaller for 'homogenous' than for 'heterogenous' projects. Thus, within the context of our model this indicates that projects being more alike (with respect to their returns on investment) should be preferred over project being diverse, if the extent of misforecasting is perceived to be substantial. The result that aspiring 'homogeneity' pays-off in terms of averting losses in SHV is quite remarkable since the probability of supporting a suboptimal project *always* increases if projects become more similar.

Noteworthy, we find that within the context of our computational budget allocation framework a lacking competence of forecasting the ability to operate projects has, by far, the strongest negative impact on SHV followed by misforecasts in the cash flow time series and misestimated initial cash outlays. It is important news that, within our simulation model, the key to avoid losses in SHV is being accurate when forecasting the departmental ability of operating projects, and not, as it might be expected, the precision in predicting money necessary to launch a project. Thus, we have provided advice to crank up robustness.

At the same time our results might be extended in the following ways. So far, we assumed communication channels among departments to be non-existent. Future research should render our model variant into an agent-based model. The agent-based model should consider intraorganizational communication at the departmental level in a fully mashed network manner. Some exchange on local information could alter

[9] Recall that project homogeneity only indicates that projects are similar in their returns on investment, *ceteris paribus*. Thus, if projects are getting more homogenous this does not imply that the money necessary to launch a project, the cash flow time series, and the departmental ability to operate a project are becoming more similar.

the quality of forecasts in a positive way, seen from the corporation's point of view (cf. also the work done by Stark and Behrens, 2010). Moreover, in our model, some variables are assumed to be uniformly distributed. Future research may investigate whether our results also hold for other distributions. Usually, errors do not necessarily occur one at a time. Thus, the effect of combining errors is another avenue for further research (for the effect of combinations of systematic and nonsystematic errors see, e.g., Behrens et al (2014) and Leitner (2012), respectively).

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## References

Axtell RL (2007) What economic agents do: How cognition and interaction lead to emergence and complexity. Rev Austrian Econ 20(2-3):105–122

Baldenius T, Dutta S, Reichelstein S (2007) Cost allocation for capital budgeting decisions. Account Rev 82(4):837–867

Behrens DA, Berlinger S, Wall F (2014) Phrasing and timing information dissemination in organizations: Results of an agent-based simulation. In: Leitner S, Wall F (eds) Artificial Economics and Self Organization, Lect Notes Econ Math, vol 669, Springer International, pp 179–190

Brigham EF (1975) Hurdle rates for screening capital expenditure proposals. Finance Manage 4(3):17–26

Christensen M, Knudsen T (2007) Design of decision-making organization. Manage Sci 56(1):71–89

Eisenhardt KM (1989) Agency theory: An assessment and review. Acad Manage Rev 14(1):57–74

Fisher FM (1989) Games economists play: a noncooperative view. RAND J Econ 20(1):113–124

Fremgen JM (1973) Capital budgeting practices: A survey. Manage Account 54(11):19–25

Furubotn EG, Richter R (2000) Institutions and economic theory, 3rd edn. Univ. of Michigan Press, Ann Arbor, Michigan

Ghoshal S, Moran P (1996) Bad for practice: A critique of the transaction cost theory. Acad Manage Rev 21(1):13–47

Guerrero OA, Axtell RL (2011) Using agentization for exploring firm and labor dynamics. A methodological tool for theory exploration and validation. In: Osinga S, Hofstede GJ, Verwaart T (eds) Emergent Results of Artificial Economics, Lect Notes Econ Math, vol 652, Springer, Heidelberg, Berlin, New York, pp 139–150

Hendry J (2002) The principal's other problems: honest incompetence and the specification of objectives. Acad Manage Rev 27(1):98–113

Kahneman D, Tversky A (1979) Prospect theory: An analysis of decision under risk. Econometrica 47(2):263–292

Kirman AP (1992) Whom or what does the representative individual represent? J Econ Persp 6(2):117–136

Laffont JJ, Martimort D (2002) The theory of incentives. The principal-agent problem. Princeton University Press, Princeton, Oxford

Leitner S (2012) A simulation analysis of interactions among intended biases in costing systems and their effects on the accuracy of decision-influencing information. Cent Eur J Operat Res doi: 10.1007/s10100-012-0275-2

Leitner S (2013) Information Quality and Management Accounting, Lecture Notes in Economics and Mathematical Systems, vol 664. Springer, Berlin, Heidelberg, New York

Leitner S, Behrens DA (2013) Coordination of distributed investment decisions: The agentization of the competitive hurdle rate mechanism, Working Paper, Alpen-Adria Universität Klagenfurt (in submission)

Leitner S, Behrens DA (2014) On the robustness of coordination mechanisms involving incompetent agents. In: Leitner S, Wall F (eds) Artificial Economics and Self Organization, Lect Notes Econ Math, vol 669, Springer International, pp 191–203

Leitner S, Wall F (2011a) Effectivity of multi criteria decision-making in organisations: Results of an agent-based simulation. In: Osinga S, Hofstede GJ, Verwaart T (eds) Emergent Results of Artificial Economics, Lect Notes Econ Math, vol 652, Springer Berlin Heidelberg, pp 79–90

Leitner S, Wall F (2011b) Unexpected positive effects of complexity on performance in multiple criteria setups. In: Hu B, Morasch K, Pickl S, Siegle M (eds) Operations Research Proceedings 2010, Operat Res Proceed, Springer Berlin Heidelberg, pp 577–582

Ma T, Nakamori Y (2005) Agent-based modeling on technological innovation as an evolutionary process. Eur J Operat Res 166(3):741–755

Martin R (1993) The new behaviorism: A critique of economics and organization. Hum Relat 46(9):1085–1101

Meier H, Christofides N, Salkin G (2001) Capital budgeting under uncertainty - an integrated approach using contingent claims analysis and integer programming. Operat Res 49(March-April):196–206

