Online Appendix for "Managerial Mental Accounting and Downstream Project Decisions"

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Appendix B: Second-Period Uncertainty

In this extension, we allow cost and scope uncertainties to run until the end of the project. That is, in contrast to the base model where uncertainty is fully resolved by t_1, deviations can still occur after t_1. We confirm that all of our results and main insights continue to hold.

B.1. Model Setup

We define cost and scope deviations as $\tilde{\epsilon}_c = \tilde{\epsilon}_{c_1} + \tilde{\epsilon}_{c_2}$ and $\tilde{\epsilon}_q = \tilde{\epsilon}_{q_1} + \tilde{\epsilon}_{q_2}$, respectively, where $(\tilde{\epsilon}_{c_1}, \tilde{\epsilon}_{q_1})$ are the uncertainties to be realized in Period 1, and $(\tilde{\epsilon}_{c_2}, \tilde{\epsilon}_{q_2})$ to be realized in Period 2.[14] We assume that $E[\tilde{\epsilon}_{c_i}] = E[\tilde{\epsilon}_{q_i}] = 0$, $i = 1,2$, that uncertainties in different periods are independent of each other, and that $\sum_{i=1}^{n} \tilde{\epsilon}_{c_i} > -1$ and $\sum_{i=1}^{n} \tilde{\epsilon}_{q_i} > -1$ for $n = 1,2$. Throughout, we denote yet-to-be realized uncertainties with a tilde, $(\tilde{\epsilon}_{c_i}, \tilde{\epsilon}_{q_i})$, and already realized uncertainties without the tilde, $(\epsilon_{c_i}, \epsilon_{q_i})$.

From the viewpoint of $t = 0$, the projected cost and scope of the project are

$$C(t) = (1 + \tilde{\epsilon}_{c_1} + \tilde{\epsilon}_{c_2})g(t) + h(t), \quad \text{and}$$
$$Q(t) = (1 + \tilde{\epsilon}_{q_1} + \tilde{\epsilon}_{q_2})f(g(t)).$$

It is easy to see that the deterministic plan $(\hat{C}_0, \hat{Q}_0, \hat{T}_0)$ remains the same as in the base model. At t_1, the realized cost and scope are as in the base model, namely,

$$c_1 = (1 + \epsilon_{c_1})g(t_1) + h(\underline{t}) \quad \text{and} \quad q_1 = (1 + \epsilon_{q_1})f(g(t_1)).$$

At the beginning of Period 2, the PL revises the project by setting the optimal completion time T. If the PL does not abandon the project, i.e., $T > t_1$, then the final cost and scope are $C(T)$ and $Q(T)$, and we define $c_2 = C(T) - c_1$ and $q_2 = Q(T) - q_1$.[15] If the PL abandons the project, $T = t_1$, then the PL does not get to observe $(\epsilon_{c_2}, \epsilon_{q_2})$, and thus the final cost and scope are c_1 and q_1, and we set $c_2 = q_2 = 0$.

[14] For a more explicit formulation, we can define $(\tilde{\epsilon}_{c_1}, \tilde{\epsilon}_{q_1})$ as functions of t_1 and $(\tilde{\epsilon}_{c_2}, \tilde{\epsilon}_{q_2})$ as functions of $T - t_1$, where T is the completion time. However, this does not affect our analysis, because t_1 is exogenously given and the second period uncertainties do not affect the PL's decision at t_1 because $E[\tilde{\epsilon}_{c_2}] = E[\tilde{\epsilon}_{q_2}] = 0$. Therefore, we omit the explicit dependence on time.

[15] Note that it is mathematically possible that $c_2, q_2 < 0$ if the second period uncertainties $(\epsilon_{c_2}, \epsilon_{q_2})$ turn out to be very small. However, our model still works even for $c_2, q_2 < 0$. In practice, a negative q_2 is possible if the monetary value of the project drops due to external factors such as an economic recession. A negative c_2 is possible, for example, if the project is sourcing some of the inputs from another country with delayed payment while the exchange rate fluctuates over time. If needed, we can guarantee that $c_2, q_2 > 0$ by making the revision time t_1 sufficiently early and/or making the support of the deviations sufficiently narrow.

Let $E_{t_1}[\,\cdot\,]$ indicate that expectation is taken at time t_1. The following observation simplifies our analysis: $E_{t_1}[C(T)]$, $E_{t_1}[Q(T)]$, $E_{t_1}[c_2]$, and $E_{t_1}[q_2]$ are continuous in $T \geq t_1$ regardless of abandonment. This is because

$$E_{t_1}[C(T)] = (1+\epsilon_{c_1})g(T) + h(\underline{t}) \qquad \text{and} \qquad E_{t_1}[Q(T)] = (1+\epsilon_{q_1})f(g(T)), \tag{13}$$

and thus $\lim_{T\to t_1^+} E_{t_1}[C(T)] = c_1$ and $\lim_{T\to t_1^+} E_{t_1}[Q(T)] = q_1$.

B.1.1. Rational Project Leader The rational PL's profit function remains as in (4). At the beginning of Period 2, the PL decides on the completion time T to maximize the *expected profit-to-go* at t_1, by solving

$$T^{*R} = \text{argmax}_{T\geq t_1} E_{t_1}[(1-\phi_c)\hat{C}_0 - c_2 + q_2 - (1-\phi_q)\hat{Q}_0].$$

Note that $\hat{C}_0$ and $\hat{Q}_0$ are constant. Therefore, the above optimization is equivalent to maximizing the expected value-to-go, $E_{t_1}[q_2 - c_2]$, or equivalently, the expected financial profit, $E_{t_1}[Q-C]$, under the constraint that $T \geq t_1$, because $E_{t_1}[q_2 - c_2] = E_{t_1}[Q-C] - (q_1 - c_1)$ and (c_1, q_1) is fixed.

We confirm that Proposition 1 and Table 1 continue to hold, except that (ϵ_c, ϵ_q) are now $(\epsilon_{c_1}, \epsilon_{q_1})$ and the final cost C^{*R} and scope Q^{*R} are now *expected* cost and scope at t_1, $E_{t_1}[C^{*R}]$ and $E_{t_1}[Q^{*R}]$.

B.1.2. Behavioral Project Leader At t_1, when the BPL evaluates the perceived profit or updates reference points, he replaces $(\tilde{\epsilon}_{c_2}, \tilde{\epsilon}_{q_2})$ with $(0,0)$ due to flaw of averages. We observe that $c_2|_{\tilde{\epsilon}_{c_2}=0} = E_{t_1}[c_2]$ and $q_2|_{\tilde{\epsilon}_{q_2}=0} = E_{t_1}[q_2]$ at t_1. Therefore, for ease of comparison with the rational PL, we can pretend that the BPL is using $(E_{t_1}[c_2], E_{t_1}[q_2])$ instead of $(c_2|_{\tilde{\epsilon}_{c_2}=0}, q_2|_{\tilde{\epsilon}_{q_2}=0})$.

The BPL's perceived profit function remains the same as (6). The reference point updating remains the same as (7) at the end of Period 1, but it changes slightly from (8) at the beginning of Period 2 as follows, replacing (c_2, q_2) with $(E_{t_1}[c_2], E_{t_1}[q_2])$.

$$(\hat{C}_2, \hat{Q}_2) = \alpha\left(\frac{E_{t_1}[c_2]}{1-\phi_c}, \frac{E_{t_1}[q_2]}{1-\phi_q}\right) + (1-\alpha)(\hat{C}_1, \hat{Q}_1).$$

The BPL chooses the completion time T that maximizes the *perceived profit-to-go* at t_1, which replaces (c_2, q_2) with $(E_{t_1}[c_2], E_{t_1}[q_2])$ from (9), solving

$$T^{*B} = \text{argmax}_{T\geq t_1} v((1-\phi_c)\hat{C}_2 - E_{t_1}[c_2]) + v(E_{t_1}[q_2] - (1-\phi_q)\hat{Q}_2).$$

Based on T^{*B}, the BPL's estimate at t_1 of the final cost and scope are $C(T^{*B})|_{\tilde{\epsilon}_{c_2}=0}$ and $Q(T^{*B})|_{\tilde{\epsilon}_{q_2}=0}$ due to the flaw of averages. Again, we observe that $C(T^{*B})|_{\tilde{\epsilon}_{c_2}=0} = E_{t_1}[C(T^{*B})]$ and $Q(T^{*B})|_{\tilde{\epsilon}_{q_2}=0} = E_{t_1}[Q(T^{*B})]$ at t_1. For ease of exposition, we denote the BPL's estimate at t_1 of the final cost and scope by $E_{t_1}[C^{*B}] = E_{t_1}[C(T^{*B})]$ and $E_{t_1}[Q^{*B}] = E_{t_1}[Q(T^{*B})]$.

B.2. Behavioral Revision

The main difference from the base model is that now the axes of Figure 3 are *expected* final cost and scope at t_1, $(E_{t_1}[C], E_{t_1}[Q])$, instead of (C, Q). Yet, $(E_{t_1}[C], E_{t_1}[Q])$ are still one-to-one functions of T as we have seen in (13). Therefore, all analysis in this extension parallels that of the base model, where (C, Q) and (c_2, q_2) in the base model are replaced by $(E_{t_1}[C], E_{t_1}[Q])$ and $(E_{t_1}[c_2], E_{t_1}[q_2])$, respectively. In particular, the anchoring point $(\bar{C}, \bar{Q})$ remains the same as in the base model.

