A Note on the Benefits of Aggregate Evaluation of Budget Proposals

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ABSTRACT: Budgeting admits significant management control problems due to information asymmetries within organizations. We extend the Antle, Bogetof and Stark (1999) principal agent analysis of budgeting, performing comparative statics on the potential benefit of bundling projects. Bundling projects confers a type of diversification benefit similar to portfolio diversification. We find this benefit is maximized at intermediate levels of profitability. The rationale for this finding is that at high levels of profitability the control problem is trivial and at low levels of profitability individual evaluation is necessary to screen for only the most profitable projects. For similar reasons bundling is most beneficial at intermediate levels of slack potential. We further find that when bundling is strictly beneficial to the principal its benefit is decreasing in the correlation between the projects’ profitability. The intuition for this finding is (positive) correlation diminishes the diversification benefit found with aggregation. Finally, we sketch a setting with heterogeneous projects that differ with respect to ex ante profitability. We demonstrate that the benefit of aggregation is decreasing in project heterogeneity. The intuition is that when projects are sufficiently heterogeneous the ability to tailor the contracts to the individual projects dominates the diversification benefits.

Keywords: budgets; agency; aggregation.

INTRODUCTION

The study of capital budgeting has largely resided in the domain of finance, where the focus is on the relationship between financing and investing (Modigliani and Miller 1958; Myers 1974). However, capital budgeting decisions are often affected by management control problems that arise from informational asymmetries within the organization. It is natural that when discussions of capital budgeting processes and procedures relate to information issues, they should reside in accounting (Antle and Fellingham 1997, 890). In this vein, we extend recent theoretical

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results on how bundling budgeting proposals can help control information rents that arise when information asymmetries exist (Antle, Bogetoft, and Stark 1999; Arya and Glover 2001; Nikias, Schwartz, and Young 2009). Bundling budgets allows the principal to evaluate the investment opportunities individually or in aggregate; without bundling, only individual evaluation is possible. Aggregation confers a type of diversification benefit: less profitable projects that would ordinarily be rejected in an effort to control information rents are accepted when evaluated together with more profitable projects.

The simple capital budgeting setting was originally formulated by Antle and Eppen (1985). A better-informed but resource-constrained agent and a lesser-informed but resource-endowed principal contract over an investment project. In an optimal contract the principal reduces the agent's ability to extract slack by committing to a target level of profitability that exceeds its own cost of capital. As a result, in equilibrium there exists both rejection of positive net present value (NPV) projects and organizational slack. Thus, information concerns in this setting are sufficient to invalidate the familiar NPV rule that is the hallmark of introductory finance (Arya, Fellingham, and Glover 1998). These interpretations are readily apparent because of the linear structure of the model.

More closely related to our model, Antle et al. (1999) extend the setting to multiple projects where the agent observes each project's profitability. Under individual evaluation, the projects are contracted upon separately; under bundled evaluation the contract allows the agent to choose whether to have the projects evaluated individually or in aggregate. This is a basic and important issue in a capital budgeting setting. Interpreting this setting, the questions of interest are: how often should managers be called in to present proposals, and at what level of detail are they asked to report?

Under the assumptions in Antle et al. (1999), bundling the projects is a straightforward expansion of the contract space—there are no costs to bundling. Therefore, the principal is weakly better off with a bundled evaluation. Further, the principal is strictly better off if the projects under consideration are strictly profitable. Also, whenever a strict benefit is available there is always a region of the costs where the agent can simply report the sum of the costs and the principal in turn either accepts both projects or neither project. In that region, managers need only provide aggregate reports, i.e., the total cost of the two projects.

Our note extends the linear two-project model of capital budgeting of Antle et al. (1999). It also is closely related to Armstrong and Rochet (1999), who analyze a two-dimensional adverse selection model in a non-linear setting that does not lend itself easily to a capital budgeting interpretation. Our main contribution relative to these models is our parameterization, which facilitates comparative statics. Comparative statics help us develop intuition about the forces at work that transcend the model specifics and provide a level of generality that is not available from numerical examples alone. Both of these contributions are important when using the model to interpret real institutions.

Specifically, we use our analysis to identify situations where the ability to aggregate is most beneficial and, hence, where bundling would still be preferred even after consideration of the

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1 Aggregation is often discussed in the context of the quality and credibility of financial reporting, e.g., Hirst, Koonce, and Venkataraman (2007). Aggregation has also been explored in a somewhat different management control setting wherein the principal is concerned about motivating the agent to perform several tasks (Gigler and Hemmer 2002; Arya, Glover, and Liang 2004; Nikias, Schwartz, and Young 2005).

2 We thank an anonymous reviewer for pointing out this reference.

3 Antle et al. (1999) do not perform comparative statics, per se. However, in a two-project numerical example they vary the slack potential (information asymmetry) for one project while keeping that for the other project constant. In the example, the benefit of bundling is at first increasing then decreasing in the slack potential of the non-constant project.
extra-model costs due to bundling. This is important because bundling is likely to be costly in practice. First, Arya and Glover (2001) examine a situation where bundling can only be achieved if the principal waits for a second project to become available. In their model, the cost of waiting for the second project to become available is the lost opportunity to take advantage of the agent’s uncertainty about the second project’s profitability. Second, by waiting for the second project the first project may lose profitability or even become unavailable, as in Antle, Bogetoft, and Stark (2007) and Arya et al. (1998). Finally, bundling links multiple projects together under the same contracting unit; there may be reasons why the principal wishes to contract with different agents for each of the projects, such as specialized skills or time constraints on the agents (Arya, Glover, and Young 1996).

We analyze three relevant factors in determining the benefit of bundled evaluation; we also provide a sketch of the effects of a fourth factor. Specifically, comparative statics are performed on expected profitability, slack potential (a more general treatment of the numerical example in Antle et al. [1999]), and correlation in the projects’ profits (not addressed in Antle et al. [1999] and Armstrong and Rochet [1999]). Our analysis yields two major results. First, the ability to aggregate is most beneficial for intermediate levels of profitability and slack potential. Second, if the aggregation option is strictly beneficial, its benefit is decreasing in the correlation between the projects’ profitability. We then sketch the case where the two projects differ in expected profitability. Perhaps surprisingly, we find that the benefit of the aggregation option is decreasing in the difference in their expected profitability.

