Technical Appendix to Accompany

"Self-Sabotage in the Procurement of Distributed Energy Resources"

by David Brown and David Sappington

We begin by identifying the outcomes the regulator might conceivably implement in order to minimize the expected payment required to induce the utility to undertake one of the projects.

Case 1. For one $i \in \{1, 2\}$, the regulator always induces the utility to undertake project i and implement cost structure H.

Conclusion 1. *In Case 1, the regulator's minimum expected procurement cost is* c^e_{iH} *and the utility's corresponding profit is* 0.

Proof. When the utility undertakes project i and implements cost structure H, its expected cost is c^e_{iH}. This is the lowest possible expected procurement cost the regulator can secure in Case 1. It is readily verified that the regulator can secure this cost by setting $\underline{r}_i = \underline{c}$, $\overline{r}_i = \overline{c}$, and $\underline{r}_j = \overline{r}_j < \underline{c}_j$ $(j \neq i)$ ■

Case 2. For one $i \in \{1, 2\}$, the regulator induces the utility to always undertake project i and implement cost structure L.

Conclusion 2. *Suppose* $c^e_{iH} - c^e_{iL} \geq \overline{k}_i$. *Then in Case 2: (i) the regulator's minimum expected procurement cost is* $c^e_{iL} + \overline{k}_i$ *; and (ii) the utility's corresponding expected profit is* 0 *if* $k_i = \overline{k}_i$ *and* $\overline{k}_i - \underline{k}_i$ *if* $k_i = \underline{k}_i$.

Proof. When the utility always undertakes project i and implements cost structure L, its expected cost is $c^e_{iL} + \underline{k}_i$ when $k_i = \underline{k}_i$ and $c^e_{iL} + \overline{k}_i$ when $k_i = \overline{k}_i$. Therefore, the regulator must cede a rent of at least $\overline{k}_i - \underline{k}_i$ to the utility when $k_i = \underline{k}_i$ to ensure it always undertakes project i and implements cost structure L. Consequently, the minimum expected procurement cost the regulator can secure in Case 2 is $c^e_{iL} + \overline{k}_i$. It is readily verified that the regulator can ensure this minimum expected cost when $c^e_{iH} - c^e_{iL} \leq \overline{k}_i$ by setting $\underline{r}_i = \overline{r}_i = c^e_{iL} + \overline{k}_i$ and $\underline{r}_j = \overline{r}_j < \underline{c}_j$ $(j \neq i)$. ■

Case 3. For one $i \in \{1, 2\}$, the regulator induces the utility to always undertake project i and to implement cost structure H when $k_i = \overline{k}_i$ and cost structure L when $k_i = \underline{k}_i$.

Conclusion 3. *In Case 3, the regulator's minimum expected procurement cost is* $\phi_i\,[\,c^e_{iL} + \underline{k}_i\,]$ $+\,[\,1-\phi_i\,]\,c^e_{iH}$ *and the utility's corresponding expected profit is* 0.

Proof. Under the identified behavior, the utility's expected cost is: (i) $c^e_{iL} + \underline{k}_i$ when $k_i = \underline{k}_i$; and (ii) c^e_{iH} when $k_i = \overline{k}_i$. Therefore, the lowest possible expected procurement cost the regulator can achieve in Case 3 is $\phi_i\,[\,c^e_{iL} + \underline{k}_i\,] + [\,1-\phi_2\,]\,c^e_{iH}$. The regulator can ensure this cost by setting $\underline{r}_i \;=\; \underline{c}_i + \left[\frac{1-p_{iH}}{p_{iL}-p_{iH}}\right]\underline{k}_i\,,\; \overline{r}_i \;=\; \overline{c}_i - \left[\frac{p_{iH}}{p_{iL}-p_{iH}}\right]\underline{k}_i$, and $\underline{r}_j \;=\; \overline{r}_j < \underline{c}_j\;(j \neq i)$. Under this payment structure, the utility's expected profit when it undertakes project i and implements cost structure H is:

$$p_{iH}\,[\,\underline{r}_i - \underline{c}_i\,] + [\,1-p_{iH}\,]\,[\,\overline{r}_i - \overline{c}_i\,] \;=\; p_{iH}\left[\frac{1-p_{iH}}{p_{iL}-p_{iH}}\right]\underline{k}_i - [\,1-p_{iH}\,]\left[\frac{p_{iH}}{p_{iL}-p_{iH}}\right]\underline{k}_i$$

$$=\; \frac{\underline{k}_i}{p_{iL}-p_{iH}}\,[\,p_{iH}\,(1-p_{iH}) - (1-p_{iH})\,p_{iH}\,] \;=\; 0\,.$$

The utility's expected profit when it undertakes project i and implements cost structure L when $k_i = \underline{k}_i$ is:

$$p_{iL}\,[\,\underline{r}_i - \underline{c}_i\,] + [\,1-p_{iL}\,]\,[\,\overline{r}_i - \overline{c}_i\,] - \underline{k}_i \;=\; p_{iL}\left[\frac{1-p_{iH}}{p_{iL}-p_{iH}}\right]\underline{k}_i - [\,1-p_{iL}\,]\left[\frac{p_{iH}}{p_{iL}-p_{iH}}\right]\underline{k}_i - \underline{k}_i$$

$$=\; \frac{\underline{k}_i}{p_{iL}-p_{iH}}\,[\,p_{iL}\,(1-p_{iH}) - (1-p_{iL})\,p_{iH}\,] - \underline{k}_i \;=\; \underline{k}_i - \underline{k}_i \;=\; 0\,.$$

Observe that $p_{iL}\,[\,\underline{r}_i - \underline{c}_i\,] + [\,1-p_{iL}\,]\,[\,\overline{r}_i - \overline{c}_i\,] - \overline{k}_i \;<\; p_{iL}\,[\,\underline{r}_i - \underline{c}_i\,] + [\,1-p_{iL}\,]\,[\,\overline{r}_i - \overline{c}_i\,] - \underline{k}_i =$ 0. Therefore, the identified payment structure will eliminate the utility's rent while inducing the utility to implement cost structure H when $k_i = \overline{k}_i$ and cost structure L when $k_i = \underline{k}_i$. ■

Observation. Under the $(\underline{r}_i\,,\,\overline{r}_i)$ compensation structure identified in the proof of Conclusion 3, $\underline{r}_i - \underline{c}_i - (\,\overline{r}_i - \,\overline{c}_i) < \overline{c}_i - \underline{c}_i$ so $\overline{r}_i > \underline{r}_i$.

Proof.

$$\underline{r}_i - \underline{c}_i - (\,\overline{r}_i - \,\overline{c}_i) \;=\; \left[\frac{1\;-\;p_{iH}}{p_{iL}\;-\;p_{iH}}\right]\underline{k}_i + \left[\frac{p_{iH}}{p_{iL}\;-\;p_{iH}}\right]\underline{k}_i \;=\; \frac{\underline{k}_i}{p_{iL}\;-\;p_{iH}} \;<\; \frac{c^e_{2H} - c^e_{2L}}{p_{iL}\;-\;p_{iH}}$$

$$=\; \frac{1}{p_{iL}\;-\;p_{iH}}\,\{\,p_{iH}\,[\,\underline{r}_i - \underline{c}_i\,] + [\,1-p_{iH}\,]\,[\,\overline{r}_i - \overline{c}_i\,] - p_{iL}\,[\,\underline{r}_i - \underline{c}_i\,] - [\,1-p_{iL}\,]\,[\,\overline{r}_i - \overline{c}_i\,]\,\}$$

$$=\; \frac{[\,p_{iL}\;-\;p_{iH}\,]\,[\,\overline{c}_i - \underline{c}_i\,]}{p_{iL}\;-\;p_{iH}} \;=\; \overline{c}_i - \underline{c}_i\,. \quad ■$$

Explanation. The identified policy provides an incremental reward for realizing $\underline{c}_i$ that is just sufficient to compensate the utility for its personal cost $(\underline{k}_i)$ of increasing the likelihood of $\underline{c}_i$. This personal cost is less than the expected reduction in production cost that cost management provides. Thus, the utility is optimally awarded less than the full cost saving from realizing $\underline{c}_i$ rather than $\overline{c}_i$.

