# Budget selection when agents compete*

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**Abstract**

A principal selects a budget $k$ of how many projects to fund within an organization and then consults $n$ agents, each of whom has private information about his own project's value. After receiving cheap talk reports from the agents the principal decides which projects to implement subject to the budget, and agents report on new i.i.d. projects every period until the budget is exhausted. When the number of funded projects $k < n$ and agents are biased towards their own projects, competition between agents degrades the quality of information conveyed in equilibrium and lowers the principal's payoff. A larger budget induces less competition and therefore may be selected in order to extract more information from the agents, even though this will lead to some unprofitable projects being adopted.

Keywords: competitive cheap talk, multiple agents, resource allocation, asymmetric information

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# 1 Introduction

Information is often diffused throughout an organization, with less informed decision makers relying on the advice of more informed agents. For example, the CEO of a multi-division firm may consult division managers before determining which projects to fund within the organization. A vast principal-agency literature has examined how the decision maker can best cope when the agents' incentives are misaligned with his own. Potential solutions include fully delegating decision making authority to the agent (Dessein 2002, Marino 2007) or more limited forms of delegation, in which the principal retains the right to veto actions (Gilligan & Krehbiel 1987, Krishna & Morgan 2001a, Lubensky & Schmidbauer 2016), or commits to exercise veto authority only in restricted cases (Marino & Matsusaka, 2005). More generally performance can be improved by restricting the agent's choice to be from among those in an optimal delegation set (Alonso & Matouschek, 2008), or in cases where competing agents are consulted (Gilligan & Krehbiel 1989, Krishna & Morgan 2001a, 2001b, and Battaglini 2002).

In this paper I consider a model of project selection in which a single principal consults multiple agents. Interests are *aligned* as respects which projects agents prefer to select; for example, given a particular agent's project will be adopted both the principal and that agent prefer a more profitable project to a less profitable one. However, since information is dispersed across agents who are biased in favor of their own projects, a misalignment between the principal and each individual agent arises. This is because when resources are limited agents must compete for the adoption of their projects, causing each to recommend adoption more liberally than a fully informed principal would prefer. Thus in this setting competition between agents actually harms the principal by inducing acceptance of some undesirable projects. However, when the principal controls the budget, and therefore the scarcity of resources within the firm, the extent of competition is endogenous and thus so too is the incentive conflict between principal and agent. In other words, the marginal value to the principal of a larger budget includes the shadow value of relaxing competition between agents.

In my model a budget-setting principal decides which projects to adopt within an organization. After announcing how many projects will be funded (the budget), the principal receives reports from agents about the profitability of available projects. Each project is "owned" by a single agent who privately observes its value and is biased in favor of its adoption. Thus agent $i$ does not observe agent $j$'s project, the idea being that in modern organizations information is often compartmentalized within highly specialized divisions. Whereas each agent prefers his own project be adopted, the principal wishes to adopt the best projects irrespective of their source. After receiving reports from all agents, the principal makes a binary decision to accept or reject each project[1], with new independently distributed projects available and reported on each period until the budget is exhausted.

While a multi-division firm is a prime example of this setting, others can be found. Consider the administrator of a government agency who has some discretion over how its budget is spent. The administrator consults different units within the agency who report on the social benefit from their own favored interventions, with the budget rolling-over to next period if it is not depleted. A similar explanation applies to the overseer of a charitable foundation or government agency when deciding which third parties to award grants to; or to activists and lobbyists who advise a politician about their own favored projects. As a final example, consider a business school dean who decides how many new faculty positions to fund across the school. After the dean announces the total number of positions, each department performs interviews to learn the quality of their own best candidate. Upon receiving recommendations from the departments the dean decides who to hire, or to continue the search next year if

[1]In an extension I allow the principal to adopt fractional projects.

suitable candidates have not been found.

I study an environment without transfers in which agents' messages are ex-post unverifiable, and so the model is one of 'competitive cheap talk' (Li, Rantakari, & Yang 2016) in a multi-period setting (Schmidbauer 2017). Implicitly, agents possess "soft" information that the principal cannot acquire or verify. It is shown that agents' equilibrium reporting strategies admit use of only two meaningful messages. Projects exceeding a threshold value are recommended for acceptance while those below the threshold are recommended for rejection. An agent that recommends rejection of his own project is wagering that the budget will not be depleted by next period and that he obtains a better project that is accepted then. For this reason the rate of time discounting and the distribution of project values affects the equilibrium threshold value. However, it also crucially depends on the size of the budget relative to the number of competing agents, since this affects the likelihood the budget will be used up.

Competition between agents is shown to harm communication and lower the principal's payoff. Each agent fears preemption by the other and so more freely recommends acceptance than the principal would prefer. However, competition can be relaxed by the inclusion of an additional project to the budget: more funded projects means the probability the budget is exhausted in any period decreases, inducing each agent to more selectively recommend acceptance. Intuitively, when there are more resources available within the firm there is less reason for an agent to exaggerate to gain funding. A larger budget benefits the principal from the improved communication resulting from decreased competition, a fact that has implications for the size of the optimal budget. I find the principal may fund marginal projects that are unprofitable themselves but improve communication overall, since this raises the expected payoff from *all* recommended projects. Thus a static analysis that ignores the benefits of improved communication can result in the possible underfunding of the budget. The optimal budget trades off between accommodating increasingly unprofitable projects and the communication spillover benefits they bestow.

I conclude the paper with two extensions. First, I allow the agents' rate of time discounting to be higher than the principal's, capturing the idea that agents may be more short-sighted than the principal. Accommodating this is straightforward given a main strategic tension in the game is that agents already discount the future more than the principal owing to fears of preemption. For a fixed budget, the more agents discount the future the more the equilibrium threshold falls, which is shown to decrease the principal's payoff; however, the principal can partially offset this by reoptimizing the budget size. I next consider an extension in which projects are perfectly divisible so that the principal need not make an all-or-nothing decision as respects each agent's project. However, since each agent always wishes to induce either the most favorable or pessimistic beliefs about their project it is shown the reporting strategies do not change and the previously identified equilibrium survives.

