Intertemporal capital budgeting

Andrew H. Roper [a], Martin E. Ruckes [b],*

[a] *Cornerstone Research, 1000 El Camino Real, Menlo Park, CA 94025, United States*
[b] *Karlsruhe Institute of Technology (KIT), Kaiserstrasse 12, 76131 Karlsruhe, Germany*

ARTICLE INFO

ABSTRACT

This paper analyzes the optimal capital budgeting mechanism when divisional managers are privately informed about the arrival of future investment projects. Consistent with field study evidence, an optimal allocation mechanism can include a stipulation that a capital request for discretionary investment will be declined with positive probability in the period after a significant investment was made even though this is *ex post* suboptimal. The model derives a number of empirical predictions regarding capital budgeting and the investment of financially constrained firms.

© 2012 Elsevier B.V. All rights reserved.

1. Introduction

In determining the allocation of a firm's scarce capital budget, headquarters weighs investment alternatives identified by informed division managers. In some cases, the best alternative is a competing project that occurs contemporaneously. However, the best alternative use of the firm's capital is often an investment opportunity that arrives with uncertainty in the future. Therefore, even if headquarters can costlessly monitor the quality of all projects proposed by division managers, division managers may still possess an information advantage with respect to the likelihood that profitable opportunities are on the horizon. Division managers may, for example, know more than headquarters about subtle changes in customer demand. Those changes do not necessarily warrant an immediate response entailing capital investment, but, if they turn out to be permanent or become more pronounced, do so in the future. Division managers are also likely to be better informed than headquarters about the probability of market entry or exit, quality or pricing adjustments of existing competitors, or new production technologies in development. Any of these changes in market structure may involve capital investment in the future. Without this information, headquarters cannot efficiently allocate its scarce capital today. This paper is concerned with identifying the optimal capital budgeting strategies of headquarters in such settings.

Informed division managers are not likely to credibly communicate the likelihood of future profitable investment opportunities. Even though division managers may benefit from profitable projects, their investment incentives are often not perfectly aligned with those of headquarters. For example, a division manager obtains utility not only when the project is profitable but also derive private benefits that increase with the amount of resources under their control. This agency problem creates an incentive for a division manager to understate the probability of profitable future projects in financially constrained firms: smaller future investment needs increase the capital allocated to current projects as capital conservation concerns are diminished. In such circumstances, the capital allocation mechanism serves not only the purpose of allocating capital efficiently but may also be designed to elicit information about the probability of new projects in the future from a privately informed division manager.

We show that in these circumstances headquarters frequently finds it optimal to grant a capital request for a discretionary project under the condition that the division accepts that positive net present value discretionary projects will be rejected in the second period with some pre-announced probability. Such an intertemporal capital allocation mechanism restricts the level of overall investment in the division and therefore limits the need to raise costly external capital. In addition, this policy enables headquarters to induce the truthful revelation of the division manager's assessment of the division's investment outlook.

Under such a rule, a division manager who expects a profitable project in the coming period has the incentive to pass up the current marginal discretionary project, because accepting it implies

* Corresponding author. Tel.: +49 721 608 43427; fax: +49 721 359 200.
E-mail addresses: aroper@cornerstone.com (A.H. Roper), martin.ruckes@kit.edu (M.E. Ruckes).

foregoing a high level of expected utility from investing next period. A manager who associates a low probability to having a profitable project next period prefers to accept the capital allocation in the current period. This truthful revelation allows headquarters to reduce the hurdle rate in the current period as the division manager accepts a grant when he predicts a low probability of investment. The cost of such an intertemporal capital allocation mechanism is that headquarters may deny funding to second-period projects that are value enhancing when judged as stand-alone projects.

We show that dynamic capital allocation mechanisms are expected to be frequently found in firms facing financial constraints. Ross (1986) describes how the degree of financial constraints affects the type of capital budgeting mechanism employed within the firm. He finds that more financially constrained firms tend to not allocate capital according to posted hurdle rates but through a process in which projects compete for allocation from a fixed budget. If a division wants to fund projects beyond its typical allocation, the division uses up "credit" with headquarters. The latter indicates that it is impossible for a division to receive additional funds every period, but rather that there is a limit to how often an additional budget will be available. Thus, such a policy is an example of a capital allocation mechanism that makes it harder to receive capital after a period of large investment as described in this paper.

While it is not surprising that capital preservation considerations are more important in firms with tighter financial constraints, our results are consistent with the empirical result that when a significant investment is observed in a division, it takes on average longer to observe another large investment when, ceteris paribus, financial constraints are more severe (Whited, 2006). In our model, since the dynamic capital allocation mechanism reduces the expected size of next period's budget whenever a significant investment is made in the current period, a larger fraction of overall investment in a division (or plant) is concentrated in one period. Thus, the model demonstrates how a dynamic capital allocation mechanism can lead to "lumpy" intertemporal investment flows (Doms and Dunne, 1998; Cooper et al., 1999).

When the firm's financial constraint becomes binding because of profitable investment opportunities in other divisions, the optimal dynamic capital budgeting process implies that headquarters moves resources away from divisions plagued by asymmetric information and towards other divisions. Thus, it is relatively likely that after investing in a significant project in one division, the next large investment will be in a different one.

A growing literature examines capital allocation mechanisms in internal capital markets. Our paper is most closely related to the literature that analyzes capital allocation rules of headquarters subject to agency problems or asymmetric information. This literature typically describes capital allocation mechanisms when divisional managers have a preference for capital and private information about the quality of *current* investment opportunities. Harris et al. (1982) and Antle and Eppen (1985) focus on transfer prices to allocate capital across divisions, Harris and Raviv (1996, 1998) and Malenko (2012) study the possibility of costly monitoring and Zhang (1997) and Bernardo et al. (2001) analyze situations in which managers are also expected to exert value-enhancing effort. Stoughton and Zechner (2007) study capital allocation in financial firms where capital is related to risk. Different from these papers, Berkovitch and Israel (2004) assume that headquarters can costlessly observe the quality of all projects presented to it. In their model, a manager can, however, hide projects that are more profitable to the firm's owners and less valuable to themselves. The authors show that in this context the net present value criterion maybe inefficient in determining capital budgets and alternative criteria are preferred. We introduce asymmetric information about

the probability of future project arrival. This renders our setting inherently dynamic and leads to a dynamic capital allocation mechanism.

