The Effects of Mental Accounting on Project Performance

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Problem Definition: Project managers are responsible for setting and then revising projects' goals. As uncertainty related to project performance is resolved, a project manager is tasked with comparing ongoing costs, and potentially achieved scope, to a baseline plan. We question whether project managers can rationally anticipate and track this revision process.

Academic/Practical Relevance: In practice, projects often fail to meet their goals and are subject to changes in scope, cost, and scheduled time. We consider the implications of behavioral tendencies and the revision strategy on decisions made and on overall project performance.

Methodology: Our stylized model compares a rational project manager to a behavioral one. Specifically, we offer a framework for modeling mental accounting—which includes loss aversion and reference point updating—and narrow framing. We use the model to explore how project-level decisions are made.

Results: We show that mental accounting results in insufficient adjustments of project scope and cost during revisions, and prevents abandoning projects even when doing so is optimal. Ultimately, mental accounting and narrow framing decrease projects' actual profits.

Managerial Implications: We offer practical prescriptions for mitigating harmful effects of loss aversion, reference-point updating, and narrow framing. Beyond training, hiring less loss averse project managers, and practicing scenario planning, we show that reviewing a project using a cost milestone instead of a scope milestone helps maintain the reference cost equal to the budgeted cost, thereby inducing overall better decisions.

Key words: project management, behavioral operations, mental accounting, planning fallacy, earned value analysis

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1. Introduction

In 2016, New York City's (NYC) Department of Citywide Administrative Services began a major capital project of relocating the Brooklyn Civil Court (Navarro 2014). At the time, the relocation was estimated to take 4 years and cost $81 million. As of August 2018, the project has gone through three budget and three timeline adjustments. The budget has increased from $81 million to $248 million and the overall duration has been extended by 15 months.

The "Queens Public School 19 Addition" project, administered by the NYC School Construction Authority, started in 2015. The scope of the project included a major renovation to the largest and most crowded public elementary school in NYC, P.S. 19.[1] The expansion project included a new 5-story, 97,000-square-foot addition and major alterations to the existing building. The initial approved budget was $109 million. Following 4 budgetary updates and 2 schedule revisions, the project budget increased by a total of $2 million and the project was completed 13 months early.

A review of all of NYC capital projects with a budget exceeding $25 million suggests that most projects have their scope, budget, and timeline adjusted several times throughout the projects' life-cycle. As of August 2018, NYC capital projects' budgets were adjusted 3.1 times on average and the project durations changed an average of 2.5 times. Multiple adjustments to initial project plans is not only common amongst NYC projects. Analyzing 3,145 IT projects completed by all United States government agencies (projects dated 1992-2018, data downloaded September 2018) suggests that 1,345 projects had their schedule revised and 2,317 experienced a budget revision. Only 576 projects are completed on the originally planned time and at the originally planned budget. Data on projects from the private sector, collected by Batselier and Vanhoucke (2015) and Vanhoucke et al. (2016), similarly suggests that privately funded projects, run for profit, are frequently revised and that such revisions often coincide with cost overruns and project delays. Appendix A contains details on the NYC and federal IT project data.

Our focus in this paper is on those adjustments, or revisions, to projects' initial plans. Revisions are made as information is gained, with the passing of time, but also with spending of the budget, and when attempting to accomplish the stated scope. A project manager is likely to compare ongoing cost to some reference cost and achieved scope to some reference scope. Methods commonly used in practice such as Earned Value Management encourage such comparisons (Fleming and Koppelman 2003, Vanhoucke 2013). However, such comparisons are often subject to project mangers' behavioral biases, and models of mental accounting help us understand when and how those comparisons are made (Thaler 1985, Prelec and Loewenstein 1998, Baucells and Hwang 2017). A project manager is also likely to use static valuation processes that ignore future optionality (a form of narrow framing). Our goal is to understand the implications of mental accounting and narrow framing on project management and performance.

We develop a stylized model based on a technology curve that specifies the relationships between a project's scope and cost, and that gets updated in the middle of the project. To calculate mental

[1] `https://maketheroadny.org/victory-students-at-p-s-19-will-finally-have-room-to-learn/`

profits and losses, we employ the notion of transaction utility (Thaler 1985), whereby costs and benefits are compared to a reference cost and benefit. An alternative model of mental accounting is Prelec and Loewenstein (1998), who introduce two-way hedonic interactions between payments and consumption. Their model applies to consumption (e.g., to explain why individuals prefer to pay for consumption in advance), but fails to capture the mental process of a project manager. Kőszegi and Rabin (2006) propose a general model of reference point formation, given by the rational stochastic expectation of what is to come. While theoretically elegant, there is scant evidence that reference points are anticipatory and stochastic. Baucells and Hwang (2017) generalize Thaler's model to multiple periods, and include a process of reference point updating inspired by the empirical findings of Baucells et al. (2011). We adapt Baucells and Hwang (2017) generalization of Thaler's model—initially intended to explain consumer anomalies such as sunk-cost and reference-price effects—to project management.

We are not the first to consider how reference points influence decision-making in a project setting. Long et al. (2017) consider how reference point updating at review points affects the continue/abandon decisions. Their work shows that frequent reviews do not imply better decisions. Moreover, the results from their lab study suggest that decisions in projects tend to be path dependent, where projects can be abandoned either prematurely or too late. Raz and Erel (2000) consider project reviews and control, given progress updates and reported delays. However, their focus is on the timing of the project reviews, and do not take into account the behavioral components we include.

In our model, a project manager that is not loss averse, does not change her reference points, and uses broad framing, acts rationally. Her expectations on cost and scope are on average accurate, and she optimally scales the project up (down) when the realized technology curve shifts up (down). We show that, by contrast, a project manager that ignores future optionality and is loss averse tends to anchor on the original plan exhibiting insufficient adjustments, because of his reluctance to reduce the intended scope or run over budget. We also find that such insufficient adjustments result in reluctance to abandon the project even when it is optimal to do so, which is a form of the sunk-cost effect and is consistent with other theoretical models (McCardle et al. 2018) and experimental findings (Arkes and Blumer 1985, Long et al. 2017). Overall, insufficient adjustments reduce the project's profit. These insufficient adjustments stem from a form of anchoring to insignificant information (Lorko et al. 2019), whereby the insignificant information here is the original plan.

To emotionally digest the news, the reference points will partially adapt. This process of adjustment depends critically on how project revisions are framed. If the manager uses scope as milestone, then his reference scope will not change, but his reference cost will get updated. Hence, he will be willing to go over budget in order to avoid sacrifices in scope. Thus, mental accounting can explain

Table 1 Effects of Behavioral Factors (D: direct effect, P: partial effect, N: no effect)

	Behavioral Factors		
Predicted Effect	Loss aversion	Adaptation	Narrow framing
Insufficient adjustment	D (scope, cost, time)	P (scope, time), N (cost)	P (scope, cost, time)
Reluctance to abandon	D (scope, cost, time)	P (scope, time), N (cost)	P (scope, cost, time)
Lower profit	D (scope, cost, time)	P (scope, time), N (cost)	P (scope, cost, time)

why project managers often end up spending more than their initial plans, even when the additional spending is not justified (Kahneman and Tversky 1977, Kahneman and Lovallo 1993). This explanation for cost overruns is new in that it focuses on behavior during the revision/execution phase of the project, rather than erroneous estimation at the outset, during the planning phase (Lovallo and Kahneman 2003, Flyvbjerg 2008).

We offer prescriptions to mitigate some harmful effects of loss aversion, reference-point updating, and narrow framing. We propose that project managers can make more rational decisions if they keep their reference cost constant. To this end, we show that using cost milestones for progress control helps maintain the reference cost at the budgeted level, and induces less suboptimal decisions, as compared to using scope milestones.

In practice, project controls and review points are often set along the dimensions of scope, time, or cost, with little guidance as to advantages, or in fact the differences, of the different type of review milestones. Stage-gate processes, for instance, often used in new product development projects, can be viewed as cases where progress reviewers are set based on scope (Cooper 2019). Monthly or quarterly check-ins are time-based reviews. The Project Management Institute (PMI), the largest project management certifier, in its Project Management Book of Knowledge (PMBOK), defines three types of project controls for monitoring projects: controls for project scope, project schedule or project costs, without clarifying when to utilize each type (Project Management Institute 2017).

Table 1 summarizes our results of how each behavioral factor (loss aversion, reference-point adaptation, and narrow framing) explains each predicted effect of anchoring to the initial plan (i.e., insufficient adjustment), reluctance to abandon, and lower profitability, under each type of milestone used to review the project (scope, cost, or time). We distinguish between direct, partial, and no effect. By partial effect we indicate that a behavioral factor may cause a phenomenon, conditional on the existence of another behavioral factor.

The main contributions of our work are twofold. First, we analytically model and decompose the factors that lead to suboptimal decisions of insufficient adjustment, beyond faulty judgments or forecasts. Second, based on the decomposed factors and our analytical model, we provide prescriptions to mitigate insufficient adjustments in project management. We offer guidelines for practice as to which review scheme is best for the firm, given the behavioral project manager's choices. This proposal has direct implications for how firms report progress and can be formalized as an alternative to current standard practices.

2. Model Setup

A project manager (PM) must decide the cost of a project, $C \geq 0$, hoping to achieve some scope, $Q \geq 0$. The relationship between Q and C is given by $Q = (1+\epsilon)f(C)$, where $f(C)$ is the deterministic component of the technology curve, increasing and concave with $f(0) = 0$; and $\epsilon > -1$ is a random deviation, with $E[\epsilon] = 0$. Here, ϵ is a deviation in scope, such that a positive deviation is good. We normalize the units of scope so that Q is also the revenue of the project, or its social benefit, measured in dollars. Hence, the profit of the project, or net social benefit of a non-profit project, is $Q - C$, which we refer to as just *profit* hereafter. For simplicity, we ignore time value of money. Considering time value of money would not alter our main results.

The *deterministic* plan, which will serve as a benchmark in our analysis, is the plan that maximizes profit assuming the project faces no uncertainty, or $\epsilon = 0$ with probability 1. Formally, $C^{\text{DET}} = \text{argmax}_C\, f(C) - C$ and $Q^{\text{DET}} = f(C^{\text{DET}})$. For concreteness, and without any loss of qualitative insight, we employ a power technology $f(C) = kC^{\gamma}$, $k > 0$ and $0 < \gamma < 1$, as our base model.[2] Then, the deterministic plan is given by

$$C^{\text{DET}} = (k\gamma)^{\frac{1}{1-\gamma}} \quad \text{and} \quad Q^{\text{DET}} = k\,(k\gamma)^{\frac{\gamma}{1-\gamma}}\,. \tag{1}$$

In a realistic setting, the relationship between C and Q would be progressively learned as the project advances. Here, we make the simplifying assumption that ϵ is learned at once at a certain milestone. The milestone is described by some given fraction of the project, denoted by ϕ, that must be completed before the most important uncertainties are revealed (e.g., design of a new engine when developing a new aircraft, or the construction of building foundations and the first floor for a new building). There are several ways to measure progress. The fraction ϕ could indicate that (*i*) a certain percentage of the scope Q^{DET} has been concluded, or (*ii*) a certain percentage of the cost C^{DET} has been spent, or (*iii*) a certain fraction of the planned completion time has passed. Such project milestones or controls are typically used in practice (Project Management Institute 2017).

We explore revision at scope and cost milestones in the base model, and examine a revision at time-based milestone in Section 6. Specifically, when using a scope milestone, the review is performed when a scope of $q_1 = \phi Q^{\text{DET}}$ is achieved, at which point the PM learns ϵ. In the absence of deviations, $\epsilon = 0$, the cost incurred by then would be $c_1 = \phi^{\frac{1}{\gamma}} C^{\text{DET}}$. To maintain parallelism, when using a cost milestone the PM learns ϵ after spending $c_1 = \phi^{\frac{1}{\gamma}} C^{\text{DET}}$.

[2] Any technology curve $f(C)$ that is concave would generate the same main insights. Also, the alternative of defining the technology curve in terms of the cost associated with each choice of scope is mathematically equivalent. Let $C = (1+\epsilon_A)f_A(Q)$, where f_A is increasing and convex, and $E[\epsilon_A] = 0$. In the power case, $f_A(Q) = k_A Q^{\gamma_A}$, $\gamma_A > 1$. Define $\gamma_A = 1/\gamma$, $k_A = (\theta/k)^{\gamma_A}$, $\epsilon_A = (\theta(1+\epsilon))^{-\gamma_A} - 1$, and $\theta = E[(1+\epsilon)^{-\gamma_A}]^{1/\gamma_A}$. We verify that our $Q = (1+\epsilon)kC^{\gamma}$, $\gamma \in (0,1)$, is equivalent to $C = (1+\epsilon_A)k_A Q^{\gamma_A}$, $\gamma_A > 1$, and both exhibit $E[\epsilon] = E[\epsilon_A] = 0$.

The following is the sequence of events. At the beginning of Period 1, the PM sets up an initial plan, including a budget and a targeted scope, and launches the project. The project advances until learning ϵ, which is the end of Period 1. Under scope milestone, upon achieving $q_1 = \phi Q^{\text{DET}}$ the PM learns the actual cost of doing the work, c_1, and deduces that $\epsilon = \phi Q^{\text{DET}}/f(c_1) - 1$. Thus, as a function of ϵ and ϕ, a scope milestone review can be characterized as:

$$\text{Scope milestone:} \quad (c_1, q_1) = ((\phi/(1+\epsilon))^{\frac{1}{\gamma}} C^{\text{DET}}, \phi Q^{\text{DET}}). \tag{2}$$

By contrast, under a cost milestone approach, upon spending $c_1 = \phi^{\frac{1}{\gamma}} C^{\text{DET}}$ the PM learns the scope achieved, q_1, and deduces that $\epsilon = q_1/f(\phi^{\frac{1}{\gamma}} C^{\text{DET}}) - 1$. Thus, as a function of ϵ and ϕ, a cost milestone review can be characterized as:

$$\text{Cost milestone:} \quad (c_1, q_1) = (\phi^{\frac{1}{\gamma}} C^{\text{DET}}, (1+\epsilon)\phi Q^{\text{DET}}). \tag{3}$$

Regardless of the revision method, the learned value of ϵ fixes the technology curve at $(1+\epsilon)f(C)$ for the rest of the project. In Period 2, with the updated technology curve, the PM can either abandon the project or revise the scope and adjust the remaining cost, c_2. In case of continuing, the project is completed at the end of period 2, at a total cost of $C = c_1 + c_2$, and a realized profit of $(1+\epsilon)f(C) - C$, with ϵ known.

To avoid uninteresting cases where abandonment is the only option, we assume $\epsilon \geq \phi - 1$, ensuring precisely that c_1 does not exceed the deterministic cost for the entire project, $c_1 \leq C^{\text{DET}}$.