## Literature review

The current paper is one of a handful of 'competitive cheap talk' models found in the literature. Li, Rantakari, & Yang (2016) coined that term in their one-period model in which two agents with additive and/or multiplicative bias compete for the funding of a single project. Li (2016) extends this model to a dynamic setting where the principal consults a single agent in each period and must alternate between two agents over time with some known probability. However, the current paper most closely relates to the modeling framework of Schmidbauer (2017) in which agents compete via cheap talk for the adoption of a single project in a multi-period setting. In that paper a symmetric equilibrium involves each agent recommending acceptance of his own project only if it exceeds a stationary threshold value. The present paper shares many features but differs crucially in allowing the principal to select a budget in advance. This leads to a non-stationary equilibrium threshold and allows for a new comparative static that illuminates how competition between agents affects the principal's optimal budget size. The current paper also considers extensions allowing for divisible projects and differing time discount factors between the principal and agents.

This paper also relates to the project selection literature more generally. Bonatti & Rantakari (2016), Friebel & Raith (2010) and Rantakari (2016) develop models that allow for the exertion of costly effort to probabilistically increase the value of the project to the principal. Rantakari (2014) allows the principal to ex-ante publicly commit to a decision mechanism when agents have an unknown bias. In Moldovanu & Shi (2013) new projects arrive each period until a committee unanimously agrees to adopt one. Finally, Armstrong & Vickers (2010) consider a model of delegated project selection in which the principal is not aware of all the projects available to the agent. Although these papers differ in their approaches each assumes there is an exogenous budget of one project to be adopted.

Finally, the present paper relates to the capital budgeting literatures in accounting and finance (Harris & Raviv 1996, 1998, 2005; Stein 1997). In most such models a single agent has private information about the optimal scale of a project and prefers a larger size than the principal. When the principal has commitment power, it has been shown the optimal mechanism may include capital rationing or the use of a higher hurdle rate than the principal's cost of funds (Antle & Eppen 1985, Berkovitch & Israel 2004, Marino & Matsusaka 2005). Although these papers address some of the same questions as the present one, the modeling approaches are quite different. First, in my model agents with their own private information *compete* for a share of the budget, a feature that is absent in much of the above literature.[2] Second, I assume

[2]One exception is Harris et al. (1982) in which competing managers must pay for a common resource pursuant to their reported transfer prices and a mechanism selected by the principal. Another is Brown et al. (1992) in which a particular mechanism used by some U.S. government agencies is considered.

the agents' reports are cheap talk and the principal cannot commit (other than to a budget).

## 2 Model

A principal determines the number of projects that will be funded $k \in \{0, 1, ..., n\}$, which I refer to as the budget, where $n$ is the number of agents. Let $C(k)$ be the cost of funding $k$ projects, with $C(0) = 0$ and, abusing notation, let $C'(k) = C(k) - C(k-1)$ with $C'(k)$ increasing in $k$. Thus I assume a project from any division consumes the same amount of resources and that the cost of obtaining funds for this purpose is increasing with each project. After announcing the budget, each agent $i$ receives an independent and identically distributed project of profitability $\theta_i \sim F$, where $F$ is a $C^1$ function with finite expectation and full support on a closed interval $A \subseteq \mathbb{R}_+$, with $\min A = 0$, for $i = 1, ..., n$. The distribution $F$ is assumed to be common knowledge while the realization of $\theta_i$ is private information to agent $i$. In contrast to other multiple-sender models, agent $i$ does not observe the outcome of $\theta_j$, for $j \neq i$. Agents simultaneously send cheap talk messages to the principal, who then chooses which projects to accept subject to the budget. I initially assume the adoption decision is binary for each project (adopt or not), but in an extension allow for divisible projects.

While the principal need not use up the entire budget immediately, I assume he cannot adopt more than $k$ projects after the budget has been announced. At the end of any period if the principal has not yet adopted $k$ projects over the course of the game, the next period is reached with new i.i.d. draws for each $\theta_i$, and continues indefinitely until the total budget is exhausted.[3] Projects are short-lived; any rejected project is lost and cannot be brought back.[4] For simplicity, I assume that if agent

[3]It can be shown the qualitative results of the paper remain unchanged if the game had a known ending period. However, this would increase notational burden without any added insight.

[4]However, in the equilibria identified in Proposition 1 below it would never be optimal to return to any project that was previously rejected.

$i$'s project is chosen in period $s$ then that agent is removed from consideration in all subsequent periods. This may arise, for example, if expert $i$ begins working on the approved project and so is unavailable to pursue other projects in future periods.[5]

The principal chooses $\overline{x}_t \in X_t \equiv \left\{(x_{1t},...,x_{nt}) : x_{it} \in \{0,1\}\,,\ \sum_{i=1}^{n} x_{it} \leq \overline{k}_t\right\}$, where $x_{it} = 1$ if agent $i$'s project is adopted in period $t$ and $x_{it} = 0$ if it is not, for $i = 1,...,n$, and $\overline{k}_t$ is the unused portion of the budget at period $t$.[6] All agents are aware of $\overline{k}_t$ before making their reports in period $t$. Payoffs in period $t$ are as follows. The principal's payoff is the sum of the adopted project's types, $U_p(\overline{x}_t) = \sum_{i=1}^{n} x_{it}\theta_i$. Agents are biased in that they only receive positive utility if their own project is adopted

$$U_i(\overline{x}_t) = \begin{cases} 0 & \text{if } x_{it} = 0 \\ \theta_i & \text{if } x_{it} = 1 \end{cases},$$

but otherwise have aligned incentives with the principal. Future payoffs are discounted by $\delta \in (0,1)$ and all players are expected utility maximizers. Finally, the principal's payoff is additively separable in the benefits of project adoption and cost of funding the budget, giving an overall payoff function of $\sum_{t=1}^{\infty} \delta^{t-1} U_p(\overline{x}_t) - C(k)$.