Harris and Raviv (1998) also discuss a dynamic capital allocation mechanism. They argue that when monitoring project quality is costly for headquarters, it may be optimal to allow divisions to "roll over" capital budgets to future periods. This rollover of unused funds reduces a division manager's incentive to invest immediately as the funds are certain to be available in the future. Malenko (2012) shows that with costly auditing the optimal arrangement may be to provide the manager with a discretionary spending account that he can use to finance investment projects. In our setting, headquarters will never delegate the investment decision to the division manager because headquarters is fully informed about project quality at the time of the investment decision. In addition, our model examines the relation between the degree of financing constraints and the extent to which a dynamic capital allocation mechanism is optimal.

A strand of literature analyzes the extent to which delegation of capital budgeting decisions within the firm can lead to increased investment efficiency (see Harris and Raviv, 1998, 2005; Marino and Matsusaka, 2005; Ozbas, 2005). In our setup it is never optimal to delegate investment authority as informational problems can be addressed more efficiently by introducing dynamic capital allocation mechanisms.

The remainder of the paper is organized as follows: Section 2 outlines the model and Section 3 describes the optimal capital allocation in the benchmark case of symmetric information about the probability of the arrival of a profitable future project. Section 4.1 shows how capital is optimally allocated when the division manager is better informed about the project arrival rate and headquarters lacks the power to commit to restricting its action space in the future. Section 4.2 allows for such commitment and derives predictions regarding the capital budgeting of firms. Section 5 describes empirical predictions for corporate investment. Section 6 concludes.

2. Model

2.1. Players

We model a firm with a headquarters and one division operating over two periods. Headquarters has access to capital but possesses relatively coarse information about second-period investment opportunities. The division is headed by a manager who has private information regarding the arrival rate of investment projects but has no access to capital on his own. Headquarters would like to use the manager's private information to allocate capital across the two periods, but the manager has preferences that prevent him from revealing his information truthfully unless provided with incentives to do so. Our objective is to characterize the capital budgeting mechanism that maximizes expected profits to shareholders.

2.2. Investment opportunities

At the beginning of each of two periods, $t = 0, 1$, the division manager identifies an investment project. Each project requires a capital outlay of one unit and yields a positive gross cash flow at the end of the second period, $t = 2$. The cash flow of the first-period project is labeled $b_1 > 0$. We also assume that the first-period project has to be initiated at $t = 0$ to yield b_1. If delayed, its cash flow is non-positive. At $t = 1$ a profitable project may be available. Its cash flow is denoted by b_2 and the project is available either with probability 1 (which we will refer to as favorable investment outlook) or with probability $p \in (0, 1)$ (unfavorable investment outlook).

2.3. Capital budget

Headquarters is endowed with one unit of capital and has access to an additional unit of capital at a cost $c > 0$, i.e., headquarters faces a "soft capital constraint". The additional cost may result from informational asymmetries associated with accessing external finance.[1] Since we are interested in the internal allocation of capital within the firm, we assume the manager can only obtain capital from headquarters.

2.4. Preferences

Both headquarters and the division manager are risk neutral. We assume headquarters maximizes the net present value of investment. Headquarters' utility U^H is defined as

$$U^H = \begin{cases} (b_1 - 1) & \text{when headquarters funds first-period investment} \\ (b_2 - 1) & \text{when headquarters funds second-period investment} \\ (b_1 - 1) + (b_2 - 1 - c) & \text{when headquarters funds first- and second-period investment} \end{cases}$$

Whenever headquarters chooses to fund only one investment project, either first- or second-period investment but not both, the cost of investment is 1. However, when headquarters chooses to fund both first- and second-period investment projects, headquarters must raise additional capital at cost c. Hence, the cost of capital is path-dependent and varies across headquarters' time horizon.

To introduce a preference for capital allocation in a simple way, the division manager is assumed to ignore the cost of investment and to obtain a private, non-contractible benefit proportional to gross project cash flow. [2] Division manager utility U^M is defined as

$$U^M = \begin{cases} qb_1 & \text{when headquarters funds first-period investment} \\ qb_2 & \text{when headquarters funds second-period investment} \\ q(b_1 + b_2) & \text{when headquarters funds first- and second-period investment} \end{cases}$$

where q is a positive constant. Because the manager ignores the cost of investment, he prefers to submit all projects for approval to headquarters regardless of their economic value.

2.5. Information

In order to focus on the role of financial constraints on capital budgeting, we abstract from costly monitoring and assume that headquarters can observe project cash flows at no cost during the process of a capital request by the division manager. There remains, however, one informational advantage of the manager at $t = 0$. At $t = 1$ a profitable project is observed either with probability 1 or with probability p. While the manager knows perfectly whether the investment opportunity arises with probability 1 or with probability p, headquarters *ex-ante* assigns a probability of 0.5 to each of the two investment outlooks.

2.6. Sequence of actions

Fig. 1 provides a time line for the model. At the beginning of the first period, $t = 0$, the division manager learns the cash flow of the first period project to be received at $t = 2$. As monitoring by headquarters is perfect and without cost, we assume that headquarters observes the level of project cash flows as well. Based on this information, headquarters announces a rule according to which capital is allocated. In the analysis we distinguish whether this rule can credibly govern also the capital allocation at $t = 1$ or not. This rule may or may not distinguish between investment outlooks. As the investment outlook is private information to the divisional manager, the capital allocation can only be based on the outlook reported by the manager. Afterwards, money is potentially transferred to the division and if so, investment takes place.