Miller JH (1960) A glimpse at practice in calculating and using return on investment. NAA Bulletin (Manage Account) June:65–76

Miller P, O'Leary T (2005) Capital budgeting, coordination, and strategy: a field study of interfirm and intrafirm mechanisms. In: Chapman CS (ed) Controlling strategy: management, accounting, and performance measurement, Oxford University Press, Oxford, UK, pp 151–191

Minton BA, Schrand C, Walther B (2002) The role of volatility in forecasting. Rev Account Stud 7:195–215

Rogerson WP (1997) Intertemporal cost allocation and managerial investment incentives: A theory explaining the use of economic value added as a performance measure. J Polit Econ 105:770–795

Rogerson WP (2008) Intertemporal cost allocation and investment decisions. J Polit Econ 116(5):931–950

Ross SA (1973) The economic theory of agency: The principal's problem. Am Econ Rev 63(2):134–139

Ryan PA, Ryan GP (2002) Capital budgeting practices of the fortune 1000: How have things changed? J Bus Manage 8(4):355

Schall LD, Sundem GL, Geijsbeek WR (1978) Survey and analysis of capital budgeting methods. J Financ 33(1):281–287

Simon HA (1991) Organizations and markets. J Econ Perspect 5(2):25–44

Stark O, Behrens DA (2010) An evolutionary edge of knowing less (or: On the curse of global information). J Evol Econ 20(1):77–94

Tesfatsion L (2006) Agent-based computational economics: A constructive approach to economic theory. In: Tesfatsion L, Judd KL (eds) Handbook of Computational Economics. Agent-Based Computational Economics, vol 2, Elsevier, Amsterdam, Boston, London et al., pp 831–880

Young SD, O'Byrne SF (2002) EVA and value-based management. A practical guide to implementation, 6th edn. McGraw-Hill, New York

# A Appendix

**Table A1** Forecasting error cash flow time series, $T = 3$

*Average foregone NPV,* $\tilde{\Lambda}$ | *Probability for suboptimal decisions,* $\tilde{P}$

| | Heterogeneity $\mathscr{H}$ | | | | | Heterogeneity $\mathscr{H}$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $T = 3$ | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 |
| *Number of departments,* $n = 2$ | | | | | | | | | | |
| Std.dev. σ 0.05 | -450.34 | -330.22 | -282.89 | -282.66 | -272.58 | 0.1101 | 0.0669 | 0.0504 | 0.0441 | 0.0386 |
| 0.10 | -1,456.50 | -1,190.88 | -1,055.56 | -1,027.57 | -1,010.13 | 0.1985 | 0.1285 | 0.0982 | 0.0844 | 0.0737 |
| 0.15 | -2,491.40 | -2,322.48 | -2,172.86 | -2,086.42 | -2,134.90 | 0.2641 | 0.1788 | 0.1422 | 0.1191 | 0.1073 |
| 0.20 | -3,335.04 | -3,586.39 | -3,533.76 | -3,472.67 | -3,498.66 | 0.3093 | 0.2234 | 0.1814 | 0.1549 | 0.1380 |
| 0.25 | -4,036.13 | -4,759.82 | -4,852.44 | -5,002.83 | -5,183.01 | 0.3456 | 0.2589 | 0.2125 | 0.1856 | 0.1690 |
| 0.30 | -4,436.65 | -5,790.79 | -6,280.71 | -6,606.45 | -6,874.11 | 0.3649 | 0.2906 | 0.2424 | 0.2124 | 0.1942 |
| *Number of departments,* $n = 4$ | | | | | | | | | | |
| Std.dev. σ 0.05 | -910.94 | -724.96 | -700.37 | -712.69 | -707.28 | 0.1049 | 0.0687 | 0.0554 | 0.0483 | 0.0442 |
| 0.10 | -2,726.58 | -2,383.19 | -2,357.29 | -2,407.91 | -2,476.02 | 0.1779 | 0.1225 | 0.1016 | 0.0887 | 0.0811 |
| 0.15 | -4,416.46 | -4,421.53 | -4,414.96 | -4,644.23 | -4,780.80 | 0.2226 | 0.1642 | 0.1374 | 0.1219 | 0.1121 |
| 0.20 | -5,875.39 | -6,415.74 | -6,655.18 | -7,178.27 | -7,344.25 | 0.2547 | 0.1964 | 0.1659 | 0.1516 | 0.1376 |
| 0.25 | -6,904.64 | -8,308.67 | -8,810.05 | -9,475.23 | -10,170.13 | 0.2739 | 0.2212 | 0.1902 | 0.1728 | 0.1608 |
| 0.30 | -7,669.55 | -9,851.29 | -11,013.01 | -11,914.18 | -12,934.46 | 0.2891 | 0.2386 | 0.2102 | 0.1913 | 0.1802 |
| *Number of departments,* $n = 6$ | | | | | | | | | | |
| Std.dev. σ 0.05 | -1,212.53 | -1,053.85 | -1,004.92 | -1,049.40 | -1,106.03 | 0.0931 | 0.0651 | 0.0522 | 0.0472 | 0.0434 |
| 0.10 | -3,297.71 | -3,196.61 | -3,252.72 | -3,393.48 | -3,567.55 | 0.1473 | 0.1097 | 0.0929 | 0.0828 | 0.0767 |
| 0.15 | -5,250.87 | -5,472.97 | -5,841.79 | -6,202.06 | -6,678.08 | 0.1798 | 0.1409 | 0.1219 | 0.1105 | 0.1032 |
| 0.20 | -6,766.14 | -7,704.43 | -8,310.50 | -9,046.58 | -9,850.64 | 0.1994 | 0.1624 | 0.1431 | 0.1313 | 0.1235 |
| 0.25 | -7,978.90 | -9,648.74 | -10,735.66 | -11,699.64 | -12,814.45 | 0.2126 | 0.1790 | 0.1594 | 0.1472 | 0.1396 |
| 0.30 | -8,933.93 | -11,432.43 | -12,884.80 | -14,325.73 | -15,672.88 | 0.2226 | 0.1908 | 0.1720 | 0.1607 | 0.1516 |