Two commonly used monitoring metrics in project management are Earned Value (EV) and Actual Cost (AC) (Vanhoucke 2013). Our model relates to EV and AC as follows. At the end of Period 1, the actual cost is always $AC = c_1$. Earned Value (EV) is defined as the cost required to achieve the accomplished scope according to the initial plan, which in our case is given by

$$EV = f^{-1}(q_1) = \begin{cases} \phi^{\frac{1}{\gamma}} C^{\text{DET}}, & \text{(scope milestone)}, \\ (1+\epsilon)^{\frac{1}{\gamma}} \phi^{\frac{1}{\gamma}} C^{\text{DET}}, & \text{(cost milestone)}. \end{cases}$$

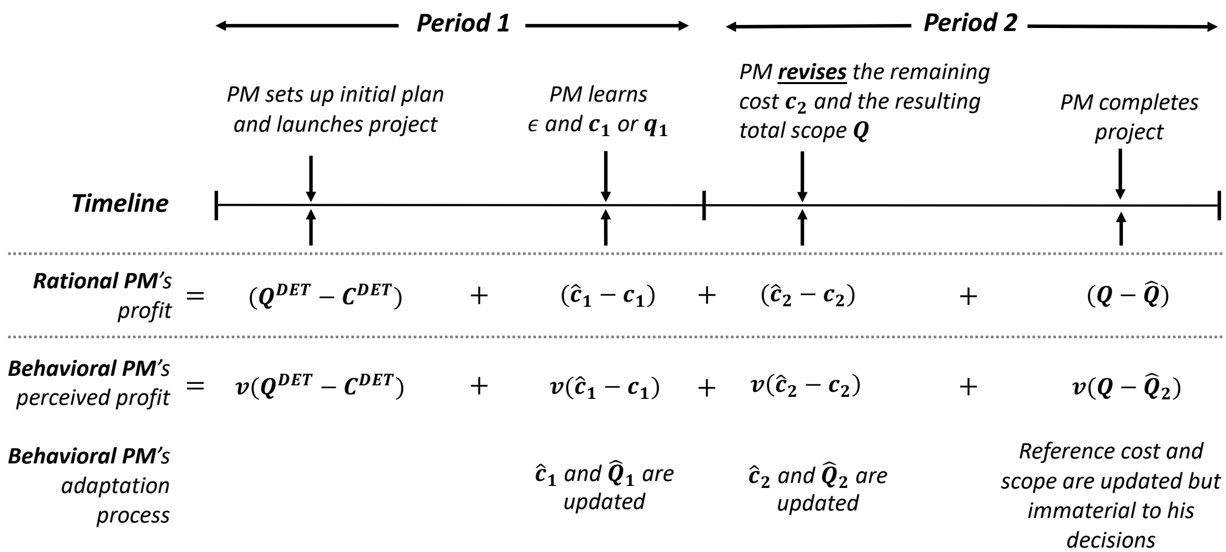
Note that $\phi^{1/\gamma}$ is the fraction of the total cost the PM was planning to spend to achieve a fraction ϕ of the scope under the deterministic plan. If $\epsilon = 0$, then $EV|_{\epsilon=0} = \phi^{\frac{1}{\gamma}} C^{\text{DET}}$ is equal to AC under both scope and cost milestones.

To help understand the model, we use the following numerical example throughout the paper.

EXAMPLE 1. *Let the technology curve be $f(C) = 2C^{1/2}$ [\$M] and set the review fraction at $\phi =$ 40%. Also assume that the random deviations in scope are given by ϵ = 0.2, 0, or -0.2.*

Here, the deterministic plan is $(C^{\text{DET}}, Q^{\text{DET}}) = (\$1M, \$2M)$. With a scope milestone, the PM learns ϵ after achieving a scope of $q_1 = \$0.8M$. When the news is neutral, $\epsilon = 0$, the actual cost is equal to the earned value, $AC = EV|_{\epsilon=0} = \$0.16M$. When the news is bad, $\epsilon = -0.2$ (good, $\epsilon = 0.2$),

Figure 1 **Timeline and Components of the Rational PM's Profit and the Behavioral PM's Perceived Profit**



the cost for completing 40% of the project is $c_1 = (\phi/(1+\epsilon))^{\frac{1}{\gamma}} C^{\text{DET}} = \$0.25M$ $(c_1 = \$0.11M)$. By contrast, with a cost milestone, the PM learns ϵ after spending $c_1 = \$0.16M$. When the news is neutral, $\epsilon = 0$, the scope is equal to $q_1 = \$0.8M$. When the news is bad, $\epsilon = -0.2$ (good, $\epsilon = 0.2$), the achieved scope is $q_1 = \$0.64M$ $(q_1 = \$0.96M)$ and the EV is $\$0.10M$ $(\$0.23M)$.

2.1. Rational Project Manager

A rational PM ("she") employs an accounting process to bank or amortize costs and benefits, and hence calculates the gains and losses in each period. To do so, she sets a plan, a natural choice for which is the deterministic plan $(C^{\text{DET}}, Q^{\text{DET}})$. She also employs reference costs $\hat{c}_1$ and $\hat{c}_2$ and reference scope $\hat{Q}$ to track the progression of the project, where $\hat{c}_1 + \hat{c}_2 = C^{\text{DET}}$ and $\hat{Q} = Q^{\text{DET}}$. Importantly, these three reference points remain constant throughout the project.

At the beginning of Period 1, she budgets a profit of $Q^{\text{DET}} - C^{\text{DET}}$. As the project progresses, she calculates the profit differences relative to budget. Specifically, at the end of Period 1, she observes ϵ and incorporates the deviation of the actual cost from the plan, $\hat{c}_1 - c_1$. At the beginning of Period 2, she adjusts the remaining cost of the project and incorporates the cost deviation, $\hat{c}_2 - c_2$. Finally, at the end of Period 2, she accounts for the total scope deviation, $Q - \hat{Q}$. To sum up, the rational PM evaluates the project using the following profit function:

$$\Pi^R = \underbrace{(Q^{\text{DET}} - C^{\text{DET}})}_{\substack{\text{Beginning of Period 1:} \\ \text{budgeted profit}}} + \underbrace{(\hat{c}_1 - c_1)}_{\substack{\text{End of Period 1:} \\ \text{cost comparison}}} + \underbrace{(\hat{c}_2 - c_2)}_{\substack{\text{Beginning of Period 2:} \\ \text{cost comparison}}} + \underbrace{(Q - \hat{Q})}_{\substack{\text{End of Period 2:} \\ \text{scope comparison}}} . \tag{4}$$

See Figure 1 for depiction of these components. Note that there are two (or more) cost adjustments, but only one scope adjustment. This is inherent in the nature of projects: Costs are spent throughout the project, thus requiring multiple comparisons, but the benefit is realized only once at the end of the project. The accounting system in (4) is a natural one to make dynamic profit adjustments to an original plan.

It is trivial to see that the reference points, which remain constant, cancel out in (4), and the calculated profit is equal to the actual profit, or $\Pi^R = Q - c_1 - c_2$. That is, stable reference points do not distort the rational decision at launch, nor do they distort the rational revision at the beginning of Period 2: having observed the realized uncertainty ϵ, the PM decides on the second period cost c_2 to maximize the last two terms in (4), or her accounting profit-to-go, solving

$$c_2^{*R} = \operatorname{argmax}_{c_2} \hat{c}_2 - c_2 + Q - \hat{Q}. \tag{5}$$

Because $\hat{c}_2$ and $\hat{Q}$ are constant, this objective is identical to maximizing the profit-to-go, $Q - c_2$. The optimally revised project possesses the following characteristics.

PROPOSITION 1. *The optimal project cost and scope (C^{*R}, Q^{*R}) that maximizes Π^R is as follows:*

(i) The project is abandoned, that is, $C^{*R} = c_1$ and $Q^{*R} = q_1$, whenever

$$\epsilon \leq \begin{cases} \phi^{1-\gamma} - 1, & \textit{(scope milestone)}, \\ \phi^{\frac{1-\gamma}{\gamma}} - 1, & \textit{(cost milestone)}. \end{cases}$$

(ii) Otherwise, the revised plan is $C^{*R} = (1+\epsilon)^{\frac{1}{1-\gamma}} C^{\text{DET}}$ and $Q^{*R} = (1+\epsilon)^{\frac{1}{1-\gamma}} Q^{\text{DET}}$. Both C^{*R} and Q^{*R} are increasing with ϵ, and $(C^{*R}, Q^{*R})|_{\epsilon=0} = (C^{\text{DET}}, Q^{\text{DET}})$.

All proofs can be found in the Appendix. If the news is terrible, case (i), then the PM abandons the project. If the news is bad but not terrible, then the PM scales down the project by decreasing both the cost and scope relative to the deterministic plan. If the news is neutral, then she carries out the deterministic plan. Finally, if the news is good, then the rational PM scales up the project relative to the deterministic plan, both in terms of cost and scope. Thus, regardless of the news, the rational PM would neither spend more while achieving a smaller scope, nor spend less while achieving a larger scope, relative to the deterministic plan.

At the beginning of Period 1, the rational PM fully anticipates how she will update her plan contingent on the realized uncertainty ϵ; and that the final cost and scope will be revised to $C^{*R} = c_1 + c_2^{*R}$ and $Q^{*R} = (1+\epsilon) f(C^{*R})$. Thus, her expected cost and scope at project launch are

$$E[C^{*R}] = E[\max\{(1+\epsilon)^{\frac{1}{1-\gamma}} C^{\text{DET}}, c_1\}] \text{ and}$$
$$E[Q^{*R}] = E[\max\{(1+\epsilon)^{\frac{1}{1-\gamma}} Q^{\text{DET}}, q_1\}].$$

These expectations differ from the plan at project launch, $(C^{\text{DET}}, Q^{\text{DET}})$, and a rational PM would be aware of such bias. Of course, the rational PM could avoid the bias and set her initial plan to $(E[C^{*R}], E[Q^{*R}])$. This plan, however, may not be easy to visualize or communicate, because $E[C^{*R}]$ and $E[Q^{*R}]$ may not lie in the deterministic technology curve, i.e., $E[Q^{*R}] \neq f(E[C^{*R}])$. Given that the choice of initial plan is immaterial to the decisions, the rational PM may as well use the deterministic plan in order to facilitate the visualization and communication of the project.

Note that the expected cost and scope are on average greater than the deterministic cost and scope, respectively, because concavity of the technology curve recommends greater expansions under good news than it recommends contractions under bad news. For example, when project abandonment is never optimal, applying Jensen's inequality to Proposition 1 results in that $E[C^{*R}] = E[(1+\epsilon)^{\frac{1}{1-\gamma}} C^{\text{DET}}] \geq C^{\text{DET}}$.

2.2. Behavioral Project Manager

A behavioral PM ("he"), whose plan is also set to the deterministic plan $(C^{\text{DET}}, Q^{\text{DET}})$, follows the same accounting process as the rational PM's, but with some psychological 'distortions', namely:

(1) When he compares the cost or scope to a reference point, he experiences loss aversion if the actual value negatively deviates from the reference value. To capture this, we use a piecewise linear value function, $v(x) = x$, $x \geq 0$, and $v(x) = \lambda x$, $x < 0$, with $\lambda \geq 1$, as commonly assumed in the behavioral literature (Barberis et al. 2006, Wang and Webster 2009).

(2) Instead of using reference points that stay constant over time, he partially adapts to news and changes in the project by updating the reference point towards the new reality. The update occurs at the end of period 1, after learning ϵ, at the beginning of period 2, after revising the project, and at the end of period 2, when the project terminates. We follow Baucells and Hwang (2017)'s modeling choice, and have the updating of reference points occur before the evaluation. Thus, adaptation makes losses less painful, and gains less enjoyable; a fact well grounded in the happiness literature (Brickman et al. 1978).

(3) The behavioral PM suffers from narrow framing, defined as follows:

  (i) *Flaw of the Averages*: He has a hard time solving stochastic problems, e.g., creating scenarios and incorporating future optionality, and prefers to replace future uncertainties by their expected values and solve a deterministic plan (Savage 2012). In our case, this implies acting as if $\epsilon = 0$ when setting the plan.

  (ii) *Projection Bias*: He fails to anticipate that his reference points will update (Loewenstein, O'Donoghue, and Rabin 2003).

The flaw of the averages predicts what is often seen in practice, namely, that profit calculations result from a cash flow model of a deterministic scenario; and that projet managers do not use a stochastic model when analyzing the option value of downstream decisions.

Accordingly, the behavioral PM's *perceived profit* is (see Figure 1)

$$\Pi^B = \underbrace{v(Q^{\text{DET}} - C^{\text{DET}})}_{\substack{\text{Beginning of Period 1:} \\ \text{budgeted profit}}} + \underbrace{v(\hat{c}_1 - c_1)}_{\substack{\text{End of Period 1:} \\ \text{cost comparison}}} + \underbrace{v(\hat{c}_2 - c_2)}_{\substack{\text{Beginning of Period 2:} \\ \text{cost comparison}}} + \underbrace{v(Q - \hat{Q}_2)}_{\substack{\text{End of Period 2:} \\ \text{scope comparison}}} .$$

At the beginning of Period 1, under the naïve view that the reference points will remain constant and ϵ will be zero, all terms are gains, and Π^B is equal to $Q - c_1 - c_2$. Accordingly, the behavioral PM optimizes Π^B and obtains our deterministic plan. Therefore, it is only natural that the behavioral PM will set the reference point at $(C^{\text{DET}}, Q^{\text{DET}})$, and use earned value to break the planned cost into $EV|_{\epsilon=0}$ and $C^{\text{DET}} - EV|_{\epsilon=0}$ for Periods 1 and 2, respectively. At this point in time, the behavioral PM mimics quite well the rational PM, except that the latter is fully aware that the deterministic plan is a biased expectation, whereas the former is not.

The reference points update as the project progresses according to a simple rule. Let $0 \le \alpha < 1$ be the speed of adaptation, where a higher α represents a stronger deviation from rationality, since the rational PM keeps constant reference points. At the end of Period 1, learning about the deviation ϵ triggers an update of the reference cost from $EV|_{\epsilon=0} = \phi^{1/\gamma} C^{\text{DET}}$ towards the actual value,

$$\hat{c}_1 = \alpha c_1 + (1 - \alpha)\phi^{1/\gamma} C^{\text{DET}}. \tag{6}$$

Similarly, the PM updates the reference scope as follows:

$$\hat{Q}_1 = \alpha \left(\frac{1}{\phi} q_1 \right) + (1 - \alpha) Q^{\text{DET}}. \tag{7}$$

Recall that ϕ is the fraction of the total scope the PM should have achieved by the end of Period 1. Therefore, $\frac{1}{\phi} q_1$ is the projected scope for the entire project. This process captures that when news is bad, for example, one comes partially to terms that the cost will be higher than anticipated, and the scope lower than anticipated.

At the beginning of Period 2, revising the project and choosing c_2 triggers another updating of the reference cost for the remainder of the project as follows:

$$\hat{c}_2 = \alpha c_2 + (1 - \alpha) \frac{1 - \phi^{1/\gamma}}{\phi^{1/\gamma}} \hat{c}_1. \tag{8}$$

Recall that $\phi^{1/\gamma}$ is the fraction of the total cost the PM should have spent by the end of Period 1. Hence, $\frac{1}{\phi^{1/\gamma}} \hat{c}_1$ is the updated reference cost for the entire project, and $\frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}} \hat{c}_1$ is the updated reference cost for the second period (before revisions are made). Similarly, revising the scope to $Q = (1 + \epsilon) f(c_1 + c_2)$ triggers another update of the reference scope to

$$\hat{Q}_2 = \alpha Q + (1 - \alpha) \hat{Q}_1. \tag{9}$$

The reference points affect behavior as follows. The behavioral PM revises the project at the beginning of Period 2 so as to maximize his perceived profit-to-go,

$$c_2^{*B} = \text{argmax}_{c_2}\, v(\hat{c}_2 - c_2) + v(Q - \hat{Q}_2), \tag{10}$$

where $\hat{c}_2$ and $\hat{Q}_2$ are given by (8) and (9). Note that if one sets c_2 higher than $\frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$, then $\hat{c}_2$ increases. Thus, one partially adapts to the higher cost before utility is realized. The revised plan resulting from solving (10) is $C^{*B} = c_1 + c_2^{*B}$ and $Q^{*B} = (1+\epsilon)f(C^{*B})$. Consistent with our definition of narrow framing, the behavioral PM fails to anticipate that $\hat{c}_2$ and $\hat{Q}_2$ will subsequently update upon completing the project. This final updating does not impact any decisions in our model, and hence we omit its description.