Let each agent's message space be denoted by $M$, where $M = \mathbb{R}_+$. A strategy for agent $i$ is then a sequence of functions $g_{i,s}$ that for each period $s$ maps from the history of the game into $\Delta M$, the set of all probability distributions over $M$. Formally, at period $s$ the history of the game for agent $i$ is $k \times (\theta_{i,1},...,\theta_{i,s}) \times (m_{i,1},...,m_{i,s-1}) \times (\overline{x}_1,...,\overline{x}_{s-1})$, where $m_{i,l}$ is the message agent $i$ sent in period $l$. A strategy for the principal is a probability distribution over budget sizes $k \in \{0,1,...,n\}$ together with a sequence of functions $h_s$ that map from any history $k \times (\overline{x}_1,...,\overline{x}_{s-1}) \times \prod_{j=1}^{n} (m_{j,1},...,m_{j,s})$ into probability distributions over actions, $\Delta X$. I look for a symmetric perfect

[5] Additionally, it will be shown that the symmetric equilibria of the model given this assumption are in fact asymmetric equilibria of an otherwise identical model without this assumption.

[6] Thus the assumption made in the prior sentence can be stated formally as requiring $x_{js'} = 0$ for all $s' > s$ when agent $j$'s project was selected in period $s$.

Bayesian equilibrium.

# 3 Results

The principal makes a two-stage decision: *how many* projects will be funded and *which ones*? As I will show, the answer to the former question affects the answer to the latter, so I first focus on the communication subgame that ensues after the budget has been selected.

## Communication subgame

After setting the budget the principal takes the binary action of adopting each agent's current project or not. For this reason any equilibrium reporting strategy will consist of at most two meaningful messages: one for attempting to induce acceptance and one for rejection, which I will refer to as a recommendation to accept or reject, respectively. To see how competition between agents affects such reporting it is instructive to initially consider how agents report in the absence of competition. This is achieved within the model when the largest possible budget $k = n$ is in place since in this case each will eventually have a project funded.[7] That is, regardless of when agent $j$ recommends adoption agent $i$ can make his own recommendation without fear of being preempted. Absent competition, each agent faces a stationary optimal stopping problem, the well-known solution to which is to adopt a project (i.e., stop searching) only if its value exceeds a stationary threshold $c^*$ (DeGroot, 2005). The basic tradeoff an agent faces is that by recommending acceptance now he forgoes a possibly better project next period but avoids time delay costs. The threshold type is indifferent between accepting now and the discounted expected payoff from continuing, and thus the optimal threshold increases in the discount factor $\delta$.

[7] Recall I assume an agent is removed from future consideration after one of his projects has been adopted.

Given agents are symmetric and report using a stationary threshold strategy, any recommended project in any period is worth $E[\theta|\theta > c^*]$ to the principal and would be accepted immediately. In fact, with the full budget $k = n$ each agent's interests are fully aligned with the principal's and so $c^*$ is the same threshold that would be used by a fully informed principal; i.e, the first-best outcome is achieved. These findings are summarized in the remark below.

**Remark 1** *Conditional on the maximal budget ($k = n$), the first-best outcome in the communication subgame is achieved. Each agent uses a symmetric stationary threshold $c^*$ where projects are recommended for adoption only if $\theta_i > c^*$, and all recommendations are followed by the principal.*

Now suppose that $k = n - 1$ so that all but one agent will eventually have his project adopted, and conjecture an equilibrium in which each agent still uses the threshold $c^*$ from Remark 1. By construction agent $i$'s threshold type $\theta_i = c^*$ was indifferent to acceptance or rejection when $k = n$, though I claim when $k = n - 1$ it strictly prefers acceptance. This is because given the conjectured strategies all $n - 1$ other agents' projects exceed the threshold and are adopted in the current period with probability $(1 - F(c^*))^{n-1} > 0$, thus giving no continuation value to agent $i$. Type $c^*$ must then strictly prefer adoption, implying the equilibrium threshold must fall. Thus when agents compete for the adoption of their projects each discounts the future more since there is a chance future periods will not be reached. In the proposition below I solidify the intuitions developed so far, namely that an equilibrium strategy for the agents employs of a symmetric reporting threshold, and that as the size of the budget declines so too does this threshold.

Recall $\overline{k}_t$ is the size of the remaining budget at period $t$. I drop the subscript when the period need not be specified.

**Proposition 1** *A symmetric equilibrium of the communication subgame exists. In any such equilibrium agents use a threshold* $c^*(\delta, \overline{k})$*, increasing in* $\delta$ *and* $\overline{k}$*, such that projects* $\theta \leq c^*$ *are rejected while* $\theta > c^*$ *are recommended for acceptance. If* $\overline{k}$ *or fewer projects are recommended then each recommended project is accepted; otherwise the principal chooses* $\overline{k}$ *of the recommended projects to adopt with equal probability.*

**Proof** See the appendix. ■

The proposition tells us that a symmetric equilibrium of the communication subgame always exists.[8,9] In any such equilibrium with $c^* > 0$ each agent's threshold type is indifferent to recommending acceptance or rejection of his own project. When recommending rejection an agent hopes to receive a better project in the future but faces both a time delay cost and runs the risk of being preempted by other agents. Preemption can occur since with some known probability enough other agents will have recommended acceptance in the current period, thus exhausting the budget and ending the game. All else equal, this probability decreases in the equilibrium threshold used by each agent, which itself depends on the remaining number of projects left in the budget, $\overline{k}$. Specifically, the proposition states that as the remaining budget $\overline{k}$ decreases so too does the reporting threshold $c^*$, a result that can be interpreted in terms of competition between agents. Using the ratio of the number of agents to

[8]However, this equilibrium may be trivial in that no information is conveyed by the agents. Indeed one can easily verify that $c^* = 0$, in which all projects are recommended irrespective of type, is always an equilibrium. Conditions ensuring the existence of an equilibrium threshold $c^* > 0$ are discussed in the appendix, where it is also shown that multiple non-trivial equilibrium thresholds may exist. The question of equilibrium selection is addressed after Lemma 1 below.

[9]Asymmetric equilibria of the subgame also exist. For example, given $n$ and $k$ it can be shown that for any symmetric equilibrium there is a corresponding asymmetric equilibrium in which $m \in \{1, ..., n-k\}$ agents babble and are ignored while the principal and remaining $n-m$ agents act as they do in a symmetric equilibrium of a game with $n-m$ total agents and budget $k$. Similar logic explains the claim made in footnote 5 that the symmetric equilibria identified in Proposition 1 are asymmetric equilibria of an otherwise identical model in which agents may remain in the game for all subsequent periods after having their project selected.

projects remaining as a measure of competition,

$$\frac{\text{Agents remaining}}{\text{Budget remaining}} = \frac{n - \left(k - \overline{k}\right)}{\overline{k}}, \tag{1}$$

it can be seen that for $k < n$ competition increases as the budget is spent (i.e., as $\overline{k}$ decreases). That is, as more projects are adopted the remaining agents are chasing after relatively fewer opportunities for funding. This implies it is increasingly likely that one's own project will not be selected by the principal, and the probability of continuing in the game is lower, thus inducing each agent to use a lower threshold. In order to interpret this result in terms of the principal's payoff, I establish the next lemma.