**Table A2** Forecasting error cash flow time series, $T = 5$

*Average foregone NPV,* $\tilde{\Lambda}$ | *Probability for suboptimal decisions,* $\tilde{P}$

| | Heterogeneity $\mathscr{H}$ | | | | | Heterogeneity $\mathscr{H}$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $T = 5$ | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 |
| *Number of departmentsn* $n = 2$ | | | | | | | | | | |
| Std.dev. σ 0.05 | -285.34 | -201.70 | -188.18 | -171.11 | -172.47 | 0.0876 | 0.0532 | 0.0417 | 0.0344 | 0.0306 |
| 0.10 | -993.22 | -744.95 | -690.59 | -641.04 | -624.25 | 0.1666 | 0.1023 | 0.0800 | 0.0665 | 0.0581 |
| 0,.15 | -1,883.07 | -1,574.27 | -1,429.67 | -1,370.12 | -1,366.92 | 0.2281 | 0.1479 | 0.1152 | 0.0974 | 0.0867 |
| 0.20 | -2,613.74 | -2,445.96 | -2,343.46 | -2,261.69 | -2,335.20 | 0.2717 | 0.1848 | 0.1456 | 0.1258 | 0.1128 |
| 0.25 | -3,293.12 | -3,477.17 | -3,367.77 | -3,322.95 | -3,360.91 | 0.3077 | 0.2210 | 0.1778 | 0.1516 | 0.1360 |
| 0.30 | -3,846.26 | -4,422.48 | -4,569.91 | -4,546.13 | -4,605.66 | 0.3359 | 0.2491 | 0.2067 | 0.1775 | 0.1601 |
| *Number of departments,* $n = 4$ | | | | | | | | | | |
| Std.dev. σ 0.05 | -582.41 | -477.20 | -435.46 | -437.03 | -445.54 | 0.0846 | 0.0556 | 0.0441 | 0.0382 | 0.0346 |
| 0.10 | -1,895.03 | -1,619.14 | -1,551.19 | -1,540.82 | -1,609.30 | 0.1504 | 0.1023 | 0.0820 | 0.0716 | 0.0655 |
| 0.15 | -3,323.39 | -3,074.80 | -3,044.81 | -3,119.16 | -3,264.20 | 0.1957 | 0.1385 | 0.1149 | 0.1013 | 0.0928 |
| 0.20 | -4,610.34 | -4,670.51 | -4,685.52 | -4,912.11 | -5,156.00 | 0.2283 | 0.1689 | 0.1408 | 0.1256 | 0.1163 |
| 0.25 | -5,696.54 | -6,224.13 | -6,529.86 | -6,849.30 | -7,314.71 | 0.2506 | 0.1944 | 0.1653 | 0.1487 | 0.1369 |
| 0.30 | -6,561.11 | -7,669.70 | -8,249.27 | -8,719.32 | -9,330.07 | 0.2672 | 0.2131 | 0.1837 | 0.1655 | 0.1549 |
| *Number of departmentsn* $n = 6$ | | | | | | | | | | |
| Std.dev. σ 0.05 | -810.01 | -682.82 | -663.21 | -672.71 | -693.96 | 0.0774 | 0.0525 | 0.0432 | 0.0378 | 0.0341 |
| 0.10 | -2,408.08 | -2,204.65 | -2,225.02 | -2,274.02 | -2,429.60 | 0.1284 | 0.0923 | 0.0771 | 0.0684 | 0.0638 |
| 0.15 | -4,001.25 | -3,976.47 | -4,169.07 | -4,406.05 | -4,643.36 | 0.1606 | 0.1219 | 0.1045 | 0.0941 | 0.0871 |
| 0.20 | -5,460.13 | -5,784.07 | -6,135.19 | -6,584.36 | -7,110.04 | 0.1830 | 0.1438 | 0.1250 | 0.1138 | 0.1063 |
| 0.25 | -6,636.51 | -7,504.18 | -8,141.22 | -8,836.05 | -9,524.21 | 0.1981 | 0.1611 | 0.1409 | 0.1294 | 0.1221 |
| 0.30 | -7,608.74 | -9,065.32 | -10,075.61 | -10,980.47 | -12,001.33 | 0.2091 | 0.1743 | 0.1550 | 0.1431 | 0.1352 |