We verify that Propositions 2, 3, 4, and 5 continue to hold, where (c_2, q_2), (C, Q), (C^{*R}, Q^{*R}), and (C^{*B}, Q^{*B}) are now replaced by their expectations at t_1. Also, in Proposition 4, the condition imposed on (ϵ_c, ϵ_q) is now imposed on $(\epsilon_{c_1}, \epsilon_{q_1})$ and the realized financial profit is now the *expected* financial profit at t_1, $E_{t_1}[Q^{*B} - C^{*B}]$.

B.3. Progress Measures to Mitigate Insufficient Adjustments

The progress measures we defined in Section 2.1 remain the same. Proposition 6 also continues to hold, where the "best" progress measure is now determined by the *expected* financial profit at t_1, instead of the final financial profit as in the base model.

In addition, Lemmas 1 and 2 and Table 5 in Appendix A continue to hold, where (ϵ_c, ϵ_q) and (C^{*R}, Q^{*R}) are now $(\epsilon_{c_1}, \epsilon_{q_1})$ and $(E_{t_1}[C^{*R}], E_{t_1}[Q^{*R}])$, respectively.

B.4. Serial Correlation of Uncertainty

In this subsection, we qualitatively explore how the insights of this extension change if the uncertainties have serial correlation. Overall, we still observe insufficient adjustments. Suppose the following relationship:

$$\tilde{\epsilon}_{c_2} = a_c \tilde{\epsilon}_{c_1} + \tilde{\epsilon}'_{c_2} \quad \text{and} \quad \tilde{\epsilon}_{q_2} = a_q \tilde{\epsilon}_{q_1} + \tilde{\epsilon}'_{q_2},$$

where $\tilde{\epsilon}_{c_1}$ and $\tilde{\epsilon}'_{c_2}$ are independent with $E[\tilde{\epsilon}_{c_1}] = E[\tilde{\epsilon}'_{c_2}] = 0$ and $\tilde{\epsilon}_{q_1}$ and $\tilde{\epsilon}'_{q_2}$ are independent with $E[\tilde{\epsilon}_{q_1}] = E[\tilde{\epsilon}'_{q_2}] = 0$. Then, we have $E[\tilde{\epsilon}_{c_2}] = E[\tilde{\epsilon}_{q_2}] = 0$, and $E[\tilde{\epsilon}_{c_2} | \epsilon_{c_1}] = a_c \epsilon_{c_1}$ and $E[\tilde{\epsilon}_{q_2} | \epsilon_{q_1}] = a_q \epsilon_{q_1}$. We assume that the serial correlation is positive, $a_c, a_q \geq 0$, a reasonable assumption in project management.

The rational PL updates the distribution of the second-period uncertainties based on the realized first-period uncertainties. At time t_1, the rational PL tries to maximize the expected financial profit $E_{t_1}[Q(T) - C(T)]$, where[16]

$$E_{t_1}[Q(T)] = (1 + \epsilon_{q_1} + E[\tilde{\epsilon}_{q_2} | \epsilon_{q_1}]) f(g(T)) = (1 + (1 + a_q)\epsilon_{q_1}) f(g(T)),$$
$$E_{t_1}[C(T)] = (1 + \epsilon_{c_1} + E[\tilde{\epsilon}_{c_2} | \epsilon_{c_1}]) g(T) + h(\underline{t}) = (1 + (1 + a_c)\epsilon_{c_1}) g(T) + h(\underline{t}).$$

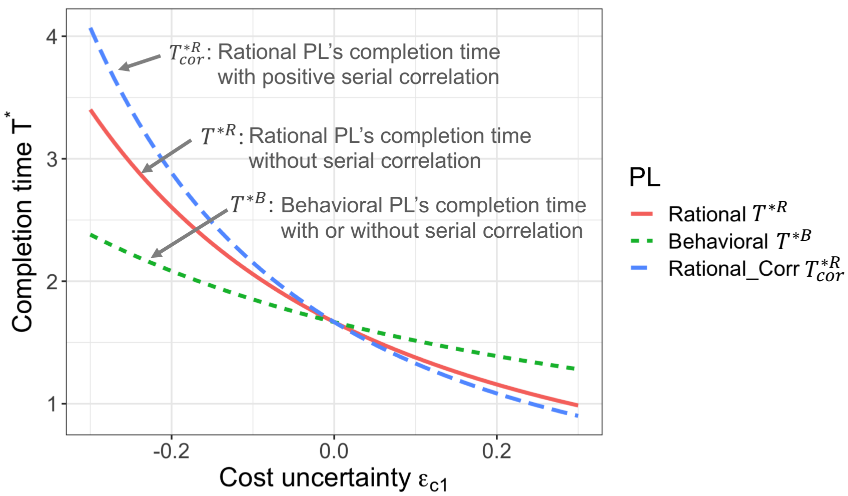
Compared to the model with no serial correlation, if the first-period news is good, $\epsilon_{c_1} < 0$ and $\epsilon_{q_1} > 0$, then the expected scope is greater and expected cost is smaller. Similarly, if the first-period news is bad, $\epsilon_{c_1} > 0$ and $\epsilon_{q_1} < 0$, then the expected scope is smaller and expected cost is greater. This, in turn, amplifies the rational PL's decision in such a way that, when it is rationally optimal to scale up, cases (i) and (iii) in Table 1, the rational PL scales up even more with serial correlation, in terms of completion time T^{*R}. Similarly, when it is rationally optimal to scale down, cases (ii) and (iv), the rational PL scales down even more with serial correlation, in terms of completion time T^{*R}. Figure 8 graphically illustrates this result.

The BPL, who suffers from the flaw of averages and projection bias, may be unable to compute the conditional expectations. Then, the BPL's expected scope and cost remain the same as (13). Thus, the BPL's decision T^{*B} remains unchanged from the case without serial correlation. This suggests that the BPL's insufficient adjustments, which can be measured by $|T^{*R} - T^{*B}|$, will worsen with serial correlation, because the BPL's decision remains the same while the rational PL's scale-up/down decisions are amplified.

[16] We mentioned in footnote 14 that, although a more complete formulation requires the uncertainties to be functions of the duration of time, this does not affect our analysis with no serial correlation. With serial correlation, however, duration-dependent uncertainties do affect our analysis, making it prohibitively more difficult. Since duration-dependent uncertainties are unlikely to change our main insights, we continue to simplify our analysis by keeping the assumption that the uncertainties are independent of the duration of time. With serial correlation, this simplifying assumption makes the expected scope and cost discontinuous at $t = t_1$, that is, $\lim_{T \to t_1^+} E_{t_1}[C(T)] \neq c_1$ and $\lim_{T \to t_1^+} E_{t_1}[Q(T)] \neq q_1$.

Figure 8 Completion time for rational and behavioral PLs with serial correlation.

Note. The parameter values are the same as in Figure 5. We fix $\epsilon_{q_1}=0$ and vary ϵ_{c_1} on the x-axis. We use the actual cost and scope measures, $\phi_c^{\wedge}$ and $\phi_q^{\wedge}$, which generate $(\bar{C},\bar{Q})=(\hat{C}_0,\hat{Q}_0)$. We use a power technology curve and $g(t)=0.6(t-\underline{t})$ for $t\geq\underline{t}$, with the following parameters: $k=2$, $\gamma=0.5$, $\underline{t}=0$, $t_1=0.6$, $\lambda=2$, and $\alpha=0.5$. As for serial correlation, the parameter values are $a_c=a_q=0.2$.



If the BPL has the ability to compute conditional expectations, then the analysis becomes more complicated because the BPL's decision T^{*B} also changes with serial correlation. In this case, it is possible that insufficient adjustments may lessen with serial correlation, especially if the rational revision lies in quadrant I. However, regardless of the BPL's ability to compute conditional expectations, we observe that the BPL's insufficient adjustments persist with serial correlation.

Appendix C: Decision on Revision Timing

Suppose that the PL can revise the project only once but can decide when to revise. To simplify the analysis, we consider only two possible revision times, t_1 and t_2, where $t_0=0\leq\underline{t}<t_1<t_2$. The cost and scope uncertainties are defined as $\tilde{\epsilon}_c=\tilde{\epsilon}_{c_1}+\tilde{\epsilon}_{c_2}+\tilde{\epsilon}_{c_3}$ and $\tilde{\epsilon}_q=\tilde{\epsilon}_{q_1}+\tilde{\epsilon}_{q_2}+\tilde{\epsilon}_{q_3}$, respectively, where $(\tilde{\epsilon}_{c_i},\tilde{\epsilon}_{q_i})$ are the uncertainties to be realized between t_{i-1} and t_i, $i=1,2$, and $(\tilde{\epsilon}_{c_3},\tilde{\epsilon}_{q_3})$ to be realized after t_2. We assume that $E[\tilde{\epsilon}_{c_i}]=E[\tilde{\epsilon}_{q_i}]=0$ for all i, that the six uncertainties, $\tilde{\epsilon}_{c_i}$ and $\tilde{\epsilon}_{q_i}$, $i=1,2,3$, are all independent of each other, and that $\sum_{i=1}^n\tilde{\epsilon}_{c_i}>-1$ and $\sum_{i=1}^n\tilde{\epsilon}_{q_i}>-1$ for $n=1,2,3$. At $t=0$, the cost and scope of the project can be written as follows:

$$C(t)=(1+\tilde{\epsilon}_{c_1}+\tilde{\epsilon}_{c_2}+\tilde{\epsilon}_{c_3})g(t)+h(t),\quad\text{and}$$
$$Q(t)=(1+\tilde{\epsilon}_{q_1}+\tilde{\epsilon}_{q_2}+\tilde{\epsilon}_{q_3})f(g(t)).$$

The PL's decision on optimal revision timing boils down to the decision at time t_1 on whether to revise now or wait until t_2 to revise. Then, we can readily apply the model in Online Appendix B to this extension. Specifically, revising at t_1 is equivalent to the model in Online Appendix B, where $(\tilde{\epsilon}_{c_1},\tilde{\epsilon}_{q_1})$ is realized in Period 1 and $(\tilde{\epsilon}_{c_2}+\tilde{\epsilon}_{c_3},\tilde{\epsilon}_{q_2}+\tilde{\epsilon}_{q_3})$ is realized in Period 2. Similarly, waiting until t_2 to revise is equivalent to the model where $(\tilde{\epsilon}_{c_1}+\tilde{\epsilon}_{c_2},\tilde{\epsilon}_{q_1}+\tilde{\epsilon}_{q_2})$ is realized in Period 1 and $(\tilde{\epsilon}_{c_3},\tilde{\epsilon}_{q_3})$ is realized in Period 2. The challenge here is to analyze the choice between these two options from the same viewpoint of time t_1.