The rest of the paper is organized as follows. The second section presents the model. The third section provides greater context and concludes the paper.

MODEL

The model is similar to the two-project models of Antle and Fellingham (1990), Antle et al. (1999), and Arya and Glover (2001). There exists a risk-neutral principal who owns the residual profits from two investment projects and a risk-neutral agent necessary for the projects to be implemented. The agent has private information about each project’s cost prior to investment and is asked to issue a report prior to the principal making the investment decision. The agent reports in his own best interest. Due to the agent’s lack of resources, the principal must transfer to the agent an amount sufficient to cover the cost of the project. The agent derives utility from slack, equal to the difference between the amount of funds provided by the principal and the realized cost. These aspects of the model guarantee a simple, yet interesting, management control problem.

Benchmark Case: One Project

It is useful to describe the optimal contract with one project. The project’s cost is denoted, \( c \in \{c_L, c_H\} \), where \( c_L < c_H \). In the language of adverse selection models, \( c_L \) indicates the “good state.” The principal’s common knowledge beliefs about the probability of cost \( c_i \) is denoted \( z_i \), and the deterministic revenue is denoted \( R \).

The principal moves first by designing a menu consisting of two pairs. Each pair indicates whether investment will occur and how much she will pay the agent. Subsequently, the agent privately observes the cost of the project. Then the agent chooses one item from the menu.

The indicator variable \( z_i \in \{0, 1\} \) for \( i \in \{L, H\} \) is equal to 1 (0) if production occurs (does not occur) given the reported cost. The payment to the agent, given the reported cost, is denoted \( r_i \). The principal motivates the agent to select the menu item that corresponds to the cost, captured by the incentive compatibility constraints (IC). The agent, by choice from the menu, effectively reports the cost. Further, the principal must supply all of the funds for investment; that is, the agent is not permitted to “go bankrupt”—these constraints are denoted (B)
### TABLE 1

#### Panel A: General Model

<table>
<thead>
<tr>
<th>Contract</th>
<th>Hurdle*</th>
<th>Condition</th>
<th>( \pi )</th>
<th>Expected Slack</th>
</tr>
</thead>
<tbody>
<tr>
<td>rationing</td>
<td>( c_L )</td>
<td>( \alpha_L(c_H - c_L) \geq \alpha_H(R - c_H) )</td>
<td>( \alpha_L(R - c_L) )</td>
<td>( \alpha_L(c_H - c_L) )</td>
</tr>
<tr>
<td>slack</td>
<td>( c_H )</td>
<td>( \alpha_L(c_H - c_L) \leq \alpha_H(R - c_H) )</td>
<td>(( R - c_H ))</td>
<td></td>
</tr>
</tbody>
</table>

#### Panel B: Reduced Model

<table>
<thead>
<tr>
<th>Contract</th>
<th>Hurdle*</th>
<th>Condition</th>
<th>( \pi )</th>
<th>Expected Slack</th>
</tr>
</thead>
<tbody>
<tr>
<td>rationing</td>
<td>( \bar{c} - \delta )</td>
<td>( 2\delta \geq \lambda \bar{c} - (\bar{c} + \delta) )</td>
<td>( 1/2[\lambda \bar{c} - (\bar{c} - \delta)] )</td>
<td>0</td>
</tr>
<tr>
<td>slack</td>
<td>( \bar{c} + \delta )</td>
<td>( 2\delta \leq \lambda \bar{c} - (\bar{c} + \delta) )</td>
<td>( \lambda \bar{c} - (\bar{c} + \delta) )</td>
<td>( \delta )</td>
</tr>
</tbody>
</table>

* The principal receives revenue of \( R \) and transfers an amount equal to the hurdle to the agent if and only if \( c_L \leq \) hurdle.

\( \pi \) = principal’s expected profit with one project.

\( c_i \) = reported cost, equal in equilibrium to the actual cost.

Reduced model:

\( R = \lambda \bar{c} \), where \( \lambda \) is a measure of expected profitability.

\( c_L = \bar{c} - \delta \) and \( c_H = \bar{c} + \delta \), where \( \delta \) is a measure of slack potential.

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Below is the principal’s program to find the optimal contract:

\[
\max_{x_i, t_i} \sum_{i=L,H} x_i(R - t_i)
\]

subject to:

- \( t_L - x_Lc_L \geq t_H - x_HC_L \)  \( (IC-L) \)
- \( t_H - x_HC_H \geq t_L - x_Lc_L \)  \( (IC-H) \)
- \( t_i - x_ic_i \geq 0, \ i \in \{L, H\} \)  \( (B-i) \)

The optimal contract with two or more costs is a hurdle contract, described in Antle and Eppen (1985): the principal commits to a constant transfer of funds that is independent of the agent’s report for reports that meets the hurdle; otherwise, the project is rejected and no funds are transferred. In a continuous state setting, an optimal contract has an interior optimum, characterized by both rationing and slack. Here, with just two possible costs, there are, of course, only two contracts that can be optimal: a slack contract or a rationing contract. In a slack contract, the principal sets a hurdle of \( c_H \) and provides funds of \( c_H \) to the agent no matter what the agent reports. The principal receives expected profit equal to \( R - c_H \) and the agent receives \( \alpha_L(c_H - c_L) \) in expected slack. In a rationing contract the principal sets a hurdle of \( c_L \). If the agent reports the cost is \( c_L \) the principal provides funds of \( c_L \); otherwise, she provides zero funds and rejects the project. The principal receives \( \alpha_L(R - c_L) \) in expected profit and the agent receives zero in slack. The optimal contract is summarized in Table 1 (Panel A).