**Table A3** Forecasting error cash flow time series, $T = 7$

| | *Average foregone NPV, $\tilde{\Lambda}$* | | | | | *Probability for suboptimal decisions, $\tilde{P}$* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Heterogeneity $\mathscr{H}$ | | | | | Heterogeneity $\mathscr{H}$ | | | | |
| $T = 7$ | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 |
| *Number of departments, $n = 2$* | | | | | | | | | | |
| Std.dev. σ 0.05 | -216.91 | -149.55 | -129.67 | -125.86 | -120.12 | 0.0770 | 0.0461 | 0.0342 | 0.0290 | 0.0255 |
| 0.10 | -751.24 | -573.19 | -487.45 | -466.78 | -457.15 | 0.1434 | 0.0889 | 0.0650 | 0.0567 | 0.0494 |
| 0.15 | -1,421.13 | -1,159.45 | -1,059.57 | -985.30 | -1,005.59 | 0.1984 | 0.1261 | 0.0983 | 0.0824 | 0.0738 |
| 0.20 | -2,139.82 | -1,902.17 | -1,731.85 | -1,728.68 | -1,712.35 | 0.2434 | 0.1614 | 0.1267 | 0.1100 | 0.0945 |
| 0.25 | -2,785.56 | -2,708.63 | -2,534.21 | -2,506.41 | -2,554.97 | 0.2787 | 0.1935 | 0.1531 | 0.1305 | 0.1174 |
| 0.30 | -3,408.16 | -3,632.28 | -3,483.40 | -3,434.83 | -3,462.50 | 0.3105 | 0.2244 | 0.1794 | 0.1519 | 0.1377 |
| *Number of departmentsn $n = 4$* | | | | | | | | | | |
| Std.dev. σ 0.05 | -437.80 | -342.03 | -317.27 | -320.84 | -334.83 | 0.0732 | 0.0476 | 0.0374 | 0.0324 | 0.0300 |
| 0.10 | -1,448.87 | -1,220.77 | -1,156.82 | -1,161.55 | -1,192.42 | 0.1320 | 0.0878 | 0.0713 | 0.0614 | 0.0562 |
| 0.15 | -2,671.70 | -2,383.27 | -2,324.42 | -2,364.56 | -2,439.65 | 0.1770 | 0.1231 | 0.0998 | 0.0883 | 0.0802 |
| 0.20 | -3,885.73 | -3,690.16 | -3,707.24 | -3,817.03 | -3,956.22 | 0.2093 | 0.1516 | 0.1261 | 0.1107 | 0.1021 |
| 0.25 | -4,961.76 | -5,065.58 | -5,146.55 | -5,402.46 | -5,629.15 | 0.2358 | 0.1750 | 0.1474 | 0.1318 | 0.1204 |
| 0.30 | -5,745.77 | -6,391.74 | -6,675.69 | -6,972.76 | -7,452.33 | 0.2518 | 0.1961 | 0.1661 | 0.1489 | 0.1388 |
| *Number of departments, $n = 6$* | | | | | | | | | | |
| Std.dev. σ 0.05 | -601.26 | -498.45 | -488.16 | -507.79 | -530.20 | 0.0667 | 0.0449 | 0.0372 | 0.0329 | 0.0302 |
| 0.10 | -1,876.26 | -1,694.55 | -1,667.43 | -1,717.00 | -1,817.48 | 0.1145 | 0.0814 | 0.0671 | 0.0596 | 0.0549 |
| 0.15 | -3,278.04 | -3,154.93 | -3,239.64 | -3,377.71 | -3,564.32 | 0.1478 | 0.1094 | 0.0926 | 0.0827 | 0.0764 |
| 0.20 | -4,557.80 | -4,704.88 | -4,846.86 | -5,191.16 | -5,512.12 | 0.1699 | 0.1311 | 0.1118 | 0.1014 | 0.0940 |
| 0.25 | -5,730.26 | -6,209.11 | -6,630.11 | -7,102.82 | -7,637.05 | 0.1867 | 0.1481 | 0.1293 | 0.1175 | 0.1099 |
| 0.30 | -6,770.41 | -7,629.34 | -8,259.62 | -8,971.81 | -9,665.86 | 0.1996 | 0.1620 | 0.1425 | 0.1307 | 0.1223 |

**Table A4** Forecasting error initial cash outlay, $T = 3$

| | *Average foregone NPV, $\tilde{\Lambda}$* | | | | | *Probability for suboptimal decisions, $\tilde{P}$* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Heterogeneity $\mathscr{H}$ | | | | | Heterogeneity $\mathscr{H}$ | | | | |
| $T = 3$ | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 |
| *Number of departments, $n = 2$* | | | | | | | | | | |
| Std.dev. σ 0.05 | -505.28 | -276.46 | -190.66 | -153.29 | -114.87 | 0.1183 | 0.0624 | 0.0426 | 0.0337 | 0.0260 |
| 0.10 | -1,597.24 | -1,017.11 | -725.95 | -566.92 | -452.02 | 0.2093 | 0.1199 | 0.0836 | 0.0649 | 0.0506 |
| 0.15 | -2,676.45 | -2,018.40 | -1,537.15 | -1,202.33 | -1,002.13 | 0.2729 | 0.1659 | 0.1209 | 0.0925 | 0.0760 |
| 0.20 | -3,532.23 | -3,182.31 | -2,553.49 | -2,032.42 | -1,711.97 | 0.3199 | 0.2132 | 0.1551 | 0.1206 | 0.0986 |
| 0.25 | -4,165.49 | -4,319.18 | -3,599.93 | -2,990.41 | -2,541.71 | 0.3515 | 0.2474 | 0.1855 | 0.1442 | 0.1205 |
| 0.30 | -4,589.05 | -5,401.91 | -4,763.03 | -4,051.50 | -3,447.66 | 0.3709 | 0.2789 | 0.2123 | 0.1693 | 0.1401 |
| *Number of departments, $n = 4$* | | | | | | | | | | |
| Std.dev. σ 0.05 | -928.61 | -518.34 | -368.80 | -268.47 | -229.95 | 0.1062 | 0.0578 | 0.0407 | 0.0298 | 0.0252 |
| 0.10 | -2,836.08 | -1,890.86 | -1,360.08 | -1,066.37 | -876.59 | 0.1801 | 0.1085 | 0.0770 | 0.0599 | 0.0486 |
| 0.15 | -4,827.78 | -3,715.01 | -2,838.75 | -2,259.48 | -1,871.08 | 0.2310 | 0.1497 | 0.1099 | 0.0861 | 0.0704 |
| 0.20 | -6,325.87 | -5,752.25 | -4,576.42 | -3,798.56 | -3,111.43 | 0.2602 | 0.1846 | 0.1368 | 0.1107 | 0.0898 |
| 0.25 | -7,540.15 | -7,650.25 | -6,611.13 | -5,508.97 | -4,732.70 | 0.2827 | 0.2105 | 0.1633 | 0.1320 | 0.1100 |
| 0.30 | -8,310.82 | -9,649.57 | -8,665.24 | -7,557.49 | -6,459.94 | 0.2973 | 0.2332 | 0.1845 | 0.1527 | 0.1276 |
| *Number of departments, $n = 6$* | | | | | | | | | | |
| Std.dev. σ 0.05 | -1,208.39 | -737.31 | -527.61 | -406.09 | -319.48 | 0.0935 | 0.0545 | 0.0385 | 0.0297 | 0.0234 |
| 0.10 | -3,477.23 | -2,447.71 | -1,864.24 | -1,487.42 | -1,240.35 | 0.1500 | 0.0967 | 0.0708 | 0.0559 | 0.0459 |
| 0.15 | -5,648.12 | -4,591.85 | -3,681.33 | -3,040.83 | -2,574.84 | 0.1836 | 0.1284 | 0.0978 | 0.0784 | 0.0656 |
| 0.20 | -7,469.44 | -6,895.14 | -5,786.82 | -4,905.73 | -4,207.00 | 0.2051 | 0.1532 | 0.1194 | 0.0977 | 0.0828 |
| 0.25 | -8,851.41 | -9,204.41 | -8,023.92 | -7,022.02 | -6,127.12 | 0.2201 | 0.1711 | 0.1387 | 0.1149 | 0.0979 |
| 0.30 | -9,866.48 | -11,362.26 | -10,284.54 | -9,149.06 | -8,206.50 | 0.2294 | 0.1874 | 0.1531 | 0.1297 | 0.1116 |