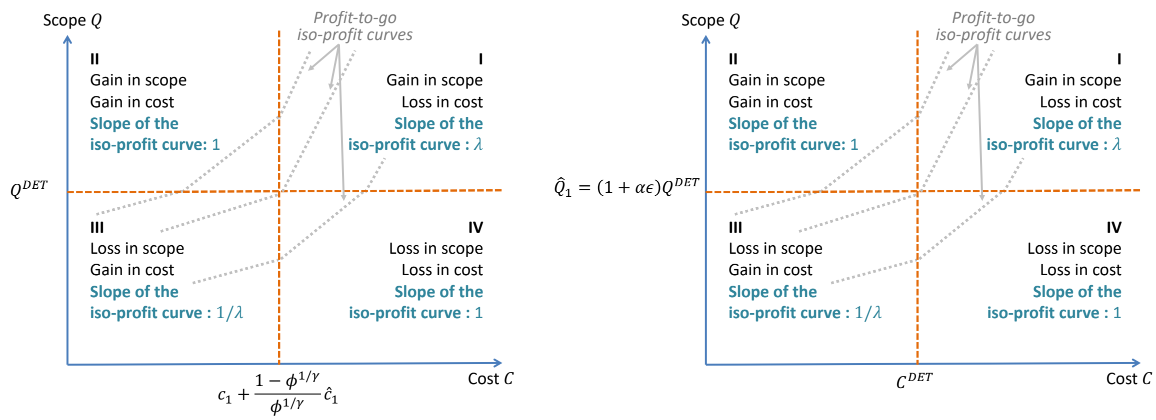
Note that a PM with α close to 1 would set the reference point close to the realized values, and hence experience little sense of loss (whatever happens is meant to be!). By contrast, a PM with α equal to 0 would always experience gains and losses relative to the initial plan, regardless of the news and revisions that occur in between. If such PM were not loss averse, $\lambda = 1$, then he would resemble the rational PM, except for the flaw of the averages.

3. Behavioral Revision: Iso-Profit Curves

It is straightforward to see that if $\epsilon = 0$, both the rational and the behavioral PMs would optimally execute the deterministic plan. When $\epsilon \neq 0$, however, the behavioral PM's revision may no longer be rational. To see what drives the difference, consider how much the PM is willing to spend to increase scope by 1. For the rational PM, the answer is always \$1. Behaviorally, if the project is doing well in scope, but over-budget, then he is willing to spend only $\$1/\lambda < \$1$ (the project is getting too expensive). By contrast, if the project is fine on cost, but falling short in scope, then he is willing to spend $\$\lambda > \$1$ (the project's scope is disappointing). We now formalize this intuition.

At the beginning of Period 2, we can think of the revision as a choice of a point $(C, Q) \in \mathbb{R}_+^2$, where $C = c_1 + c_2$ is the total cost, and Q is the total scope. In this plane, we can draw a vertical line indicating the cost beyond which the PM experiences loss aversion in the cost dimension; and a horizontal line indicating the scope below which the PM experiences loss aversion in the scope dimension, as depicted in Figure 2. If $\epsilon = 0$, then these lines coincide with the deterministic cost and scope, respectively. When $\epsilon \neq 0$, however, these lines will move. Importantly, the type of milestone chosen to review progress crucially influences how the lines move. Scope milestone anchors the horizontal line to the initial scope, while moving the vertical line depending on the actual cost. By contrast, cost milestone anchors the vertical line to the planned cost, while moving the horizontal line depending on the realized scope.

Figure 2 Gains and losses compared to the reference cost and scope at the review point.



(a) Revision at scope milestone (b) Revision at cost milestone

3.1. Scope Milestone

If scope is chosen as milestone, then the scope attained by the time of the review is by definition ϕQ^{DET}, and the reference scope $\hat{Q}_1$ stays at Q^{DET}. By contrast, the news on cost produces a shift of the reference cost for the total project: Good news decreases $\hat{c}_1$ and bad news increases $\hat{c}_1$, as given by (6). The extrapolation of this reference cost towards the second period is $\frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$; and c_2 exceeding this value will trigger loss aversion in cost.

The perceived profit-to-go at the beginning of Period 2, given in (10) and using the reference points as in (6)-(9) with (c_1, q_1) as in (2) for scope milestone, is

$$v(\hat{c}_2 - c_2) + v(Q_2 - \hat{Q}_2) = v\left((1-\alpha)\left(\frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}} \cdot \hat{c}_1 - c_2\right)\right) + v((1-\alpha)(Q - Q^{\text{DET}})). \tag{11}$$

Evaluating v on each of the four possible cases makes this expression equal to

$$\begin{cases} (1-\alpha)\left[(Q-\lambda c_2) + \lambda\frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 - Q^{\text{DET}}\right], & \text{if } c_2 \geq \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1, Q \geq Q^{\text{DET}}, \\ (1-\alpha)\left[(Q-c_2) + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 - Q^{\text{DET}}\right], & \text{if } c_2 < \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1, Q \geq Q^{\text{DET}}, \\ \lambda(1-\alpha)\left[(Q-\frac{1}{\lambda}c_2) + \frac{1}{\lambda}\frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 - Q^{\text{DET}}\right], & \text{if } c_2 < \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1, Q < Q^{\text{DET}}, \\ \lambda(1-\alpha)\left[(Q-c_2) + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 - Q^{\text{DET}}\right], & \text{if } c_2 \geq \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1, Q < Q^{\text{DET}}. \end{cases} \tag{12}$$

Note that $c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$ is the reference cost for the entire project, and thus the horizontal and vertical threshold lines cross at $(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1, Q^{\text{DET}})$, as shown in Figure 2(a).

Figure 2(a) can help visualize the behavioral revision using iso-profit curves. The slope of the iso-profit curve is given by the coefficient of c_2 divided by the coefficient of Q in (12). Loss aversion in scope is triggered if the revised scope falls below Q^{DET} and loss aversion in cost is triggered if the revised cost exceeds $c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$. Accordingly, the choice of (C, Q) at the revision point may trigger loss in cost but not in scope (upper-right quadrant), in scope but not in cost (lower-left), in both cost and scope (lower-right), or neither (upper-left). The PM's optimal revision is to find the point in the updated technology curve that touches the highest iso-profit curve. Consequently, the kinked iso-profit curves—which reflect the desire to avoid losses in either cost or scope—effectively pull the behavioral PM's decision towards the crossing point.

3.2. Cost Milestone

If cost is chosen as milestone, then the cost attained at revision is by definition $\phi^{1/\gamma}C^{\text{DET}}$, the reference cost $\hat{c}_1$ stays at $EV|_{\epsilon=0}$, and the reference cost for the entire project stays at C^{DET}. Thus, at revision, costs exceeding C^{DET} trigger loss aversion. By contrast, the news on scope produces a shift of the reference scope: Good news increases $\hat{Q}_1$ and bad news decreases $\hat{Q}_1$, as given by (7). Consequently, the reference scope that triggers loss aversion at revision is $\hat{Q}_1 = (1+\alpha\epsilon)Q^{\text{DET}}$. Thus, the vertical and horizontal threshold lines cross at $(C^{\text{DET}}, (1+\alpha\epsilon)Q^{\text{DET}})$, as shown in Figure 2(b). We confirm that the slopes in each quadrant are identical to the case of using a scope milestone, and the only difference is the location of the horizontal and vertical threshold lines.[3]

4. Behavioral vs. Rational Revision

4.1. Revision after Good News

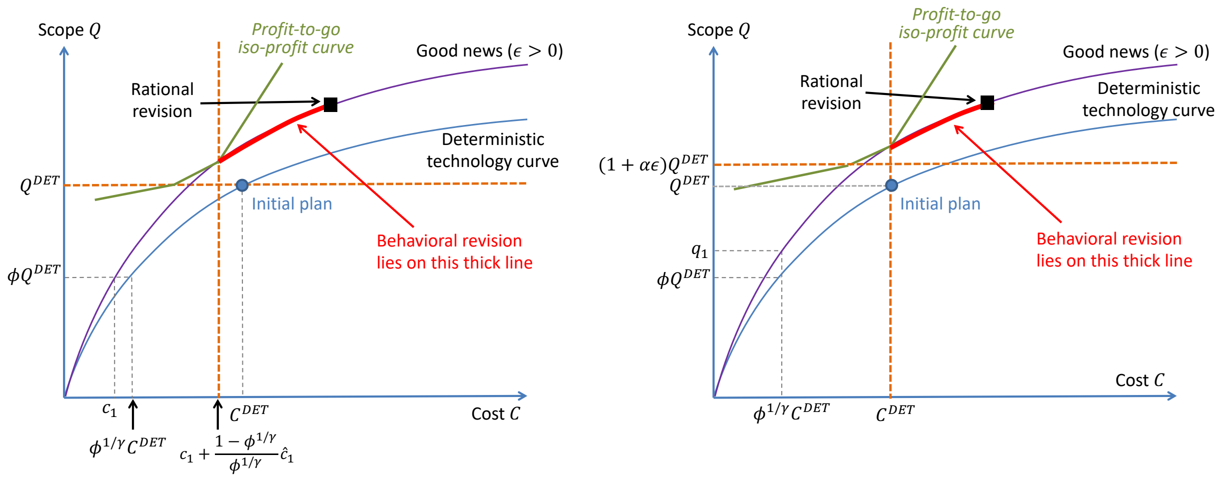
The behavioral revision following good news is illustrated in Figure 3, (a) for scope and (b) for cost milestone. The piecewise-linear solid line is the iso-profit curve of the behavioral PM's perceived profit-to-go. The blue circle represents the initial plan $(C^{\text{DET}}, Q^{\text{DET}})$, and the black square represents the rational revision, (C^{*R}, Q^{*R}). The behavioral revision (C^{*B}, Q^{*B}) lies on the thick red line between the rational revision (black square) and the dashed vertical line representing the reference cost for the entire project, $c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$ for scope milestone, and C^{DET} for cost milestone. Thus, in any review strategy, the behavioral PM experiences a pull towards the crossing point, and insufficiently adjusts the cost or the scope compared to the rational PM.

Under scope milestone, the rational revision following good news is to do more and spend more, hence going over budget. This is anathema for a loss averse PM, who following good news updated his reference budget *downwards*. For a sufficiently high λ, he instead feels that the project should "accomplish more while spending less" than originally intended. We now formalize this intuition.

[3] Using the reference points in (6)-(9) and using (c_1, q_1) defined in (3), the behavioral PM's perceived profit-to-go given in (10) can be rewritten as $v(\hat{c}_2 - c_2) + v(Q - \hat{Q}_2) = v\left((1-\alpha)((1-\phi^{1/\gamma})C^{\text{DET}} - c_2)\right) + v((1-\alpha)(Q - (1+\alpha\epsilon)Q^{\text{DET}}))$. Evaluating v on each of the four possible cases makes this expression equal to

$$\begin{cases} (1-\alpha)\left[(Q-\lambda c_2) + \lambda(1-\phi^{1/\gamma})C^{\text{DET}} - (1+\alpha\epsilon)Q^{\text{DET}}\right], & \text{if } C \geq C^{\text{DET}}, Q \geq (1+\alpha\epsilon)Q^{\text{DET}}, \\ (1-\alpha)\left[(Q-c_2) + (1-\phi^{1/\gamma})C^{\text{DET}} - (1+\alpha\epsilon)Q^{\text{DET}}\right], & \text{if } C < C^{\text{DET}}, Q \geq (1+\alpha\epsilon)Q^{\text{DET}}, \\ \lambda(1-\alpha)\left[\left(Q-\frac{1}{\lambda}c_2\right) + \frac{1}{\lambda}(1-\phi^{1/\gamma})C^{\text{DET}} - (1+\alpha\epsilon)Q^{\text{DET}}\right], & \text{if } C < C^{\text{DET}}, Q < (1+\alpha\epsilon)Q^{\text{DET}}, \\ \lambda(1-\alpha)\left[(Q-c_2) + (1-\phi^{1/\gamma})C^{\text{DET}} - (1+\alpha\epsilon)Q^{\text{DET}}\right], & \text{if } C \geq C^{\text{DET}}, Q < (1+\alpha\epsilon)Q^{\text{DET}}. \end{cases} \tag{13}$$

Figure 3 Revised plans when the news is good, $\epsilon > 0$



(a) Revision at scope milestone

(b) Revision at cost milestone

Proposition 2 **(Scope Milestone).** *Suppose the news is good, $\epsilon > 0$. The behavioral revision (C^{*B}, Q^{*B}) that maximizes Π^B after learning ϵ and c_1 is as follows:*

(i) For any $\epsilon > 0$, $Q^{*B} = (1+\epsilon)f(C^{*B})$, where

$$C^{*B} = \begin{cases} c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1, & \text{if } \lambda \geq (1+\epsilon)k\gamma(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1)^{\gamma-1}, \\ ((1+\epsilon)/\lambda)^{\frac{1}{1-\gamma}} \cdot C^{\text{DET}}, & \text{otherwise.} \end{cases}$$

(ii) Compared to the rational PM, the behavioral PM always invests less and accomplishes a smaller scope, i.e., $C^{*B} \leq C^{*R}$ and $Q^{*B} \leq Q^{*R}$.

(iii) Compared to the planned cost C^{DET}, the behavioral PM invests less if $\lambda > 1+\epsilon$, and invests more otherwise. The realized scope is larger than planned, $Q^{*B} > Q^{\text{DET}}$, regardless of λ.

Under cost milestone, recall that the reference cost for the entire project stays at C^{DET}. Hence, the reaction to good news for a sufficiently high λ is to "accomplish more while maintaining the original budget". As seen in Figure 3(b), the behavioral PM never spends less than C^{DET}, and may go over budget if loss aversion is not pronounced.

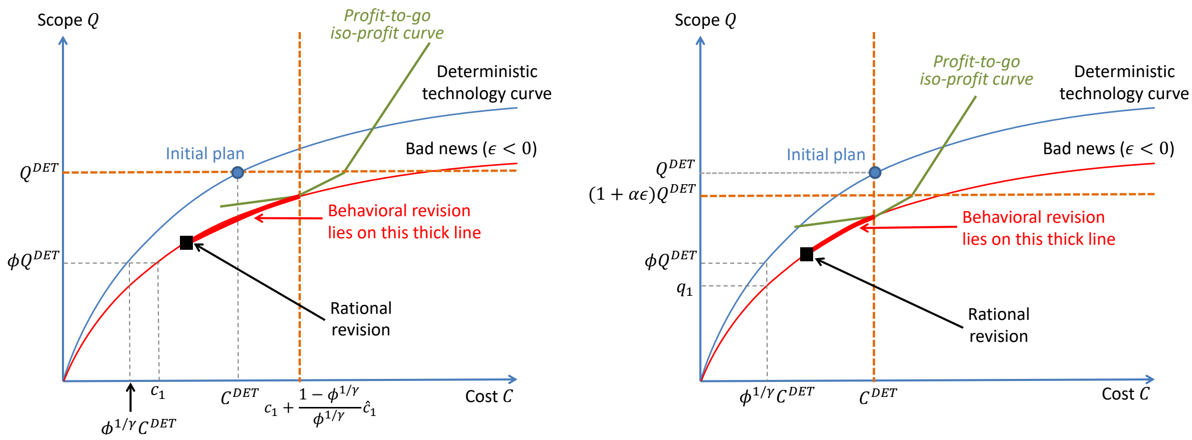
Proposition 3 **(Cost Milestone).** *Suppose the news is good, $\epsilon > 0$. The behavioral revision (C^{*B}, Q^{*B}) that maximizes Π^B after learning ϵ and q_1 is as follows:*

(i) For any $\epsilon > 0$, $Q^{*B} = (1+\epsilon)f(C^{*B})$, where

$$C^{*B} = \begin{cases} C^{\text{DET}}, & \text{if } \lambda \geq 1+\epsilon, \\ ((1+\epsilon)/\lambda)^{\frac{1}{1-\gamma}} \cdot C^{\text{DET}}, & \text{otherwise.} \end{cases}$$

(ii) Compared to the rational PM, the behavioral PM always invests less and accomplishes a smaller scope, i.e., $C^{*B} \leq C^{*R}$ and $Q^{*B} \leq Q^{*R}$.