Case 4. The regulator induces the utility to: (i) undertake project 1 and implement cost structure L when $k_1 = \underline{k}_1$ and $k_2 = \overline{k}_2$; (ii) undertake project 1 and implement cost structure H when $k_1 = \overline{k}_1$ and $k_2 = \overline{k}_2$; and (iii) undertake project 2 and implement cost structure L when $k_2 = \underline{k}_2$.

Conclusion 4. *In Case 4, the regulator's minimum expected procurement cost is* $\phi_2 [\, c^e_{2L} + \underline{k}_2 \,] + \phi_1 [\, 1 - \phi_2 \,] [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] [\, 1 - \phi_2 \,] \, c^e_{1H}$*, and the utility's corresponding expected profit is* 0.

Proof. When $k_2 = \underline{k}_2$ the utility's expected cost under the identified behavior is $c^e_{2L} + \underline{k}_2$. When the utility undertakes project 1 in Case 4, its expected cost is c^e_{1H} when $k_1 = \overline{k}_1$ and $c^e_{1L} + \underline{k}_1$ when $k_1 = \underline{k}_1$. Therefore, the lowest possible expected procurement cost the regulator can achieve in Case 4 is $\phi_2 [\, c^e_{2L} + \underline{k}_2 \,] + \phi_1 [\, 1 - \phi_2 \,] [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] [\, 1 - \phi_2 \,] \, c^e_{1H}$.

The regulator can secure this cost by setting $\underline{r}_1 = \underline{c}_1 + \left[\frac{1 - p_{1H}}{p_{1L} - p_{1H}} \right] \underline{k}_1$, $\overline{r}_1 = \overline{c}_1 - \left[\frac{p_{1H}}{p_{1L} - p_{1H}} \right] \underline{k}_1$, and $\underline{r}_2 = \overline{r}_2 = c^e_{2L} + \underline{k}_2$. This compensation structure ensures that the utility secures 0 expected profit when it undertakes the specified behavior and negative expected profit when it undertakes different behavior. Specifically:

$$p_{1H} [\, \underline{r}_1 - \underline{c}_1 \,] + [\, 1 - p_{1H} \,] [\, \overline{r}_1 - \overline{c}_1 \,]$$

$$= p_{1H} \left[\frac{1 - p_{1H}}{p_{1L} - p_{1H}} \right] \underline{k}_1 - [\, 1 - p_{1H} \,] \left[\frac{p_{1H}}{p_{1L} - p_{1H}} \right] \underline{k}_1 \; = \; 0\,;$$

$$p_{1L} [\, \underline{r}_1 - \underline{c}_1 \,] + [\, 1 - p_{1L} \,] [\, \overline{r}_1 - \overline{c}_1 \,] - \underline{k}_1$$

$$= p_{1L} \left[\frac{1 - p_{1H}}{p_{1L} - p_{1H}} \right] \underline{k}_1 - [\, 1 - p_{1L} \,] \left[\frac{p_{1H}}{p_{1L} - p_{1H}} \right] \underline{k}_1 - \underline{k}_1 \; = \; \underline{k}_1 - \underline{k}_1 \; = \; 0\,;$$

$$p_{2L} [\, \underline{r}_2 - \underline{c}_2 \,] + [\, 1 - p_{2L} \,] [\, \overline{r}_2 - \overline{c}_2 \,] - \underline{k}_2 \; = \; c^e_{2L} + \underline{k}_2 - (c^e_{2L} + \underline{k}_2) \; = \; 0\,;$$