**Table A5** Forecasting error initial cash outlay, $T = 5$

| | *Average foregone NPV, $\tilde{\Lambda}$* | | | | | *Probability for suboptimal decisions, $\tilde{P}$* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Heterogeneity $\mathscr{H}$ | | | | | Heterogeneity $\mathscr{H}$ | | | | |
| $T = 5$ | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 |
| *Number of departments, $n = 2$* | | | | | | | | | | |
| Std.dev. σ 0.05 | -503.80 | -279.31 | -196.68 | -147.03 | -113.80 | 0.1173 | 0.0631 | 0.0437 | 0.0323 | 0.0254 |
| 0.10 | -1,590.96 | -1,039.40 | -724.26 | -574.35 | -461.39 | 0.2078 | 0.1210 | 0.0823 | 0.0641 | 0.0513 |
| 0.15 | -2,692.35 | -2,026.25 | -1,517.05 | -1,201.05 | -1,018.04 | 0.2763 | 0.1688 | 0.1199 | 0.0922 | 0.0767 |
| 0.20 | -3,561.50 | -3,145.47 | -2,535.27 | -2,105.41 | -1,668.95 | 0.3222 | 0.2098 | 0.1544 | 0.1220 | 0.0975 |
| 0.25 | -4,206.15 | -4,283.58 | -3,605.43 | -2,991.20 | -2,480.50 | 0.3545 | 0.2471 | 0.1848 | 0.1448 | 0.1195 |
| 0.30 | -4,565.73 | -5,340.77 | -4,839.95 | -4,166.79 | -3,512.90 | 0.3695 | 0.2772 | 0.2126 | 0.1726 | 0.1409 |
| *Number of departments, $n = 4$* | | | | | | | | | | |
| Std.dev. σ 0.05 | -939.70 | -532.68 | -359.22 | -280.09 | -228.77 | 0.1053 | 0.0589 | 0.0397 | 0.0307 | 0.0244 |
| 0.10 | -2,891.65 | -1,884.44 | -1,376.47 | -1,066.95 | -879.73 | 0.1817 | 0.1086 | 0.0768 | 0.0591 | 0.0485 |
| 0.15 | -4,814.18 | -3,758.31 | -2,830.29 | -2,289.10 | -1,884.09 | 0.2304 | 0.1502 | 0.1100 | 0.0861 | 0.0703 |
| 0.20 | -6,331.33 | -5,802.65 | -4,623.58 | -3,768.13 | -3,221.14 | 0.2614 | 0.1841 | 0.1378 | 0.1103 | 0.0909 |
| 0.25 | -7,464.89 | -7,736.80 | -6,574.40 | -5,538.36 | -4,852.45 | 0.2820 | 0.2110 | 0.1623 | 0.1314 | 0.1113 |
| 0.30 | -8,347.32 | -9,657.78 | -8,714.18 | -7,458.02 | -6,474.45 | 0.2971 | 0.2336 | 0.1851 | 0.1515 | 0.1284 |
| *Number of departments, $n = 6$* | | | | | | | | | | |
| Std.dev. σ 0.05 | -1,205.22 | -726.76 | -529.70 | -390.64 | -321.91 | 0.0928 | 0.0544 | 0.0385 | 0.0287 | 0.0232 |
| 0.10 | -3,481.34 | -2,427.08 | -1,841.70 | -1,477.97 | -1,249.08 | 0.1501 | 0.0960 | 0.0704 | 0.0559 | 0.0462 |
| 0.15 | -5,722.26 | -4,653.71 | -3,689.25 | -3,031.41 | -2,576.06 | 0.1843 | 0.1296 | 0.0976 | 0.0776 | 0.0653 |
| 0.20 | -7,459.89 | -6,940.24 | -5,749.85 | -4,961.20 | -4,186.81 | 0.2056 | 0.1526 | 0.1195 | 0.0988 | 0.0824 |
| 0.25 | -8,885.42 | -9,256.93 | -8,108.84 | -6,939.48 | -6,127.53 | 0.2196 | 0.1721 | 0.1385 | 0.1144 | 0.0977 |
| 0.30 | -9,809.72 | -11,434.93 | -10,381.87 | -9,243.37 | -8,233.99 | 0.2291 | 0.1871 | 0.1533 | 0.1299 | 0.1122 |