At $t = 1$, the division manager and headquarters learn whether a profitable project is available. The realization of the cash flow is governed by the random variable characterizing a favorable or an unfavorable investment outlook. Then, headquarters possibly allocates capital to the division and investment takes place.

At $t = 2$, the cash flows from the projects are realized.

In our analysis, we impose the parametric assumption that $b_2 > 1 + c$. If this restriction is violated, it is never optimal to invest in both periods. Such a "hard capital constraint" is straightforward to analyze and does not permit interesting capital allocation mechanisms.

In the model, headquarters must decide whether or not to fund proposed projects using its existing unit of capital and its ability to raise additional capital at cost c. In formulating its decision, headquarters' strategy space includes the determination of hurdle rates for investment projects in both periods.[3] These hurdle rates may potentially be large, i.e., headquarters may decide to deny a project funding regardless of the level of its payoff.

In defining headquarters' capital allocation mechanism, we examine mechanisms that foster separation and those that do not. Capital budgeting mechanisms that lead to separation impose certain costs on the division manager. Mechanisms that do not foster separation impose no costs on the division manager, but can imply costs associated with asymmetric information on behalf of headquarters. We are interested in when headquarters finds it optimal to employ a separating mechanism at date 0 that restrict its flexibility to accept or reject funding proposals at date 1.

All proofs of formal results are in the appendix.

---

[1] Alternatively, the additional cost can be interpreted as the net present value lost in reallocating capital within the firm. We discuss the implications of such an interpretation in Section 5.2.

[2] This assumption is standard in the internal capital markets literature. See, for example, Stein (1997).

[3] Because we assume there is no cost associated with monitoring project cash flows, headquarters capital allocation schemes will always employ monitoring with probability one. Thus, auditing constitutes a trivial part of headquarters strategy space. In Harris and Raviv (1996, 1998), auditing is costly. Hence, headquarters' strategy space includes the monitoring probability, the amount of capital allocated with no monitoring, and the amount of capital allocated with monitoring.
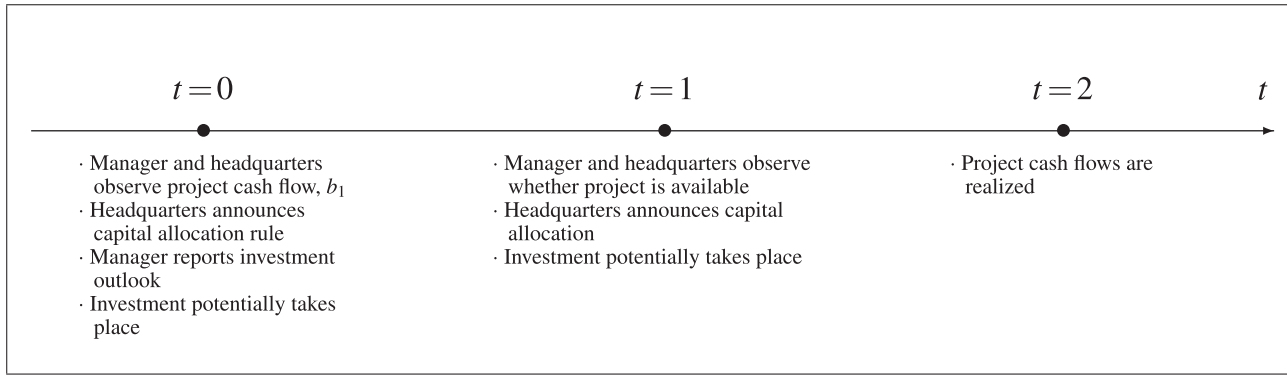
Fig. 1. Timing of decisions.

3. Benchmark case: symmetric information

Before analyzing headquarters' capital allocation problem under asymmetric information, we consider the allocation of capital when headquarters knows as of $t = 0$ the investment outlook for investment in the second period as a benchmark. Headquarters faces two choices as of $t = 0$: reserve the unit of endowed capital and focus on the potentially higher returns whenever the second-period project is available or use the unit of endowed capital to fund b_1 and raise additional capital in the event of a second-period investment opportunity.

Suppose the investment outlook is favorable. In this case, headquarters will accept the proposal for period one investment provided that the following condition holds

$$(b_1 - 1) + (b_2 - 1 - c) \geqslant (b_2 - 1). \tag{1}$$

The left hand side of Eq. (1) is the net present value of accepting the manager's first-period proposal of b_1 and accepting the second-period project proposal resulting in b_2. Since headquarters uses its unit of endowed capital to fund the first-period project, it must obtain additional capital at cost c to fund the second-period project. The second-period project is profitable, because of the parametric assumption $b_2 > 1 + c$. The right hand side of Eq. (1) is the net present value from rejecting the manager's first-period capital proposal and using the unit of endowed capital to fund the second-period project that returns b_2.

By rearranging (1), we can identify the hurdle level for first-period project cash flows when the investment outlook is favorable, b^G, as $b^G = 1 + c$. For all $b_1 \in [b^G, \infty)$, headquarters provides funding for the first-period project. Similarly, when the economic outlook is unfavorable, the hurdle rate for first-period projects is $b^B = 1 + pc$. Note that the thresholds b^G and b^B depend only indirectly on the level of the second-period revenue, b_2, via the restriction $b_2 > 1 + c$.

Due to headquarters' capital conservation considerations the hurdle level is higher than the myopic level of 1 in both environments. The hurdle rate for first-period projects is higher whenever the investment outlook is favorable. Knowing the investment outlook is favorable, headquarters realizes it is more likely to need capital for investment in the second period.