$$p_{2H} [\, \underline{r}_2 - \underline{c}_2 \,] + [\, 1 - p_{2H} \,] [\, \overline{r}_2 - \overline{c}_2 \,] \; = \; c^e_{2L} + \underline{k}_2 - c^e_{2H} \; < \; 0\,;$$

$$p_{2L} [\, \underline{r}_2 - \underline{c}_2 \,] + [\, 1 - p_{2L} \,] [\, \overline{r}_2 - \overline{c}_2 \,] - \overline{k}_2 \; = \; c^e_{2L} + \underline{k}_2 - \left(c^e_{2L} + \overline{k}_2 \right) \; = \; \underline{k}_2 - \overline{k}_2 \; < \; 0\,;$$

$$p_{1L} [\, \underline{r}_1 - \underline{c}_1 \,] + [\, 1 - p_{1L} \,] [\, \overline{r}_1 - \overline{c}_1 \,] - \overline{k}_1$$

$$= p_{1L} \left[\frac{1 - p_{1H}}{p_{1L} - p_{1H}} \right] \underline{k}_1 - [\, 1 - p_{1L} \,] \left[\frac{p_{1H}}{p_{1L} - p_{1H}} \right] \underline{k}_1 - \overline{k}_1 = \; \underline{k}_1 - \overline{k}_1 \; < \; 0\,.$$

Therefore, the utility's expected profit is 0 and the utility has no incentive to deviate from the behavior specified in Case 4.

When $k_2 = \underline{k}_2$ (which is the case with probability ϕ_2), expected procurement cost is $c^e_{2L} + \underline{k}_2$. When $k_1 = \overline{k}_1$ and $k_2 = \overline{k}_2$ (which occurs with probability $[\, 1 - \phi_1 \,] [1 - \phi_2]$), expected procurement cost is:

$$p_{1H}\left[\underline{c}_1+\frac{1-p_{1H}}{p_{1L}-p_{1H}}\right]\underline{k}_1+[1-p_{1H}]\left[\overline{c}_1-\frac{p_{1H}}{p_{1L}-p_{1H}}\right]\underline{k}_1 \;=\; c^e_{1H}\,.$$

When $k_1 = \underline{k}_1$ and $k_2 = \overline{k}_2$ (which occurs with probability $\phi_1\,[1-\phi_2]$), expected procurement cost is:

$$p_{1L}\left[\underline{c}_1+\frac{1-p_{1H}}{p_{1L}-p_{1H}}\right]\underline{k}_1+[1-p_{1L}]\left[\overline{c}_1-\frac{p_{1H}}{p_{1L}-p_{1H}}\right]\underline{k}_1 \;=\; c^e_{1L}+\underline{k}_1\,.$$

Therefore, the regulator's expected procurement cost is $\phi_2\,[\,c^e_{2L}+\underline{k}_2\,]+\phi_1\,[\,1-\phi_2\,]\,[\,c^e_{1L}+\underline{k}_1\,]+[\,1-\phi_1\,]\,[\,1-\phi_2\,]\,c^e_{1H}$. ■

Case 5. The regulator induces the utility to: (i) undertake project 1 and implement cost structure L when $k_1 = \underline{k}_1$; (ii) undertake project 2 and implement cost structure L when $k_1 = \overline{k}_1$ and $k_2 = \underline{k}_2$; and (iii) undertake project 2 and implement cost structure H when $k_1 = \overline{k}_1$ and $k_2 = \overline{k}_2$.