The intuition behind which of the two contracts is optimal can be explained in terms of the costs and benefits of offering a rationing contract in place of a slack contract. The benefit of a rationing contract is the expected savings in slack, equal to \( \alpha_L(c_H - c_L) \). The cost of a rationing contract is the expected sacrificed production, equal to \( \alpha_H(R - c_H) \). Not surprisingly, a slack contract (rationing contract) is optimal for more (less) profitable projects, wherein sacrificed production is more (less) costly. The indifference point between a rationing and slack contract is

\[
R = \frac{\alpha_L}{\alpha_H} (c_H - c_L) + c_H.
\]

Continuing, if \( c_H = 150 \), \( c_L = 50 \) and \( \alpha_H = \alpha_L = 0.5 \), a rationing (slack) contract is optimal when \( R \leq 250 \) (\( R \geq 250 \)).
TABLE 2

Joint Probability Distribution of Cost

Panel A: General Model

<table>
<thead>
<tr>
<th>Cost</th>
<th>( c_i^B )</th>
<th>( c_{ij}^B )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( c_i^L )</td>
<td>( \alpha_{LL} )</td>
<td>( \alpha_{LL} )</td>
</tr>
<tr>
<td>( c_i^H )</td>
<td>( \alpha_{HL} )</td>
<td>( \alpha_{HL} )</td>
</tr>
</tbody>
</table>

\( c_i^k \) = cost of project \( k \) in state \( i \), where \( c_i^L < c_i^H \).

\( \alpha_{LL} \alpha_{HH} - \alpha_{HL}^2 \alpha_{HH} > 0 \) implies positive correlation.

Panel B: Reduced Model

<table>
<thead>
<tr>
<th>Cost</th>
<th>( c_i^B = \bar{c} - \delta )</th>
<th>( c_i^B = \bar{c} + \delta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( c_i^L )</td>
<td>0.25(1 + ( \rho ))</td>
<td>0.25(1 - ( \rho ))</td>
</tr>
<tr>
<td>( c_i^H )</td>
<td>0.25(1 - ( \rho ))</td>
<td>0.25(1 + ( \rho ))</td>
</tr>
</tbody>
</table>

\( \bar{c} \) = expected cost of project \( i \).

\( \rho \) = correlation coefficient \((-1 \leq \rho \leq 1)\).

Two Projects

We expand the model to two projects, A and B. The principal moves first by designing a menu consisting of four three-tuples. Each three-tuple in the menu indicates the investment decision for each project and how much she will pay the agent, conditional on the vector of realized costs. The sequence of play is identical to the one-project case, except now the agent privately observes the cost of each project prior to selecting from the menu.

The notation must now be expanded to take into account the projects’ different characteristics and the principal’s ability to treat them interdependently. The projects’ costs are denoted \( \{c_i^A, c_i^B\} \), where \( c_i^L < c_i^H \), \( i, j = L, H \); \( k = A, B \). The project costs are not necessarily independent. The joint probability of cost \( c_i^A \) and \( c_i^B \) is denoted \( \alpha_{ij} \), where the first (second) subscript indicates project A’s (B’s) cost (see Panel A of Table 2), \( i, j = L, H \). The deterministic revenue is denoted \( R \).

The indicator variable \( x_{ij} \in \{0, 1\} \) for \( i, j \in \{L, H\} \) and \( k = A, B \) is used to indicate no production or production on project \( k \) given that the realized costs are \( \{c_i^A, c_i^B\} \). The payment to the agent, given the realized costs are \( c_i \) on project A and \( c_j \) on project B, is denoted \( t_{ij} \). The incentive compatibility constraints are now denoted (IC-\( ij/i'j' \)), where \( i'j' \) may be interpreted as “truth” and \( i'j' \) as some other report. As before, the principal must supply all of the funds for investment; that is, in equilibrium the agent is not permitted to “go bankrupt”—these constraints are denoted (B-\( ij \)). Below is the principal’s program to find the optimal contract in the two-project setting:

\[
\max_{x_{ij}^A, x_{ij}^B} \sum_{i=1}^{L} \sum_{j=1}^{H} \alpha_{ij}(x_{ij}^A R_A + x_{ij}^B R_B - t_{ij})
\]

subject to:

\[
t_{ij} - x_{ij}^A c_i^A - x_{ij}^B c_i^B \geq t_{ij} - x_{ij}^A c_i^A - x_{ij}^B c_i^B \\
\text{for all } i, j \in \{L, H\} \text{ and } i', j' \in \{L, H\} \text{ (IC-}\ ij/i'j' \text{)}
\]

\[
t_{ij} - x_{ij}^A c_i^A - x_{ij}^B c_i^B \geq 0 \text{ for all } i, j \in \{L, H\} \text{ (B-}\ ij \text{)}
\]

The principal cannot do worse by bundling the projects together than by treating them independently, because the principal can commit to treat them independently even if they are evaluated jointly. The major question of interest is identifying the conditions under which the principal is strictly better off by treating the projects in an interdependent fashion.
Reduced Model

Potentially the projects can differ in expected profitability, either due to differences in revenues, feasible cost outcomes, or probability distribution on costs. We explore this possibility in a later section. However, for clarity we now describe the optimal solution when the projects are homogeneous, that is, if \( R^A = R^B = R \), and \( c_i^A = c_i^B = c_i, i = L, H \). To further facilitate intuition and comparative statics, we introduce parameters that imply a type of symmetry. Specifically, we assume \( c_L = \bar{c} - \delta \), and \( c_H = \bar{c} + \delta \), with each outcome equally likely, and \( 0 \leq \delta \leq \bar{c} \). With this parameterization, for each project the expected cost and maximum available slack are \( \bar{c} \) and \( 2\delta \), respectively. The common knowledge and deterministic revenue from each project is assumed to be proportional to its expected cost, that is, \( R = \lambda \bar{c} \). Thus, \( \lambda \) is a measure of expected profitability. We naturally assume \( R > \bar{c} - \delta \), or else the project would never be taken. We allow for interdependence between project costs with correlation coefficient between project costs equal to \( \rho \), where \(-1 \leq \rho \leq 1 \). The joint probability structure of costs, as a function of \( \rho \), is found in Panel B of Table 2.

Individual Evaluation

With projects that are \textit{ex ante} identical, when restricted to Individual Evaluation (IE), the principal would offer the same contract on each project as was optimal in the one-project setting. (Panel B of Table 1 re-characterizes the optimal single project contracts for the reduced model.) The principal’s expected utility under IE is therefore twice what it would be in a one-project setting. We denote the principal’s expected profits under IE by \( \pi_I \).

Bundled Evaluation

Under Bundled Evaluation (BE) the principal is still free to offer independent slack or rationing contracts for each project, thereby ignoring the additional information bundled evaluation offers. Alternatively, she may exploit the increased contracting space available under BE by committing to a project acceptance decision rule that makes interdependent use of the agent’s reports. That is, the acceptance decision on each project may be a function of the reports on both projects.