This implies that for $b_1 \in (b^B, b^G)$, the expected investment level of a firm facing a favorable investment outlook is lower than that of one with an unfavorable outlook. This is a consequence of the firm's dynamic capital preservation motive; such a behavior would not be optimal in a static setting.[4] This result implies that in the presence of capital preservation concerns firms with higher book-to-market ratios due to better future investment opportunities may not display higher investment levels on average.

4. Asymmetric information about investment prospects

Consider a situation in which $b_1 \in (b^B, b^G)$ and headquarters applies the capital budgeting rule as specified in the section above. When the manager is privately informed about the investment outlook for the second period, he will not truthfully disclose a favorable investment outlook. This follows from a comparison of the manager's expected utility from truthful reporting, qb_2, and from misrepresenting the investment outlook, $q(b_1 + b_2)$. The latter is strictly larger as the manager prefers more investment to less and reporting an unfavorable outlook lowers the hurdle rate for first-period investment. Thus, in contrast to static models of capital allocation where headquarters devises mechanisms to overcome managers' overly optimistic portrayals of current investment opportunities (for example, Harris and Raviv, 1996) and/or fight suboptimally low managerial effort (for example, Bernardo et al., 2001), in a dynamic context headquarters has to guard against managers' understatement regarding future investment needs.

In the following, we first analyze headquarters' optimal policy when it is unable to commit to a second-period policy as a function of first-period capital allocation. Afterwards we allow headquarters to commit to such a policy.

4.1. Capital allocation under asymmetric information without commitment

Headquarters understands the incentive to understate the investment outlook and assigns equal probability to both investment outlooks, favorable and unfavorable, whenever managers are privately informed and headquarters does not provide managers with sufficient incentives to truthfully disclose the state of the world. Whenever headquarters lacks the possibility to commit to an intertemporal capital allocation schedule, in the second period it will always decide to allocate capital whenever a profitable project is available, because $b_2 > 1 + c$. Then, its only instrument to take into account the informational asymmetry is to adjust the hurdle level for b_1. It is straightforward to verify that in this case for $b_1 \in (b^B, b^G)$ truthful reporting by both parties cannot be achieved except for the case in which the investment policy for both reported states is identical. Thus, both possible types of managers are effectively pooled together. As a consequence, under asymmetric information, the hurdle rate for first-period investment is determined by the following condition:

$$(b_1 - 1) + \frac{1}{2}(1 + p)(b_2 - 1 - c) \geqslant \frac{1}{2}(1 + p)(b_2 - 1). \tag{2}$$

---

[4] To the contrary, in a repeated static setting without capital preservation concerns and constant investment opportunities, a high level in the current period indicates a high investment in the future.

Eqs. (2) and (1) are similar. The only difference being, in the present case, headquarters does not know with certainty the investment outlook and assigns equal probability to both favorable and unfavorable outlooks.

By rearranging (1), we identify the hurdle rate for first-period investment projects when managers are privately informed, i.e., $b^{NC} = 1 + \frac{1}{2}(1 + p)c$. This hurdle rate can be used to implement a capital allocation mechanism when division types are pooled. Headquarters provides funding for all first-period projects with returns $b_1 \geqslant b^{NC}$. For $b_1 < b^{NC}$, headquarters denies funding for first-period projects.

Whenever headquarters is uninformed about the future investment outlook, the hurdle rate for first-period projects lies between the hurdle rates under symmetric information described previously. This new hurdle rate has implications for the utility of both parties and the amount of investment observed in equilibrium. For a given b_1, the manager's expected utility as well as the expected investment level may be below or above those in the first-best case.

4.2. Capital allocation under asymmetric information with commitment

The capital allocation process described in the previous section does not allow headquarters to commit to a decision rule for allocating capital in the second period.

In this section, we analyze whether there exists a capital allocation mechanism that allows headquarters to improve the efficiency of capital allocation when managers are privately informed. In order to improve investment efficiency, headquarters must devise a capital allocation mechanism that leads to truthful revelation of the future investment outlook by managers despite possibly implying no first-period funding in case of a favorable outlook. Such a mechanism requires the ability for headquarters to commit to tie the second-period capital allocation to the capital allocation in the first period. Because the resulting capital allocation in the second period is optimal *ex ante* but not *ex post*, any intertemporally committing mechanism is only feasible when there exists a credible commitment device or in which similar decisions occur repeatedly and a reputation can be established.[5]

To improve upon the capital allocation by funding a first-period project only when the investment outlook is unfavorable, headquarters must design a mechanism which discourages misrepresentation of investment prospects by managers with favorable investment outlooks. In line with a significant fraction of the internal capital markets literature we focus on non-monetary incentive mechanisms and abstract from financial incentive contracts.

To achieve truthful reporting, headquarters can use the following two instruments: (1) For a given level of first-period cash flow, b_1, headquarters determines the probability of allowing the manager to invest in the first period. (2) Headquarters declines to provide funding in the second period with a certain probability even if a profitable project is available. Each instrument can be applied differently for the two reported investment outlooks. Define $a_G \in [0,1]$ and $a_B \in [0,1]$ as the probabilities that headquarters funds a first-period project with given cash flow b_1 when the manager reports a favorable and an unfavorable outlook, respectively, and $d_G \in [0,1]$ and $d_B \in [0,1]$ as the probabilities that headquarters declines funding to a profitable second-period project when the manager reports a favorable and an unfavorable investment outlook, respectively.[6]

Headquarters uses these acceptance and denial probabilities in order to achieve truthful revelation of the investment outlook. The maximization problem of headquarters can be written as

$$\max_{a_G, d_G, a_B, d_B} \frac{1}{2}\left[a_G(b_1 - 1) + (1 - d_G)(b_2 - 1) - a_G(1 - d_G)c\right]$$

$$+ \frac{1}{2}\left[a_B(b_1 - 1) + p(1 - d_B)(b_2 - 1) - pa_B(1 - d_B)c\right] \quad (3)$$

s.t.