C.1. Rational Revision

First, suppose that the rational PL considers the revision at t_1. The rational PL's objective is equivalent to maximizing the expected financial profit at t_1, which is given by

$$\begin{aligned} E_{t_1}[Q(t)-C(t)] &= E_{t_1}[(1+\epsilon_{q_1}+\tilde{\epsilon}_{q_2}+\tilde{\epsilon}_{q_3})f(g(t))] - E_{t_1}[(1+\epsilon_{c_1}+\tilde{\epsilon}_{c_2}+\tilde{\epsilon}_{c_3})g(t)+h(\underline{t})] \\ &= (1+\epsilon_{q_1})f(g(t)) - (1+\epsilon_{c_1})g(t) - h(\underline{t}), \end{aligned}$$

where $E_{t_1}[\,\cdot\,]$ indicates that the expectation is taken at time t_1. This expected profit is the same as in the base model at time t_1. Therefore, the rational PL's optimal revision T^{*R} and the corresponding expected cost and scope are the same as in Proposition 1, which are

$$(E_{t_1}[C^{*R}], E_{t_1}[Q^{*R}], T^{*R}) = \left((1+\epsilon_{c_1})g(T^{*R})+h(\underline{t}), (1+\epsilon_{q_1})f\left(g(T^{*R})\right), g^{-1}\left((f')^{-1}\left(\frac{1+\epsilon_{c_1}}{1+\epsilon_{q_1}}\right)\right)\right), \quad (14)$$

provided $T^{*R} > t_1$. Otherwise, abandoning the project is optimal, resulting in $T^{*R} = t_1$.

Second, suppose that the PL considers waiting until time t_2 to revise. By then, the PL will be able to observe the realized $(\epsilon_{c_2},\epsilon_{q_2})$ before revising the project. Thus, the expected financial profit at time t_2 is

$$\begin{aligned} E_{t_2}[Q(t)-C(t)] &= E_{t_2}[(1+\epsilon_{q_1}+\epsilon_{q_2}+\tilde{\epsilon}_{q_3})f(g(t))] - E_{t_2}[(1+\epsilon_{c_1}+\epsilon_{c_2}+\tilde{\epsilon}_{c_3})g(t)+h(\underline{t})] \\ &= (1+\epsilon_{q_1}+\epsilon_{q_2})f(g(t)) - (1+\epsilon_{c_1}+\epsilon_{c_2})g(t) - h(\underline{t}). \end{aligned}$$

At t_2, the rational PL's optimal revision T^{*R} and the corresponding expected cost and scope are

$$(E_{t_2}[C^{*R}], E_{t_2}[Q^{*R}], T^{*R}) = \left((1+\epsilon_{c_1}+\epsilon_{c_2})g(T^{*R})+h(\underline{t}), (1+\epsilon_{q_1}+\epsilon_{q_2})f\left(g(T^{*R})\right), g^{-1}\left((f')^{-1}\left(\frac{1+\epsilon_{c_1}+\epsilon_{c_2}}{1+\epsilon_{q_1}+\epsilon_{q_2}}\right)\right)\right),$$

provided $T^{*R} > t_2$. Otherwise, abandoning the project at t_2 is optimal, resulting in $T^{*R} = t_2$.

Then, from the viewpoint of time t_1, the expected financial profit of waiting until t_2 to revise is as follows.

$$E_{t_1}[Q^{*R}-C^{*R}] = E\left[(1+\epsilon_{q_1}+\tilde{\epsilon}_{q_2})\cdot f(g(T^{*R}))\right] - E\left[(1+\epsilon_{c_1}+\tilde{\epsilon}_{c_2})\cdot g(T^{*R})\right] - h(\underline{t}), \quad (15)$$

where

$$T^{*R} = \max\left\{g^{-1}\left((f')^{-1}\left(\frac{1+\epsilon_{c_1}+\tilde{\epsilon}_{c_2}}{1+\epsilon_{q_1}+\tilde{\epsilon}_{q_2}}\right)\right),\ t_2\right\}.$$

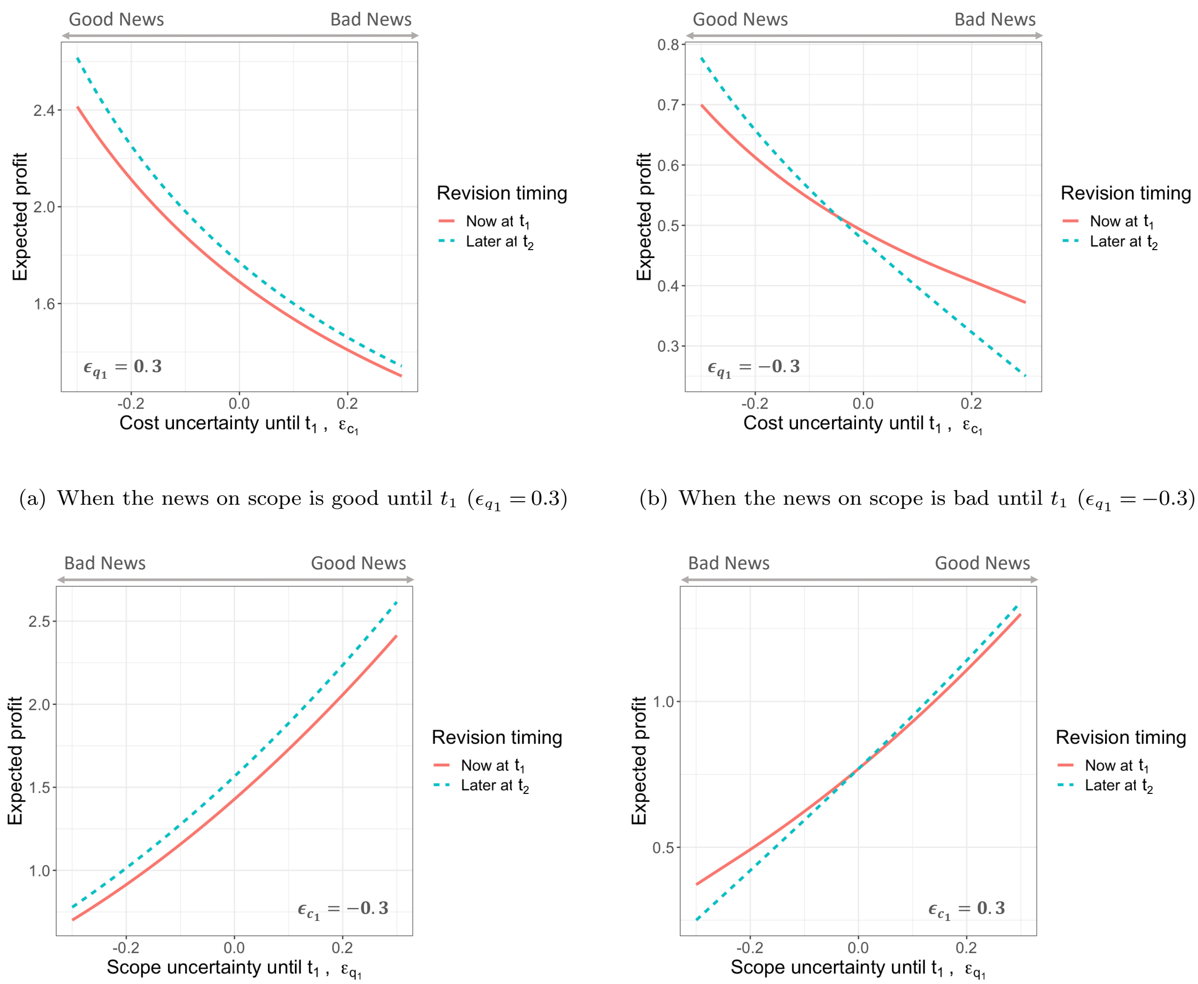
We obtain the following analytical result.

PROPOSITION 7. *Assume a power technology curve, $f(x)=kx^{\gamma}$, and that the support of uncertainties $(\tilde{\epsilon}_{c_1},\tilde{\epsilon}_{q_1})$ and $(\tilde{\epsilon}_{c_2},\tilde{\epsilon}_{q_2})$ are sufficiently narrow so that it is never optimal for the rational PL to abandon the project at t_2. Then, from the viewpoint of time t_1, waiting until t_2 to revise is always better than revising immediately at t_1 for the rational PL.*

Intuitively, waiting until t_2 is better because the rational PL has the ability to revise the project after observing the additional news. That is, the potential profit increase from good news between t_1 and t_2 is higher than the potential profit decrease from bad news, because the rational PL will have the chance to optimally revise the project based on the combined news, not just on the news up to t_1.