It is useful to briefly describe the major findings of Antle et al. (1999).\(^4\) First, as is immediate from the modeling, BE is weakly preferred to IE. Further, BE is strictly preferred if and only if in the optimal BE contract the acceptance of one project depends non-trivially on the reported cost of the other project. In Antle et al. (1999), where costs are continuous, the principal offers a “menu” contract to the agent. The agent may choose to be evaluated under individual hurdles or aggregate hurdles. In their example, where costs are uniformly distributed (0,1) and revenue is equal to 1, the individual hurdles are 0.33, and the aggregate hurdle is 1.14. If, for example, the two cost outcomes were 0.6 and 0.4, the agent would optimally submit under the aggregate hurdle, receiving total slack of 0.14. If the cost outcomes were 0.1 and 0.9, the agent would optimally submit under the individual hurdles, with only the first project being funded, producing slack of 0.23. As long as the cost outcome region where the agent prefers the aggregate hurdle rate is non-empty, BE is strictly preferred.

In our model, due to the binary cost assumption, the optimal BE contract is equivalent to the \textit{principal} establishing either aggregate or individual hurdles; there is no benefit to the principal in giving the agent a choice.\(^5\) Under BE, one of three possible hurdle contracts is

\(^4\) In their model, which looks at non-mutually exclusive projects, Antle et al. (1999) refer to the two regimes as “individual appraisal” and “batch processing.”

\(^5\) Proof is available from the authors.
TABLE 3
Optimal Contracts under Bundled Evaluation—Symmetric Projects

<table>
<thead>
<tr>
<th>Contract</th>
<th>Condition</th>
<th>$\pi_B$</th>
<th>Expected Slack</th>
</tr>
</thead>
<tbody>
<tr>
<td>rationing</td>
<td>$\delta(1 + \rho) \geq (1 - \rho)[\lambda \bar{c} - (\bar{c} + \delta)]$</td>
<td>$\lambda \bar{c} - (\bar{c} - \delta)$</td>
<td>0</td>
</tr>
<tr>
<td>partial rationing</td>
<td>$\delta(1 + \rho) \leq (1 - \rho)[\lambda \bar{c} - (\bar{c} + \delta)]$ and $0.25(1 + \rho)[\lambda \bar{c} - (\bar{c} + \delta)] \leq (1.5 - 0.5\rho)\delta$</td>
<td>$2\bar{c}(\lambda - 1)(0.75 - 0.25\rho)$</td>
<td>$0.5\delta(1 + \rho)$</td>
</tr>
<tr>
<td>slack</td>
<td>$0.25(1 + \rho)[\lambda \bar{c} - (\bar{c} + \delta)] \geq (1.5 - 0.5\rho)\delta$</td>
<td>$2[\lambda \bar{c} - (\bar{c} + \delta)]$</td>
<td>$2\delta$</td>
</tr>
</tbody>
</table>

$\pi_B$ = principal’s expected profit under bundled evaluation.

optimal; the two that are available under IE, and an additional contract only available under BE. The proof is sketched in Appendix A. The two that are also available in IE were discussed earlier: independent rationing contracts for each project and independent slack contracts for each project. The additional contract available under BE is implemented with an aggregate hurdle, which has both projects accepted or rejected based on an aggregate cost report. The only aggregate hurdle that is optimal is one wherein both projects will be accepted if and only if at least one cost is low, and the principal will supply the agent with a payment of $c_L + c_H = 2\bar{c}$. We refer to this contract as partial rationing.6

Partial rationing offers a tradeoff of slack and rationing that is unavailable under IE. Relative to two independent slack contracts, for a cost outcome of high and low, both projects are accepted under partial rationing and the slack contracts, but with less cost under partial rationing. Relative to two independent rationing contracts, for a cost outcome of two lows, partial rationing creates more slack. However, for a cost outcome of high and low, two independent rationing contracts reject the high cost project, while it is accepted under partial rationing. Note the benefits of bundling are closely tied to the intermediate cost outcome of one high and one low cost. The principal and agent’s earnings under partial rationing are found below in Equation (1) and Equation (2), respectively:

$$\text{Principal’s Earnings} = 2\bar{c}(\lambda - 1)(0.75 - 0.25\rho).$$  \hspace{1cm} (1)

$$\text{Expected Slack} = 0.5\delta(1 + \rho).$$ \hspace{1cm} (2)

Summarizing, under BE the optimal contract is either independent rationing contracts, independent slack contracts, or a partial rationing contract, while under IE either two rationing or two slack contracts are optimal. We denote the principal’s expected earnings under BE by $\pi_B$. Table 3 displays the principal’s expected profits and agent’s expected slack under BE.

Our first proposition is that BE is strictly preferred if and only if partial rationing is the optimal BE contract. The proof is immediate from the preceding discussion. Our second proposition provides the range of parameter values under which BE is strictly preferred. (See Figure 1.)

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6 IE using two rationing contracts is strictly better than an aggregate hurdle of $2(\bar{c} - \delta)$, wherein both projects are accepted if and only if both costs are low and both are rejected otherwise, as it leads to greater expected production with no additional slack (zero). Also, IE using slack contracts is equivalent to an aggregate hurdle of $2c_H = 2(\bar{c} + \delta)$. Therefore, only the partial rationing contract has the potential to improve on IE.
**Proposition 1:** A necessary and sufficient condition for bundled evaluation to be strictly preferred to individual evaluation is that partial rationing is strictly preferred under bundled evaluation.

**Proposition 2:** Let \( \Delta \pi = \pi_B - \pi_I \). \( \Delta \pi > 0 \) if and only if:

(i) \( \lambda_1 < \lambda < \lambda_2 \), where \( \lambda_1 = \frac{2 \delta}{c(1-p)} + 1 \), and \( \lambda_2 = \frac{4 \delta}{c(1+p)} + 1 \), or equivalently

(ii) \( \delta_1 > \delta > \delta_2 \), where \( \delta_1 = \frac{c(1-p)(2-1)}{2} \) and \( \delta_2 = \frac{c(1+p)(2-1)}{4} \).