**Table A6** Forecasting error initial cash outlay, $T = 7$

| | *Average foregone NPV, $\tilde{\Lambda}$* | | | | | *Probability for suboptimal decisions, $\tilde{P}$* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Heterogeneity $\mathscr{H}$ | | | | | Heterogeneity $\mathscr{H}$ | | | | |
| $T = 7$ | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 |
| *Number of departments, $n = 2$* | | | | | | | | | | |
| Std.dev. σ 0.05 | -508.05 | -283.94 | -192.97 | -145.91 | -116.56 | 0.1190 | 0.0629 | 0.0426 | 0.0322 | 0.0256 |
| 0.10 | -1,580.23 | -1,012.94 | -721.36 | -547.18 | -467.05 | 0.2083 | 0.1205 | 0.0824 | 0.0633 | 0.0526 |
| 0.15 | -2,676.65 | -2,021.23 | -1,485.19 | -1,195.72 | -989.72 | 0.2732 | 0.1680 | 0.1178 | 0.0914 | 0.0741 |
| 0.20 | -3,542.99 | -3,188.82 | -2,522.01 | -2,022.43 | -1,668.80 | 0.3205 | 0.2103 | 0.1539 | 0.1201 | 0.0976 |
| 0.25 | -4,151.11 | -4,260.87 | -3,593.90 | -2,998.51 | -2,578.79 | 0.3504 | 0.2458 | 0.1828 | 0.1475 | 0.1199 |
| 0.30 | -4,614.28 | -5,342.65 | -4,754.71 | -4,078.54 | -3,453.13 | 0.3716 | 0.2756 | 0.2105 | 0.1694 | 0.1395 |
| *Number of departments, $n = 4$* | | | | | | | | | | |
| Std.dev. σ 0.05 | -935.19 | -527.89 | -385.18 | -281.63 | -225.37 | 0.1060 | 0.0592 | 0.0418 | 0.0307 | 0.0252 |
| 0.10 | -2,862.41 | -1,904.04 | -1,389.98 | -1,073.29 | -875.16 | 0.1807 | 0.1097 | 0.0774 | 0.0597 | 0.0481 |
| 0.15 | -4,870.77 | -3,749.54 | -2,860.07 | -2,281.31 | -1,900.68 | 0.2307 | 0.1510 | 0.1100 | 0.0855 | 0.0706 |
| 0.20 | -6,325.95 | -5,794.49 | -4,695.22 | -3,807.22 | -3,191.77 | 0.2628 | 0.1835 | 0.1396 | 0.1109 | 0.0908 |
| 0.25 | -7,512.74 | -7,875.80 | -6,573.35 | -5,592.93 | -4,785.75 | 0.2833 | 0.2130 | 0.1631 | 0.1325 | 0.1104 |
| 0.30 | -8,365.99 | -9,584.92 | -8,791.04 | -7,521.66 | -6,498.05 | 0.2989 | 0.2332 | 0.1861 | 0.1524 | 0.1281 |
| *Number of departments, $n = 6$* | | | | | | | | | | |
| Std.dev. σ 0.05 | -1,208.08 | -728.18 | -511.70 | -401.63 | -331.76 | 0.0932 | 0.0538 | 0.0378 | 0.0292 | 0.0241 |
| 0.10 | -3,507.31 | -2,483.10 | -1,858.22 | -1,478.20 | -1,227.56 | 0.1505 | 0.0971 | 0.0708 | 0.0554 | 0.0456 |
| 0.15 | -5,713.30 | -4,638.77 | -3,666.64 | -3,043.58 | -2,601.88 | 0.1845 | 0.1289 | 0.0973 | 0.0784 | 0.0658 |
| 0.20 | -7,502.93 | -6,925.24 | -5,845.68 | -4,954.53 | -4,279.60 | 0.2061 | 0.1530 | 0.1209 | 0.0989 | 0.0835 |
| 0.25 | -8,852.78 | -9,236.13 | -8,137.80 | -7,078.35 | -6,200.10 | 0.2201 | 0.1728 | 0.1396 | 0.1157 | 0.0990 |
| 0.30 | -9,895.02 | -11,306.29 | -10,448.42 | -9,293.65 | -8,289.50 | 0.2291 | 0.1872 | 0.1542 | 0.1304 | 0.1123 |

**Table A7** Forecasting error departmental ability, $T = 3$

*Average foregone NPV,* $\tilde{\Lambda}$ | *Probability for suboptimal decisions,* $\tilde{P}$