Figure 9 Comparison of rational PL's expected profits between revising at t_1 and t_2.

Note. We use a power technology curve and $g(t) = 0.6(t - \underline{t})$ for $t \geq \underline{t}$, with the following parameters: $k = 2$, $\gamma = 0.5$, $\underline{t} = 0$, $t_1 = 0.6$, and $t_2 = 1.2$. The second period uncertainties, ϵ_{c_2} and ϵ_{q_2}, are each uniformly distributed with support $[-0.3, 0.3]$.



(a) When the news on scope is good until t_1 ($\epsilon_{q_1} = 0.3$)

(b) When the news on scope is bad until t_1 ($\epsilon_{q_1} = -0.3$)

(c) When the news on cost is good until t_1 ($\epsilon_{c_1} = -0.3$)

(d) When the news on cost is bad until t_1 ($\epsilon_{c_1} = 0.3$)

Now, if we allow the support of uncertainties to be wide enough so that the PL may abandon the project before t_2, then the analysis becomes intractable. This is mainly because the expected profit of waiting until t_2 in equation (15) involves a maximum operator for T^{*R} due to abandonment between t_1 and t_2. Therefore, we conduct a numerical analysis to obtain high level insights.

Figure 9 numerically compares, from the viewpoint of time t_1, the expected profits of revising now at t_1 and waiting until t_2 to revise for the rational PL. Overall, our numerical analysis shows that it is generally better to wait until t_2 unless the first-period news is bad for both cost and scope. This is consistent with Proposition 7, because if the first-period news is generally good, then it becomes unlikely that the PL needs to abandon the project at t_2, and thus it is better to wait until t_2 as per Proposition 7. By contrast, if the first-period news is generally bad, then it becomes likely that the PL may abandon the project before t_2, in which case it may be better to revise immediately at t_1 to prevent further loss coming from carrying on an unprofitable project.

Specifically, Figures 9(a) and (b) fix the first-period scope uncertainty, ϵ_{q_1}, and compare the expected profits by varying the first-period cost uncertainty ϵ_{c_1} on the x-axis. In Figure 9(a), the first-period news on scope is good, $\epsilon_{q_1} = 0.3$, and we observe that waiting until t_2 always generates higher expected profit. By contrast, in Figure 9(b), when the first-period news on scope is bad, $\epsilon_{q_1} = -0.3$, we observe that it is better to revise immediately at t_1 if the first-period news on cost is also bad. This corresponds to the right-hand side of the figure. Figures 9(c) and (d) show similar results by fixing the first-period cost uncertainty ϵ_{c_1} and varying the first-period scope uncertainty ϵ_{q_1}. Again, we observe a similar insight that it is better to wait until t_2 unless the first-period news is bad for both cost and scope, a case that corresponds to the left-hand side of Figure 9(d).

C.2. Behavioral Revision

In the base model, we assume that the BPL cannot anticipate that the reference points $(\hat{C}_i, \hat{Q}_i)$ will update due to projection bias. In this extension, we make an additional assumption that the BPL cannot anticipate that the anchoring point $(\bar{C}, \bar{Q}) = (c_1 + (1-\phi_c)\hat{C}_1, q_1 + (1-\phi_q)\hat{Q}_1)$ will update either. This is because the calculation of how the anchoring point updates requires the computation of how (c_1, q_1) and (ϕ_c, ϕ_q) will change in the future, a task that is mentally onerous for the BPL who cannot anticipate how $(\hat{C}_i, \hat{Q}_i)$ updates. Therefore, we assume that the BPL will take a mental shortcut and think that the anchoring point, just like reference points, will remain unchanged throughout the rest of the project.

At time t_1, the BPL thinks that the scope and cost functions will remain as follows for the rest of the project due to the flaw of averages:

$$Q(t) = (1+\epsilon_{q_1}) f(g(t)) \quad \text{and} \quad C(t) = (1+\epsilon_{c_1}) g(t) + h(\underline{t}).$$

Note that the BPL's decision solving problem (9) is fully determined by the position of the anchoring point $(\bar{C}, \bar{Q})$, and the slope of the iso profit-to-go curve in each quadrant, as illustrated in Figure 4. This means that, from the viewpoint of time t_1, the BPL is indifferent between revising now at t_1 and waiting until t_2 to revise, provided that the BPL does not want to stop the project before t_2, because the BPL thinks that both the anchoring points $(\bar{C}, \bar{Q})$ and the slope of the iso-profit-to-go curve in each quadrant will remain the same.

Therefore, the possibility of choosing a revision timing creates another source of inefficiency for the BPL. That is, although there is an optimal revision timing for the rational PL, either t_1 or t_2, the BPL is generally indifferent between these two timings. If both PLs decide to revise at the same time, then the BPL's financial profit suffers only from insufficient adjustments. However, if the BPL decides to revise at a different time than the rational PL, then the BPL's financial profit suffers from both 1) the insufficient adjustments that would have resulted if the revision timing had been the same and 2) the suboptimal choice of revision timing.

In this extension, we explored the PL's choice of revision timing in a stylized fashion with the assumptions that 1) the PL can revise only once and 2) there exist only two possible revision times, t_1 and t_2. A more comprehensive analysis to explore the question of multiple revisions is to adopt a continuous-time setup where the project can be revised at any instant, and both cost and scope are time-varying stochastic processes. Our problem then becomes one of finding the optimal stopping time, contingent on realized uncertainty. The stopping time is not trivial, as it must take future optionality into account. The setup and analysis of such a continuous-time model is outside the scope of the current paper.

Appendix D: Deadline and Delay Penalty

Suppose that the project has a deadline T_d, beyond which the project incurs a linear monetary penalty $\rho(T-T_d)^+ = \max\{\rho(T-T_d), 0\}$. Both the rational and behavioral PLs keep track of this penalty in a separate account in the accounting process. We assume that the deadline is not earlier than the initially planned completion time, $\hat{T}_0 \le T_d$, and thus the initial reference point for penalty is zero. The rational PL's profit in (4) now becomes

$$\Pi^R = \underbrace{(\hat{Q}_0 - \hat{C}_0)}_{\substack{\text{Budgeted profit}\\ \text{at project launch}}} + \underbrace{(\phi_c\hat{C}_0 - c_1) + (q_1 - \phi_q\hat{Q}_0)}_{\substack{\text{End of Period 1:}\\ \text{accrued mental profit}}} + \underbrace{((1-\phi_c)\hat{C}_0 - c_2) + (q_2 - (1-\phi_q)\hat{Q}_0)}_{\substack{\text{Termination of project:}\\ \text{remaining mental profit}}} - \underbrace{\rho(T-T_d)^+}_{\text{Delay penalty}}.$$

At revision, the rational PL tries to maximize the profit-to-go, $q_2 - c_2 - \rho(T-T_d)^+$. To simplify the analysis, we assume $g(t) = \theta(t - \underline{t})$ for $t \ge \underline{t}$. Then, maximizing the profit-to-go is equivalent to maximizing the following under the constraint $T \ge t_1$.

$$Q - C - \rho(T-T_d)^+ = \begin{cases} Q - C, & \text{if } T \le T_d \text{ or } C \le C(T_d), \\ Q - \left(1 + \frac{\rho}{(1+\epsilon_c)\theta}\right) C + \rho\left(\frac{h(\underline{t})}{(1+\epsilon_c)\theta} + T_d - \underline{t}\right), & \text{if } T > T_d \text{ or } C > C(T_d). \end{cases}$$

The rational PL's iso profit-to-go curve now has a kink at $T = T_d$, or at $C = C(T_d)$, unlike in the base model where it is a straight line. Before the deadline, $T \le T_d$, the slope of the iso profit-to-go curve is 1 as in the base model, but once the project has passed the deadline, $T > T_d$, the slope increases to $\left(1 + \frac{\rho}{(1+\epsilon_c)\theta}\right)$. This increased slope pushes the rational revision toward the deadline, representing the rational PL's desire to meet the deadline.