The proof of Proposition 2 is derived by comparing the principal’s earnings, found in Equation (1), to the principal’s earnings under independent rationing and slack contracts. With respect to profitability, \( \lambda_1 \) is the principal’s indifference point between a rationing and a partial rationing contract, while \( \lambda_2 \) is the indifference point between a partial rationing and a slack contract. From Proposition 1, BE is strictly preferred for \( \lambda \) between \( \lambda_1 \) and \( \lambda_2 \). Similar arguments can be made for slack potential. Figure 1 plots the regions in which contracts are optimal for an example where project costs are independent, i.e., where \( \rho = 0 \).
Corollary 2.1: Assume $\Delta \pi > 0$. Then $\Delta \pi$ is maximized at:

$$\lambda^* = \frac{3\delta + \bar{c}}{\bar{c}}, \text{ or equivalently: } \delta^* = \frac{(\lambda - 1)c}{3}.$$ 

Proposition 2 implies BE is preferred by the principal for intermediate levels of profitability and slack potential. The corollary states that the maximum advantage of BE occurs at the point where the principal would be indifferent between a rationing and slack contract under IE. It is at this point that the aggregate hurdle provides the most valuable “fine tuning” between expected slack and expected sacrificed production.

Proposition 2 is most easily illustrated when $\rho = 0$, where the probability of each cost combination is 0.25 and $\lambda_1 = \frac{26\delta + \bar{c}}{\bar{c}} < \lambda_2 = \frac{4\delta + \bar{c}}{\bar{c}}$. First, when $\lambda_1 < \lambda < \lambda^*$ a rationing contract is optimal in IE, a partial rationing contract is optimal in BE, and $\Delta \pi = 0.5[\lambda \bar{c} - (\bar{c} + \delta)] - 0.5 \delta$. The two terms arise, because under BE relative to IE: (1) the principal receives extra production, worth $[\lambda \bar{c} - (\bar{c} + \delta)]$, when $(\bar{c} + \delta, \bar{c} - \delta)$ or $(\bar{c} - \delta, \bar{c} + \delta)$ obtains, with probability 0.5, but (2) pays $2\delta$ extra to obtain production when $(\bar{c} - \delta, \bar{c} - \delta)$ obtains with probability 0.25. Within this range of $\lambda$, $d\Delta \pi/d\lambda > 0$ because increases in profitability increase the value of additional production but do not increase the costs of the higher hurdle. Second, when $\lambda^* < \lambda < \lambda_2$ a slack contract is optimal under IE, a partial rationing contract is optimal under BE, and $\Delta \pi = 1.5 \delta - 0.25[\lambda \bar{c} - (\bar{c} + \delta)]$. The two terms arise, because under BE relative to IE: (1) the principal pays $2\delta$ less to obtain production when $(\bar{c} - \delta, \bar{c} - \delta)$ results, or $(\bar{c} - \delta, \bar{c} - \delta)$ results, which occurs with probability 0.75, but (2) rejects the project if $(\bar{c} + \delta, \bar{c} + \delta)$ obtains with probability 0.25. Here $d\Delta \pi/d\lambda < 0$, because the higher production of the slack contract relative to the partial rationing contract becomes increasingly valuable, while the cost of a higher hurdle under the slack contract remains constant. In conclusion, $\Delta \pi$ is maximized at $\lambda^*$ where the partial rationing contract perfectly balances the increased production relative to a rationing contract and decreased hurdle relative to a slack contract. As long as $\rho$ is such that there exists a region where $\Delta \pi > 0$, the above logic holds. Proposition 2(ii) and its corollary can be explained in terms of slack potential in a similar fashion.

Figures 2 and 3 illustrate Proposition 2 and its corollary. Figure 2 plots $\pi_t$ and $\pi_B$ as functions of $\bar{c}$ for an example where the projects are independent ($\rho = 0$) and $\delta = 50$. Figure 3 plots $\pi_t$ and $\pi_B$ as functions of $\delta$ where $\rho = 0$ and $\lambda = 2.5$.

Correlation

In passing, Antle et al. (1999, 409) state that bundling will be helpful when the costs of the projects are negatively correlated. In this subsection we provide a more structured analysis of correlation. We begin with an observation that follows directly from Proposition 2: if the correlation in project profitability is sufficiently positive, BE cannot be strictly better than IE.

Corollary 2.2: A necessary condition for BE to strictly improve upon IE is $\rho < 1/3$.

A third corollary that follows from Proposition 2 is related to how the difference between the optimal BE and IE contracts is affected by the correlation in the costs.

Corollary 2.3: Under a partial rationing contract $d\Delta \pi/d\rho \leq 0$.

**Proof:** The proof follows from inspection of Table 1 Panel B and Equation (1). $\pi_t$ is independent of $\rho$ and (under partial rationing) $\pi_B$ is decreasing in $\rho$.

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7 Given that in the reduced model $\sigma_y = \sigma_R = 0.5$, the condition in Corollary 2.1 is equivalent to that described at the end of the “Benchmark Case: One Project” section.

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FIGURE 2
Expected Profitability: Bundled Evaluation versus Individual Evaluation
\( (\bar{c} = 100, \delta = 50, \rho = 0) \)

\[ \begin{align*}
\pi &= \text{principal’s expected profits.} \\
\lambda &= \text{measure of expected profitability.}
\end{align*} \]

The optimal contract under BE is rationing to the left of \( \lambda_1 \), partial rationing between \( \lambda_1 \) and \( \lambda_2 \), and slack to the right of \( \lambda_2 \).

Corollary 2.3 may be of interest in its own right, and is also helpful in providing sufficient conditions for BE to improve upon IE. The idea of Proposition 3 is that if the projects are sufficiently profitable, there exists a correlation, sufficiently negative, such that the optimal contract is partial rationing. Hence, by Proposition 2 BE strictly improves upon IE.

**Proposition 3:** There exists a \( \rho > -1 \) such that \( \Delta \pi > 0 \) if and only if \( R > \bar{c} + \delta \), or \( (\lambda - 1)\bar{c} > \delta \).