Figure 4 Revised plans when the news is bad, $\epsilon < 0$



(a) Revision at scope milestone (b) Revision at cost milestone

(iii) The behavioral PM sticks to the initial budget C^{DET} *if* $\lambda \geq 1+\epsilon$*, and invests more otherwise. He always accomplishes more than the planned scope* Q^{DET} *regardless of* λ*.*

4.2. Revision After Bad News

The behavioral revision following bad news is illustrated in Figure 4, (a) for scope and (b) for cost milestone. Similar to good news, in any review strategy, the behavioral PM experiences a pull towards the crossing point, and insufficiently adjusts the cost or the scope compared to the rational PM.

Under scope milestone, the rational thing to do is to do less and spend less. The behavioral PM, however, is disappointed by the idea of not achieving what he initially set out to do. Meanwhile, he becomes more comfortable with spending more because he updated his reference budget *upwards*. For a sufficiently high λ, he feels that the project should "accomplish less but spend more" than originally planned, resulting in cost overruns. The following formalizes this intuition.

PROPOSITION 2 **(Scope Milestone)**. ***(Cont.)*** *Suppose the news is bad,* $\epsilon < 0$*. The behavioral revision* (C^{*B}, Q^{*B}) *that maximizes* Π^B *after learning* ϵ *and* c_1 *is as follows:*

(iv) If $\epsilon \leq \phi^{1-\gamma}/\lambda^{\gamma} - 1$*, then* $C^{*B} = c_1$ *and* $Q^{*B} = \phi Q^{\text{DET}}$ *and the project is abandoned.*

(v) If $\epsilon > \phi^{1-\gamma}/\lambda^{\gamma} - 1$*, then* $Q^{*B} = (1+\epsilon) f(C^{*B})$*, where*

$$C^{*B} = \begin{cases} c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1, & \text{if } \lambda \geq 1/((1+\epsilon)k\gamma(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1)^{\gamma-1}), \\ (\lambda(1+\epsilon))^{\frac{1}{1-\gamma}} \cdot C^{\text{DET}}, & \text{otherwise.} \end{cases}$$

(vi) Compared to the rational PM, the behavioral PM always invests more and accomplishes a larger scope, i.e., $C^{*B} \geq C^{*R}$ *and* $Q^{*B} \geq Q^{*R}$*.*

(vii) Compared to the planned cost C^{DET}*, the behavioral PM invests more if* $\lambda > 1/(1+\epsilon)$*, and invests less otherwise. The realized scope is smaller than planned,* $Q^{*B} < Q^{\text{DET}}$*, regardless of* λ*.*

In practice, we often observe this inertia to stick to the initial scope. For instance, when the plans for the London Olympics 2012 aquatic center have been rejected for going two times over budget, the Olympic minister considered reducing the original plans of a 20,000-seat arena to a 10,000-seat one to cut costs. However, the center was eventually built to accommodate 17,500 seats (BBC 2005, 2008).

In general, it has been observed that project managers often end up spending more than their initial plans, even when the additional spending is not warranted due to the decreased value of the project (Flyvbjerg 2008, Flyvbjerg et al. 2018). Our explanation for such cost overruns is new, and stems from the suboptimal updating during the *revision/execution* phase of the project. By contrast, the literature focuses on erroneous estimation at the outset or deliberate deception during the *planning* phase (Lovallo and Kahneman 2003, Flyvbjerg 2008).

We find that one solution to prevent such cost overruns is using cost milestones instead of scope milestones. Again, under cost milestone, the reference cost for the entire project is anchored at C^{DET}. Therefore, even with a very high λ, the behavioral PM's goal is to "accomplish less while maintaining the original budget," as can be seen in Figure 4(b). Intuitively, the PM maintains the initial budget as the reference point, and hence finds it easy to avoid the temptation to spend more in order to reduce the disappointment in scope.

PROPOSITION 3 **(Cost Milestone)**. ***(Cont.)*** *Suppose the news is bad, $\epsilon < 0$. The behavioral revision (C^{*B}, Q^{*B}) that maximizes Π^B after learning ϵ and q_1 is as follows:*

(iv) If $\epsilon \leq \phi^{\frac{1-\gamma}{\gamma}}/\lambda - 1$, then $C^{*B} = \phi^{\frac{1}{\gamma}} C^{\text{DET}}$ and $Q^{*B} = q_1$ and the project is abandoned.

(v) If $\epsilon > \phi^{\frac{1-\gamma}{\gamma}}/\lambda - 1$, then $Q^{*B} = (1+\epsilon) f(C^{*B})$, where

$$C^{*B} = \begin{cases} C^{\text{DET}}, & \text{if } \lambda \geq 1/(1+\epsilon), \\ (\lambda(1+\epsilon))^{\frac{1}{1-\gamma}} C^{\text{DET}}, & \text{otherwise.} \end{cases}$$

(vi) Compared to the rational PM, the behavioral PM always invests more and accomplishes a larger scope, i.e., $C^{*B} \geq C^{*R}$ and $Q^{*B} \geq Q^{*R}$.

(vii) The behavioral PM sticks to the initial budget C^{DET} if $\lambda \geq 1/(1+\epsilon)$, and invests less otherwise. He always accomplishes less than the planned scope Q^{DET} regardless of λ.

4.3. Reluctance to Abandon

One additional downside of bad news, relative to the rational PM, is that the behavioral PM is always more reluctant to abandon the project at the review point. Under scope milestone, the rational abandonment condition is $\epsilon \leq \phi^{1-\gamma} - 1$, whereas the behavioral PM employs the less stringent condition $\epsilon \leq \phi^{1-\gamma}/\lambda^{\gamma} - 1$. Similarly, under the cost milestone, the rational abandonment condition is $\epsilon \leq \phi^{\frac{1-\gamma}{\gamma}} - 1$, whereas the behavioral one is $\epsilon \leq \phi^{\frac{1-\gamma}{\gamma}}/\lambda - 1$. If $\lambda > 1$, then the behavioral PM is more reluctant to abandon. Intuitively, abandoning produces a loss in scope, which the

Table 2 Numerical Example of Rational and Behavioral PMs' Updated Plans (in $\$M$)

	Good news ($\epsilon = 0.2$)	Bad news ($\epsilon = -0.2$)
Initial Plan ($C^{\text{DET}}, Q^{\text{DET}}$)	$(1, 2)$	$(1, 2)$
Rational revision (C^{*R}, Q^{*R})	$(1.44, 2.88)$	$(0.64, 1.28)$
Behavioral revision (C^{*B}, Q^{*B}), scope milestone	$(0.89, 2.26)\|_{\lambda \geq 1.28}$	$(1.21, 1.76)\|_{\lambda \geq 1.38}$
Behavioral revision (C^{*B}, Q^{*B}), cost milestone	$(1, 2.4)\|_{\lambda \geq 1.2}$	$(1, 1.6)\|_{\lambda \geq 1.25}$

behavioral PM seeks to avoid. More generally, when the news is bad, the behavioral PM does not scale down the project as much as the rational PM, effectively setting c_2 too high.

PROPOSITION 4 **(Scope and Cost Milestones)**. *For any ϵ, if the behavioral PM finds it optimal to abandon a project, then so does the rational PM, but not vice versa. Moreover, the behavioral PM's reluctance to abandon a project increases with λ.*

Reluctance to abandon is quite prevalent in practice. A dramatic example might be the development of the F-35, Lockheed Martin's joint strike fighter, that has been developed since 2001. Since its development, the F-35 has failed to meet many of its initial design requirements and in some aspects it is even inferior to some existing fighter jets. Yet, the F-35 program has cost far more than the initial plan: now each plane costs $100 million, roughly twice the initial budget. The U.S., however, still continues to invest in the F-35 program, because it has now become "too big to fail," having spent more than $100 billion so far (Lloyd 2017).

Surprisingly, the propensity to abandon a project does not depend on the speed of adaptation. This is because α determines only the position of the threshold lines at which the behavioral PM starts experiencing loss aversion with respect to scope and cost. It is *loss aversion*, however, that creates the pull towards the crossing point of the threshold lines. For instance, without loss aversion, the behavioral PM's iso-profit curve becomes a straight line with the slope of 1, and thus the threshold lines, which are influenced by α, do not influence the behavioral PM's decisions.

4.4. Numerical Example 1 Revisited

We use Example 1 to numerically illustrate our results in Table 2. We set $\alpha = 0.25$. Recall that $(C^{\text{DET}}, Q^{\text{DET}}) = (\$1M, \$2M)$. Suppose the news is good, $\epsilon = 0.2$. The observed cost is $c_1 = \$0.11M$ under scope milestone and $c_1 = \$0.16M$ under cost milestone, where $EV|_{\epsilon=0} = \$0.16M$. The rational PM reacts by scaling up the project to $(C^{*R}, Q^{*R}) = (\$1.44M, \$2.88M)$ regardless of the milestone used. The behavioral PM, however, adapts to the observed cost. Therefore, under scope milestone, $\hat{c}_1 = \$0.15M$, and thus his reference cost for the entire project becomes $c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 = \$0.89M$, a decrease of roughly 11.3% from his initial budget. If $\lambda \geq 1.28$, then the behavioral PM's revised plan is $(C^{*B}, Q^{*B}) = (\$0.89M, \$2.26M)$. By contrast, under cost milestone, $\hat{c}_1 = EV|_{\epsilon=0} = \$0.16M$, and thus his reference cost for the entire project stays at $C^{\text{DET}} = \$1M$. If $\lambda \geq 1.2$, then the behavioral PM's revised plan is $(C^{*B}, Q^{*B}) = (\$1M, \$2.4M)$, sticking to the initial budget.

Suppose the news is bad, $\epsilon = -0.2$. The observed cost is $c_1 = \$0.25M$ under scope milestone and $c_1 = \$0.16M$ under cost milestone. The rational PM subsequently scales down the project to $(C^{*R}, Q^{*R}) = (\$0.64M, \$1.28M)$ regardless of the milestone used. But the behavioral PM again adapts to the observed cost. Under scope milestone, $\hat{c}_1 = \$0.18M$, and the reference cost for the entire project becomes $c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 = \$1.21M$, an increase of roughly 20% from his initial budget. If $\lambda \geq 1.38$, then the behavioral PM's revised plan is $(C^{*B}, Q^{*B}) = (\$1.21M, \$1.76M)$, resulting in a cost overrun. It is only when $\lambda < 1.25$ that the behavioral PM spends less than the planned cost of \$1M. By contrast, under cost milestone, his reference cost for the entire project again stays at $C^{\text{DET}} = \$1M$. Therefore, if $\lambda \geq 1.25$, then the behavioral PM's revised plan is $(C^{*B}, Q^{*B}) = (\$1M, \$1.6M)$, preventing cost overrun.

5. Project Performance

5.1. The Planning Fallacy

We now argue that a behavioral PM with λ close to 1 and α close to 0 suffers from the *planning fallacy*, in that he spends on average more than his initial plan. Here, we assume that abandoning the project after revision is not optimal.

Proposition 5 **(Scope and Cost Milestones)**. *Suppose abandoning the project after revision is not optimal (i.e., $\epsilon > \phi^{1-\gamma}/\lambda^{\gamma} - 1$ under scope milestone and $\epsilon > \phi^{\frac{1-\gamma}{\gamma}}/\lambda - 1$ under cost milestone). Then, the behavioral PM on average spends more than his initial plan C^{DET} if λ is sufficiently close to 1 and α sufficiently close to 0.*

The source of the planning fallacy is acting as if $\epsilon = 0$ at the outset, i.e., *the flaw of averages*. To see this, consider a PM who suffers from the flaw of averages but otherwise is rational, i.e., has $\lambda = 1$ and $\alpha = 0$. This PM thinks that the budgeted cost, C^{DET}, is correct when launching the project. Because he is not loss averse, he mimics the rational decision maker and revises the project cost to $(1+\epsilon)^{\frac{1}{1-\gamma}} C^{\text{DET}}$. Because of Jensen's inequality, we have that $E[(1+\epsilon)^{\frac{1}{1-\gamma}}] > 1$, implying that this PM on average spends more than his initial plan. By continuity, the planning fallacy holds for a behavioral PM with λ close to 1 and α close to 0, regardless of the distribution.

We cannot guarantee the planning fallacy for larger values of λ or α. Such a PM suffers from the flaw of averages, which induces the planning fallacy. He also adjusts insufficiently after bad news, which also contributes to the planning fallacy. For good news, however, his insufficient adjustment runs against the planning fallacy.

5.2. The Actual Profit

We compare the behavioral PM's actual profit attained at the end of the project with the rational PM's, and the influence of λ and α on the deviations. This question is of significant interest to an individual or an organization that is considering hiring a project manager. The comparison quantifies the losses incurred by making suboptimal choices. The two actual profits are denoted by $\Pi^{*B} = Q^{*B} - C^{*B}$ and $\Pi^{*R} = Q^{*R} - C^{*R}$, respectively.

PROPOSITION 6 **(Scope and Cost Milestones)**. *The rational PM's expected and realized actual profits are always greater than or equal to the behavioral PM's, i.e.,* $E[\Pi^{*R}] \geq E[\Pi^{*B}]$ *and* $\Pi^{*R} \geq \Pi^{*B}$. *Furthermore,* $E[\Pi^{*R}]$ *and* Π^{*R} *are independent of* λ *and* α, *whereas* $E[\Pi^{*B}]$ *and* Π^{*B} *are weakly decreasing in* λ *and* α *with scope milestone, and weakly decreasing in* λ *but independent of* α *with cost milestone.*

The rational PM maximizes the actual profit for each realization of ϵ. Hence, her *realized* actual profit is necessarily higher. It follows that her *expected* actual profit is also higher. That the behavioral PM's expected and realized actual profits weakly decrease with λ and α is intuitive, because loss aversion and reference point adaptation are departures from rationality. Interestingly, we find that the effect of loss aversion is limited only up to a certain threshold.

PROPOSITION 7 **(Scope and Cost Milestones)**. *Assume there exists* $\bar{\epsilon} > 0$ *such that* $Pr(\epsilon > \bar{\epsilon}) = 0$. *Then, there exists* $\lambda_H > 1$ *such that the behavioral PM's expected and realized actual profit,* $E[\Pi^{*B}]$ *and* Π^{*B}, *are weakly decreasing in* λ *when* $\lambda < \lambda_H$, *and independent of* λ *when* $\lambda \geq \lambda_H$.

The degree of loss aversion λ only affects how much the behavioral revision deviates from the rational revision toward the vertical threshold line (in Figures 3 and 4), but it never exceeds that line. Thus, there is a limit to the damage that loss aversion can cause. Under scope milestone, because the vertical line does depend on α, the potential damage increases with α. Under cost milestone, by contrast, the vertical threshold line is anchored at C^{DET}, and thus the expected actual profit is always independent of α.

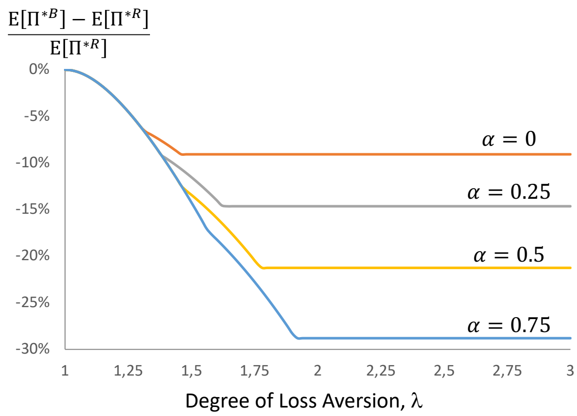
The following proposition calculates the exact value of the threshold λ_H given in Proposition 7 under a three-point distribution. Furthermore, it also shows that, even under scope milestone, the speed of adaptation α may not affect the actual profit when λ is sufficiently small.