Similarly, the BPL's perceived profit in (6) now has an additional term of penalty comparison. However, unlike the rational PL, the BPL updates its reference point for penalty over time. That is, the reference point for penalty is initially set to zero, but updates to $\alpha\rho(T-T_d)^+$ at revision. Thus, the BPL's perceived profit-to-go is

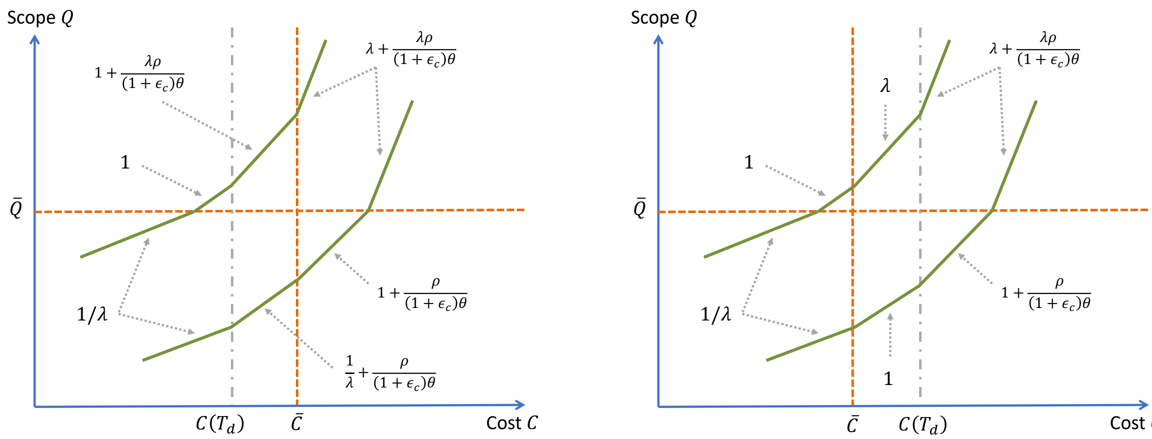
$$\begin{aligned} & v((1-\phi_c)\hat{C}_2 - c_2) + v(q_2 - (1-\phi_q)\hat{Q}_2) + v(\alpha\rho(T-T_d)^+ - \rho(T-T_d)^+) \\ & = v((1-\alpha)((1-\phi_c)\hat{C}_1 - c_2)) + v((1-\alpha)(q_2 - (1-\phi_q)\hat{Q}_1)) + v(-(1-\alpha)\rho(T-T_d)^+). \end{aligned}$$

The first two terms remain the same as (11) in the base model. The third term can be given by

$$v(-(1-\alpha)\rho(T-T_d)^+) = \begin{cases} 0, & \text{if } T \le T_d \text{ or } C \le C(T_d), \\ -\frac{\lambda(1-\alpha)\rho}{(1+\epsilon_c)\theta} C + \lambda(1-\alpha)\rho\left(\frac{h(\underline{t})}{(1+\epsilon_c)\theta} + T_d - \underline{t}\right), & \text{if } T > T_d \text{ or } C > C(T_d). \end{cases}$$

Combined with (11), we observe that the BPL's iso profit-to-go curve changes when $T > T_d$ or $C > C(T_d)$ from those in Figure 3. Specifically, Figures 10(a) and (b) illustrate the iso profit-to-go curves when $C(T_d) < \bar{C}$ and $C(T_d) \ge \bar{C}$, respectively. In both figures, when $C > C(T_d)$, the slope increases by $\frac{\lambda\rho}{(1+\epsilon_c)\theta}$ if there is no

Figure 10 Behavioral PL's iso profit-to-go curves and their slopes with delay penalty



(a) When $C(T_d) < \bar{C}$ (b) When $C(T_d) \geq \bar{C}$

loss in scope (quadrants I and II), and increases by $\frac{\rho}{(1+\epsilon_c)\theta}$ if there is loss in scope (quadrants III and IV). Note that the anchoring point $(\bar{C}, \bar{Q})$ remains the same as in the base model, and the BPL's iso profit-to-go curves still remain convex.

We find that the BPL still exhibits insufficient adjustments and verify that Proposition 3 continues to hold with one slight difference: When $C(T_d) < \bar{C}$, if the BPL is doing well on scope, $Q \geq \bar{Q}$, then the behavioral updated plan (C^{*B}, Q^{*B}) is pulled toward $(C(T_d), \bar{Q})$, rather than $(\bar{C}, \bar{Q})$. That is, the BPL tries to meet the deadline instead of the cost anchor. The following proposition formalizes this result.

Proposition 8. *The BPL's updated plan (C^{*B}, Q^{*B}) is characterized as follows.*

(1) If $C(T_d) < \bar{C}$, $C(T_d) < C^{*R}$, and $\bar{Q} \leq Q^{*R}$, then (C^{*B}, Q^{*B}) falls between $(C(T_d), \bar{Q})$ and (C^{*R}, Q^{*R}) component-wise; otherwise, the following holds.

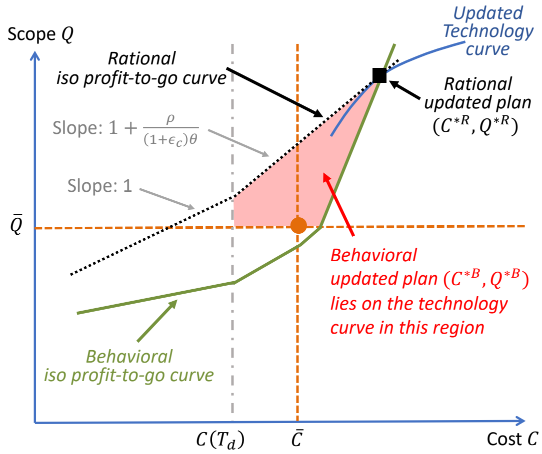
(2) If $(C^{*R}, Q^{*R}) \in I \cup III$, then (C^{*B}, Q^{*B}) falls between $(\bar{C}, \bar{Q})$ and (C^{*R}, Q^{*R}) component-wise; and

(3) If $(C^{*R}, Q^{*R}) \in II \cup IV$, then $(C^{*B}, Q^{*B}) = (C^{*R}, Q^{*R})$.

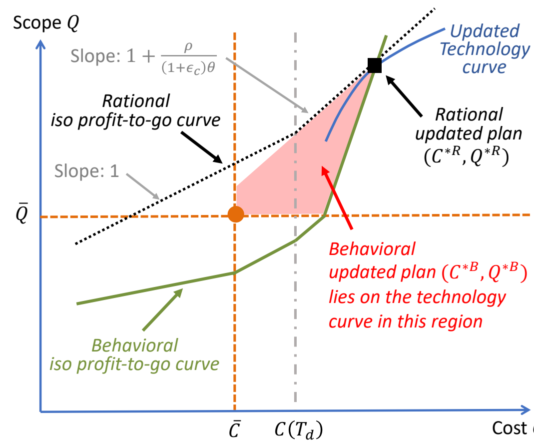
We highlight that Proposition 8 is the same as Proposition 3 except for Part (1). Figure 11 illustrates the BPL's insufficient adjustments stated in parts (1) and (2) of Proposition 8; Panel (a) corresponds to part (1) and panels (b), (c), and (d) correspond to part (2). Note that panels (a) and (c) illustrate the case when $C(T_d) < \bar{C}$ and panels (b) and (d) when $C(T_d) \geq \bar{C}$. In all cases, (C^{*B}, Q^{*B}) is pulled away from (C^{*R}, Q^{*R}) toward $(\bar{C}, \bar{Q})$ as in the base model, except in Figure 11(a) in which (C^{*B}, Q^{*B}) is pulled toward $(C(T_d), \bar{Q})$.

The intuition for Proposition 8 is as follows. In general, with delay penalty, both the rational and behavioral PLs have an incentive to meet the deadline. However, for the BPL, this incentive is especially strong if the deadline is relatively early, $C(T_d) < \bar{C}$, and the project is already doing well on scope, $Q \geq \bar{Q}$, because in this case spending even $\bar{C}$ triggers delay penalty and the associated feelings of loss from the penalty. In such a case, the desire to meet the deadline is sufficiently strong to pull the behavioral revision toward the deadline, T_d or $C(T_d)$, instead of the cost anchor, $\bar{C}$.

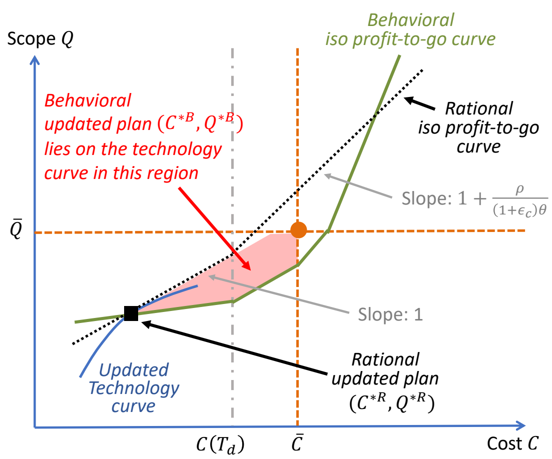
Figure 11 Rational and behavioral updated plans with delay penalty



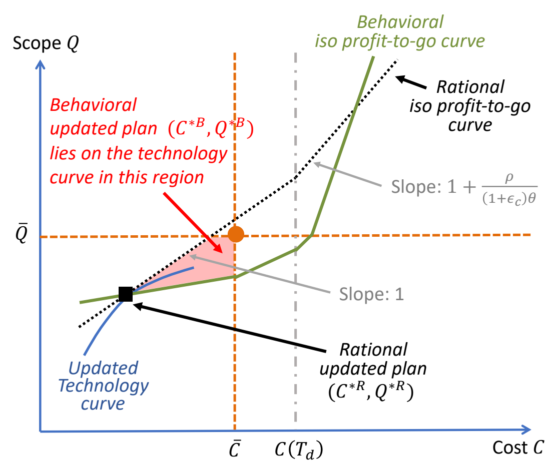
(a) When $C^{*R} > C(T_d)$ and $Q^{*R} \geq \bar{Q}$ with $C(T_d) < \bar{C}$



(b) When $C^{*R} \geq \bar{C}$ and $Q^{*R} \geq \bar{Q}$ with $C(T_d) \geq \bar{C}$



(c) When $C^{*R} < \bar{C}$ and $Q^{*R} < \bar{Q}$ with $C(T_d) < \bar{C}$

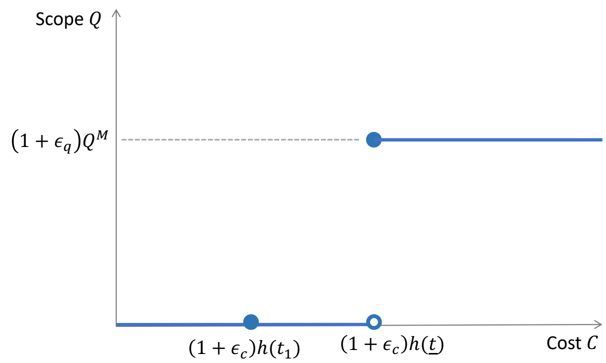


(d) When $C^{*R} < \bar{C}$ and $Q^{*R} < \bar{Q}$ with $C(T_d) \geq \bar{C}$

We observe that, if the deadline is not too early, $C(T_d) \geq \bar{C}$, then delay penalty may reduce the gap between the rational and behavioral revision by pushing the rational revision toward the behavioral one. That is, in Figure 11(b), if λ is sufficiently high, then the behavioral revision will be fixed at either the cost or scope anchor, while the delay penalty is pushing the rational revision toward the deadline. This, in turn, may reduce the gap between the rational and behavioral revision if $C(T_d)$ is not too far from $\bar{C}$. In other cases, the effect of delay penalty on the degree of the BPL's insufficient adjustments is generally ambiguous because delay penalty affects both the rational and behavioral revisions.