**Proof:** First, a necessary condition for \( \Delta \pi > 0 \) is \( R > \bar{c} + \delta \). To see this, assume \( R < \bar{c} + \delta \), and \( \rho = -1 \). By Proposition 2, under BE a rationing contract is optimal. By Corollary 2.3, \( \pi_B \) and hence \( \Delta \pi \), is non-increasing in \( \rho \). Therefore, \( \Delta \pi = 0 \) for any feasible \( \rho \) when \( R < \bar{c} + \delta \). Second, we prove sufficiency. If \( R > \bar{c} + \delta \), by Proposition 2, partial rationing is preferred under BE at \( \rho = -1 \), and hence \( \Delta \pi > 0 \) for small increases in \( \rho \).
Intuitively, if expected profitability is sufficiently high, negative correlation is quite beneficial to BE. As correlation decreases, the uncertainty over the aggregate total declines; for correlation of -1 it completely disappears. As long as the principal wants to fund both high and low cost projects, i.e., \( R > \bar{c} + \delta \), perfect negative correlation allows for a first-best solution under BE. When \( \rho = -1 \), there are conditions under which BE is strictly preferred where the optimal IE contract would be rationing and also where it would be slack. We illustrate these possibilities in Figures 4 and 5.

It may be helpful to view the potential benefit of aggregation as a form of diversification. The notion underlying diversification is that an intermediate outcome is preferred to a convex combination of extreme outcomes. Usually, we think of this is in the context of risk aversion, but in our setting the economic agents are risk neutral. To see the relation to diversification, consider a principal who does not have the option to aggregate. She can offer a slack contract and receive a payoff equal to \( R - \bar{c} - \delta \), or a rationing contract and receive \( R - \bar{c} + \delta \), with probability 50 percent. An equally weighted combination of the two is \( 0.75(R - \bar{c}) - 0.25\delta \). However, the partial rationing contract provides the principal with \( 0.75(R - \bar{c}) \) per project. Hence, the intermediate
Therefore, further profit opportunities—other-typereceived by Project B because of heterogeneity in expected profitability is increasing in $\gamma$. Aggregate cost outcomes remain the same: $2(\tilde{c} + \delta)$, $2\tilde{c}$, or $2(\tilde{c} - \delta)$, so the expected profit from partial rationing is not a function of heterogeneity. Further, the expected profit from two-slash or two-rationing contracts also remains unchanged. Therefore, the three potentially optimal contracts found previously are not affected by heterogeneity. However, with project heterogeneity it may be beneficial to customize the contract to each project, by offering a slack contract for one project and a rationing for the other—a type of independent evaluation. Recall, without heterogeneity projects would optimally receive the same contract under IE.

We use a numerical example and Figure 6 to illustrate that as the difference in expected profitability between the two projects increases, the optimal contract becomes a customized one.

**Heterogeneous Projects**

In this subsection we provide a brief sketch of the effects of project heterogeneity. In order to capture heterogeneity we assume Project A has a cost of either $\tilde{c} - \gamma + \delta$ or $\tilde{c} - \gamma - \delta$, and Project B has a cost of either $\tilde{c} + \gamma + \delta$ or $\tilde{c} + \gamma - \delta$. Therefore, heterogeneity in expected profitability is increasing in $\gamma$. Aggregate cost outcomes remain the same: $2(\tilde{c} + \delta)$, $2\tilde{c}$, or $2(\tilde{c} - \delta)$, so the expected profit from partial rationing is not a function of heterogeneity. Further, the expected profit from two-slash or two-rationing contracts also remains unchanged. Therefore, the three potentially optimal contracts found previously are not affected by heterogeneity. However, with project heterogeneity it may be beneficial to customize the contract to each project, by offering a slack contract for one project and a rationing for the other—a type of independent evaluation. Recall, without heterogeneity projects would optimally receive the same contract under IE.

We use a numerical example and Figure 6 to illustrate that as the difference in expected profitability between the two projects increases, the optimal contract becomes a customized one.
**FIGURE 5**
Correlation: Bundled Evaluation versus Individual Evaluation
($\bar{c} = 100, \lambda = 2.75, \delta = 50$)

$\pi =$ principal’s expected profits.
$\rho =$ correlation coefficient of project costs.

The optimal contract under BE is partial rationing to the left of $\rho_2$ and slack to the right of $\rho_2$.
The optimal contract under IE is slack for each project.

Assume that $\bar{c} = 80, \lambda = 1.75, \delta = 25$, and $\rho = 0$. For $\gamma = 0$, the optimal BE contract is partial rationing and the optimal IE contract is rationing, so BE is strictly preferred. As $\gamma$ increases, there is no change in the profitability of a partial rationing contract. However, the optimal IE contract changes from partial rationing for both projects to a slack contract for Project A and rationing contract for Project B. At $\gamma = \delta$ the optimal BE contract becomes slack for Project A, and rationing for Project B. For a sufficiently high $\gamma$, the optimal BE contract will change to slack for Project A and no production for Project B. The example illustrates that as projects become more heterogeneous the value of diversification remains constant while the value of customization increases. Hence, heterogeneity does not favor the use of bundling.

There is one other noteworthy result with heterogeneous projects and it occurs when negative correlation is added, as shown in Figure 7. Assume, as above, $\bar{c} = 80, \lambda = 1.75$ and $\delta = 25$, but let $\rho = -0.25$. As with the previous example, at $\gamma = 0$, the optimal BE contract is partial rationing and the optimal IE contract is rationing. However, at $\gamma = 35$, a contract displaying “asymmetric dependency” becomes optimal in BE. By asymmetric dependency we mean that the decision on Project A is dependent on the report on Project B, while the decision on Project B is independent of the report on Project A. Specifically, Project B receives a rationing contract independent of Project A, while Project A receives a slack contract if the cost on Project B is low, but a rationing contract if
the cost on Project B is high. The rationale is that a low (high) cost on Project B is bad (good) news for the cost of Project A, so the principal offers a slack (rationing) contract.\(^8\) For example, with \(\rho = -0.25\) there is a 62.5 percent chance of a high cost on Project A given a low cost on Project B. Of course the reverse is true as well: the cost report of Project A tells the principal something about the cost of Project B. But, Project B is not sufficiently profitable (when \(\gamma > 35\)) to merit a slack contract, even with the additional information. Ultimately, at \(\gamma = 48.3\), Project A is sufficiently

\(^8\) It may appear that the same logic could be used for cases of positive correlation; a high report on one project indicates a likely high cost on the other project. However, the principal cannot use this information without violating the truth-telling constraints. If, for example, she offered a rationing contract on Project B and a slack (rationing) contract on Project A conditional on a high (low) cost report on Project B, the agent would always report high on Project B. The reasoning is the agent’s expected slack on Project B would be invariant to his report, but the agent’s expected slack on Project A would be increasing in his report on Project B.
\( \pi = \) principal’s expected profits.
\( \gamma = \) measure of the difference in \textit{ex ante} expected profitability between Projects A and B.