$$q(a_G b_1 + (1 - d_G)b_2) \geqslant q(a_B b_1 + (1 - d_B)b_2) \quad (4)$$

$$q(a_G b_1 + p(1 - d_G)b_2) \leqslant q(a_B b_1 + p(1 - d_B)b_2) \quad (5)$$

$$0 \leqslant a_G, a_B \leqslant 1 \quad (6)$$

$$0 \leqslant d_G, d_B \leqslant 1 \quad (7)$$

The incentive compatibility constraint in Eq. (4) ensures that managers with favorable investment opportunities do not misrepresent their true investment opportunities. By truthfully reporting their investment opportunity and foregoing investment today with probability $(1 - a_G)$, managers with favorable investment opportunities receive funding in the second period for b_2 with probability $(1 - d_G)$. The incentive compatibility constraint in Eq. (5) ensures the managers with unfavorable investment opportunities do not overstate their investment outlook.

The possible optimal capital allocation rules derived in Section 4.1 when commitment is impossible are given by $((a_G, d_G), (a_B, d_B)) = ((0,0), (0,0))$ for $b_1 < b^{NC}$ and $((a_G, d_G), (a_B, d_B)) = ((1,0), (1,0))$ for $b_1 \geqslant b^{NC}$. Note that both of these rules fulfill the incentive compatibility constraint of the manager for both investment outlooks. A benefit of commitment can only be achieved when investment policies are different for the different outlooks. In the remainder of this paper we refer to a policy rule that creates truthful reporting *while establishing different investment policies for the two investment outlooks* as intertemporal separation. Establishing such a rule may provide a benefit to headquarters only for the parameter range in which the first best policy includes differential investment, $b_1 \in (b^B, b^G)$. Thus we restrict our analysis to that set of parameters.

The resulting equilibrium is characterized in the following proposition.

Proposition 1. *For* $b_2 > \frac{p(2 + (1+p)c)(1+c)}{p(2 + (1+p)c) - (1-p)c} \equiv \hat{b}_2$, *headquarters' allocation policy when commitment is possible is identical to the policy when commitment is impossible.*

For $b_2 \leqslant \hat{b}_2$, *headquarters' allocation policy when commitment is possible is*

$$((a_G, d_G), (a_B, d_B)) = \begin{cases} ((0,0), (0,0)) & \text{for } b_1 \in \left(1 + pc, \dfrac{1+pc}{1 - p\left(1 - \frac{1+c}{b_2}\right)}\right) \\[3mm] \left((0,0), \left(1, \frac{b_1}{b_2}\right)\right) & \text{for } b_1 \in \left[\dfrac{1+pc}{1 - p\left(1 - \frac{1+c}{b_2}\right)}, \dfrac{1+c}{1 + p\left(1 - \frac{1+c}{b_2}\right)}\right] \\[3mm] ((1,0), (1,0)) & \text{for } b_1 \in \left(\dfrac{1+c}{1 + p\left(1 - \frac{1+c}{b_2}\right)}, 1 + c\right) \end{cases}$$

If $b_2 \leqslant \hat{b}_2$, intertemporal separation may be optimal. It is achieved by declining to fund a second-period project with probability b_1/b_2 in case of an unfavorable investment outlook. Doing so allows headquarters to decline first-period funding if the investment outlook is favorable by maintaining the manager's incentive to report truthfully. Thus, the model is able to rationalize a capital budgeting process where upon a significant capital allocation to a division headquarters will unlikely provide a large capital allocation in the period thereafter. This is consistent with Ross (1986) who provides

---
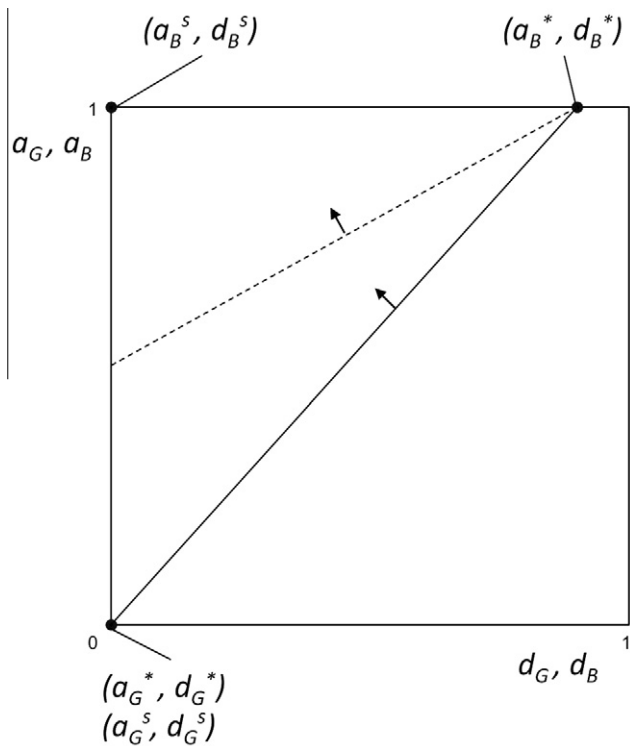
Fig. 2. The figure depicts headquarters' optimal policy choices under symmetric information, $\left(a_G^S,\ d_G^S\right)$ and $\left(a_B^S,\ d_B^S\right)$, and under asymmetric information with commitment and intertemporal separation, $(a_G^*,\ d_G^*)$ and $(a_B^*,\ d_B^*)$. The figure also shows the indifference curves relevant to the division manager with favorable (solid line) and unfavorable investment prospects (dashed line), respectively, under headquarters' policy of intertemporal separation; arrows indicate the direction of higher managerial utility. Parameters used: $p = 0.5$, $c = 0.2$, $b_1 = 1.125$, $b_2 = 1.25$.

field study evidence that firms with financial constraints do not set hurdle rates for project approval but rather provide limited budgets to divisions. These budgets are only initially fixed: "If division management wanted to, they could increase capital allocation by making a good case for it. But this would require a major effort and would use up some of the division's "credit" with corporate headquarters (Ross, 1986)". The latter statement indicates that albeit increasing current capital allocation is possible, it comes with a cost to the division. As credit with headquarters is not unlimited, a current increase in the division's capital budget makes it harder to obtain capital in the future. This dynamic component of the capital budgeting process may well serve as the instrument to distinguish between those divisions that have a high likelihood of profitable future projects and those that do not.