**Lemma 1** *The principal's payoff in the subgame is single-peaked at his first-best project adoption threshold $\widehat{c}(\delta, k)$, which increases in $\delta$ and decreases in $k$. In addition, any equilibrium threshold $c^*(\delta, k) < \widehat{c}(\delta, k)$ when $k < n$ while they are equal when $k = n$.*

**Proof** In the first-best the principal directly observes each project's value and so he faces an optimal stopping problem. It is well known the solution entails a threshold $\widehat{c}$ at which the principal is indifferent to continuing, and: (i) increases in the discount factor $\delta$, and (ii) at which the principal's payoff is single-peaked (DeGroot, 2005). The comparative static on $k$ follows from the fact that the distribution of the $k^{th}$ highest project first order stochastically dominates the distribution of the $(k+1)^{th}$ highest.

When instead the principal must rely on the agents' reports, he adopts a project or not based on posterior beliefs that are consistent with the agents' reporting strategies. These agents likewise face an optimal stopping problem given discount factor $\delta$ but additionally discount the future since there is some probability the game terminates and some agents receive payoff 0. Thus $c^* < \widehat{c}$ when $k < n$ by (i) above since adding a probability of termination to a game is equivalent to lowering $\delta$. Finally, $\widehat{c} = c^*$ when $k = n$ by Remark 1. ■

One implication of the lemma is that if multiple equilibrium thresholds exist, the highest is preferred by the principal and in fact is Pareto dominant. The former claim follows since the highest equilibrium threshold is closest to the first best threshold at which the principal's payoff is single peaked. Pareto dominance follows because in a symmetric equilibrium with $n$ ex-ante identical agents each agent has the same probability of having his project selected and so receives $\frac{1}{n}$ of the principal's payoff. For this reason if there are multiple equilibrium thresholds in the subgame I select the largest one.

## The full game with budget selection

In order to determine the principal's optimal choice of budget and explore its properties, the costs and benefits from $k$ must be understood. In the proposition below I use Lemma 1 one more time to see how competition between agents affects the benefit derived from $k$.

**Proposition 2** *A larger budget (higher $k$) improves communication and benefits all players.*

**Proof** By Lemma 1 and the arguments after its proof, it suffices to track the principal's payoff. The direct effect is clearly positive as the principal enjoys payoffs from more projects. I now argue the indirect communication effect is also positive. Consider an initial budget $k$ that is increased to $k + 1 \leq n$. Then

$$c^*(\delta, k) < c^*(\delta, k+1) \leq \widehat{c}(\delta, k+1) < \widehat{c}(\delta, k),$$

where the first inequality follows from Proposition 1 and the other two follow from Lemma 1. Further, this chain of inequalities holds for all $k$ and $n$ and thus it holds in every period for each possible history of the game. The claim then follows since the principal's payoff is single-peaked at $\widehat{c}(\delta, k)$ while the equilibrium threshold increases from $c^*(\delta, k)$ to $c^*(\delta, k+1)$ and thus gets closer to this peak. ■

Since higher $k$ decreases the measure of competition found in line (1), it can be seen that decreased competition between agents increases the principal's payoff. This follows because when more projects will be funded each agent is less likely to be preempted by the others, so that a recommendation to reject one's own project is less likely to result in termination of the game. This leads to improved communication in the form of a higher equilibrium threshold, which by Lemma 1 increases the principal's payoff. Ultimately the principal trades off this benefit with the cost of expanding the budget to determine its optimal value $k^*$, the determination of which is straightforward since there are only finitely many possible budgets $k \in \{0, 1, ..., n\}$.

The proposition has two implications for the principal in the budget-setting stage of the game. First, since a marginal expansion of the budget not only provides payoffs from an additional project but also raises the expected payoff from the previously budgeted projects, if the principal naively ignores the communication effect a suboptimally low $k$ will be selected. A second and related implication of Proposition 2 is also available. Since there is an increasing marginal cost of expanding the budget and by Proposition 1 each adopted project has the same expected value to the principal, one can think of the projects as being ordered from high to low net profitability, with the lowest net profitable project adopted "last". Then the principal may adopt a larger budget even if the marginal project is itself unprofitable provided the indirect communication effect identified in Proposition 2 is strong enough.

**Remark 2** *The principal chooses a budget he knows will lead to the adoption of some unprofitable projects in order to induce more information revelation from the agents.*

One final observation is in order. While Remark 2 posits the principal expands the budget to include unprofitable projects, it is not immediate that the budget size under second-best exceeds that under first-best since a different adoption threshold is used in each case. That is, because the principal receives lower quality information when agents strategically communicate the projects adopted in this case are on average less profitable than under first-best, and this tends to make the second-best budget lower than first-best. However, militating against this is Remark 2's observation that the principal is willing to take on marginal projects that are unprofitable under second-best. Thus while a general comparison of budgets is not available, it can be shown it is possible the second-best budget exceeds the first-best.[10] In such cases a bloated budget can be viewed as a strategic response by the principal to the agency problem rather than a manifestation of the agents' ability to appropriate resources for themselves.

**An example**

Here I present an explicit example. Suppose there are $n = 5$ agents with i.i.d. projects $\theta_i \sim B\left(\frac{1}{5}, \frac{1}{5}\right)$ having a Beta distribution. Let $\delta = 0.7$ and the cost function be $C(k) = 0.3k + 0.1k^2$. Table 1 shows how the equilibrium threshold $c_k^*$, the expectation conditional on this threshold $E\left[\theta | \theta > c_k^*\right]$, and the principal's expected payoff in the subgame $\Pi^p$ change with the budget $k$. In addition, it reports the marginal benefit and cost from expanding the budget.