Conclusion 5. *In Case 5, the regulator's minimum expected procurement cost is* $\phi_1\,[\,c^e_{1L}+\underline{k}_1\,]+[\,1-\phi_1]\,\phi_2\,[\,c^e_{2L}+\underline{k}_2\,]+[\,1-\phi_1\,]\,[\,1-\phi_2\,]\,c^e_{2H}$*, and the utility's corresponding expected profit is* 0*.*

Proof. When $k_1 = \underline{k}_1$ and the utility undertakes project 1 and implements cost structure L, its expected cost is $c^e_{1L}+\underline{k}_1$. When the utility undertakes project 2, its expected cost is: (i) c^e_{2H} when it implements cost structure H; and (ii) $c^e_{2L}+\underline{k}_2$ when $k_2 = \underline{k}_2$ and it implements cost structure L. Therefore, the lowest possible expected procurement cost the regulator can achieve in Case 5 is $\phi_1\,[\,c^e_{1L}+\underline{k}_1\,]+[\,1-\phi_1]\,\phi_2\,[\,c^e_{2L}+\underline{k}_2\,]+[\,1-\phi_1\,]\,[\,1-\phi_2\,]\,c^e_{2H}$.

The regulator can secure this cost by setting $\underline{r}_1 = \overline{r}_1 = c^e_{1L}+\underline{k}_1$, $\underline{r}_2 = \underline{c}_2+\left[\frac{1-p_{2H}}{p_{2L}-p_{2H}}\right]\underline{k}_2$, and $\overline{r}_2 = \overline{c}_2-\left[\frac{p_{2H}}{p_{2L}-p_{2H}}\right]\underline{k}_2$. This compensation structure ensures that the utility secures 0 expected profit when it undertakes the specified behavior and non-positive expected profit when it undertakes different behavior. Specifically:

$$p_{1L}\,[\,\underline{r}_1-\underline{c}_1\,]+[\,1-p_{1L}\,]\,[\,\overline{r}_1-\overline{c}_1\,]-\underline{k}_1 \;=\; c^e_{1L}+\underline{k}_1-(c^e_{1L}+\underline{k}_1) \;=\; 0\,;$$

$$\begin{aligned} &p_{2H}\,[\,\underline{r}_2-\underline{c}_2\,]+[\,1-p_{2H}\,]\,[\,\overline{r}_2-\overline{c}_2\,] \\ &\quad=\; p_{2H}\left[\frac{1-p_{2H}}{p_{2L}-p_{2H}}\right]\underline{k}_2-[\,1-p_{2H}\,]\left[\frac{p_{2H}}{p_{2L}-p_{2H}}\right]\underline{k}_2 \;=\; 0\,; \end{aligned}$$

$$\begin{aligned} &p_{2L}\,[\,\underline{r}_2-\underline{c}_2\,]+[\,1-p_{2L}\,]\,[\,\overline{r}_2-\overline{c}_2\,]-\underline{k}_2 \\ &\quad=\; p_{2L}\left[\frac{1-p_{2H}}{p_{2L}-p_{2H}}\right]\underline{k}_2-[\,1-p_{2L}\,]\left[\frac{p_{2H}}{p_{2L}-p_{2H}}\right]\underline{k}_2-\underline{k}_2 \;=\; \underline{k}_2-\underline{k}_2 \;=\; 0\,; \end{aligned}$$

$$p_{1H}\,[\,\underline{r}_1-\underline{c}_1\,]+[\,1-p_{1H}\,]\,[\,\overline{r}_1-\overline{c}_1\,] = \; c^e_{1L}+\underline{k}_1-c^e_{1H} \;<\; 0\,;$$

$$p_{1L}\,[\,\underline{r}_1 - \underline{c}_1\,] + [\,1 - p_{1L}\,]\,[\,\overline{r}_1 - \overline{c}_1\,] - \overline{k}_1 \;=\; c^e_{1L} + \underline{k}_1 - c^e_{1L} - \overline{k}_1 \;=\; \underline{k}_1 - \overline{k}_1 \;<\; 0\,;$$

$$p_{2L}\,[\,\underline{r}_2 - \underline{c}_2\,] + [\,1 - p_{2L}\,]\,[\,\overline{r}_2 - \overline{c}_2\,] - \overline{k}_2$$

$$= \; p_{2L}\left[\frac{1 - p_{2H}}{p_{2L} - p_{2H}}\right]\underline{k}_2 - [\,1 - p_{2L}\,]\left[\frac{p_{2H}}{p_{2L} - p_{2H}}\right]\underline{k}_2 - \overline{k}_2 \;=\; \underline{k}_2 - \overline{k}_2 \;<\; 0\,.$$