It is never optimal to complement declining second-period funding in case of an unfavorable outlook by accepting a first-period project with positive probability if the investment outlook is favorable. In order to avoid underreporting of investment prospects, headquarters restricts access to second-period capital for a manager with an unfavorable outlook rather than allowing a manager with a favorable outlook to invest some of the time. The reason is that whereas a change in d_B affects the incentive constraint of both manager types differently, this is not the case for a change in a_G (see constraints (4) and (5)). This implies that a policy of intertemporal separation leads to underinvestment relative to the level under symmetric information.

Fig. 2 illustrates headquarters' considerations by depicting first-period project acceptance probabilities and second-period project rejection probabilities for the two types of divisional managers.

Points $\left(a_G^S, d_G^S\right)$ and $\left(a_B^S, d_B^S\right)$ characterize headquarters' optimal policies under symmetric information for a division with favorable and with unfavorable investment prospects, respectively. As division manager types' indifference curves show, this policy cannot be implemented under asymmetric information, because both types receive a higher utility at $\left(a_B^S, d_B^S\right)$. With a slope of b_2/b_1, the indifference curve of the manager with a favorable investment outlook is the steeper of the indifference curves. Thus, that manager's incentive compatibility constraint (4) is the binding one in an equilibrium allocation with intertemporal separation. For the parameter values of b_1 satisfying the restrictions in the middle segment of the equation in the proposition, the firm's maximum expected profit is reached by maintaining the optimal policy for the manager with favorable prospects, $(a_G^*, d_G^*) = \left(a_G^S, d_G^S\right)$, and adjusting the policy for the manager with unfavorable prospects, (a_B^*, d_B^*), such that (4) is satisfied with equality. If b_1 exceeds $(1 + c)/\left(1 + p\left(1 - \frac{1+c}{b_2}\right)\right)$, the firm's expected profit increases as the policy combination moves along the indifference curve of the manager with favorable prospects towards the left upper corner. Because expected profits vary linearly with changes in the policy combination, headquarters' optimal policy is to offer an identical policy for both manager types investing with probability one in the first period and in the second period whenever a project is available, $((a_G, d_G),\ (a_B, d_B)) = ((1,0),\ (1,0))$. If b_1 is small, $b_1 < (1 + pc)/1 - p\left(1 - \frac{1+c}{b_2}\right)$, the inefficiency generated by implementing a policy with a significant probability of declining a second-period project for the manager with an unfavorable investment outlook, (a_B^*, d_B^*), is too large such that headquarters declines to invest in the first period and accepts second-period project proposals of both manager types $((a_G, d_G),\ (a_B, d_B)) = ((1,0),\ (1,0))$.

If b_2 exceeds the threshold $\hat{b}_2$, intertemporal separation is not desirable from headquarters' point of view as the alternative allocation policies are more profitable. This implies that headquarters does not apply a "policy of dynamic rationing" in divisions or units whose (unplanned) investment opportunities are typically large in profitability. One example for this are the production units of firms, in which unscheduled investment opportunities typically arise if machines break down and it is very costly for the firm to not replace the machine. Then, even if unit management is privately informed about the probability of machine breakdowns, headquarters refrains from eliciting unit management's information by creating intertemporal separation. In contrast, headquarters tends to apply a policy of dynamic rationing in divisions with predominantly discretionary investment opportunities. The result that b_2 cannot be too large for a policy of dynamic rationing to be optimal implies also that such policies tend to be applied in firms of at least a certain degree of maturity rather than in young firms with strong growth, where investment opportunities are highly profitable.

5. Implications for corporate investment

Besides providing predictions regarding the use of intertemporal budgeting processes, the model has a number of implications for the investment of financially constrained firms.

5.1. Investment and financial constraints

Relative to exclusively setting hurdle rates, intertemporal separation tends to concentrate investment in one of the two periods as it reduces the probability of investment in the period after a

substantial capital allocation. Empirical studies document that at the plant level a large percentage of investments occurs in very few years. For example, Doms and Dunne (1998) report that from 25% to 40% of an average plant's cumulative investment over 17 years is concentrated in a single year. Our results suggest that internal capital allocation procedures may affect the level of the "lumpiness" of investment as such rules tie the probability of future investment to the current capital allocation. Macroeconomic models generate this lumpiness of investment by assuming a linear or convex cost of adjusting the capital stock (see, for example, Cooper et al., 1999). This model suggests that capital budgeting processes that combat problems of asymmetric information may contribute to the existence of adjustment costs.

Using an intertemporal capital budgeting process is more attractive for firms facing more severe capital constraints. This affects investment as described in the following result:

Corollary 1. *Consider two levels of severity of financial constraints, $0 \leqslant c^- < c^+ \leqslant b_2 - 1$.*

For a given set of remaining parameters, suppose an investment takes place in the first period for both c^- and c^+. Then, the probability of an investment in the second period for c^- is larger or equal to that for c^+, with a strict inequality for a non-empty set of remaining parameters.