Various useful observations can be gleaned from the table. For example, when $k = 1$ competition between agents is so fierce that the reporting threshold is $c^* = 0$ (i.e., all agents always recommend adoption). In this case the principal learns nothing

[10] Denote the first- and second-best budgets as $\widehat{k}$ and $k^*$, respectively and define $B'_{FB}(k)$ and $B'_{SB}(k)$ as the marginal benefit from the $k^{th}$ project under first and second-best, respectively. Now suppose the full budget $k^* = n$ is optimal, which in particular implies $B'_{SB}(n) \geq C'(n)$ . Since $B'_{FB}(n) < B'_{SB}(n)$ it is possible that $B'_{SB}(n) > C'(n) > B'_{FB}(n)$ and thus $\widehat{k} < n$. To see why $B'_{SB}(n) > B'_{FB}(n)$, note that when $k = n$ the total payoff under second-best equals that under first-best (Remark 1). However, for $k = n - 1$ (and indeed any $k < n$) the total payoff under second-best is less than that under first-best by Lemma 1. The statement then follows. Given this, $k^* > \widehat{k}$ so that the budget is larger under second-best.

| Budget $k$ | Equilibrium Threshold $c_k^*$ | $E[\theta \mid \theta > c_k^*]$ | $\Pi^p$ | Marginal Benefit | Marginal Cost |
|---|---|---|---|---|---|
| 1 | 0 | 0.5 | 0.5 | 0.5 | 0.4 |
| 2 | 0.004 | 0.605 | 1.208 | 0.708 | 0.6 |
| 3 | 0.086 | 0.735 | 2.139 | 0.931 | 0.8 |
| 4 | 0.299 | 0.840 | 2.966 | 0.826 | 1.0 |
| 5 | 0.484 | 0.895 | 3.457 | 0.492 | 1.2 |

Table 1: The budget $k$, threshold $c_k^*$, conditional expectation given this threshold, principal's discounted expected payoff in the subgame, and the marginal benefit and cost of adopting an additional project for the current example.

from the reports and uses his prior, so any agent's project is worth $E[\theta] = 0.5$, which is profitable to fund since the marginal cost of the first project is 0.4. The marginal cost of the second project is 0.6, though, so it might appear that the principal would choose to fund only one project. However, when $k = 2$ agents will use a higher threshold, which a calculation shows is approximately 0.004. A typical accepted project then yields the principal $E[\theta \mid \theta > 0.004] \approx 0.605$ and results in a total discounted expected payoff of 1.208. The marginal benefit from expanding the budget is thus $1.208 - 0.5 = 0.708 > 0.6$, providing a net increase in payoffs. Likewise, calculations show including a third project in the budget is profitable even though its marginal cost is 0.8. Thus for low values of $k$ there is a virtuous cycle, in which the funding of one extra project causes all agents to use a more favorable threshold, increasing the profits to the principal from adopting them, thus causing yet another project to be profitably funded. However, owing to increasing marginal costs it can be seen that a fourth project would not provide a net benefit and so the optimal budget is $k^* = 3$.

Given Proposition 2, the marginal benefit from an expanded budget can be decomposed into a direct effect representing the discounted expected value of an additional project and an indirect communication effect from a higher reporting threshold used for all projects. This decomposition is illustrated in Figure 1. The green dot-

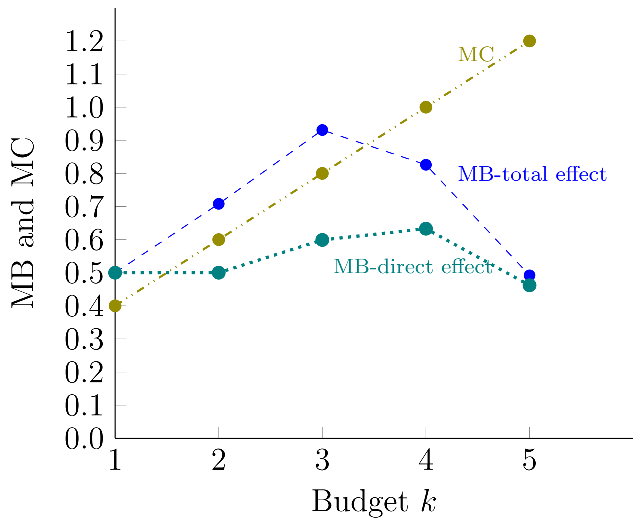


Figure 1: The marginal benefit (MB) from the direct effect, the total marginal benefit from the combined direct and indirect effect, and the marginal cost (MC) of expanding the budget in the example under consideration.

ted line shows the direct effect of funding one more project, which is calculated as $\Pi^p(c^*_{k'}, k'+1) - \Pi^p(c^*_{k'}, k')$, where $\Pi^p(c, k)$ is the principal's expected payoff with threshold $c$ and budget $k$. That is, to find the direct effect one asks what the expected benefit from a larger budget would be if the threshold remains fixed. As the figure shows, this effect can decrease in $k$ since for fixed $n$ and a budget that is already large, the waiting time for another success will be longer so that its present value is smaller.

The blue dashed line in Figure 1 plots the total marginal benefit from an expanded budget, whose values are simply taken from Table 1. The residual between the gold and blue lines is then the indirect communication effect. For any budget $k < n$ Lemma 1 states $c^*_k$ is too low for the principal and so the increase in the threshold induced by a larger budget always improves the principal's payoff (see Proposition 2). The indirect effect is calculated as $\Pi^p(c^*_{k'+1}, k'+1) - \Pi^p(c^*_{k'}, k'+1)$, and in the example it initially increases with $k$ since there are more projects that benefit from a higher threshold while it eventually declines in $k$ as the gains from getting closer to the optimal threshold are smaller.

Another salient feature of the example is that while the optimal budget size is $k^* = 3$, the third project is itself unprofitable. This follows since its direct effect of 0.599 added to its share of the indirect effect, $\frac{0.332}{3}$, is approximately 0.710, which is less than its marginal cost 0.8. That is, the discounted expected value of the third project (which uses threshold $c_3^*$) is $0.710 < 0.8$, and thus this project is unprofitable. However, when the remaining portion of the indirect effect, $\frac{2\times 0.332}{3}$, is included the total marginal benefit $\frac{2\times 0.332}{3} + 0.710 \approx 0.931 > 0.8$. Consistent with Remark 2, the principal finds it optimal to adopt a budget that includes an unprofitable project.