As for progress measures, we find that the best progress measures we identified in Proposition 6 are still valid for cases (ii) and (iv), which correspond to overall bad news for a power technology curve. In these cases, the rational revision lies below the scope anchor $\bar{Q}$ even with delay penalty. This means that the rational revision remains in quadrant III or IV for case (ii) and in quadrant III for case (iv), as in Table 5 of the base model. This, in turn, ensures that the best progress measures in the base model continue to be

Figure 12 **Relationship between scope Q and cost C under the fixed scope model.**



valid with delay penalty. For other cases, however, we observe that the rational revision can fall in any of the four quadrants depending on the progress measures employed, and therefore the best progress measures depend on the specific parameter values of the model.

Appendix E: Binary Project Outcomes

In this extension, we consider a project that has a fixed scope at completion and thus cannot be scaled up or down at revision. We show that this model boils down to a simple decision of whether to abandon or continue the project at revision. The main result is that the BPL is more likely to continue the project than the rational PL regardless of the progress measures, a finding that is consistent with the traditional sunk cost effect. This extension inherently does not allow for insufficient adjustments because all decisions are binary in nature, and we find that progress measures do not influence the results.

We tweak the setup of cost and scope in (1) as follows:

$$C(t) = g(t) + (1+\epsilon_c)h(t),$$
$$Q(t) = (1+\epsilon_q)f(h(t)).$$

Also, we redefine the technology curve as $f(x) = 0$ if $x < h(\underline{t})$ and $f(x) = Q^M$ if $x \geq h(\underline{t})$, where Q^M is a constant satisfying $Q^M > h(\underline{t})$. We assume that $t_1 < \underline{t}$ in contrast to the base model where $t_1 > \underline{t}$. That is, when the PL revises the project at time t_1, the PL fully observes the realized deviations (ϵ_c, ϵ_q) and the cost spent, $c_1 = (1+\epsilon_c)h(t_1)$, but has not achieved any scope yet. All other elements of the model remain unchanged. The relationship between scope and cost is illustrated in Figure 12.

The deterministic plan under this model is $(\hat{C}_0, \hat{Q}_0, \hat{T}_0) = (h(\underline{t}), Q^M, \underline{t})$. That is, without deviations, the plan that maximizes financial profit, $Q - C$, is spending the minimum amount of cost, $h(\underline{t})$, to achieve the fixed scope Q^M.

E.1. Rational Project Leader

A fixed scope is achieved only at the termination of the project, and thus the rational PL evaluates the accrued mental profit in scope only once at the end. Therefore, we update the rational PL's profit function in (4) as follows.

$$\Pi^R = \underbrace{(\hat{Q}_0 - \hat{C}_0)}_{\substack{\text{Budgeted profit} \\ \text{at project launch}}} + \underbrace{(\phi_c \hat{C}_0 - c_1)}_{\substack{\text{End of Period 1:} \\ \text{accrued mental profit}}} + \underbrace{((1-\phi_c)\hat{C}_0 - c_2) + (Q - \hat{Q}_0)}_{\substack{\text{Termination of project:} \\ \text{remaining mental profit}}}. \tag{16}$$

At the beginning of Period 2, the PL decides on the completion time T to maximize the profit-to-go at t_1, by solving

$$T^{*R} = \text{argmax}_{T \geq t_1} (1-\phi_c)\hat{C}_0 - c_2 + Q - \hat{Q}_0. \tag{17}$$

Because $\hat{C}_0$ and $\hat{Q}_0$ are constant, this is equivalent to maximizing the value-to-go, $Q - c_2$. We can reduce the feasible set of this problem into two discrete points, which are the two blue solid dots in Figure 12: abandoning the project, $(C, Q, T) = ((1+\epsilon_c)h(t_1), 0, t_1)$, and continuing the project until achieving Q^M, $(C, Q, T) = ((1+\epsilon_c)h(\underline{t}), (1+\epsilon_q)Q^M, \underline{t})$.

If the rational PL abandons, $T = t_1$, then the value-to-go is $Q - c_2 = 0$. Therefore, the rational PL continues the project if and only if continuing the project produces a positive value-to-go,

$$Q - c_2 = (1+\epsilon_q)Q^M - (1+\epsilon_c)(h(\underline{t}) - h(t_1)) \geq 0,$$

where we assume that, when the PL is indifferent between the two options, the PL continues the project.

E.2. Behavioral Project Leader

Similar to the rational PL, the BPL also evaluates the accrued mental profit in scope only once at the termination of the project. Therefore, we update the BPL's perceived profit in (6) as follows.

$$\Pi^B = \underbrace{v(\hat{Q}_0 - \hat{C}_0)}_{\substack{\text{Budgeted profit} \\ \text{at project launch}}} + \underbrace{v(\phi_c \hat{C}_1 - c_1)}_{\substack{\text{End of Period 1:} \\ \text{accrued mental profit}}} + \underbrace{v((1-\phi_c)\hat{C}_2 - c_2) + v(Q - \hat{Q}_2)}_{\substack{\text{Termination of project:} \\ \text{remaining mental profit}}}. \tag{18}$$

The updating of reference costs, $\hat{C}_1$ and $\hat{C}_2$, remain the same as in the base model, but now the reference scope is updated only once as follows.

$$\hat{Q}_2 = \alpha Q + (1-\alpha)\hat{Q}_0.$$

At the beginning of Period 2, the BPL chooses T to maximize the perceived profit-to-go at t_1, by solving

$$T^{*B} = \text{argmax}_{T \geq t_1} v((1-\phi_c)\hat{C}_2 - c_2) + v(Q - \hat{Q}_2). \tag{19}$$

The anchoring point is now $(\bar{C}, \bar{Q}) = (c_1 + (1-\phi_c)\hat{C}_1, \hat{Q}_0)$, and the perceived profit-to-go can be given by

$$\begin{cases} (1-\alpha)\left[(Q - \lambda c_2) + \lambda(\bar{C} - c_1) - \bar{Q}\right], & \text{if } (C,Q) \in I, \\ (1-\alpha)\left[(Q - c_2) + \bar{C} - c_1 - \bar{Q}\right], & \text{if } (C,Q) \in II, \\ \lambda(1-\alpha)\left[\left(Q - \frac{1}{\lambda}c_2\right) + \frac{1}{\lambda}(\bar{C} - c_1) - \bar{Q}\right], & \text{if } (C,Q) \in III, \\ \lambda(1-\alpha)\left[(Q - c_2) + \bar{C} - c_1 - \bar{Q}\right], & \text{if } (C,Q) \in IV. \end{cases} \tag{20}$$

Same as the rational PL, the feasible set of the BPL's problem can be also reduced to two discrete points: abandoning the project, $(C, Q, T) = ((1+\epsilon_c)h(t_1), 0, t_1)$, and continuing the project until achieving Q^M, $(C, Q, T) = ((1+\epsilon_c)h(\underline{t}), (1+\epsilon_q)Q^M, \underline{t})$. However, the BPL's continuation decision is different from the rational PL as follows.

Proposition 9. *The BPL is more likely to continue the project than the rational PL, provided* $\epsilon_c \leq \frac{Q^M}{h(\underline{t})-h(t_1)} - 1$*, regardless of the progress measures.*

The intuition is that the BPL hates the feelings of loss in scope when abandoning the project, and thus is more likely to continue than the rational PL. In this sense, Proposition 9 is consistent with the traditional sunk cost effect. Note that the right-hand side of the condition in Proposition 9 is always strictly positive and likely to be well above zero, because $Q^M > h(\underline{t})$ by assumption. If the condition in Proposition 9 is not satisfied, then the BPM may or may not be more likely to continue than the rational PL.

In this extension, all choices are binary (continue vs. abandon), and thus there is no insufficient adjustment to discuss. Also, progress measures do not influence our result in Proposition 9 because the BPL's propensity to continue the project is mainly driven by the aversion to feelings of loss in scope when abandoning the project, irrespective of the progress measures.