The corollary states that more severe financial restrictions tend to reduce the probability of a second-period investment if a significant first-period investment takes place. This result implies that on average an increase in the severity of financial constraints increases the expected time between significant investments. Whited (2006) empirically distinguishes between firms with more and less severe financial restrictions by examining whether a business has recently paid dividends, is smaller or operates on a stand-alone basis (rather than being a division of a conglomerate). She indeed documents that firms with more severe financial constraints display larger time intervals between large investments. Note that in our setting the result follows purely from an optimal decision by headquarters to switch to a capital allocation process with dynamic rejection. In other words, this result does not hold under symmetric information or under asymmetric information without commitment.

The choice of capital budgeting process influences the expected relative investment volumes for the two different investment outlooks.

Corollary 2. *When headquarters chooses to not implement a policy of intertemporal separation, the expected investment volume is higher for the favorable investment outlook than for the unfavorable outlook. The opposite holds when an intertemporal separation policy is implemented.*

This result implies that among firms that do not apply budgeting policies of dynamic rationing, such as firms with strong growth, the empirical relationships between the quality of investment opportunities and the actual investment levels is stronger than among firms that tend to use intertemporal separation policies, such as somewhat mature firms. If for such firms markets form opinions about investment prospects from current investment, a significant investment in a moderately profitable project indicates a low arrival rate of a more profitable project in the future. Headquarters of a firm with a high probability of a more profitable investment opportunity finds it optimal to not invest. Thus, an investment may negatively affect valuation. This bears some resemblance to Carlson et al. (2004) who show that an investment as a result of exercising a timing option tends to provide negative information about firm value and where a firm's refraining from making an investment tends to be perceived positively. The implication is typically different, however, from a set-

ting without capital preservation concerns. Then, the firm invests in each profitable project available. If, as in our model, having a moderately profitable investment is uninformative about future opportunities, the investment in such a project itself is not a negative signal.[7]

5.2. Implications for investment in multi-division firms

Alternatively to representing the cost of raising a unit of external funds, the cost of capital of a second unit of investment, c, can be understood as the profitability of an investment opportunity in the second period of a second division with an investment amount of one and a return of $1 + c$. The firm is assumed to have two units of capital and no access to external finance. Thus, the second division's project will have to be passed up if the first division implements two projects.

Implicit in the present formulation is that c is common knowledge and the second division is not affected by a problem of asymmetric information as the first division is. This model structure is obviously quite specific, but it allows us to capture in a simple way that divisions are associated with different degrees of problems of asymmetric information. The first division is one where headquarters faces its share of surprises and where division management that receives information relatively early on enjoys a material information advantage. In the second division investment opportunities can be predicted accurately. Thus, it may be a division that operates in a mature industry.

Consider first the investment amounts of the two divisions under symmetric information. In case of a favorable investment outlook no investment is made in the first period and each division invests one unit in the second period. If the investment outlook is unfavorable, the first division invests one unit in the first period and one unit in the second with probability p, i.e. if a project is available. The second division invests one unit in the second period with the complementary probability $(1 - p)$.

Under asymmetric information and a policy of intertemporal separation, investment is identical to that under symmetric information if the investment outlook is positive. If investment prospects are unfavorable, the first division still invests one unit in the first period, but one unit in the second period only with probability $\left(1 - \frac{b_1}{b_2}\right) p < p$. Again, the second division's second-period investment is one unit with the complementary probability $1 - \left(1 - \frac{b_1}{b_2}\right) p > (1 - p)$. The following corollary summarizes this investment behavior:

Corollary 3. *Suppose parameters are such that headquarters implements a policy of intertemporal separation in the first division. If the first division invests in the first period, the firm is more likely to invest in the second division in the second period than under symmetric information.*

This implies investment distortions in financially constrained multi-division firms take the form that after a significant capital investment in one division, the firms tends to invest available capital in a different division next (relative to its allocation under symmetric information). Doing so keeps a division from requesting in the present capital when it is likely that it can be used even more effectively in the future.

---

[7] If, however, an investment of moderate profitability provides negative information to the market about the *quality* of future investments, headquarters may ration capital in case of poor prospects. Then, first-period investment may indicate an increased probability of second-period investment.

6. Concluding remarks

This paper demonstrates that, consistent with field study evidence, firms facing capital restrictions can find it optimal to stipulate that after a division accepts a significant capital allocation it will likely have to wait some time until it receives another significant allocation (a policy of dynamic rationing). This result is based on the notion that in the agency relationship between headquarters and divisional managers headquarters has to guard against the understatement of tomorrow's investment prospects. The described policy leads the division manager to disclose his information about the extent of future investment opportunities.

The budgeting policy of dynamic rationing is consistent with empirical evidence that investment at the plant level is concentrated in few periods, that firms facing ceteris paribus more severe financial constraints display more periods of idleness after significant investments and that firms bias investment towards divisions with weaker investment opportunities.

The paper's results are derived under the assumption that the divisional manager's compensation cannot be made contingent on the manager's report regarding the division's investment outlook. Allowing compensation to depend on this report would provide headquarters with an additional instrument to elicit truthful reporting. Even though the manager's limited liability may render contingent compensation relatively costly in certain circumstances, an optimally chosen compensation contract is likely to diminish investment distortions.

Implementing a policy of dynamic rationing may provide benefits to the firm beyond those captured in the model. While intertemporal separation requires that the divisional manager know his type, this is not the case under the alternative policies. Thus, a policy of dynamic rationing incentives for managers to identify their investment outlook. In the case of a positive investment outlook this leads to a perfect forecast of second-period investment. One advantage of this may be that communication with capital markets becomes more effective and may provide long-term benefits for the firm.