Therefore, the utility's expected profit is 0 and the utility has no incentive to deviate from the behavior specified in Case 5. It is readily verified that expected procurement cost is $\phi_1\,[\,c^e_{1L} + \underline{k}_1\,] + [\,1 - \phi_1\,]\;\phi_2\,[\,c^e_{2L} + \underline{k}_2\,] + [\,1 - \phi_1\,]\,[\,1 - \phi_2\,]\,c^e_{2H}$ under the identified compensation structure.[1] ■

<u>Case 6</u>. The regulator induces the utility to: (i) undertake project 1 and implement cost structure L when $k_2 = \overline{k}_2$; and (ii) undertake project 2 and implement cost structure L when $k_2 = \underline{k}_2$.

Conclusion 6. *Suppose $c^e_{1H} - c^e_{1L} \;\geq\; \overline{k}_1$ and $\overline{k}_2 - \underline{k}_2 \;\geq\; \overline{k}_1 - \underline{k}_1$. Then in Case 6, the regulator's minimum expected procurement cost is $\phi_2\left[\,c^e_{2L} + \underline{k}_2 + \overline{k}_1 - \underline{k}_1\,\right] + [\,1 - \phi_2\,]\left[\,c^e_{1L} + \overline{k}_1\,\right]$, and the utility's corresponding expected profit is $[\,\phi_2 + (\,1 - \phi_2\,)\,\phi_1\,]\left[\,\overline{k}_1 - \underline{k}_1\,\right]$.*

<u>Proof</u>. When the utility undertakes project 1 and implements cost structure L, its expected cost is $c^e_{1L} + \underline{k}_1$ when $k_1 = \underline{k}_1$ and $c^e_{1L} + \overline{k}_1$ when $k_1 = \overline{k}_1$. Therefore, the regulator must cede a rent of at least $\overline{k}_1 - \underline{k}_1$ to the utility when $k_1 = \underline{k}_1$ to ensure it always undertakes project 1 and implements cost structure L when $k_2 = \overline{k}_2$. When the utility undertakes project 2 and implements cost structure L, its expected cost is $c^e_{2L} + \underline{k}_2$ when $k_2 = \underline{k}_2$. To ensure the utility does not undertake project 1 when $k_2 = \underline{k}_2$ and $k_1 = \underline{k}_1$, the utility must receive profit of at least $\overline{k}_1 - \underline{k}_1$. Consequently, the lowest possible expected procurement cost the regulator can achieve in Case 6 is $[\,1 - \phi_2\,]\left[\,c^e_{1L} + \overline{k}_1\,\right] + \phi_2\left[\,c^e_{2L} + \underline{k}_2 + \overline{k}_1 - \underline{k}_1\,\right]$.

The regulator can secure this cost by setting $\underline{r}_1 = \overline{r}_1 = c^e_{1L} + \overline{k}_1$ and $\underline{r}_2 = \underline{c}_2 + \left[\frac{1 - p_{2H}}{p_{2L} - p_{2H}}\right]\left[\,\underline{k}_2 + \overline{k}_1 - \underline{k}_1\,\right]$, and $\overline{r}_2 = \overline{c}_2 - \left[\frac{p_{2H}}{p_{2L} - p_{2H}}\right]\left[\,\underline{k}_2 + \overline{k}_1 - \underline{k}_1\,\right]$. This compensation policy ensures that the utility secures nonnegative expected profit when it undertakes the specified behavior and non-positive expected profit when it undertakes different behavior. Specifically:

$$p_{1L}\,[\,\underline{r}_1 - \underline{c}_1\,] + [\,1 - p_{1L}\,]\,[\,\overline{r}_1 - \overline{c}_1\,] - \underline{k}_1 \;=\; c^e_{1L} + \overline{k}_1 - c^e_{1L} - \underline{k}_1 \;=\; \overline{k}_1 - \underline{k}_1 \;>\; 0\,;$$

$$p_{2L}\,[\,\underline{r}_2 - \underline{c}_2\,] + [\,1 - p_{2L}\,]\,[\,\overline{r}_2 - \overline{c}_2\,] - \underline{k}_2$$

$$= \; \frac{p_{2L}\,[\,1 - p_{2H}\,] - [\,1 - p_{2L}\,]\,p_{2H}}{p_{2L} - p_{2H}}\left[\,\underline{k}_2 + \overline{k}_1 - \underline{k}_1\,\right] - \underline{k}_2 \;=\; \overline{k}_1 - \underline{k}_1 \;>\; 0\,;$$

[1] The proof parallels the proof of Conclusion 4.

$$p_{1L}\,[\,\underline{r}_1 - \underline{c}_1\,] + [\,1 - p_{1L}\,]\,[\,\overline{r}_1 - \overline{c}_1\,] - \overline{k}_1 \;=\; c^e_{1L} + \overline{k}_1 - c^e_{1L} - \overline{k}_1 \;=\; 0\,;$$

$$p_{1H}\,[\,\underline{r}_1 - \underline{c}_1\,] + [\,1 - p_{1H}\,]\,[\,\overline{r}_1 - \overline{c}_1\,] \;=\; c^e_{1L} + \overline{k}_1 - c^e_{1H} \;\le\; 0\,;$$

$$p_{2H}\,[\,\underline{r}_2 - \underline{c}_2\,] + [\,1 - p_{2H}\,]\,[\,\overline{r}_2 - \overline{c}_2\,]$$

$$= \frac{p_{2H}\,[\,1 - p_{2H}\,] - [\,1 - p_{2H}\,]\,p_{2H}}{p_{2L} - p_{2H}}\,\left[\,\underline{k}_2 + \overline{k}_1 - \underline{k}_1\,\right] \;=\; 0\,;$$

$$p_{2L}\,[\,\underline{r}_2 - \underline{c}_2\,] + [\,1 - p_{2L}\,]\,[\,\overline{r}_2 - \overline{c}_2\,] - \overline{k}_2$$

$$= \frac{p_{2L}\,[\,1 - p_{2H}\,] - [\,1 - p_{2L}\,]\,p_{2H}}{p_{2L} - p_{2H}}\,\left[\,\underline{k}_2 + \overline{k}_1 - \underline{k}_1\,\right] - \overline{k}_2 \;=\; \overline{k}_1 - \underline{k}_1 - \left(\overline{k}_2 - \underline{k}_2\right) \;\le\; 0\,.$$

Therefore, the utility's expected profit is $[\,\phi_2 + \phi_1\,(1 - \phi_2)\,]\,\left[\,\overline{k}_1 - \underline{k}_1\,\right]$ and it has no incentive to deviate from the behavior specified in Case 6. It is readily verified that the regulator's expected procurement cost is $[\,1 - \phi_2\,]\left[\,c^e_{1L} + \overline{k}_1\,\right] + \phi_2\left[\,c^e_{2L} + \underline{k}_2 + \overline{k}_1 - \underline{k}_1\,\right]$. ■

<u>**Case 7**</u>. The regulator induces the utility to: (i) undertake project 2 and implement cost structure L when $k_1 = \overline{k}_1$; and (ii) undertake project 1 and implement cost structure L when $k_1 = \underline{k}_1$.