Appendix F: Proof of All Results in Online Appendix

Proof of Proposition 7. Using (14) and $f(x)=kx^\gamma$, the expected profit of revising at t_1 is as follows.

$$E_{t_1}[Q^{*R}]-E_{t_1}[C^{*R}]=(1+\epsilon_{q_1})\cdot f\left((f')^{-1}\left(\frac{1+\epsilon_{c_1}}{1+\epsilon_{q_1}}\right)\right)-(1+\epsilon_{c_1})\cdot(f')^{-1}\left(\frac{1+\epsilon_{c_1}}{1+\epsilon_{q_1}}\right)-h(\underline{t})$$
$$=(k\gamma)^{\frac{1}{1-\gamma}}\frac{(1+\epsilon_{q_1})^{\frac{1}{1-\gamma}}}{(1+\epsilon_{c_1})^{\frac{\gamma}{1-\gamma}}}\left(\frac{1}{\gamma}-1\right)-h(\underline{t}).$$

Also, using (15), if the PL never abandons the project at t_2, then the expected profit of waiting until t_2 to revise is as follows.

$$E_{t_1}[Q^{*R}]-E_{t_1}[C^{*R}]=E_{t_1}\left[(1+\epsilon_{q_1}+\tilde{\epsilon}_{q_2})\cdot f\left((f')^{-1}\left(\frac{1+\epsilon_{c_1}+\tilde{\epsilon}_{c_2}}{1+\epsilon_{q_1}+\tilde{\epsilon}_{q_2}}\right)\right)-(1+\epsilon_{c_1}+\tilde{\epsilon}_{c_2})\cdot(f')^{-1}\left(\frac{1+\epsilon_{c_1}+\tilde{\epsilon}_{c_2}}{1+\epsilon_{q_1}+\tilde{\epsilon}_{q_2}}\right)\right]-h(\underline{t})$$
$$=E_{t_1}\left[(k\gamma)^{\frac{1}{1-\gamma}}\frac{(1+\epsilon_{q_1}+\tilde{\epsilon}_{q_2})^{\frac{1}{1-\gamma}}}{(1+\epsilon_{c_1}+\tilde{\epsilon}_{c_2})^{\frac{\gamma}{1-\gamma}}}\left(\frac{1}{\gamma}-1\right)\right]-h(\underline{t}).$$

Therefore, waiting until t_2 generates a higher expected profit than revising at t_1 if and only if

$$E_{t_1}\left[\frac{(1+\epsilon_{q_1}+\tilde{\epsilon}_{q_2})^{\frac{1}{1-\gamma}}}{(1+\epsilon_{c_1}+\tilde{\epsilon}_{c_2})^{\frac{\gamma}{1-\gamma}}}\right]>\frac{(1+\epsilon_{q_1})^{\frac{1}{1-\gamma}}}{(1+\epsilon_{c_1})^{\frac{\gamma}{1-\gamma}}}. \tag{21}$$

Note that $\tilde{\epsilon}_{q_2}$ and $\tilde{\epsilon}_{c_2}$ are independent, and thus

$$E_{t_1}\left[\frac{(1+\epsilon_{q_1}+\tilde{\epsilon}_{q_2})^{\frac{1}{1-\gamma}}}{(1+\epsilon_{c_1}+\tilde{\epsilon}_{c_2})^{\frac{\gamma}{1-\gamma}}}\right]=E_{t_1}\left[(1+\epsilon_{q_1}+\tilde{\epsilon}_{q_2})^{\frac{1}{1-\gamma}}\right]\cdot E_{t_1}\left[(1+\epsilon_{c_1}+\tilde{\epsilon}_{c_2})^{-\frac{\gamma}{1-\gamma}}\right].$$

We observe that $(1+\epsilon_{q_1}+\tilde{\epsilon}_{q_2})^{\frac{1}{1-\gamma}}$ and $(1+\epsilon_{c_1}+\tilde{\epsilon}_{c_2})^{-\frac{\gamma}{1-\gamma}}$ are convex functions of $\tilde{\epsilon}_{q_2}$ and $\tilde{\epsilon}_{c_2}$, respectively, because $\gamma\in(0,1)$. Then, by Jensen's inequality, $E_{t_1}[(1+\epsilon_{q_1}+\tilde{\epsilon}_{q_2})^{\frac{1}{1-\gamma}}]>(1+\epsilon_{q_1})^{\frac{1}{1-\gamma}}$ and $E_{t_1}[(1+\epsilon_{c_1}+\tilde{\epsilon}_{c_2})^{-\frac{\gamma}{1-\gamma}}]>(1+\epsilon_{c_1})^{-\frac{\gamma}{1-\gamma}}$, because $E_{t_1}[\tilde{\epsilon}_{q_2}]=E_{t_1}[\tilde{\epsilon}_{c_2}]=0$. Therefore, inequality (21) always holds, and thus it is always better to wait until t_2 to revise. □

Proof of Proposition 8. This proof consists of two steps: We show the result when $C(T_d)<\bar{C}$ in Step 1 and when $C(T_d)\geq\bar{C}$ in Step 2. Note that $t_1<\hat{T}_0\leq T_d$ by assumption, and thus $c_1<C(T_d)$. Also, the rational PL's iso profit-to-go curve is piecewise linear with a kink at $C(T_d)$, and has a slope of 1 when $C<C(T_d)$ and a slope of $\left(1+\frac{\rho}{(1+\epsilon_c)\theta}\right)$ when $C>C(T_d)$. The slopes of the BPL's iso profit-to-go curves are illustrated in Figure 10. Both (C^{*R},Q^{*R}) and (C^{*B},Q^{*B}) are on the same updated technology curve $Q(C)=(1+\epsilon_q)f\left(\frac{C-h(\underline{t})}{1+\epsilon_c}\right)$. Abandonment is possible only in quadrant III because $c_1<\bar{C}$ and $q_1<\bar{Q}$.

Step 1. Consider the case when $C(T_d)<\bar{C}$. For quadrants I and II, we rearrange the combined area into $C>C(T_d)$ and $C\leq C(T_d)$. For quadrants III and IV, we consider the original quadrants as they are.

First, suppose that $C^{*R}>C(T_d)$ and $Q^{*R}\geq\bar{Q}$. Then, the rational revision is not at the kink $C(T_d)$, and thus it is the point on the updated technology curve that the highest iso profit-to-go curve with a slope of $\left(1+\frac{\rho}{(1+\epsilon_c)\theta}\right)$ touches upon. Then, it is necessarily the case that $C^{*B}\leq C^{*R}$ because $Q(C)=(1+\epsilon_q)f\left(\frac{C-h(\underline{t})}{1+\epsilon_c}\right)$ is strictly concave in $C\geq h(\underline{t})$, and the BPL's iso profit-to-go curve is convex with a minimum slope of $\left(1+\frac{\lambda\rho}{(1+\epsilon_c)\theta}\right)$ when $C>C(T_d)$. However, it cannot be the case that $C^{*B}<C(T_d)$ or $Q^{*B}<\bar{Q}$, because in these cases the highest slope of the BPL's iso profit-to-go curve is $\left(1+\frac{\rho}{(1+\epsilon_c)\theta}\right)$ but the lowest slope of $Q(C)$ is strictly greater than $\left(1+\frac{\rho}{(1+\epsilon_c)\theta}\right)$ due to its concavity. Therefore, (C^{*B}, Q^{*B}) satisfies that $C(T_d) \leq C^{*B} \leq C^{*R}$ and $\bar{Q} \leq Q^{*B} \leq Q^{*R}$.

Second, suppose that $C^{*R} \leq C(T_d)$ and $Q^{*R} \geq \bar{Q}$, including the case where the solution is at the kink $C(T_d)$. In this case, both the rational and behavioral PLs' iso profit-to-go curves have the slope of 1. Also, their iso profit-to-go curves are both convex, where the BPL's iso profit-to-go curve has a higher slope when $C > C(T_d)$ and lower slope when $Q < \bar{Q}$, compared to the rational PL's. Therefore, $(C^{*B}, Q^{*B}) = (C^{*R}, Q^{*R})$, regardless of whether (C^{*R}, Q^{*R}) is at the kink $C^{*R} = C(T_d)$ or a tangent solution.

Third, suppose that (C^{*R}, Q^{*R}) is in quadrant III. If the rational PL abandons the project, $(C^{*R}, Q^{*R}) = (c_1, q_1)$, then it is obvious that $C^{*R} \leq C^{*B}$ and $Q^{*R} \leq Q^{*B}$. Otherwise, (C^{*R}, Q^{*R}) is at the kink $C(T_d)$ or on the updated technology curve that the highest iso profit-to-go curve with a slope of 1 or $\left(1+\frac{\rho}{(1+\epsilon_c)\theta}\right)$ touches upon. Then, it is necessarily the case that $C^{*R} \leq C^{*B}$ because $Q(C)$ is strictly concave in $C \geq h(\underline{t})$, and the BPL's iso profit-to-go curve is convex with a smaller slope than the rational PL's for any given C in quadrant III. However, it cannot be the case that $C^{*B} > \bar{C}$ (i.e., (C^{*B}, Q^{*B}) cannot be in quadrants I or IV), because in these quadrants the lowest slope of the BPL's iso profit-to-go curve is $\left(1+\frac{\rho}{(1+\epsilon_c)\theta}\right)$ but the highest slope of $Q(C)$ is strictly less than $\left(1+\frac{\rho}{(1+\epsilon_c)\theta}\right)$ due to its concavity. Also, it cannot be the case that $C^{*B} \leq \bar{C}$ and $Q^{*B} > \bar{Q}$ (i.e., (C^{*B}, Q^{*B}) cannot be in quadrant II) because of the following reasons. Suppose that $Q(C)$ passes quadrant II. If $C^{*R} < C(T_d)$, then the highest slope of $Q(C)$ in quadrant II is strictly less than 1 due to its concavity, but the lowest slope of the BPL's iso profit-to-go curve is 1. If $C^{*R} \in [C(T_d), \bar{C}]$, including the solution at the kink $C(T_d)$, then the highest slope of $Q(C)$ in quadrant II is strictly less than $\left(1+\frac{\rho}{(1+\epsilon_c)\theta}\right)$ due to its concavity, but the slope of the BPL's iso profit-to-go curve is $\left(1+\frac{\lambda\rho}{(1+\epsilon_c)\theta}\right)$ when $C \in [C(T_d), \bar{C}]$ in quadrant II. Therefore, we have $C^{*R} \leq C^{*B} \leq \bar{C}$ and $Q^{*R} \leq Q^{*B} \leq \bar{Q}$.