The optimal contracts under BE are as follows:
\( \gamma \leq \gamma_A \) partial rationing;
\( \gamma_A \leq \gamma \leq \gamma_1 \) for Project A slack (rationing) conditional on a low (high) cost report for Project B, and for Project B rationing;
\( \gamma \geq \gamma_1 \) for Project A slack, and for Project B rationing:
The optimal contracts under IE are as follows:
\( \gamma \leq \gamma^* \) rationing for both projects;
\( \gamma \geq \gamma^* \) slack for Project A, and rationing for Project B.

profitable so that it receives a slack contract unconditionally, and bundling is no longer strictly preferred.\(^9\)

What is interesting about our finding on heterogeneity and negative correlation is that in the prior literature, the only benefit of bundling was the possibility of using an aggregate hurdle. Of course bundling is always weakly preferred to simply aggregating because bundling leaves available the potential for individual evaluation, while aggregation does not. However, with asymmetric dependence, we have a contract that cannot be executed through individual

\(^9\) One can show that \(d\pi/dp < 0\) continues to hold for heterogeneous projects as modeled in this section, including conditions under which “asymmetric dependency” is optimal.
evaluation, but is not aggregation either. In this sense, we have found an extended use of bundling.

DISCUSSION AND CONCLUSION

In this note we extend recent findings on budgeting for investment projects with a privately informed agent. As in related models that preceded ours, the interpretations of "organizational slack" and "capital rationing" follow from the model's linearity. These interpretations are not readily available (if at all) from non-linear multidimensional adverse selection models such as Armstrong and Rochet (1999) and Rochet and Chone (1998).

There is a potential to bundle budgets wherein the principal sets profitability hurdles such that sometimes the acceptance of one project depends non-trivially on the report for another project. Typically, although not exclusively, this conditionality takes the form of an aggregate hurdle. We find that bundling is most beneficial when the principal faces the greatest tension between reducing organizational slack and maintaining profitable production. Further, the diversification benefit of aggregation is decreasing in the correlation in investment outcomes, suggesting that the principal should consider bundling projects with negatively correlated profitability. Given the simple nature of our model, one possibly interesting avenue to pursue is the strategic assignment of projects to managers.

There are several analogs to our results in practice. First, with respect to correlation, consider the case of a retail manager who is evaluated on monthly sales. In many countries the date on which Easter falls can affect the sales in March and April. If Easter arrives early, some sales shift from April to March; if it arrives late, sales shift from March to April. A bundled evaluation system, where March and April are combined, can be helpful in avoiding difficult-to-compute seasonal adjustments (Notte 2011; Waters 2007). Another example to consider is the travel budget for a division that uses a combination of air and automobile transport. It is intuitive that the two transportation costs will be negatively correlated, as they are partial substitutes. Under these circumstances an aggregate travel budget seems to make sense, as employees who have used up their "auto budget" may be forced to fly short distances and employees who have used up their "air budget" may be driving from New York to Chicago.

As an analog to our results on expected profitability, for a company that judges maintenance to be generally of value, it seems reasonable that an aggregate maintenance budget would be used rather than a budget for each small project, perhaps to ease the cost of constant budget negotiations in addition to reducing slack. If, however, maintenance projects are costly relative to their potential value, individual project budgeting would be expected. Finally, as an analog to our results on slack potential and differences in expected profitability, it seems unlikely that firms in the mineral extraction or oil exploration industries would use aggregation when budgeting capital projects—the difference in project attributes is too great. Likewise, pharmaceutical companies likely do not aggregate the budgets for several different drug candidates—failures are simply too costly for aggregation to be beneficial.

Given the growing theoretical literature on aggregation and budgeting, empirical validation is important. Field studies and surveys might be particularly useful in this endeavor. Experiments might also be useful. However, thus far, experiments on aggregation and budgeting such as Nikias, Schwartz, Spires, Wollseheid, and Young (2010), and Schwartz, Spires, Wallin, and Young (2012)

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10 Bhappu and Guzman (1995) report from their survey of budget practices for mining companies, "Many of the respondents indicated that the minimum required rate of return was highly project dependent with the primary risk factors being political risk, commodity risk and, to a lesser extent, technological risk."
have focused more on the effect of non-pecuniary motivations of aggregation and, therefore, cannot be seen as direct tests of the theory herein.

REFERENCES


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APPENDIX A

Below, the general contracting program in the text is rewritten for the special case where the projects are symmetric, i.e., $c_i^A = c_i^B = c_i$, $i = L, H$ and $R^A = R^B = R$.

$$\begin{align*}
\text{Max} & \quad \alpha_{LL}(x_{LL}^A R + x_{LL}^B R - t_{LL}) + \alpha_{LH}(x_{LH}^A R + x_{LH}^B R - t_{LH}) + \alpha_{LL}(x_{LH}^A R + x_{LH}^B R - t_{LH}) \\
& \quad + \alpha_{HH}(x_{HH}^A R + x_{HH}^B R - t_{HH})
\end{align*}$$

subject to:

$$\begin{align*}
t_{LL} - x_{LL}^A c_L - x_{LL}^B c_L & \geq t_{LH} - x_{LH}^A c_L - x_{LH}^B c_L & (IC-LL/LH) \\
t_{LL} - x_{LL}^A c_L - x_{LL}^B c_L & \geq t_{HH} - x_{HH}^A c_L - x_{HH}^B c_L & (IC-LL/HH) \\
t_{LH} - x_{LH}^A c_L - x_{LH}^B c_L & \geq t_{LL} - x_{LL}^A c_L - x_{LL}^B c_L & (IC-LH/LL) \\
t_{LH} - x_{LH}^A c_L - x_{LH}^B c_L & \geq t_{LH} - x_{LH}^A c_L - x_{LH}^B c_L & (IC-LH/HH) \\
t_{HH} - x_{HH}^A c_L - x_{HH}^B c_L & \geq t_{LH} - x_{LH}^A c_L - x_{LH}^B c_L & (IC-HH/LH) \\
t_{HH} - x_{HH}^A c_L - x_{HH}^B c_L & \geq t_{HH} - x_{HH}^A c_L - x_{HH}^B c_L & (IC-HH/HH)
\end{align*}$$

$$\begin{align*}
x_{LL}^A & \geq 0 & (B-LL) \\
x_{LL}^B & \geq 0 & (B-LH) \\
x_{HH}^A & \geq 0 & (B-HL) \\
x_{HH}^B & \geq 0 & (B-HH)
\end{align*}$$

In our setting, no “upward” incentive compatibility constraints ever bind, meaning, herein, that the principal is not concerned about the agent understating the cost. Additionally, as demonstrated by Armstrong and Rochet (1999), if the projects are symmetric, no “off-diagonal” incentive constraints bind. That is, neither (IC-HL/LL) nor (IC-LH/HL) are tight. This further implies that the optimal contract sets production levels of low-cost projects to their first-best levels.