| | Average foregone NPV: Heterogeneity $\mathscr{H}$ | | | | | Probability for suboptimal decisions: Heterogeneity $\mathscr{H}$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $T = 3$ | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 |
| *Number of departments,* $n = 2$ | | | | | | | | | | |
| Std.dev. σ 0.05 | -951.23 | -732.64 | -633.90 | -616.30 | -605.71 | 0.1609 | 0.1008 | 0.0765 | 0.0651 | 0.0579 |
| 0.10 | -2,568.79 | -2,442.38 | -2,232.00 | -2,131.93 | -2,161.88 | 0.2690 | 0.1852 | 0.1446 | 0.1205 | 0.1089 |
| 0.15 | -3,738.49 | -4,300.98 | -4,400.32 | -4,352.38 | -4,428.46 | 0.3297 | 0.2444 | 0.2010 | 0.1743 | 0.1552 |
| 0.20 | -4,521.37 | -5,911.91 | -6,335.79 | -6,839.38 | -7,127.53 | 0.3664 | 0.2916 | 0.2436 | 0.2168 | 0.1989 |
| 0.25 | -5,017.74 | -7,206.81 | -8,344.47 | -9,064.68 | -9,727.46 | 0.3942 | 0.3256 | 0.2818 | 0.2535 | 0.2330 |
| 0.30 | -5,396.95 | -8,245.10 | -9,858.64 | -11,075.46 | -12,156.77 | 0.4122 | 0.3529 | 0.3110 | 0.2802 | 0.2613 |
| *Number of departments,* $n = 4$ | | | | | | | | | | |
| Std.dev. σ 0.05 | -1,793.83 | -1,545.19 | -1,464.90 | -1,511.47 | -1,524.81 | 0.1464 | 0.1003 | 0.0800 | 0.0710 | 0.0635 |
| 0.10 | -4,532.66 | -4,541.71 | -4,627.56 | -4,717.46 | -4,975.51 | 0.2263 | 0.1674 | 0.1402 | 0.1236 | 0.1136 |
| 0.15 | -6,472.59 | -7,530.51 | -7,953.67 | -8,544.26 | -8,932.54 | 0.2657 | 0.2117 | 0.1798 | 0.1646 | 0.1497 |
| 0.20 | -7,823.42 | -10,037.87 | -11,264.49 | -12,119.05 | -13,180.33 | 0.2907 | 0.2406 | 0.2138 | 0.1933 | 0.1829 |
| 0.25 | -8,688.99 | -12,120.89 | -14,052.76 | -15,588.19 | -17,039.86 | 0.3062 | 0.2630 | 0.2344 | 0.2181 | 0.2043 |
| 0.30 | -9,325.61 | -13,686.27 | -16,398.51 | -18,397.32 | -20,474.77 | 0.3156 | 0.2777 | 0.2521 | 0.2326 | 0.2236 |
| *Number of departments,* $n = 6$ | | | | | | | | | | |
| Std.dev. σ 0.05 | -2,296.19 | -2,139.60 | -2,133.04 | -2,210.07 | -2,305.38 | 0.1266 | 0.0912 | 0.0761 | 0.0682 | 0.0620 |
| 0.10 | -5,349.13 | -5,610.86 | -6,014.24 | -6,410.39 | -6,785.39 | 0.1825 | 0.1431 | 0.1243 | 0.1129 | 0.1048 |
| 0.15 | -7,475.37 | -8,952.02 | -9,804.65 | -10,684.70 | -11,781.61 | 0.2083 | 0.1739 | 0.1538 | 0.1423 | 0.1352 |
| 0.20 | -8,930.24 | -11,503.24 | -13,271.66 | -14,655.92 | -15,992.54 | 0.2227 | 0.1921 | 0.1749 | 0.1621 | 0.1545 |
| 0.25 | -9,995.01 | -13,649.69 | -15,987.27 | -18,227.56 | -20,167.55 | 0.2328 | 0.2052 | 0.1882 | 0.1784 | 0.1694 |
| 0.30 | -10,757.56 | -15,293.43 | -18,398.87 | -21,002.57 | -23,606.16 | 0.2391 | 0.2144 | 0.1990 | 0.1884 | 0.1816 |

**Table A8** Forecasting error departmental ability, $T = 5$

*Average foregone NPV,* $\tilde{\Lambda}$ | *Probability for suboptimal decisions,* $\tilde{P}$

| | Average foregone NPV: Heterogeneity $\mathscr{H}$ | | | | | Probability for suboptimal decisions: Heterogeneity $\mathscr{H}$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $T = 5$ | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 | 0.50 | 1.00 | 1.50 | 2.00 | 2.50 |
| *Number of departments,* $n = 2$ | | | | | | | | | | |
| Std.dev. σ 0.05 | -941.69 | -704.76 | -635.88 | -606.57 | -606.43 | 0.1604 | 0.0986 | 0.0769 | 0.0654 | 0.0577 |
| 0.10 | -2,615.66 | -2,361.81 | -2,267.26 | -2,206.32 | -2,115.76 | 0.2697 | 0.1799 | 0.1444 | 0.1252 | 0.1073 |
| 0.15 | -3,787.90 | -4,307.47 | -4,277.77 | -4,478.32 | -4,435.87 | 0.3325 | 0.2468 | 0.1973 | 0.1754 | 0.1566 |
| 0.20 | -4,515.14 | -5,944.88 | -6,604.61 | -6,744.34 | -7,088.90 | 0.3661 | 0.2915 | 0.2475 | 0.2174 | 0.1974 |
| 0.25 | -5,064.43 | -7,279.87 | -8,322.72 | -9,079.93 | -9,729.56 | 0.3922 | 0.3278 | 0.2832 | 0.2511 | 0.2323 |
| 0.30 | -5,362.04 | -8,127.84 | -10,096.63 | -11,135.12 | -12,256.71 | 0.4095 | 0.3478 | 0.3143 | 0.2829 | 0.2634 |
| *Number of departments,* $n = 4$ | | | | | | | | | | |
| Std.dev. σ 0.05 | -1,837.91 | -1,537.40 | -1,457.16 | -1,524.87 | -1,544.04 | 0.1480 | 0.0989 | 0.0798 | 0.0708 | 0.0639 |
| 0.10 | -4,525.89 | -4,562.75 | -4,533.84 | -4,747.43 | -5,010.28 | 0.2257 | 0.1673 | 0.1382 | 0.1244 | 0.1141 |
| 0.15 | -6,477.49 | -7,663.61 | -8,036.97 | -8,563.52 | -9,080.92 | 0.2663 | 0.2133 | 0.1820 | 0.1645 | 0.1527 |
| 0.20 | -7,810.04 | -10,116.78 | -11,323.24 | -12,195.33 | -13,231.71 | 0.2907 | 0.2422 | 0.2126 | 0.1939 | 0.1819 |
| 0.25 | -8,687.44 | -11,985.93 | -14,076.64 | -15,602.15 | -17,110.52 | 0.3061 | 0.2610 | 0.2360 | 0.2174 | 0.2056 |
| 0.30 | -9,262.92 | -13,623.31 | -16,333.26 | -18,684.40 | -20,495.24 | 0.3149 | 0.2774 | 0.2523 | 0.2363 | 0.2229 |
| *Number of departments,* $n = 6$ | | | | | | | | | | |
| Std.dev. σ 0.05 | -2,301.74 | -2,107.99 | -2,099.01 | -2,210.99 | -2,286.51 | 0.1260 | 0.0914 | 0.0756 | 0.0679 | 0.0621 |
| 0.10 | -5,273.39 | -5,628.09 | -5,976.98 | -6,363.71 | -6,869.72 | 0.1805 | 0.1420 | 0.1229 | 0.1121 | 0.1052 |
| 0.15 | -7,475.46 | -8,797.72 | -9,677.08 | -10,655.59 | -11,550.72 | 0.2082 | 0.1723 | 0.1531 | 0.1410 | 0.1326 |
| 0.20 | -8,960.02 | -11,462.12 | -13,116.87 | -14,578.17 | -16,123.66 | 0.2228 | 0.1911 | 0.1737 | 0.1626 | 0.1546 |
| 0.25 | -10,041.48 | -13,732.48 | -15,947.29 | -17,976.09 | -19,873.50 | 0.2324 | 0.2052 | 0.1877 | 0.1771 | 0.1681 |
| 0.30 | -10,694.47 | -15,308.86 | -18,342.14 | -20,960.70 | -23,400.24 | 0.2385 | 0.2134 | 0.1977 | 0.1867 | 0.1805 |