In this paper we consider the existence of a second division only in a specific way. A generalization of the setting would potentially prove economically interesting. For example, the existence of multiple divisions may affect the possibility for headquarters to commit to a policy of dynamic rationing. With multiple divisions, several budgets have to be allocated in each period, which may increase headquarters' possibility to acquire a reputation for intertemporal separation. However, with multiple divisions, the budgeting process becomes more complex and transparency may be reduced for divisional managers. This would make it harder for headquarters to commit to applying a policy of dynamic rationing. As there is uncertainty about the other divisions' investment outlooks, the existence of multiple divisions also creates a timing incentive for divisional managers. This may lead to a coordination problem. For example, there may be a tendency to compete for a positive capital budget early when the other divisions are assumed to do so as well. A policy of dynamic rationing may provide an effective way to mitigate this problem and improve the investment policy of a firm.

Acknowledgements

Appendix A. Proof of Proposition 1

Proof. All functions of the optimization problem are continuously differentiable. Thus, the problem describes a closed set and a maximum exists. The Hessian of the objective function is positive definite, which implies that the maximum is on the boundary of the problem's domain.

Inequality (4) can be written as $a_G - a_B \geqslant \frac{b_2}{b_1}(d_G - d_B)$ and inequality (5) as $a_G - a_B \leqslant p\frac{b_2}{b_1}(d_G - d_B)$. As $p \in (0, 1)$, this implies $d_G - d_B \leqslant 0$ and $a_G - a_B \in \left[\frac{b_2}{b_1}(d_G - d_B), p\frac{b_2}{b_1}(d_G - d_B)\right]$. Invoking these restrictions, the boundaries of the problem's domain can now be analyzed and the result described in the proposition obtains. □

Appendix B. Proof of Corollary 1

Proof. A first-period investment may occur for $b_1 \in \left[\frac{1+pc}{1-p\left(1-\frac{1+c}{b_2}\right)}, 1+c\right)$. Suppose a first-period investment does indeed take place. In the parameter range where no intertemporal separation is induced, $b_1 \in \left(\frac{1+c}{1+p\left(1-\frac{1+c}{b_2}\right)}, 1+c\right)$, the probability of second-period investment after a first period investment is $\frac{1}{2}(1 + p)$. In the parameter range where an intertemporal process is employed, $b_1 \in \left[\frac{1+pc}{1-p\left(1-\frac{1+c}{b_2}\right)}, \frac{1+c}{1+p\left(1-\frac{1+c}{b_2}\right)}\right]$, this probability is $\left(1 - \frac{b_1}{b_2}\right)p$, which is strictly smaller than $\frac{1}{2}(1 + p)$. The condition for the separation of the regimes reveals that an increase in c may mean that headquarters moves from the former to the latter but not the other way around, $d\frac{1+c}{1+p\left(1-\frac{1+c}{b_2}\right)}/dc = b_2^2\frac{1+p}{(b_2(1+p)-p(1+c))^2} > 0$ which establishes the result. □

Appendix C. Proof of Corollary 2

Proof. In case of no intertemporal separation, headquarters does not discriminate between investment outlooks in the first period and grants an investment budget whenever a profitable project is available in the second period. Because a favorable investment outlook is characterized by a higher probability of a second-period project, investment is more likely in this state. In case of intertemporal separation, a favorable investment outlook results in an expected level of investment of 1 and an unfavorable outlook in an expected investment of $1 + \left(1 - \frac{b_1}{b_2}\right) > 1$. □

References

Antle, R., Eppen, G., 1985. Capital rationing and organizational slack in capital budgeting. Management Science 31, 163–174.
Berkovitch, E., Israel, R., 2004. Why the NPV criterion does not maximize the NPV. Review of Financial Studies 17, 239–255.
Bernardo, A.E., Cai, H., Luo, J., 2001. Capital budgeting and compensation with asymmetric information and moral hazard. Journal of Financial Economics 61, 311–344.
Carlson, M., Fisher, A., Giammarino, R., 2004. Corporate investment and asset price dynamics: implications for the cross-section of returns. Journal of Finance 59, 2577–2603.

Cooper, R., Haltiwanger, J.C., Power, L., 1999. Machine replacement and the business cycle: lumps and bumps. American Economic Review 89, 921–946.

Doms, M., Dunne, T., 1998. Capital adjustment patterns in manufacturing plants. Review of Economic Dynamics 1, 409–429.

Harris, M., Kriebel, C.H., Raviv, A., 1982. Asymmetric information, incentives and intrafirm resource allocation. Management Science 28, 604–620.

Harris, M., Raviv, A., 1996. The capital budgeting process: incentives and information. Journal of Finance 51, 1139–1174.

Harris, M., Raviv, A., 1998. Capital budgeting and delegation. Journal of Financial Economics 50, 259–289.

Harris, M., Raviv, A., 2005. Allocation of decision-making authority. Review of Finance 9, 352–383.

Malenko, A. 2012. Optimal design of internal capital markets. Working paper, Massachusetts Institute of Technology.

Marino, A.M., Matsusaka, J.G., 2005. Decision processes, agency problems, and information: an economic analysis of capital budgeting procedures. Review of Financial Studies 18, 301–325.

Ozbas, O., 2005. Integration, organizational processes and allocation of resources. Journal of Financial Economics 75, 201–242.

Ross, M., 1986. Capital budgeting practices of twelve large manufacturers. Financial Management 15, 15–22.

Stein, J.C., 1997. Internal capital markets and the competition for corporate resources. Journal of Finance 52, 111–133.

Stoughton, N.M., Zechner, J., 2007. Optimal capital allocation using RAROC and EVA. Journal of Financial Intermediation 16, 312–342.

Whited, T.M., 2006. External financing constraints and the intertemporal pattern of intermittent investment. Journal of Financial Economics 81, 467–502.

Zhang, G., 1997. Moral hazard in corporate investment and the disciplinary role of voluntary capital rationing. Management Science 43, 737–750.