Each production decision $x_{i,j}^k$ is binary, so there are $2^8 = 256$ potentially optimal production schedules to consider. Given the assumption $R > c_1$, production always occurs when the cost is low; specifically, $x_{LL}^A = x_{LH}^A = x_{LL}^B = x_{HL}^B = 1$. This leaves $2^4 = 16$ production schedules to consider along with the corresponding transfer schedules. In Table 4 we characterize the optimal transfer schedule for each of the 16 production schedules. Comparing the principal’s expected payoff for each schedule reveals the three contracts that are potentially optimal, depending on the parameters.
TABLE 4

Elimination of Dominated Contracts with Symmetric Projects

<table>
<thead>
<tr>
<th>Panel A: Potential Contracts with Optimal Payment $y_q$</th>
<th>Principal’s Expected Payoff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contract</td>
<td>$x^A_{HM}$</td>
</tr>
<tr>
<td>(1)</td>
<td>0</td>
</tr>
<tr>
<td>(2)</td>
<td>$c_I + c_H$</td>
</tr>
<tr>
<td>(3)</td>
<td>$c_I + c_H$</td>
</tr>
<tr>
<td>(4)</td>
<td>$c_I + c_H$</td>
</tr>
<tr>
<td>(5)</td>
<td>$c_I + c_H$</td>
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<tr>
<td>(6)</td>
<td>$c_I + c_H$</td>
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<tr>
<td>(7)</td>
<td>$c_I + c_H$</td>
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<td>(8)</td>
<td>$c_I + c_H$</td>
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<td>(9)</td>
<td>$c_I + c_H$</td>
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<td>(10)</td>
<td>$c_I + c_H$</td>
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<td>(11)</td>
<td>$c_I + c_H$</td>
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<td>$c_I + c_H$</td>
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<td>(13)</td>
<td>$c_I + c_H$</td>
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<tr>
<td>(14)</td>
<td>$c_I + c_H$</td>
</tr>
<tr>
<td>(15)</td>
<td>$c_I + c_H$</td>
</tr>
<tr>
<td>(16)</td>
<td>$c_I + c_H$</td>
</tr>
</tbody>
</table>

The principal chooses production decisions $\{x^A_{HM}, x^B_{HM}, x^A_{HL}, x^B_{HL}, x^A_{LM}, x^B_{LM}, x^A_{LH}, x^B_{LH}\}$ and conditional payments $\{a^A, a^B, b^A, b^B, c^A, c^B, d^A, d^B\}$ to maximize her expected payoff. Symmetric projects and $R = c$ imply $a^A = a^B = c^A = c^B = 0$, and $x^A_{LM} = x^A_{LH} = 1$. The table catalogs all combinations of the remaining $c^I_c$, and provides the associated transfer schedules and payoffs. The table shows that with symmetric projects, only three contracts can be optimal: (1), (11), and (16).
<table>
<thead>
<tr>
<th>Contract</th>
<th>Logic for Elimination</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>Possibly optimal: “Rationing contract”</td>
</tr>
<tr>
<td>(2)</td>
<td>Dominated by (1) for ( R \leq c_H ) and by (4) for ( R &gt; c_H )</td>
</tr>
<tr>
<td>(3)</td>
<td>Dominated by (1) for ( R \leq c_H ) and by (11) for ( R &gt; c_H )</td>
</tr>
<tr>
<td>(4)</td>
<td>Dominated by (1) when (1) dominates (11) and (16); dominated by (11) when (11) dominates (1) and (16); dominated by (16) when (16) dominates (1) and (11)</td>
</tr>
<tr>
<td>(5)</td>
<td>Dominated by (1) for ( R \leq c_H ) and by (13) for ( R &gt; c_H )</td>
</tr>
<tr>
<td>(6)</td>
<td>Dominated by (1) for ( R \leq c_H ) and by (16) for ( R &gt; c_H )</td>
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<td>(7)</td>
<td>Dominated by (1) for ( R \leq c_H ) and by (15) for ( R &gt; c_H )</td>
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<tr>
<td>(8)</td>
<td>Dominated by (1) for ( R \leq c_H ) and by (16) for ( R &gt; c_H )</td>
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<td>(9)</td>
<td>Dominated by (1) for ( R \leq c_H ) and by (11) for ( R &gt; c_H )</td>
</tr>
<tr>
<td>(10)</td>
<td>Dominated by (1) for ( R \leq c_H ) and by (16) for ( R &gt; c_H )</td>
</tr>
<tr>
<td>(11)</td>
<td>Possibly optimal: “Partial rationing contract”</td>
</tr>
<tr>
<td>(12)</td>
<td>Dominated by (1) for ( R \leq c_H ) and by (16) for ( R &gt; c_H )</td>
</tr>
<tr>
<td>(13)</td>
<td>Dominated by (1) when (1) dominates (11) and (16); dominated by (11) when (11) dominates (1) and (16); dominated by (16) when (16) dominates (1) and (11)</td>
</tr>
<tr>
<td>(14)</td>
<td>Dominated by (1) for ( R \leq c_H ) and by (16) for ( R &gt; c_H )</td>
</tr>
<tr>
<td>(15)</td>
<td>Dominated by (1) for ( R \leq c_H ) and by (16) for ( R &gt; c_H )</td>
</tr>
<tr>
<td>(16)</td>
<td>Possibly optimal: “Slack contract”</td>
</tr>
</tbody>
</table>