PROPOSITION 7. ***(Cont.)*** *Suppose that* ϵ *follows a three-point distribution with* $Pr(\epsilon = \delta) = Pr(\epsilon = -\delta) \leq 1/2$, $Pr(\epsilon = 0) = 1 - 2 \cdot Pr(\epsilon = \delta)$, $\delta > 0$. *Then, the behavioral PM's expected and realized actual profits,* $E[\Pi^{*B}]$ *and* Π^{*B} *satisfy the following.*

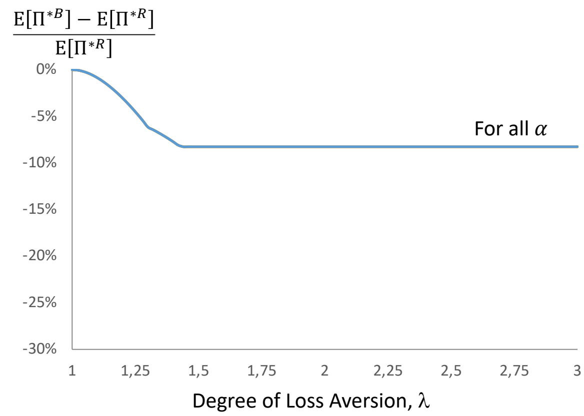
(i) ***Scope milestone.*** *Let* $\lambda_L = 1 + \delta$ *and* $\lambda_H = 1/(1-\delta)^{1/\gamma}$, *and note that* $1 < \lambda_L < \lambda_H$. *Then,* $E[\Pi^{*B}]$ *and* Π^{*B} *are independent of the degree of loss aversion* λ *when* $\lambda \geq \lambda_H$ *and independent of the speed of adaptation* α *when* $\lambda \leq \lambda_L$.

(ii) ***Cost milestone.*** *Let* $\lambda_H = 1/(1-\delta)$. *Then,* $E[\Pi^{*B}]$ *and* Π^{*B} *are independent of* λ *when* $\lambda \geq \lambda_H$.

Figure 5 Loss in Expected Actual Profit Relative to Rational Revision ($\delta = 0.3, k = 1, \phi = 0.2, \gamma = 0.5$)



(a) Revision at scope milestone



(b) Revision at cost milestone

The intuition is as follows. With scope milestone, when λ is large, the revised plan is determined by the vertical threshold line, $c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$, which depends on α. By contrast, when λ is small, the revised plan is an interior tangent solution, which does not depend on α. We note, however, that this particular result hinges on ϵ being zero or bounded away from zero. If ϵ is close to zero (e.g., follows a continuous distribution), then even a small λ can set the revision at the vertical threshold line.

Figures 5 illustrates the loss in the behavioral PM's expected actual profit under scope and cost milestones, compared to the rational PM's when $Pr(\epsilon = \delta) = Pr(\epsilon = -\delta) = 1/2$. Under scope milestone in Figure 5(a), when $\lambda \leq \lambda_L = 1.3$, the behavioral PM's expected actual profit $E[\Pi^{*B}]$ is influenced only by the degree of loss aversion λ, and when $\lambda \geq \lambda_H = 2.04$, $E[\Pi^{*B}]$ is influenced only by the speed of adaptation α. By contrast, under cost milestone in Figure 5(b), $E[\Pi^{*B}]$ is always independent of α, and when $\lambda \geq \lambda_H = 1.43$, $E[\Pi^{*B}]$ is independent of λ too.

5.3. Prescriptions

Individual project managers are likely to differ in how "biased" they are in terms of λ and α. Then who will bring a higher actual profit? As we have seen in Proposition 7, employers need to pay attention to the degree of loss aversion λ only up to a certain point. For instance, under scope milestone in Figure 5(a), PMs with $\lambda = 2.1$ and $\lambda = 3$ achieve the same profit, as long as they have the same speed of adaptation α. Moreover, when the uncertainty is of a binary nature, the speed of adaptation matters only when the PM is sufficiently loss averse. In Figure 5(a), no matter how fast the behavioral PM updates his reference points, he makes the same decision as long as his degree of loss aversion is mild, e.g., $\lambda \leq 1.3$. Under cost milestone in Figure 5(b), λ has even more limited role.

We have shown how the behavioral PM behaves suboptimally in terms of project revision, abandonment, and the resulting profit. Given that, one may wonder if there is a way to improve his suboptimal decisions. We offer three prescriptions. First, we can hire a "less biased" PM with λ close to 1 and α close to 0, or train the behavioral PM accordingly. Second, we can fight the flaw of averages by encouraging scenario planning to help identify downstream opportunities, anticipate the skewness in cost revisions, and better adjust the initial budget. These two suggestions are somewhat intuitive and straightforward in that they focus on mitigating the behavioral PM's "biasedness."

Our third prescription takes a different approach and focuses on the revision method; we recommend revising a project at cost milestone instead of at scope milestone. Under scope milestone, the behavioral PM adapts to the observed cost, and thus updates his reference cost in the wrong direction, suboptimally reducing investment under good news and overrunning the budget under bad news. Under cost milestone, however, the behavioral PM always anchors his reference cost to the budgeted cost, thereby preventing the worst outcomes that could occur with a scope milestone, although he still insufficiently adjusts the plan, just like under scope milestone. Therefore, using a cost milestone can lead to higher expected and realized actual profits than using a scope milestone. The following proposition formally establishes this result, where Π^{*B}_{cost} and Π^{*B}_{scope} denote the behavioral PM's actual profits with cost and scope milestones, respectively.

PROPOSITION 8. *The behavioral PM's expected and realized actual profits under cost milestone are no worse than those under scope milestone, i.e.,* $E[\Pi^{*B}_{cost}] \geq E[\Pi^{*B}_{scope}]$ *and* $\Pi^{*B}_{cost} \geq \Pi^{*B}_{scope}$.

The inequality is strict when λ is sufficiently high so that revision at scope milestone results in either cost overrun for bad news or suboptimal investment reduction for good news. Cost milestone eliminates the behavioral effect of adaptation (as per Proposition 6), and thus it could be particularly effective in improving the decisions of project managers with high speed of adaptation.

6. Revision at Time Milestone

We now explore a third revision method, where the PM reviews the project at a predetermined time. With a time-based review milestone all our main insights hold, including the behavioral PM's insufficient adjustments, reluctance to abandon the project, and lower profits.

To model this, we assume that both cost and scope are stochastic functions of time. Specifically, let $g(t)$ be a continuous and increasing function of time $t \geq 0$, and $\epsilon_1, \epsilon_2 > -1$ be random variables with $E[\epsilon_1] = E[\epsilon_2] = 0$. We define $C(t) = (1+\epsilon_1)g(t)$ and $Q(t) = (1+\epsilon_2)kg(t)^\gamma$. Note that $\epsilon_1 < 0$ is good news for cost while $\epsilon_2 > 0$ is good news for scope. Then, scope and cost have the following relationship: $Q = (1+\epsilon)kC^\gamma$, where $\epsilon = (1+\epsilon_2)/(1+\epsilon_1)^\gamma - 1$ is the "overall news." In this extended model, news is two-dimensional: we may have good news for cost but bad news for scope.

Let $(T^{\text{DET}}, C^{\text{DET}}, Q^{\text{DET}})$ be the deterministic plan that maximizes the profit $Q - C$ when $Pr(\epsilon_1 = 0) = Pr(\epsilon_2 = 0) = 1$. Specifically, $T^{\text{DET}} = \text{argmax}_T\, kg(T)^\gamma - g(T)$, from which we can obtain $T^{\text{DET}} = g^{-1}((k\gamma)^{\frac{1}{1-\gamma}})$, $C^{\text{DET}} = (k\gamma)^{\frac{1}{1-\gamma}}$, and $Q^{\text{DET}} = k(k\gamma)^{\frac{\gamma}{1-\gamma}}$. Note that C^{DET} and Q^{DET} agree with the base model. We stipulate that ϵ_1 and ϵ_2 are revealed when the project reaches $t_1 = g^{-1}(\phi^{\frac{1}{\gamma}} C^{\text{DET}})$. Note that if $\epsilon_1 = \epsilon_2 = 0$, then $c_1 = g(t_1) = \phi^{\frac{1}{\gamma}} C^{\text{DET}}$ and $q_1 = kg(t_1)^\gamma = \phi Q^{\text{DET}}$, as in our previous analysis. The cost and scope associated with learning ϵ_1 and ϵ_2 are

$$\text{Time milestone:} \quad (c_1, q_1) = ((1+\epsilon_1)\phi^{\frac{1}{\gamma}} C^{\text{DET}}, (1+\epsilon_2)\phi Q^{\text{DET}}). \tag{14}$$

The rational PM reacts by optimizing $Q - c_2 = Q - (C - c_1) = (1+\epsilon_2)kg(T)^\gamma - (1+\epsilon_1)g(T) + (1+\epsilon_1)g(t_1)$. It is straightforward to see that the rational revision remains the same as in Proposition 1, except for the abandonment condition, which is $\frac{1+\epsilon_2}{1+\epsilon_1} \leq \phi^{\frac{1-\gamma}{\gamma}}$ under time milestone. As for time, she finishes the project earlier than the planned completion time T^{DET} if $\epsilon_1 > \epsilon_2$, and later otherwise. For example, if the news is bad for both cost and scope ($\epsilon_1 > 0, \epsilon_2 < 0$), then the rational PM wraps up the project earlier than the plan and achieves a smaller scope. By contrast, if the news is good for both cost and scope ($\epsilon_1 < 0, \epsilon_2 > 0$), then she extends the completion time to achieve a larger scope. In other cases, the completion time depends on the relative values of ϵ_1 and ϵ_2.

The behavioral PM's perceived profit-to-go at the beginning of period 2, given in (10), can be rewritten as follows using the reference points defined in (6)-(9):

$$v(\hat{c}_2 - c_2) + v(Q - \hat{Q}_2) = v\left((1-\alpha)\left(\frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}} \cdot \hat{c}_1 - c_2\right)\right) + v((1-\alpha)(Q - \hat{Q}_1)),$$

where $\hat{c}_1$ and $\hat{Q}_1$ can be obtained using (c_1, q_1) in (14). Under time milestone, neither the reference scope nor the reference cost is anchored to the deterministic plan; the behavioral PM experiences loss aversion if the total cost exceeds $c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$ or if the total scope falls below $\hat{Q}_1 = (1+\alpha\epsilon_2)Q^{\text{DET}}$. That is, both the vertical and horizontal threshold lines that trigger loss aversion may shift depending on the realized ϵ_1 and ϵ_2. Yet, we still observe that the PM experiences a pull towards these thresholds lines, resulting in insufficient adjustments (including in the time dimension), reluctance to abandon a project, and lower actual profits.

We further elaborate on the results and intuition for two different cases. First, when the news is of the same nature for both cost and scope, the performance of time milestone is in between those of scope and cost milestones. For example, when the overall news is bad ($\epsilon_1 > 0, \epsilon_2 < 0$), the rational thing to do is to do less, spend less, and finish the project earlier than the plan. The behavioral PM, however, adjusts his reference budget upward after observing higher-than-expected cost, but not as much as under scope milestone due to lower-than-expected scope. Therefore, when λ is sufficiently high, the behavioral PM spends and accomplishes more than under cost milestone, but less than under scope milestone. Moreover, if the budget increase is greater than the factor of $1+\epsilon_1$ (i.e., $C^{*B}/C^{\text{DET}} > 1+\epsilon_1$), then the behavioral PM delays the project deadline. This is in fact what we typically observe in practice: projects that struggle with cost overrun tend to delay the completion time too. We argue, however, that the rational thing to do is to cut their losses and wrap up the projects early.

Second, when the news is of different nature for cost and scope, the performance of time milestone is either the best or the worst. For example, suppose the news is good for cost but bad for scope ($\epsilon_1 < 0, \epsilon_2 < 0$). Then, the behavioral PM adjusts his reference budget downward because of lower-than-expected cost, and does so more than under scope milestone because of lower-than-expected scope. Therefore, with a sufficiently high λ, the behavioral PM reduces his budget and scope more than under scope or cost milestone. This means that, if the overall news is good, $\epsilon > 0$, using time milesetone is the worst, because increasing the budget and scope is rationally optimal. However, using time milestone is the best if the overall news is bad, $\epsilon < 0$.

The following proposition compares the realized profits under time, scope, and cost milestones.

Proposition 9. *When the overall news is good,* $\epsilon = (1+\epsilon_2)/(1+\epsilon_1)^\gamma - 1 > 0$,

(i) $\boldsymbol{\Pi^{*B}_{time}} \geq \Pi^{*B}_{cost} \geq \Pi^{*B}_{scope}$, *if the news is bad for cost but good for scope,* $\epsilon_1 > 0$ *and* $\epsilon_2 > 0$;

(ii) $\Pi^{*B}_{cost} \geq \boldsymbol{\Pi^{*B}_{time}} \geq \Pi^{*B}_{scope}$, *if the news is good for both cost and scope,* $\epsilon_1 < 0$ *and* $\epsilon_2 > 0$;

(iii) $\Pi^{*B}_{cost} \geq \Pi^{*B}_{scope} \geq \boldsymbol{\Pi^{*B}_{time}}$, *if the news is good for cost but bad for scope,* $\epsilon_1 < 0$ *and* $\epsilon_2 < 0$.

By contrast, when the overall news is bad, $\epsilon = (1+\epsilon_2)/(1+\epsilon_1)^\gamma - 1 < 0$,

(iv) $\Pi^{*B}_{cost} \geq \Pi^{*B}_{scope} \geq \boldsymbol{\Pi^{*B}_{time}}$, *if the news is bad for cost but good for scope,* $\epsilon_1 > 0$ *and* $\epsilon_2 > 0$;

(v) $\Pi^{*B}_{cost} \geq \boldsymbol{\Pi^{*B}_{time}} \geq \Pi^{*B}_{scope}$, *if the news is bad for both cost and scope,* $\epsilon_1 < 0$ *and* $\epsilon_2 > 0$;

(vi) $\boldsymbol{\Pi^{*B}_{time}} \geq \Pi^{*B}_{cost} \geq \Pi^{*B}_{scope}$, *if the news is good for cost but bad for scope,* $\epsilon_1 < 0$ *and* $\epsilon_2 < 0$.

7. Conclusion

We offer a behavioral view on project management. Project-related decisions are made complex due, in part, to the time horizon over which the decisions are made. While costs occur throughout a project, benefits are typically realized only much later, once a project is completed. Thus, a project manager tracking performance against a pre-determined plan, must update his expectations and attempt to identify optimal courses of action on three dimensions: costs, scope, and time. Our model demonstrates the impact of loss aversion, reference point updating, and narrow framing on revisions made to budgets and projects' scope. The results suggest that the behavioral project manager will fail to adjust appropriately both in cases of good news and bad.

Specifically, the behavioral PM insufficiently adjusts the plan compared to his rational counterpart when revising the project. When the news is bad, insufficient adjustment is a result of aversion to loss on the scope dimension. When the news is good, it is due to aversion to going over budget, now that the scope can be expanded.

We also consider how the behavioral tendencies influence project abandonment. We find that the behavioral PM is more reluctant to abandon a project because he has an inertia to stick to the planned scope due to loss aversion. Overall, the behavioral project manager's decisions result in lower expected and realized profits from the project.

On a practical level, our work suggests that some apparently innocuous metrics to monitor and control a project may actually impact the decisions of a loss averse project manager, because they induce different updating of the reference points. Therefore, the revision process could be planned such that deviations from rational thinking are minimized. We demonstrate this with the proposal of using cost- or time-based review milestones.