Last, suppose that (C^{*R}, Q^{*R}) is in quadrant IV. In this case, both the rational and behavioral PLs' iso profit-to-go curves have the same slope of $\left(1+\frac{\rho}{(1+\epsilon_c)\theta}\right)$. Also, their iso profit-to-go curves are both convex, where the BPL's iso profit-to-go curve has a lower slope when $C < \bar{C}$ and higher slope when $Q > \bar{Q}$, compared to the rational PL's. Therefore, $(C^{*B}, Q^{*B}) = (C^{*R}, Q^{*R})$.

Step 2. Consider the case when $C(T_d) \geq \bar{C}$. First, suppose that (C^{*R}, Q^{*R}) is in quadrant I. Then, (C^{*R}, Q^{*R}) is at the kink $C(T_d)$ or on the updated technology curve that the highest iso profit-to-go curve with a slope of 1 or $\left(1+\frac{\rho}{(1+\epsilon_c)\theta}\right)$ touches upon. We observe that it is necessarily the case that $C^{*B} \leq C^{*R}$ because $Q(C)$ is strictly concave in $C \geq h(\underline{t})$, and the BPL's iso profit-to-go curve is convex with a greater slope than the rational PL's for any given C in quadrant I. However, it cannot be the case that $C^{*B} < \bar{C}$ (i.e., (C^{*B}, Q^{*B}) cannot be in quadrant II or III), because in these quadrants the highest slope of the BPL's iso profit-to-go curve is 1 but the lowest slope of $Q(C)$ is strictly greater than 1 due to its concavity. Also, it cannot be the case that $C^{*B} \geq \bar{C}$ and $Q^{*B} < \bar{Q}$ (i.e., (C^{*B}, Q^{*B}) cannot be in quadrant IV) because of the following reasons. Suppose that $Q(C)$ passes quadrant IV. If $C^{*R} > C(T_d)$, then the lowest slope of $Q(C)$ in quadrant IV is strictly greater than $\left(1+\frac{\rho}{(1+\epsilon_c)\theta}\right)$ due to its concavity, but the highest slope of the BPL's iso profit-to-go curve is $\left(1+\frac{\rho}{(1+\epsilon_c)\theta}\right)$. If $C^{*R} \in [\bar{C}, C(T_d)]$, including the solution at the kink $C(T_d)$, then the lowest slope of $Q(C)$ in quadrant IV is strictly greater than 1, but the slope of the BPL's iso profit-to-go curve is 1 when $C \in [\bar{C}, C(T_d)]$ in quadrant IV. Therefore, we have $\bar{C} \leq C^{*B} \leq C^{*R}$ and $\bar{Q} \leq Q^{*B} \leq Q^{*R}$.

Second, suppose that (C^{*R}, Q^{*R}) is in quadrant III. If the rational PL abandons the project, $(C^{*R}, Q^{*R}) = (c_1, q_1)$, then it is obvious that $C^{*R} \leq C^{*B}$ and $Q^{*R} \leq Q^{*B}$. Otherwise, (C^{*R}, Q^{*R}) is on the updated technology curve that the highest iso profit-to-go curve with a slope of 1 touches upon. We observe that it is necessarily the case that $C^{*B} \geq C^{*R}$ because $Q(C)$ is strictly concave in $C \geq h(\underline{t})$ and the BPL's iso profit-to-go curve is convex with a smaller slope than the rational PL's in quadrant III. However, (C^{*B}, Q^{*B}) cannot be in quadrants I, II, or IV, because in these quadrants the lowest slope of the BPL's iso profit-to-go curve is 1 but the highest slope of $Q(C)$ is strictly less than 1. Therefore, we have $C^{*R} \leq C^{*B} \leq \bar{C}$ and $Q^{*R} \leq Q^{*B} \leq \bar{Q}$.

Last, suppose that (C^{*R}, Q^{*R}) is in quadrant II or IV. In these two quadrants, both the rational and behavioral PLs' iso profit-to-go curves have the same slopes. Also, their iso profit-to-go curves are both convex, where the BPL's iso profit-to-go curve has a lower slope in quadrant III and higher slope quadrant I, compared to the rational PL's. Therefore, $(C^{*B}, Q^{*B}) = (C^{*R}, Q^{*R})$, regardless of whether (C^{*R}, Q^{*R}) is at the kink $C^{*R} = C(T_d)$ or a tangent solution. □

Proof of Proposition 9. The feasible set of both the rational and behavioral PLs' problems (17) and (19) can be reduced to two discrete points: abandoning the project, $(C^{AB}, Q^{AB}, T^{AB}) = ((1+\epsilon_c)h(t_1), 0, t_1)$, and continuing the project until a positive scope is achieved, $(C^{CT}, Q^{CT}, T^{CT}) = ((1+\epsilon_c)h(\underline{t}), (1+\epsilon_q)Q^M, \underline{t})$. This is because one of these two points can achieve the same scope with smaller cost than any other points.

Both the rational and behavioral PLs continue the project if and only if continuing the project results in higher (perceived) profit-to-go than abandoning the project. For the rational PL, this condition is equivalent to $Q^{CT} - c_2^{CT} \geq 0$, where $c_2^{CT} = C^{CT} - c_1$. For the BPL, if the BPL abandons the project, then (C^{AB}, Q^{AB}) always lies in quadrant III, and thus the perceived profit-to-go is $(1-\alpha)[\bar{C} - c_1 - \lambda\bar{Q}]$ by (20). If the BPL continues the project, then we need to consider the four cases in (20) depending on the quadrant of (C^{CT}, Q^{CT}).

(i) When $(C^{CT}, Q^{CT}) \in I$, the BPL continues the project if and only if

$$\begin{aligned}&(1-\alpha)\left[\left(Q^{CT} - \lambda c_2^{CT}\right) + \lambda(\bar{C} - c_1) - \bar{Q}\right] - (1-\alpha)[\bar{C} - c_1 - \lambda\bar{Q}] \\ &= (1-\alpha)[(Q^{CT} - c_2^{CT}) + (\lambda - 1)(\bar{C} - c_1 + \bar{Q} - c_2^{CT})] \geq 0.\end{aligned}$$

This inequality holds if $Q^{CT} - c_2^{CT} \geq 0$, but the converse is not true, because $\bar{Q} - c_2^{CT} = Q^M - (1+\epsilon_c)(h(\underline{t}) - h(t_1)) \geq 0$ by the assumption $\epsilon_c \leq \frac{Q^M}{h(\underline{t}) - h(t_1)} - 1$, and $\bar{C} - c_1 = (1-\phi_c)\hat{C}_1 > 0$.

(ii) When $(C^{CT}, Q^{CT}) \in II$, the BPL continues the project if and only if

$$\begin{aligned}&(1-\alpha)\left[\left(Q^{CT} - c_2^{CT}\right) + (\bar{C} - c_1) - \bar{Q}\right] - (1-\alpha)[\bar{C} - c_1 - \lambda\bar{Q}] \\ &= (1-\alpha)[(Q^{CT} - c_2^{CT}) + (\lambda - 1)\bar{Q}] \geq 0.\end{aligned}$$

This inequality holds if $Q^{CT} - c_2^{CT} \geq 0$, but the converse is not true.

(iii) When $(C^{CT}, Q^{CT}) \in III$, the BPL continues the project if and only if

$$\begin{aligned}&\lambda(1-\alpha)\left[\left(Q^{CT} - \frac{1}{\lambda}c_2^{CT}\right) + \frac{1}{\lambda}(\bar{C} - c_1) - \bar{Q}\right] - (1-\alpha)[\bar{C} - c_1 - \lambda\bar{Q}] \\ &= (1-\alpha)[(Q^{CT} - c_2^{CT}) + (\lambda - 1)Q^{CT}] \geq 0.\end{aligned}$$

This inequality holds if $Q^{CT} - c_2^{CT} \geq 0$, but the converse is not true.

(iv) When $(C^{CT}, Q^{CT}) \in IV$, the BPL continues the project if and only if

$$\lambda(1-\alpha)\left[\left(Q^{CT}-c_2^{CT}\right)+\bar{C}-c_1-\bar{Q}\right]-(1-\alpha)[\bar{C}-c_1-\lambda\bar{Q}]$$
$$=\lambda(1-\alpha)\left[(Q^{CT}-c_2^{CT})+\frac{\lambda-1}{\lambda}(\bar{C}-c_1)\right]\geq 0.$$

This inequality holds if $Q^{CT}-c_2^{CT}\geq 0$, but the converse is not true.

Therefore, the BPL is more likely to continue the project than the rational PL. □