**Table A9** Forecasting error departmental ability, $T = 7$

*Average foregone NPV, $\tilde{\Lambda}$*

| $T=7$ | Heterogeneity $\mathscr{H}$ 0.50 | 1.00 | 1.50 | 2.00 | 2.50 |
|---|---|---|---|---|---|
| *Number of departments, $n=2$* | | | | | |
| Std.dev. σ 0.05 | -946.07 | -712.17 | -630.05 | -604.15 | -610.96 |
| 0.10 | -2,550.00 | -2,411.19 | -2,225.10 | -2,194.67 | -2,189.59 |
| 0.15 | -3,759.97 | -4,344.57 | -4,383.19 | -4,264.13 | -4,450.66 |
| 0.20 | -4,518.97 | -5,926.57 | -6,494.50 | -6,778.68 | -7,041.77 |
| 0.25 | -5,067.90 | -7,236.84 | -8,362.59 | -9,127.75 | -9,716.09 |
| 0.30 | -5,402.04 | -8,212.18 | -9,892.30 | -11,381.68 | -12,354.07 |
| *Number of departments, $n=4$* | | | | | |
| Std.dev. σ 0.05 | -1,842.98 | -1,539.61 | -1,465.27 | -1,491.54 | -1,548.90 |
| 0.10 | -4,469.67 | -4,548.58 | -4,586.12 | -4,667.19 | -4,939.14 |
| 0.15 | -6,492.82 | -7,501.61 | -7,990.98 | -8,627.51 | -9,133.57 |
| 0.20 | -7,779.70 | -10,077.39 | -11,326.57 | -12,121.23 | -13,042.66 |
| 0.25 | -8,637.04 | -12,069.54 | -13,892.14 | -15,690.89 | -17,028.77 |
| 0.30 | -9,226.98 | -13,645.94 | -16,340.82 | -18,398.38 | -20,430.20 |
| *Number of departmentsn $n=6$* | | | | | |
| Std.dev. σ 0.05 | -2,288.44 | -2,102.90 | -2,131.77 | -2,215.74 | -2,314.35 |
| 0.10 | -5,273.01 | -5,572.41 | -5,930.30 | -6,390.97 | -6,836.69 |
| 0.15 | -7,572.72 | -8,930.07 | -9,814.68 | -10,696.62 | -11,624.71 |
| 0.20 | -9,000.28 | -11,540.85 | -13,178.09 | -14,690.36 | -16,164.54 |
| 0.25 | -9,986.56 | -13,639.92 | -15,946.68 | -17,921.73 | -19,941.63 |
| 0.30 | -10,808.69 | -15,533.86 | -18,618.56 | -21,207.78 | -23,612.29 |

*Probability for suboptimal decisions, $\tilde{P}$*

| $T=7$ | Heterogeneity $\mathscr{H}$ 0.50 | 1.00 | 1.50 | 2.00 | 2.50 |
|---|---|---|---|---|---|
| *Number of departments, $n=2$* | | | | | |
| Std.dev. σ 0.05 | 0.1600 | 0.0995 | 0.0765 | 0.0643 | 0.0580 |
| 0.10 | 0.2673 | 0.1841 | 0.1440 | 0.1235 | 0.1103 |
| 0.15 | 0.3286 | 0.2478 | 0.2014 | 0.1712 | 0.1560 |
| 0.20 | 0.3680 | 0.2927 | 0.2463 | 0.2160 | 0.1973 |
| 0.25 | 0.3959 | 0.3280 | 0.2819 | 0.2544 | 0.2331 |
| 0.30 | 0.4113 | 0.3510 | 0.3083 | 0.2855 | 0.2641 |
| *Number of departments, $n=4$* | | | | | |
| Std.dev. σ 0.05 | 0.1482 | 0.0989 | 0.0806 | 0.0697 | 0.0640 |
| 0.10 | 0.2237 | 0.1679 | 0.1391 | 0.1231 | 0.1144 |
| 0.15 | 0.2665 | 0.2100 | 0.1812 | 0.1644 | 0.1529 |
| 0.20 | 0.2895 | 0.2411 | 0.2132 | 0.1929 | 0.1805 |
| 0.25 | 0.3052 | 0.2610 | 0.2338 | 0.2187 | 0.2046 |
| 0.30 | 0.3136 | 0.2777 | 0.2515 | 0.2333 | 0.2224 |
| *Number of departmentsn $n=6$* | | | | | |
| Std.dev. σ 0.05 | 0.1259 | 0.0911 | 0.0757 | 0.0674 | 0.0620 |
| 0.10 | 0.1812 | 0.1416 | 0.1229 | 0.1122 | 0.1047 |
| 0.15 | 0.2083 | 0.1728 | 0.1536 | 0.1414 | 0.1333 |
| 0.20 | 0.2229 | 0.1917 | 0.1730 | 0.1618 | 0.1538 |
| 0.25 | 0.2323 | 0.2045 | 0.1875 | 0.1760 | 0.1685 |
| 0.30 | 0.2388 | 0.2149 | 0.1984 | 0.1878 | 0.1804 |