We also recommend to reduce the loss aversion and speed of adaptation of the project manager, by either providing appropriate training, or hiring project managers with λ as close to 1 as possible, and α close to 0. Moreover, we encourage scenario planning which help identify downstream opportunities, anticipate skewness in cost revisions, and better adjust the planned budget.

Finally, we acknowledge that our model is stylized. While we have reasons to believe that our main insights are robust, it is an open question to explore how project complexities (e.g., multiple stakeholders, leadership changes, partial resolution of uncertainty) affect outcomes in a boundedly rational world.

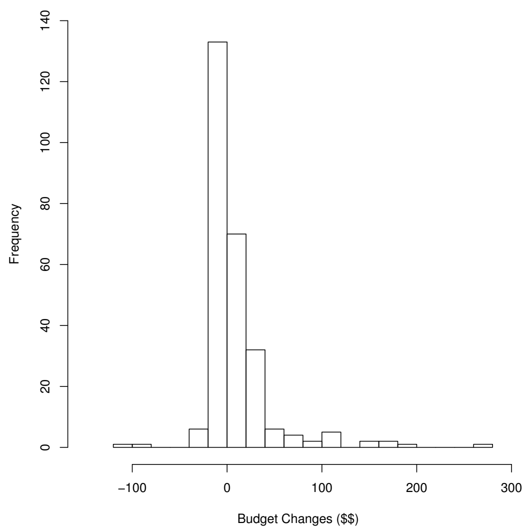
Appendix A: Capital Projects Data

A.1. New York City Capital Projects Data

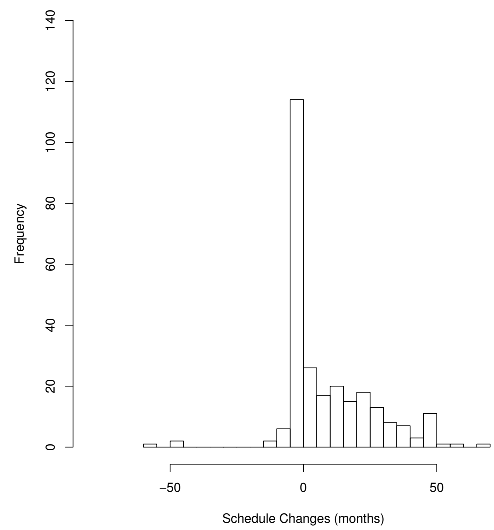
New York City provides a public facing website with up-to-date information on currently active capital infrastructure and information technology projects, with a budget of $25 million and higher. The dashboard includes details on some of the city's most critical projects, such as schools, roads, bridges, sewers, sanitation, and technology. The projects in this data set are in either the design, procurement, or the construction phase. The data is collected by the Mayor's Office of Operations and updated three times each year. Each record represents one active project. The dashboard includes information about each project, such as, project ID, name, description, purpose, borough where the project is being built, managing agency, client agency, current phase, design start date, budget forecast, latest budget change, total budget changes, forecast completion date, latest schedule change, and total schedule changes since the design start date.

Data on each project can be found here: `https://www1.nyc.gov/site/capitalprojects/dashboard/dashboard.page` and the entire database can be downloaded here: `https://data.cityofnewyork.us/City-Government/Capital-Projects/n7gv-k5yt`. For our analysis, we downloaded the data in August 2018. At this time, there were 266 active projects in the dataset. Of these projects, 97 were in the design phase, 38 in construction procurement and 124 in the construction phase. Seven were IT projects. Budget

Figure 6 Budget and schedule changes of New York City capital projects.



(a) Budget changes



(b) Schedule changes

changes ranged from −\$109 million to \$279 million. Schedule changes were from 58 months early to 66 months late. More than half had one or more budget or schedule changes, and about 1/4 had four or more changes in budget or schedule. See Figure 6 for the summary.

A.2. Federal IT Projects

Data on all Federal information technology investments (IT) can be found here: `https://www.itdashboard.gov/drupal/data/datafeeds`. The online IT Dashboard was launched on June 1, 2009, to provide Federal agencies and the public with the ability to view details of the federal investments and to track their progress. As of September 2018, there are 4,129 projects reported on in the data set, of which 3,145 are completed.

Appendix B: Proof of All Results

Proof of Proposition 1 The rational PM solves $c_2^{*R} = \text{argmax}_{c_2}\, Q - c_2 + (\hat{c}_2 - \hat{Q})$ by (5). It is trivial that c_2^{*R} also maximizes $Q - c_1 - c_2$, because $(\hat{c}_2 - \hat{Q})$ is constant and c_1 is a sunk cost.

$(i-ii)$ The FOC for c_2^{*R} is $\partial Q(c_1+c_2)/\partial c_2 - 1 = (1+\epsilon)k\gamma(c_1+c_2)^{\gamma-1} - 1 = 0$, which generates $c_1 + c_2 = (1+\epsilon)^{\frac{1}{1-\gamma}} C^{\text{DET}}$. Since the rational PM already spent c_1 in the first period, she abandons the project if $(1+\epsilon)^{\frac{1}{1-\gamma}} C^{\text{DET}} \le c_1 = (\phi/(1+\epsilon))^{\frac{1}{\gamma}} C^{\text{DET}}$, or equivalently, $(1+\epsilon) \le \phi^{1-\gamma}$ with scope milestone, and if $(1+\epsilon)^{\frac{1}{1-\gamma}} C^{\text{DET}} \le c_1 = \phi^{\frac{1}{\gamma}} C^{\text{DET}}$, or equivalently, $(1+\epsilon) < \phi^{\frac{1-\gamma}{\gamma}}$ with cost milestone. If the rational PM abandons the project, then $C^{*R} = c_1$ and $Q^{*R} = q_1$. Otherwise, $C^{*R} = (1+\epsilon)^{\frac{1}{1-\gamma}} C^{\text{DET}}$ and $Q^{*R} = (1+\epsilon) f(C^{*R}) = (1+\epsilon)^{\frac{1}{1-\gamma}} Q^{\text{DET}}$, both of which increase with ϵ. If $\epsilon = 0$, then $C^{*R} = C^{\text{DET}}$ and $Q^{*R} = Q^{\text{DET}}$. □

Proof of Proposition 2 (i) We characterize the behavioral PM's revised plan in 3 steps.

Step 1. We prove that $c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 < C^{\text{DET}}$ and $Q(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1) > Q^{\text{DET}}$. We have that $c_1 < \hat{c}_1 \le \phi^{1/\gamma}C^{\text{DET}}$, where $c_1 = (\phi/(1+\epsilon))^{\frac{1}{\gamma}}C^{\text{DET}}$ and $\hat{c}_1 = \alpha c_1 + (1-\alpha)\phi^{1/\gamma}C^{\text{DET}}$, because $(1+\epsilon) > 1$ and $\alpha \in [0,1)$. Therefore,

$$c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 < \phi^{1/\gamma}C^{\text{DET}} + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}} \cdot \phi^{1/\gamma}C^{\text{DET}} = C^{\text{DET}}.$$

Moreover, using $c_1 = (\phi/(1+\epsilon))^{\frac{1}{\gamma}}C^{\text{DET}}$, we have

$$Q\left(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1\right) = (1+\epsilon)k\left(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1\right)^{\gamma} > (1+\epsilon)k\left(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}c_1\right)^{\gamma} = (1+\epsilon)k\left(\frac{c_1}{\phi^{1/\gamma}}\right)^{\gamma} = Q^{\text{DET}}.$$

Step 2. We show that the behavioral PM's revised plan should satisfy $C^{*B} \ge c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$. The behavioral PM maximizes the profit-to-go in (12). Since $Q(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1) > Q^{\text{DET}}$ by Step 1, there exists $\bar{C} < c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$ such that $Q(\bar{C}) = Q^{\text{DET}}$. When $C < \bar{C}$, we have $Q < Q^{\text{DET}}$ and thus the PM maximizes $Q - (1/\lambda)c_2$, and the slope of the iso-profit curve is $1/\lambda$. When $\bar{C} \le C < c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$, we have $Q \ge Q^{\text{DET}}$ and thus the PM maximizes $Q - c_2$, and the iso-profit curve has the slope of 1. When $C \ge c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$, we have $Q > Q^{\text{DET}}$ and thus the PM maximizes $Q - \lambda c_2$, and the iso-profit curve has the slope of λ. Therefore, the iso-profit curve is piecewise linear and convex.

Furthermore, $Q'(C^{\text{DET}}) = (1+\epsilon)f'(C^{\text{DET}}) = (1+\epsilon) > 1$. Therefore, $Q'(C) > 1$ for all $C < c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$, because $Q(C)$ is concave in C and $c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 < C^{\text{DET}}$. Since the iso-profit curve is piecewise linear and convex, and its slope is less than or equal to 1 when $C < c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$, the behavioral PM's revised plan should satisfy $C^{*B} \ge c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$.

Step 3. We characterize the behavioral PM's revised plan. When $C \ge c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$, the slope of the iso-profit curve is λ. Therefore, if $\lambda \ge Q'(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1) = (1+\epsilon)k\gamma(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1)^{\gamma-1}$, then the revised plan is $C^{*B} = c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$. Otherwise, the revised plan is determined by the following problem: $\max_C\ Q(C) - \lambda C = \max_C\ (1+\epsilon)kC^{\gamma} - \lambda C$, the solution of which is $C^{*B} = ((1+\epsilon)k\gamma/\lambda)^{\frac{1}{1-\gamma}} = ((1+\epsilon)/\lambda)^{\frac{1}{1-\gamma}} \cdot C^{\text{DET}}$ and $Q^{*B} = (1+\epsilon)f(C^{*B})$.

(ii) First, $C^{*R} > c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$, because $C^{*R} > C^{\text{DET}}$ by Proposition 1 and $C^{\text{DET}} > c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$ by Step 1. Second, $C^{*R} = (1+\epsilon)^{\frac{1}{1-\gamma}}C^{\text{DET}} \ge ((1+\epsilon)/\lambda)^{\frac{1}{1-\gamma}}C^{\text{DET}}$, because $\lambda \ge 1$. Therefore, $C^{*R} \ge C^{*B}$, and thus $Q^{*R} \ge Q^{*B}$.

(iii) First, suppose $\lambda \ge (1+\epsilon)k\gamma(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1)^{\gamma-1}$. Then, $C^{*B} = c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 < C^{\text{DET}}$ by Step 1. Note that in this case $\lambda > (1+\epsilon)$, because $\lambda \ge (1+\epsilon)k\gamma(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1)^{\gamma-1} > (1+\epsilon)k\gamma(C^{\text{DET}})^{\gamma-1} = (1+\epsilon)$, where $C^{\text{DET}} = (k\gamma)^{\frac{1}{1-\gamma}}$. Second, suppose $\lambda < (1+\epsilon)k\gamma(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1)^{\gamma-1}$. Then, $C^{*B} = ((1+\epsilon)/\lambda)^{\frac{1}{1-\gamma}} \cdot C^{\text{DET}}$. Therefore, $C^{*B} < C^{\text{DET}}$ if and only if $((1+\epsilon)/\lambda)^{\frac{1}{1-\gamma}} < 1$, or equivalently, $\lambda > (1+\epsilon)$. Thus, combining the two cases, $C^{*B} < C^{\text{DET}}$ if and only if $\lambda > (1+\epsilon)$. Also, $Q^{*B} > Q^{\text{DET}}$ regardless of λ, because $Q(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1) > Q^{\text{DET}}$ and $C^{*B} \ge c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$ by Steps 1 and 2. □

Proof of Proposition 3 (i) We characterize the behavioral PM's revised plan in two steps.

Step 1. We show that $C^{*B} \ge C^{\text{DET}}$. We have that $Q(C^{\text{DET}}) = (1+\epsilon)f(C^{\text{DET}}) = (1+\epsilon)Q^{\text{DET}} > (1+\alpha\epsilon)Q^{\text{DET}} \ge Q^{\text{DET}}$, because $\epsilon > 0$ and $\alpha \in [0,1)$. Therefore, there exists $\bar{C} < C^{\text{DET}}$ such that $(1+\epsilon)f(\bar{C}) = (1+\alpha\epsilon)Q^{\text{DET}}$. The behavioral PM maximizes the profit-to-go in (13). When $C < \bar{C}$, we have $Q < (1+\alpha\epsilon)Q^{\text{DET}}$, and thus the PM maximizes $Q-(1/\lambda)c_2$ and the iso-profit curve has the slope of $1/\lambda$. When $\bar{C} \le C < C^{\text{DET}}$, we have $Q \ge (1+\alpha\epsilon)Q^{\text{DET}}$, and thus the PM maximizes $Q-c_2$ and the iso-profit curve has the slope of 1. When $C^{\text{DET}} \le C$, we have $Q > (1+\alpha\epsilon)Q^{\text{DET}}$, and thus the PM maximizes $Q-\lambda c_2$ and the iso-profit curve has the slope of λ. Therefore, the iso-profit curve is piecewise linear and convex.

Furthermore, $Q'(C^{\text{DET}}) = (1+\epsilon)f'(C^{\text{DET}}) = (1+\epsilon) > 1$. Therefore, $Q'(C) > 1$ for all $C \le C^{\text{DET}}$, because $Q(C)$ is concave. Since the iso-profit curve is piecewise linear and convex, and its slope is less than or equal to 1 when $C \le C^{\text{DET}}$, the behavioral PM's revised plan should satisfy $C^{*B} \ge C^{\text{DET}}$.

Step 2. We characterize C^{*B}. Since $Q'(C^{\text{DET}}) = (1+\epsilon)$, if $\lambda \ge (1+\epsilon)$, then $C^{*B} = C^{\text{DET}}$. Otherwise, we solve $\max_C (1+\epsilon)f(C) - \lambda C$, the solution of which is $C^{*B} = ((1+\epsilon)k\gamma/\lambda)^{\frac{1}{1-\gamma}} = ((1+\epsilon)/\lambda)^{\frac{1}{1-\gamma}} \cdot C^{\text{DET}}$.

(ii) It is easy to see that $C^{*R} = (1+\epsilon)^{\frac{1}{1-\gamma}} \cdot C^{\text{DET}} > C^{\text{DET}}$ and $C^{*R} = (1+\epsilon)^{\frac{1}{1-\gamma}} \cdot C^{\text{DET}} > ((1+\epsilon)/\lambda)^{\frac{1}{1-\gamma}} \cdot C^{\text{DET}}$. Therefore, $C^{*B} \le C^{*R}$, and hence $Q^{*B} \le Q^{*R}$.

(iii) This follows from Steps 1 and 2 in the proof of (i). □

Proof of Proposition 2 (Cont.) (iv−v) We characterize the behavioral PM's revised plan in 3 steps.

Step 1. We prove that $c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 > C^{\text{DET}}$ and $Q(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1) < Q^{\text{DET}}$. We have that $\phi^{1/\gamma}C^{\text{DET}} \le \hat{c}_1 < c_1$, where $c_1 = (\phi/(1+\epsilon))^{\frac{1}{\gamma}}C^{\text{DET}}$ and $\hat{c}_1 = \alpha c_1 + (1-\alpha)\phi^{1/\gamma}C^{\text{DET}}$, because $(1+\epsilon) < 1$ and $\alpha \in [0,1)$. Therefore,

$$c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 > \phi^{1/\gamma}C^{\text{DET}} + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}} \cdot \phi^{1/\gamma}C^{\text{DET}} = C^{\text{DET}}.$$

Moreover, using $c_1 = (\phi/(1+\epsilon))^{\frac{1}{\gamma}}C^{\text{DET}}$, we have

$$Q\left(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1\right) = (1+\epsilon)k\left(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1\right)^\gamma < (1+\epsilon)k\left(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}c_1\right)^\gamma = (1+\epsilon)k\left(\frac{c_1}{\phi^{1/\gamma}}\right)^\gamma = Q^{\text{DET}}.$$

Step 2. We show that the behavioral PM's revised plan should satisfy $C^{*B} \le c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$. The behavioral PM maximizes the profit-to-go in (12). By Step 1, there exists $\bar{C} > c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$ such that $Q(\bar{C}) = Q^{\text{DET}}$. When $C < c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$, we have $Q < Q^{\text{DET}}$ and thus the PM maximizes $Q-(1/\lambda)c_2$, and the slope of the iso-profit curve is $1/\lambda$. When $c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 \le C < \bar{C}$, we have $Q < Q^{\text{DET}}$, and thus the PM maximizes $Q-c_2$ and the iso-profit curve has the slope of 1. When $\bar{C} \le C$, we have $Q \ge Q^{\text{DET}}$, and thus the PM maximizes $Q-\lambda c_2$ and the iso-profit curve has the slope of λ. Therefore, the iso-profit curve is piecewise linear and convex.