Lastly, the present example also demonstrates that a general comparison of $k^*$ and $\widehat{k}$, the equilibrium and principal's preferred threshold, respectively, is not possible. As argued in footnote 10, the marginal benefit of adopting the maximal budget is always greater under second-best than first. Then if $B'_{FB}(k = n) < C'(k = n) < B'_{SB}(k = n)$ the full budget is optimal under second best but not first best. However, as the present example shows, the marginal benefit from the very first project could be as low as $E[\theta]$, which is always less than the first-best payoff when $k = 1$. If $E[\theta] < C'(k = 1) < B'_{FB}(k = 1)$, then $k^* = 0$ and $\widehat{k} > 0$ is possible.

# 4 Extensions

## Differing discount factors

I now consider the possibility that the agents and principal have different time-discounting rates. For example, the principal may be long-lived while each agent may exit the game each period with some exogenous probability due to outside job opportunities. For this reason I will consider discount factors $\delta_a$ for the agents and $\delta_p$ for the principal such that $\delta_a \leq \delta_p$. Accommodating this extension will prove straightforward given that a main strategic tension in the game is that agents already discount the future more than the principal due to fear of preemption.

**Proposition 3** *$\delta_p$ has no effect on the equilibrium threshold $c^*$. In contrast, lower $\delta_a$ decreases $c^*$ and results in a lower payoff for the principal.*

**Proof** The threshold $c^*$ does not depend on $\delta_p$ since its value was determined by the sender constraints (and therefore $\delta_a$), as seen in lines (2) and (5) in the proof of Proposition 1. Further, the principal will still follow the agents' recommendations since $\delta_a \leq \delta_p$. Next, denoting the expression in line (5) as $D(n, k, c, \delta_a)$, by inspection $\frac{\partial D}{\partial \delta_a} > 0$. Also, Claim 2 in the proof of Proposition 1 establishes $\lim_{c \to \infty} D = 0$, which implies the highest equilibrium threshold $c^*$ must satisfy $\frac{\partial D}{\partial c}(c^*) \leq 1$. Applying the implicit function theorem, these two facts imply $\frac{\partial c^*}{\partial \delta_a} > 0$. Finally, since $c^*$ increases in $\delta_a$ and $\delta_a \leq \delta_p$, Lemma 1 implies the principal's payoff in the subgame increases in $\delta_a$, and thus also increases in the full game when $k$ is reoptimized. ■

While $\delta_p$ affects the principal's preferred threshold it does not affect the equilibrium threhold, which is determined by competitive considerations between the agents and their own discount factor. As the agents become less patient they use a lower threshold, which harms the principal since any equilibrium threshold is already too low from his perspective (Lemma 1). The principal's reoptimized budget will also therefore result in a lower payoff, though how $k^*$ changes in $\delta_a$ is ambiguous in general.

## Divisibility of projects

I have assumed that projects are indivisible. In some situations this is reasonable, as for example in the academic job market example given in the introduction, while in other settings it may be more natural to assume projects can be divided. In this subsection I explore what effect the divisibility of projects has on the results when the budget is still restricted to be an integer.

Suppose projects are infinitely divisible, so that any fraction $x_i \in [0,1]$ of agent $i$'s project can be accepted by the principal. The message space for each agent remains unchanged at $M = \mathbb{R}_+$, while the principal's choice is the vector $x = (x_1, ..., x_n)$ such that $\sum_{j=1}^{n} x_j \leq \bar{k}_t$ in period $t$. In the stage game, agent $i$ of type $\theta_i$ receives payoff $x_i\theta_i$ if $x_i$ of his project is adopted and 0 otherwise, while the principal's payoff in a period is $\sum_{j=1}^{n} x_j\theta_j$ and remains additively separable with respect to $C(k)$. The next proposition shows that due to agents' reporting incentives allowing for divisible projects does not affect the previous equilibrium characterization.

**Proposition 4** *When the principal can adopt fractions of projects the equilibrium found in Proposition 1 still exists and its properties remain unchanged.*

**Proof** Agent $i$ would never send a message inducing partial adoption of his project since his payoff increases in $x_i$. Instead, he would either prefer full adoption of his project, or possibly rejection if there is a high enough chance of reaching the next period. Thus the agents will employ a threshold strategy with only two meaningful messages: "accept" or "reject". But then the equilibrium characterization and existence proofs, and therefore all subsequent propositions, follow as before. In particular, the principal is indifferent between any recommended projects, and so is willing to adopt all of ($x_i = 1$) each recommended project if $\bar{k}$ or fewer projects are recommended; and if more than $\bar{k}$ are recommended he is willing to adopt the entire portion of $\bar{k}$ projects selected randomly with a uniform distribution. ■

# 5 Conclusion

The questions of how many and which projects to fund within an organization are of primary concern to decision makers. In this paper I explore these questions in the context of an uninformed budget-setting principal relying on cheap talk reports from biased agents to make project adoption decisions. In the first-stage the principal selects the number of projects that will be funded and in the second stage each agent reports on his own project's quality which is privately observed. At the end of any period if the global budget has not been exhausted the agents get new independently drawn projects and again make reports to the principal.

I find that when agents compete for the funding of their own favored projects in this manner the quality of information degrades, lowering all players' payoffs. This follows since competing agents know there is some chance the game will not continue because the budget will have been exhausted, causing them to discount the future more than the principal. Therefore the effect of a marginally larger budget is two-fold: it provides payoffs from another project but also lessens competition between the agents and thereby improves the quality of information and payoffs from all other funded projects. For this reason the principal is willing to fund some projects he expects to be ex-post unprofitable in order to elicit more information on all projects. While these results have assumed that adopting a project is a binary yes/no decision, in an extension I show this is without loss of generality since agents will not provide messages more informative than "accept" or "reject." Finally, I show that when agents have a higher rate of time-discounting (lower discount factor) than the principal communication problems are exacerbated and therefore reduce the principal's payoff.

# 6 Appendix – proof of Proposition 1

The proof consists of two parts. I first verify the equilibrium characterization of the proposition is correct by showing that any symmetric equilibrium entails the use of a threshold strategy, and that the principal's conjectured strategy is therefore a best response. Next, I give conditions such that a non-trivial equilibrium threshold exists.