Furthermore, $Q'(C^{\text{DET}}) = (1+\epsilon)f'(C^{\text{DET}}) = (1+\epsilon) < 1$. Therefore, $Q'(C) < 1$ for all $C \ge c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$, because $Q(C)$ is concave in C and $c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 > C^{\text{DET}}$. Since the iso-profit curve is piecewise linear and convex, and its slope is greater than or equal to 1 when $C \ge c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$, the behavioral PM's revised plan should satisfy $C^{*B} \le c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$.

Step 3. We characterize the behavioral PM's revised plan. When $C \le c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$, the slope of the iso-profit curve is $1/\lambda$ by Step 2. Therefore, if $1/\lambda \le Q'(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1) = (1+\epsilon)k\gamma(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1)^{\gamma-1}$, or equivalently, $\lambda \ge 1/((1+\epsilon)k\gamma(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1)^{\gamma-1})$, then the revised plan is $C^{*B} = c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$. Otherwise, the revised plan is determined by the following problem: $\max_C\ Q(C) - (1/\lambda)C = \max_C\ (1+\epsilon)kC^\gamma - (1/\lambda)C$, the solution of which is $C = (\lambda(1+\epsilon)k\gamma)^{\frac{1}{1-\gamma}} = (\lambda(1+\epsilon))^{\frac{1}{1-\gamma}} \cdot C^{\text{DET}}$. Since $c_1 = (\phi/(1+\epsilon))^{\frac{1}{\gamma}}C^{\text{DET}}$, the behavioral PM abandons the project if and only if $(\lambda(1+\epsilon))^{\frac{1}{1-\gamma}} \leq (\phi/(1+\epsilon))^{\frac{1}{\gamma}}$, or equivalently, $(1+\epsilon) \leq \phi^{1-\gamma}/\lambda^{\gamma}$, in which case $C^{*B} = c_1$ and $Q^{*B} = \phi Q^{\text{DET}}$. Otherwise, $C^{*B} = (\lambda(1+\epsilon))^{\frac{1}{1-\gamma}} \cdot C^{\text{DET}}$. (Note that $c_1 = (\phi/(1+\epsilon))^{\frac{1}{\gamma}} C^{\text{DET}} \leq C^{\text{DET}} < c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$ by assumption $(1+\epsilon) \geq \phi$ and by Step 1.)

(vi) First, $C^{*R} < c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$, because $C^{*R} < C^{\text{DET}}$ by Proposition 1 and $C^{\text{DET}} < c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$ by Step 1. Second, $C^{*R} = \max\{(1+\epsilon)^{\frac{1}{1-\gamma}} C^{\text{DET}}, c_1\} \leq \max\{(\lambda(1+\epsilon))^{\frac{1}{1-\gamma}} C^{\text{DET}}, c_1\}$, because $\lambda \geq 1$. Therefore, $C^{*R} \leq C^{*B}$, and thus $Q^{*R} \leq Q^{*B}$.

(vii) First, suppose that $\lambda \geq 1/((1+\epsilon)k\gamma(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1)^{\gamma-1})$. Then, $C^{*B} = c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 > C^{\text{DET}}$ by Step 1. Note that in this case $\lambda > 1/(1+\epsilon)$, because $\lambda \geq 1/((1+\epsilon)k\gamma(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1)^{\gamma-1}) > 1/((1+\epsilon)k\gamma(C^{\text{DET}})^{\gamma-1}) = 1/(1+\epsilon)$, where $C^{\text{DET}} = (k\gamma)^{\frac{1}{1-\gamma}}$. Second, suppose that $\lambda < 1/((1+\epsilon)k\gamma(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1)^{\gamma-1})$. Then, $C^{*B} = \max\left\{(\lambda(1+\epsilon))^{\frac{1}{1-\gamma}} C^{\text{DET}}, c_1\right\}$. Since $c_1 \leq C^{\text{DET}}$ (or equivalently, $(1+\epsilon) \geq \phi$) by assumption, we have that $C^{*B} > C^{\text{DET}}$ if and only if $(\lambda(1+\epsilon))^{\frac{1}{1-\gamma}} > 1$, or equivalently, $\lambda > 1/(1+\epsilon)$. Therefore, combining the two cases, $C^{*B} > C^{\text{DET}}$ if and only if $\lambda > 1/(1+\epsilon)$. Also, $Q^{*B} < Q^{\text{DET}}$ regardless of λ, because $C^{*B} \leq c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$ and $Q(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1) < Q^{\text{DET}}$ by Steps 1 and 2. □

Proof of Proposition 3 (Cont.) (iv−v) We characterize the behavioral PM's revised plan in two steps.
Step 1. We show that $C^{*B} \leq C^{\text{DET}}$. We have that $Q(C^{\text{DET}}) = (1+\epsilon)f(C^{\text{DET}}) = (1+\epsilon)Q^{\text{DET}} < (1+\alpha\epsilon)Q^{\text{DET}} \leq Q^{\text{DET}}$, because $\epsilon < 0$ and $\alpha \in [0,1)$. Therefore, there exists $\bar{C} > C^{\text{DET}}$ such that $(1+\epsilon)f(\bar{C}) = (1+\alpha\epsilon)Q^{\text{DET}}$. The behavioral PM maximizes the profit-to-go in (13). When $C < C^{\text{DET}}$, we have $Q < (1+\alpha\epsilon)Q^{\text{DET}}$, and thus the PM maximizes $Q - (1/\lambda)c_2$ and the iso-profit curve has the slope of $1/\lambda$. When $C^{\text{DET}} \leq C < \bar{C}$, we have $Q < (1+\alpha\epsilon)Q^{\text{DET}}$, and thus the PM maximizes $Q - c_2$ and the iso-profit curve has the slope of 1. When $\bar{C} \leq C$, we have $Q \geq (1+\alpha\epsilon)Q^{\text{DET}}$, and thus the PM maximizes $Q - \lambda c_2$ and the iso-profit curve has the slope of λ. Therefore, the iso-profit curve is piecewise linear and convex.

Furthermore, $Q'(C^{\text{DET}}) = (1+\epsilon)f'(C^{\text{DET}}) = (1+\epsilon) < 1$. Therefore, $Q'(C) < 1$ for all $C \geq C^{\text{DET}}$, because $Q(C)$ is concave. Since the iso-profit curve is piecewise linear and convex, and its slope is greater than or equal to 1 when $C \geq C^{\text{DET}}$, the behavioral PM's revised plan should satisfy $C^{*B} \leq C^{\text{DET}}$.
Step 2. We characterize C^{*B}. Since $Q'(C^{\text{DET}}) = (1+\epsilon)$, if $1/\lambda \leq (1+\epsilon)$, or equivalently $\lambda \geq 1/(1+\epsilon)$, then $C^{*B} = C^{\text{DET}}$. If $\lambda < 1/(1+\epsilon)$, then we solve $\max_C (1+\epsilon)f(C) - (1/\lambda)C$, the solution of which is $C = (\lambda(1+\epsilon)k\gamma)^{\frac{1}{1-\gamma}} = (\lambda(1+\epsilon))^{\frac{1}{1-\gamma}} C^{\text{DET}}$. Since the behavioral PM already spent $c_1 = \phi^{\frac{1}{\gamma}} C^{\text{DET}}$, he abandons the project if $(\lambda(1+\epsilon))^{\frac{1}{1-\gamma}} C^{\text{DET}} \leq \phi^{\frac{1}{\gamma}} C^{\text{DET}}$, or equivalently, $(1+\epsilon) \leq \phi^{\frac{1-\gamma}{\gamma}}/\lambda$, in which case $C^{*B} = \phi^{\frac{1}{\gamma}} C^{\text{DET}}$ and $Q^{*B} = q_1$. Otherwise, $C^{*B} = (\lambda(1+\epsilon))^{\frac{1}{1-\gamma}} C^{\text{DET}}$.

(vi) It is easy to see that $C^{*R} = \max\{(1+\epsilon)^{\frac{1}{1-\gamma}}, \phi^{\frac{1}{\gamma}}\} \cdot C^{\text{DET}} < C^{\text{DET}}$ and $C^{*R} = \max\{(1+\epsilon)^{\frac{1}{1-\gamma}}, \phi^{\frac{1}{\gamma}}\} \cdot C^{\text{DET}} \leq \max\{(\lambda(1+\epsilon))^{\frac{1}{1-\gamma}}, \phi^{\frac{1}{\gamma}}\} \cdot C^{\text{DET}}$. Therefore, $C^{*B} \geq C^{*R}$, and thus $Q^{*B} \geq Q^{*R}$.

(vii) This follows from Steps 1 and 2 in the proof of (iv−v). □

Proof of Proposition 4 The statement follows trivially from the thresholds that trigger abandonment. □

Proof of Proposition 5 A PM who suffers from the flaw of averages but otherwise is rational, i.e., has $\lambda = 1$ and $\alpha = 0$, updates his cost to $(1+\epsilon)^{\frac{1}{1-\gamma}} C^{\text{DET}}$ by Proposition 1. By Jensen's inequality, $E[(1+\epsilon)^{\frac{1}{1-\gamma}}]C^{\text{DET}} > C^{\text{DET}}$. By continuity, this holds when λ is sufficiently close to 1 and α sufficiently close to 0. $\square$

Proof of Proposition 6 By Proposition 1, the rational PM's revised plan always maximizes the profit $Q - C$, and hence $\Pi^{*R} \geq \Pi^{*B}$ for any realized value of ϵ. Trivially, $E[\Pi^{*R}] \geq E[\Pi^{*B}]$. Note that C^{*R} is independent of λ and α, and thus so are Π^{*R} and $E[\Pi^{*R}]$. Below, we show that Π^{*B} is weakly decreasing with λ and α, from which it trivially follows that $E[\Pi^{*B}]$ is also weakly decreasing with λ and α.

(1) Scope milestone. We prove that Π^{*B} is weakly decreasing with λ and α by showing that $|C^{*R} - C^{*B}|$ is weakly increasing with λ and α. The reason is that, for any ϵ, Π^{*B} strictly decreases with $|C^{*R} - C^{*B}|$, because the profit $\Pi = (1+\epsilon)kC^{\gamma} - C$ is strictly concave in C and maximized at C^{*R} by Proposition 1.

First, suppose the news is bad ($\epsilon < 0$). Then, $|C^{*R} - C^{*B}|$ is weakly increasing with λ and α if C^{*B} is weakly increasing with λ and α, because $C^{*R} \leq C^{*B}$ by Proposition 2. If $\lambda < 1/((1+\epsilon)k\gamma(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1)^{\gamma-1})$, then $C^{*B} = \max\{(\lambda(1+\epsilon))^{\frac{1}{1-\gamma}}, (\phi/(1+\epsilon))^{\frac{1}{\gamma}}\} \cdot C^{\text{DET}}$ by Proposition 2, which is weakly increasing with λ and independent of α. If $\lambda \geq 1/((1+\epsilon)k\gamma(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1)^{\gamma-1})$, then

$$C^{*B} = c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 = \left((\phi/(1+\epsilon))^{1/\gamma} + (1-\phi^{1/\gamma})(\alpha(1+\epsilon)^{-1/\gamma} + (1-\alpha))\right) C^{\text{DET}}, \tag{15}$$

because $c_1 = (\phi/(1+\epsilon))^{1/\gamma} C^{\text{DET}}$ and $\hat{c}_1 = \alpha c_1 + (1-\alpha)\phi^{1/\gamma} C^{\text{DET}}$. Therefore, C^{*B} is independent of λ and strictly increasing with α because $(1+\epsilon)^{-\frac{1}{\gamma}} > 1$.

Second, suppose the news is good ($\epsilon > 0$). Then, $|C^{*R} - C^{*B}|$ is weakly increasing with λ and α if C^{*B} is weakly decreasing with λ and α, because $C^{*R} \geq C^{*B}$ by Proposition 2. If $\lambda < (1+\epsilon)k\gamma(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1)^{\gamma-1}$, then $C^{*B} = ((1+\epsilon)/\lambda)^{\frac{1}{1-\gamma}} \cdot C^{\text{DET}}$ by Proposition 2, which is strictly decreasing with λ and independent of α. If $\lambda \geq (1+\epsilon)k\gamma(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1)^{\gamma-1}$, then $C^{*B} = c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$, which can be expressed as (15). C^{*B} is independent of λ and strictly decreasing with α because $(1+\epsilon)^{-\frac{1}{\gamma}} < 1$.

Finally, when the news is neutral ($\epsilon = 0$), $C^{*R} = C^{*B}$ and thus $|C^{*R} - C^{*B}|$ is independent of λ and α.

(2) Cost milestone. Similar to scope milestone, we prove that Π^{*B} is weakly decreasing with λ and independent of α by showing that $|C^{*R} - C^{*B}|$ is weakly increasing with λ and independent of α.

First, suppose the news is bad ($\epsilon < 0$). Then, $|C^{*R} - C^{*B}|$ is weakly increasing with λ and independent of α if C^{*B} is weakly increasing with λ and independent of α, because $C^{*R} \leq C^{*B}$ by Proposition 3. If $\lambda < 1/(1+\epsilon)$, then $C^{*B} = \max\{(\lambda(1+\epsilon))^{\frac{1}{1-\gamma}}, \phi^{\frac{1}{\gamma}}\} \cdot C^{\text{DET}}$, which is weakly increasing with λ and independent of α. If $\lambda \geq 1/(1+\epsilon)$, then $C^{*B} = C^{\text{DET}}$, which is independent of λ and α. Second, suppose the news is good ($\epsilon > 0$). Then, $|C^{*R} - C^{*B}|$ is weakly increasing with λ and independent of α if C^{*B} is weakly decreasing with λ and independent of α, because $C^{*R} \geq C^{*B}$ by Proposition 3. If $\lambda < (1+\epsilon)$, then $C^{*B} = ((1+\epsilon)/\lambda)^{\frac{1}{1-\gamma}} C^{\text{DET}}$, which is strictly decreasing with λ and independent of α. If $\lambda \geq (1+\epsilon)$, then $C^{*B} = C^{\text{DET}}$, which is independent of λ and α. Finally, when the news is neutral ($\epsilon = 0$), $C^{*R} = C^{*B}$ and thus $|C^{*R} - C^{*B}|$ is independent of λ and α. $\square$

Proof of Proposition 7 We have that $\phi \leq (1+\epsilon) \leq (1+\bar{\epsilon}) < \infty$, where $\phi \leq (1+\epsilon)$ by assumption.

(1) Scope milestone. Note that

$$c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 = \left((\phi/(1+\epsilon))^{1/\gamma} + (1-\phi^{1/\gamma})(\alpha(1+\epsilon)^{-1/\gamma} + (1-\alpha))\right) C^{\text{DET}},$$

when defined as a function of $\epsilon \in [\phi-1, \bar{\epsilon}]$ and $\alpha \in [0,1)$, has a strictly positive infimum and a finite supremum. This means that $1/((1+\epsilon)k\gamma(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1)^{\gamma-1})$ and $(1+\epsilon)k\gamma(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1)^{\gamma-1}$ have finite supremums. Then, by Proposition 2, there exists $\lambda_H > 1$ such that when $\lambda \geq \lambda_H$, the behavioral PM's revised plan is $C^{*B} = c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$ regardless of ϵ and α. In this case, $\Pi^{*B} = Q^{*B} - C^{*B} = (1+\epsilon)f(C^{*B}) - C^{*B}$ and $E[\Pi^{*B}]$ are independent of λ, because $c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$ is independent of λ, for any ϵ and α. When $\lambda < \lambda_H$, Π^{*B} and $E[\Pi^{*B}]$ are weakly decreasing with λ by Proposition 6.