## Equilibrium characterization

To see that a threshold strategy must be used by the agents, note that for any strategy the continuation value from inducing rejection is invariant to type while the expected payoff from inducing acceptance is increasing in type. Thus any message will be sent by a connected set of types. Next, there cannot be more than one message that induces adoption since the message that induces a lower posterior would never be sent. Thus agents' strategy must use a threshold $c^*$.

I now show the principal is best responding by rejecting all projects recommended for rejection and adopting all those recommended (subject to the budget). If a single agent prefers his project be rejected then the principal does *a fortiori* since the latter benefits when *any* agent's future project is above $c^*$. Thus a recommendation to reject will be followed. Finally, it will be proved below that the agents' threshold weakly decreases over time, from which it follows that immediate acceptance of a recommended project is a best response.

## Equilibrium existence

I proceed iteratively by showing that existence when $k = 1$ implies existence for $k = 2$, which in turn implies existence for $k = 3$, and so on. First, I define several terms. Let $M_{j,q}(c) \equiv \binom{q}{j} F(c)^{q-j} (1 - F(c))^j$ be the probability that exactly $j$ of $q$ agents recommend acceptance given threshold $c$. Let $A_{j,q}(c)$ be the probability an agent's recommended project is selected when $q$ other agents use threshold $c$ and there are $j$ projects left to be selected by the principal; thus $A_{j,q}(c) \equiv \sum_{i=0}^{q} M_{i,q} \left( \frac{j}{\max\{j, 1+i\}} \right)$. Let $\Pi_{j,n}$ be an agent's ex-ante equilibrium payoff in a game with $j$ projects to be selected and $n$ agents. A calculation shows $\Pi_{1,n} = \frac{1-F(c)^n}{1-\delta F(c)^n} E[\theta|\theta > c]$ (see Lemma 3, p.247 of Schmidbauer, 2017), and clearly $\Pi_{0,n} = 0$; define $\Pi_{-s,n} = 0$ for any $s > 0$.

**The $k = 1$ case**

It is shown in Schmidbauer (2017) (see Lemma 2 and Proposition 2, p.245) that existence of an equilibrium for the $k = 1$ case reduces to finding a fixed point of $G(c) \equiv \frac{\delta F(c)^{n-1}}{1-\delta F(c)^n} \int_c^\infty \theta dF(\theta)$, and that at least one non-zero fixed point exists if $n = 2$ and $E[\theta] = 1/\delta \; f(0)$, and otherwise at least two non-zero fixed points exist if there is a $c$ such that $G(c) > c$.[11] For $k \geq 1$ it will be shown the equilibrium threshold in period $t$ depends only on the remaining number of projects to be funded, $\overline{k}_t$. Since the project generation process is stationary, I reduce notation and denote an equilibrium threshold when there are $\overline{k}$ remaining projects to be funded as $c_k$. Candidate thresholds are denoted simply by $c$.

**The $k = 2$ case**

The indifference condition for the threshold type is

$$\begin{aligned} c\;A_{2,n-1}(c) &= \delta\left(M_{1,n-1}(c)\Pi_{1,n-1} + M_{0,n-1}(c)\left(\int_c^\infty \theta dF(\theta) A_{2,n-1}(c) + F(c)c\;A_{2,n-1}(c)\right)\right) \\ c\left(1-\delta F(c)^n\right) &= \delta\left(\frac{M_{1,n-1}(c)\Pi_{1,n-1}}{A_{2,n-1}(c)} + F(c)^{n-1}\int_c^\infty \theta dF(\theta)\right) \\ c &= \frac{\delta M_{1,n-1}(c)}{1-\delta F(c)^n}\frac{\Pi_{1,n-1}}{A_{2,n-1}(c)} + G(c)\,. \end{aligned} \tag{2}$$

In the first line the payoff from recommending acceptance (left side) is equated to the value from recommending rejection (right side). Rejection gives $\Pi_{1,n-1}$ if exactly one other agent recommended acceptance; if none did then integrate over types above $c$ while types below $c$ get payoff $c\;A_{2,n-1}(c)$; otherwise the payoff is zero. In the second line I substitute $M_{0,n-1}(c) = F(c)^{n-1}$, divide each side by $A_{2,n-1}(c)$, and subtract off the rightmost term on the right hand side of the first line. The last line divides by

[11] Recall if there are multiple equilibrium thresholds I select the highest, which is Pareto dominant.

$1 - \delta F(c)^n$ and substitutes for $G(c)$.

I claim the existence of $c_1 > 0$ that solves the $k = 1$ case (i.e., $G(c_1) = c_1$) implies the existence of a $c_2 > c_1$ that solves line (2). First, $\frac{\delta M_{1,n-1}(c)}{1-\delta F(c)^n} \frac{\Pi_{1,n-1}}{A_{2,n-1}(c)} > 0$ for all $c > 0$ and so $c_1$ is not a solution of line (2), and by inspection this term is continuous in $c$. I now claim that this term converges to 0 as $c \to \infty$. Recalling $\Pi_{1,n-1}$ is a constant with respect to $c$ (the conjectured threshold for the $k = 2$ case), $\delta < 1$ implies

$$\begin{aligned} & \lim_{c\to\infty} \frac{\delta M_{1,n-1}(c)}{1-\delta F(c)^n} \frac{\Pi_{1,n-1}}{A_{2,n-1}(c)} \\ = & \lim_{c\to\infty} \frac{\delta \binom{n-1}{1} F(c)^{n-2} (1 - F(c))}{1-\delta F(c)^n} \frac{\Pi_{1,n-1}}{A_{2,n-1}(c)} \\ = & \frac{0}{1-\delta} \Pi_{1,n-1} = 0 \end{aligned} \tag{3}$$

since $F(c)^i \to 1$ for all $i$, $1 - F(c) \to 0$, and $A_{2,n-1}(c) \to 1$. Next, $\lim_{c\to\infty} G(c) = \lim_{c\to\infty} \frac{\delta F(c)^{n-1}}{1-\delta F(c)^n} \int_c^\infty \theta dF(\theta) = \frac{\delta}{1-\delta} \times 0 = 0$ and thus the left hand side of line (2) must exceed the right hand side for sufficiently high $c$. Thus there exists a fixed point $c_2 > c_1$.

Given $c_2$ exists $\Pi_{2,n}$ can be calculated. With probability $M_{0,n}(c_2)$ all projects are rejected and the identical situation is faced next period; with probability $M_{1,n}(c_2)$ precisely one project is adopted and so the game reduces to $k = 1$ with $n - 1$ agents; and with the remaining probability at least two projects are adopted and the game ceases. Thus

$$\begin{aligned} \Pi_{2,n} &= 2E[\theta|\theta > c_2](1 - M_{0,n}(c_2) - M_{1,n}(c_2)) + (E[\theta|\theta > c_2] + \delta\Pi_{1,n-1}) M_{1,n}(c_2) + F(c_2)^n \delta \Pi_{2,n} \\ \Pi_{2,n} &= \frac{2E[\theta|\theta > c_2](1 - M_{0,n}(c_2) - M_{1,n}(c_2)) + (E[\theta|\theta > c_2] + \delta\Pi_{1,n-1}) M_{1,n}(c_2)}{1 - \delta F(c_2)^n}. \end{aligned}$$

Thus with $\Pi_{1,n-1}$ one can calculate $\Pi_{2,n}$, and it can be seen more generally that $\Pi_{j,n'}$

can be constructed from $\Pi_{j-1,n'-1}$. This fact is pertinent since, as in line (3) in the construction of $c_2$, knowing $\Pi_{j-1,n}$ is required to find $c_j$.

**Induction on $k$**

Having solved the $k=1$ and $k=2$ cases I now proceed by induction. By the induction hypothesis suppose there is a $c_i$ which is a fixed point of

$$G(c) + \sum_{j=1}^{i-1} \frac{\delta M_{i-j,n-1}(c)}{1-\delta F(c)^n} \frac{\Pi_{j,n-i+j}}{A_{i,n-1}(c)}. \tag{4}$$

To establish the $k=i+1$ case I must show there exists a fixed point of

$$G(c) + \sum_{j=0}^{i-1} \frac{\delta M_{i-j,n-1}(c)}{1-\delta F(c)^n} \frac{\Pi_{j+1,n-i+j}}{A_{i+1,n-1}(c)}, \tag{5}$$

which follows from the two claims below.

**Claim 1** *Line (5) is greater than line (4) since the $j=0$ term of line (5) is positive for $t>0$ and each term $j>0$ in the sum in line (5) exceeds its counterpart in line (4); i.e.,*

$$\frac{\delta M_{i-j,n-1}(c)}{1-\delta F(c)^n} \frac{\Pi_{j+1,n-i+j}}{A_{i+1,n-1}(c)} \geq \frac{\delta M_{i-j,n-1}(c)}{1-\delta F(c)^n} \frac{\Pi_{j,n-i+j}}{A_{i,n-1}(c)} \tag{6}$$

*for all $j \in \{1,2,...,i-1\}$.*

**Claim 2** *$G(c)$ and each of the terms $j \in \{0,1,...,i-1\}$ in the sum in line (5) approach $0$ as $c \to \infty$.*

These claims together with the continuity of the expression in line (5) then imply there exists a $c_{i+1} > c_i$ that solves line (5), and one can calculate the value of $\Pi_{i+1,n}$ for all $n$. Then, since it can be seen than $G(0)=0$ for any $k$, a symmetric equilibrium always exists. Further, this equilibrium involves a non-zero threshold for any $k$ when $c_1 > 0$ exists.

**Proof of Claim 1** First, $\lim_{c\to\infty} G(c) = \lim_{c\to\infty} \frac{\delta F(c)^{n-1}}{1-\delta F(c)^n} \int_c^\infty \theta dF(\theta) = \frac{\delta}{1-\delta} \times 0 = 0$. By inspection the $j = 0$ term of line (5) is positive for $c > 0$. Next, to establish line (6) holds for $j \in \{1, 2, ..., i-1\}$, I show

$$\frac{A_{i+1,n-1}(c)}{A_{i,n-1}(c)} < \frac{j+1}{j} < \frac{\Pi_{j+1,n-i+j}}{\Pi_{j,n-i+j}}. \tag{7}$$

For the first inequality in line (7) it suffices to show the $j = i-1$ case:

$$\frac{A_{i+1,n-1}(c)}{A_{i,n-1}(c)} < \frac{i}{i-1} \quad \iff \quad A_{i+1,n-1}(c) < \frac{i}{i-1} A_{i,n-1}(c) \quad \iff$$

$$\sum_{l=0}^{n-1} \binom{n-1}{l} F(c)^{n-1-l}(1-F(c))^l \left(\frac{i+1}{\max\{i+1, l+1\}}\right)$$
$$< \sum_{l=0}^{n-1} \binom{n-1}{l} F(c)^{n-1-l}(1-F(c))^l \left(\frac{i\left(\frac{i}{i-1}\right)}{\max\{i, l+1\}}\right),$$

which follows since $i\left(\frac{i}{i-1}\right) > i+1 \iff i^2 > i^2 - 1$.

I now establish the second inequality in line (7). For any symmetric threshold each agent has the same ex-ante probability $\frac{k}{n}$ of having his project selected, and thus comparing any game with $j+1$ projects to be selected to any game with $j$, each agent is $\frac{j+1}{n} \big/ \frac{j}{n} = \frac{j+1}{j}$ times more likely to have his project selected in the former than the latter. Additionally, the ex-ante expectation of an accepted project is greater in the former case than the latter since the adoption threshold is higher, which itself is known to be true for $k \leq i$ by the induction hypothesis. Thus the inequality $\frac{j+1}{j} < \frac{\Pi_{j+1,n-i+j}}{\Pi_{j,n-i+j}}$ holds for all $n$. *QED Claim 1.* ■

**Proof of Claim 2** Substituting for $M_{i-j,n-1}$, a generic term of the sum in line (5) is

$$\left(\frac{\delta\binom{n-1}{i-j} F(c)^{n-1-i+j}(1-F(c))^{i-j}}{1-\delta F(c)^n}\right) \frac{\Pi_{j+1,n-i+j}}{A_{i+1,n-1}(c)}$$

and the term in large parentheses converges to $\frac{0}{1-\delta}$ and thus the entire expression converges to 0. *QED Claim 2.* ■

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