(2) Cost milestone. Let $\lambda_H = \max_{\epsilon\in[\phi-1,\bar{\epsilon}]}\{1+\epsilon, 1/(1+\epsilon)\}$. If $\lambda \geq \lambda_H$, then $C^{*B} = C^{\text{DET}}$ for any ϵ by Proposition 3, which is independent of λ. If $\lambda < \lambda_H$, then Π^{*B} and $E[\Pi^{*B}]$ are weakly decreasing with λ by Proposition 6. □

Proof of Proposition 7 (Cont.) (i) Scope milestone. Note that

$$\lambda_H - \lambda_L = \frac{1-(1+\delta)^{1-\frac{1}{\gamma}}(1-\delta^2)^{\frac{1}{\gamma}}}{(1-\delta)^{\frac{1}{\gamma}}} > 0.$$

We prove that, for any ϵ, Π^{*B} is independent of α when $\lambda \leq \lambda_L$ and independent of λ when $\lambda \geq \lambda_H$. Then, trivially the same result holds for $E[\Pi^{*B}]$.

First, suppose $\epsilon = 0$ (neutral news). Then, $C^{*B} = C^{\text{DET}}$ is independent of α and λ, and so is Π^{*B}.

Second, suppose $\epsilon = -\delta$ (bad news). If $\lambda \leq \lambda_L$, then using $C^{\text{DET}} = (k\gamma)^{\frac{1}{1-\gamma}}$,

$$\lambda \leq 1+\delta < \frac{1}{1-\delta} = \frac{1}{(1-\delta)k\gamma(C^{\text{DET}})^{\gamma-1}} < \frac{1}{(1-\delta)k\gamma\left(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1\right)^{\gamma-1}},$$

where the first strict inequality holds because $1/(1-\delta) - (1+\delta) = \delta^2/(1-\delta) > 0$ and the second strict inequality holds because $c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 > C^{\text{DET}}$ by the proof of Proposition 2. Then, by Proposition 2, $C^{*B} = \max\{(\lambda(1+\epsilon))^{\frac{1}{1-\gamma}}, (\phi/(1+\epsilon))^{\frac{1}{\gamma}}\} \cdot C^{\text{DET}}$, which is independent of α and so is Π^{*B}. If $\lambda \geq \lambda_H$, then using $C^{\text{DET}} = (k\gamma)^{\frac{1}{1-\gamma}}$,

$$\lambda \geq \frac{1}{(1-\delta)^{\frac{1}{\gamma}}} = \frac{1}{(1-\delta)k\gamma((1-\delta)^{-\frac{1}{\gamma}}C^{\text{DET}})^{\gamma-1}} > \frac{1}{(1-\delta)k\gamma(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1)^{\gamma-1}},$$

where the strict inequality holds because

$$c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 = \left((\phi/(1+\epsilon))^{1/\gamma} + (1-\phi^{1/\gamma})(\alpha(1+\epsilon)^{-\frac{1}{\gamma}} + (1-\alpha))\right) C^{\text{DET}} \tag{16}$$

is increasing with $\alpha \in [0,1)$ (since $(1+\epsilon)^{-1/\gamma} > 1$), and thus $c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 < (1+\epsilon)^{-\frac{1}{\gamma}}C^{\text{DET}} = (1-\delta)^{-\frac{1}{\gamma}}C^{\text{DET}}$. Then, by Proposition 2, $C^{*B} = c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$, which is independent of λ and so is Π^{*B}.

Last, suppose $\epsilon = \delta > 0$ (good news). If $\lambda \leq \lambda_L$, then using $C^{\text{DET}} = (k\gamma)^{\frac{1}{1-\gamma}}$,

$$\lambda \leq 1+\delta = (1+\delta)k\gamma(C^{\text{DET}})^{\gamma-1} < (1+\delta)k\gamma\left(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1\right)^{\gamma-1},$$

where the strict inequality holds because $c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 < C^{\text{DET}}$ by the proof of Proposition 2. Then, by Proposition 2, $C^{*B} = ((1+\epsilon)/\lambda)^{\frac{1}{1-\gamma}} \cdot C^{\text{DET}}$, which is independent of α and so is Π^{*B}. If $\lambda \geq \lambda_H$, then using $C^{\text{DET}} = (k\gamma)^{\frac{1}{1-\gamma}}$,

$$\lambda \geq \frac{1}{(1-\delta)^{\frac{1}{\gamma}}} > (1+\delta)^{\frac{1}{\gamma}} = (1+\delta)k\gamma((1+\delta)^{-\frac{1}{\gamma}}C^{\text{DET}})^{\gamma-1} > (1+\delta)k\gamma\left(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1\right)^{\gamma-1},$$

where the first strict inequality holds because $1/(1-\delta)^{1/\gamma} - (1+\delta)^{1/\gamma} = (1-(1-\delta^2)^{1/\gamma})/(1-\delta)^{1/\gamma} > 0$ and the second strict inequality holds because $c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$, expressed as (16), decreases with $\alpha \in [0,1)$ (since $(1+\epsilon)^{-1/\gamma} < 1$) and thus $c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 > (1+\epsilon)^{-\frac{1}{\gamma}}C^{\text{DET}} = (1+\delta)^{-\frac{1}{\gamma}}C^{\text{DET}}$. Then, by Proposition 2, $C^{*B} = c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$, which is independent of λ and so is Π^{*B}.

(ii) Cost milestone. First, suppose $\epsilon = 0$ (neutral news). Then, $C^{*B} = C^{\text{DET}}$ is independent of λ, and so is Π^{*B}. Second, suppose $\epsilon = -\delta$ (bad news). If $\lambda \geq 1/(1-\delta)$, then by Proposition 3, $C^{*B} = C^{\text{DET}}$ is independent of λ, and so is Π^{*B}. Last, suppose $\epsilon = \delta$ (good news). If $\lambda \geq 1/(1-\delta)$, then $\lambda \geq 1/(1-\delta) > 1+\delta$, and thus by Proposition 3, $C^{*B} = C^{\text{DET}}$ is independent of λ, and so is Π^{*B}. The same result trivially holds for $E[\Pi^{*B}]$. □

Proof of Proposition 8 We first note that, for any ϵ, Π^{*B} strictly decreases with $|C^{*R} - C^{*B}|$, because the profit $\Pi = (1+\epsilon)kC^{\gamma} - C$ is strictly concave in C and maximized at C^{*R} by Proposition 1.

When the news is good, $\epsilon > 0$, the behavioral revision lies in $[c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1, C^{*R}]$ with scope milestone where $c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 < C^{\text{DET}}$ by the proof of Proposition 2, while it lies in $[C^{\text{DET}}, C^{*R}]$ with cost milestone by the proof of Proposition 3. Similarly, when the news is bad, $\epsilon < 0$, the behavioral revision lies in $[C^{*R}, c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1]$ with scope milestone where $c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 > C^{\text{DET}}$, while it lies in $[C^{*R}, C^{\text{DET}}]$ with cost milestone. In both cases, the maximum value of $|C^{*R} - C^{*B}|$ is greater with scope milestone than with cost milestone. Therefore, $\Pi^{*B}_{cost} \geq \Pi^{*B}_{scope}$ for any ϵ. Then, it naturally follows that $E[\Pi^{*B}_{cost}] \geq E[\Pi^{*B}_{scope}]$. □

Proof of Proposition 9 We first establish the following three results, which we use in the proof. First, if $\epsilon_1 < 0$ ($\epsilon_1 > 0$), then the vertical threshold line $C = c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$ is less (greater) than that with cost milestone, C^{DET}. This is because $c_1 = (1+\epsilon_1)\phi^{1/\gamma}C^{\text{DET}} < \phi^{1/\gamma}C^{\text{DET}}$, and thus $\hat{c}_1 = \alpha c_1 + (1-\alpha)\phi^{1/\gamma}C^{\text{DET}} < \phi^{1/\gamma}C^{\text{DET}}$.

Second, if $\epsilon_2 < 0$ ($\epsilon_2 > 0$), then the vertical threshold line $C = c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$ is less (greater) than that with scope milestone. This is because if $\epsilon_2 < 0$, then $q_1 = (1+\epsilon_2)\phi Q^{\text{DET}} < \phi Q^{\text{DET}}$, and thus q_1 smaller with time milestone than with scope milestone. This means that c_1, and consequently $\hat{c}_1$, are smaller with time milestone than with scope milestone too, because $Q(C)$ is an increasing function of C. The case when $\epsilon_2 > 0$ can be similarly shown.

Finally, for any ϵ, Π^{*B} strictly decreases with $|C^{*R} - C^{*B}|$, because the profit $\Pi = (1+\epsilon)kC^{\gamma} - C$ is strictly concave in C and maximized at C^{*R} by Proposition 1. Now, we consider the following four cases.

(1) Good news for both cost and scope ($\epsilon_1 < 0$ and $\epsilon_2 > 0$). This is overall good news, $(1+\epsilon) = (1+\epsilon_2)/(1+\epsilon_1)^{\gamma} > 1$. The vertical and horizontal threshold lines satisfy that $c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 < C^{\text{DET}}$ and $\hat{Q}_1 = (1+\alpha\epsilon_2)Q^{\text{DET}} > Q^{\text{DET}}$. The behavioral revision always falls in quadrant I because of the following reasons.

First, in quadrants II and III (when $C < c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$), the slope of the iso-profit curve is less than or equal to 1, whereas the slope of the technology curve is greater than $Q'(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1) > Q'(C^{\text{DET}}) = (1+\epsilon)f'(C^{\text{DET}}) = (1+\epsilon) > 1$, because $Q(C)$ is concave. Second, the slope of the iso-profit curve in quadrant IV is 1. However, if the technology curve passes through quadrant IV, its minimum slope in quadrant IV is greater than $Q'(C^{\text{DET}}) = (1+\epsilon)f'(C^{\text{DET}}) = (1+\epsilon) > 1$, because $Q(C)$ is concave and quadrant IV is bounded above by $(1+\alpha\epsilon_2)Q^{\text{DET}} < (1+\epsilon_2)Q^{\text{DET}} < (1+\epsilon)Q^{\text{DET}} = Q(C^{\text{DET}})$ (note that $(1+\epsilon) = (1+\epsilon_2)/(1+\epsilon_1)^\gamma > (1+\epsilon_2)$).

In quadrant I, C^{*B} may be bounded by either the vertical or horizontal threshold line. Regardless of that, the minimum C^{*B} satisfies $C^{*B} < C^{\text{DET}}$. This is because the vertical threshold satisfies $c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 < C^{\text{DET}}$, and the horizontal threshold satisfies $(1+\alpha\epsilon_2)Q^{\text{DET}} < (1+\epsilon_2)Q^{\text{DET}} < (1+\epsilon)Q^{\text{DET}} = Q(C^{\text{DET}})$. We know that C^{*B} also falls in quadrant I with scope or cost milestone and they are bounded only by the vertical threshold line by the proofs of Propositions 2 and 3. Therefore, when $\epsilon_1 < 0$ and $\epsilon_2 > 0$, the minimum C^{*B} with time milestone is greater than that with scope milestone but smaller than that with cost milestone. Therefore, $\Pi^{*B}_{cost} \geq \boldsymbol{\Pi^{*B}_{time}} \geq \Pi^{*B}_{scope}$.

(2) Bad news for both cost and scope ($\epsilon_1 > 0$ and $\epsilon_2 < 0$). This is overall bad news, $(1+\epsilon) = (1+\epsilon_2)/(1+\epsilon_1)^\gamma < 1$. Following a similar analysis to Case (1), we can show that the behavioral revision C^{*B} falls in quadrant III, and the maximum C^{*B} with time milestone is smaller than that with scope milestone but greater than that with cost milestone. Therefore, $\Pi^{*B}_{cost} \geq \boldsymbol{\Pi^{*B}_{time}} \geq \Pi^{*B}_{scope}$.

(3) Good news for cost, bad news for scope ($\epsilon_1 < 0$ and $\epsilon_2 < 0$). The vertical and horizontal threshold lines satisfy that $c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 < C^{\text{DET}}$ and $\hat{Q}_1 = (1+\alpha\epsilon_2)Q^{\text{DET}} < Q^{\text{DET}}$. There are two sub-cases depending on the overall news.

- Suppose the overall news is good, $(1+\epsilon) = (1+\epsilon_2)/(1+\epsilon_1)^\gamma > 1$. The behavioral revision always falls in quadrant I because of the following reasons. First, in quadrants II and III (when $C < c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$), the slope of the iso-profit curve is less than or equal to 1, whereas the slope of the technology curve is greater than $Q'(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1) > Q'(C^{\text{DET}}) = (1+\epsilon)f'(C^{\text{DET}}) = (1+\epsilon) > 1$, because $Q(C)$ is concave. Second, it cannot fall in quadrant IV, because $Q(c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1) > Q^{\text{DET}} \geq (1+\alpha\epsilon_2)Q^{\text{DET}}$ by the proof of Proposition 2. Therefore, C^{*B} falls in quadrant I and is only bounded by the vertical threshold line $C = c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1$. Thus, when $\epsilon_1 < 0$ and $\epsilon_2 < 0$, the minimum C^{*B} with time milestone is less than that with scope or cost milestone. Therefore, $\Pi^{*B}_{cost} \geq \Pi^{*B}_{scope} \geq \boldsymbol{\Pi^{*B}_{time}}$.
- Suppose the overall news is bad, $(1+\epsilon) = (1+\epsilon_2)/(1+\epsilon_1)^\gamma < 1$. The behavioral revision satisfies $C^{*B} < C^{\text{DET}}$, because when $C \geq C^{\text{DET}}$ (in quadrants I and IV), the slope of the iso-profit curve is greater than or equal to 1, whereas the slope of the technology curve is less than or equal to $Q'(C^{\text{DET}}) = (1+\epsilon)f'(C^{\text{DET}}) = (1+\epsilon) < 1$, because $Q(C)$ is concave. Thus, the maximum C^{*B} with time milestone is smaller than that with scope or cost milestone. Therefore, $\boldsymbol{\Pi^{*B}_{time}} \geq \Pi^{*B}_{cost} \geq \Pi^{*B}_{scope}$.

(4) Bad news for cost, good news for scope ($\epsilon_1 > 0$ and $\epsilon_2 > 0$). The vertical and horizontal threshold lines satisfy that $c_1 + \frac{1-\phi^{1/\gamma}}{\phi^{1/\gamma}}\hat{c}_1 > C^{\text{DET}}$ and $\hat{Q}_1 = (1+\alpha\epsilon_2)Q^{\text{DET}} > Q^{\text{DET}}$. There are two sub-cases depending on the overall news.

- Suppose the overall news is good, $(1+\epsilon) = (1+\epsilon_2)/(1+\epsilon_1)^\gamma > 1$. The analysis is analogous to the second sub-case of Case (3), and thus $\boldsymbol{\Pi^{*B}_{time}} \geq \Pi^{*B}_{cost} \geq \Pi^{*B}_{scope}$.
- Suppose the overall news is bad, $(1+\epsilon) = (1+\epsilon_2)/(1+\epsilon_1)^\gamma < 1$. The analysis is analogous to the first sub-case of Case (3), and thus $\Pi^{*B}_{cost} \geq \Pi^{*B}_{scope} \geq \boldsymbol{\Pi^{*B}_{time}}$. □

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