Conclusion 7. *Suppose* $c^e_{2H} - c^e_{2L} \ge \overline{k}_2$ *and* $\overline{k}_1 - \underline{k}_1 \ge \overline{k}_2 - \underline{k}_2$*. Then in Case 7, the regulator's minimum expected procurement cost is* $\phi_1\left[\,c^e_{1L} + \underline{k}_1 + \overline{k}_2 - \underline{k}_2\,\right] + [\,1 - \phi_1\,]\left[\,c^e_{2L} + \overline{k}_2\,\right]$*, and the utility's corresponding expected profit is* $[\,\phi_1 + \phi_2\,(1 - \phi_1)\,]\left[\,\overline{k}_2 - \underline{k}_2\,\right]$.

<u>Proof</u>. When the utility undertakes project 2 and implements cost structure L, its expected cost is $c^e_{2L} + \underline{k}_2$ when $k_2 = \underline{k}_2$ and $c^e_{2L} + \overline{k}_2$ when $k_2 = \overline{k}_2$. Therefore, the regulator must cede a rent of at least $\overline{k}_2 - \underline{k}_2$ to the utility when $k_2 = \underline{k}_2$ to ensure it always implements cost structure L when $k_1 = \overline{k}_1$. When the utility undertakes project 1 and implements cost structure L, its expected cost is $c^e_{1L} + \underline{k}_1$ when $k_1 = \underline{k}_1$. To ensure the utility does not undertake project 2 when $k_1 = \underline{k}_1$ and $k_2 = \underline{k}_2$, the utility must receive profit of at least $\overline{k}_2 - \underline{k}_2$. Consequently, the lowest possible expected procurement cost the regulator can achieve in Case 7 is $[\,1 - \phi_1\,]\left[\,c^e_{2L} + \overline{k}_2\,\right] + \phi_1\left[\,c^e_{1L} + \underline{k}_1 + \overline{k}_2 - \underline{k}_2\,\right]$.

The regulator can secure this cost by setting $\underline{r}_1 = \underline{c}_1 + \left[\frac{1 - p_{1H}}{p_{1L} - p_{1H}}\right]\left[\,\underline{k}_1 + \overline{k}_2 - \underline{k}_2\,\right]$, $\overline{r}_1 = \overline{c}_1 - \left[\frac{p_{1H}}{p_{1L} - p_{1H}}\right]\left[\,\underline{k}_1 + \overline{k}_2 - \underline{k}_2\,\right]$, and $\underline{r}_2 = \overline{r}_2 = c^e_{2L} + \overline{k}_2$. This compensation policy ensures that the utility secures nonnegative expected profit when it undertakes the specified behavior and non-positive expected profit when it undertakes different behavior. Specifically:

$$p_{2L}\,[\,\underline{r}_2 - \underline{c}_2\,] + [\,1 - p_{2L}\,]\,[\,\overline{r}_2 - \overline{c}_2\,] - \underline{k}_2 \;=\; c^e_{2L} + \overline{k}_2 - c^e_{2L} - \underline{k}_2 \;=\; \overline{k}_2 - \underline{k}_2 \;>\; 0\,;$$

$$p_{1L}\,[\,\underline{r}_1 - \underline{c}_1\,] + [\,1 - p_{1L}\,]\,[\,\overline{r}_1 - \overline{c}_1\,] - \underline{k}_1$$

$$= \frac{p_{1L}[1-p_{1H}] - [1-p_{1L}]\,p_{1H}}{p_{1L}-p_{1H}} \left[\underline{k}_1 + \overline{k}_2 - \underline{k}_2\right] - \underline{k}_1 \;=\; \overline{k}_2 - \underline{k}_2 \;>\; 0\,;$$

$$p_{2L}[\underline{r}_2 - \underline{c}_2] + [1-p_{2L}][\overline{r}_2 - \overline{c}_2] - \overline{k}_2 \;=\; c^e_{2L} + \overline{k}_2 - c^e_{2L} - \overline{k}_2 \;=\; 0\,;$$

$$p_{2H}[\underline{r}_2 - \underline{c}_2] + [1-p_{2H}][\overline{r}_2 - \overline{c}_2] \;=\; c^e_{2L} + \overline{k}_2 - c^e_{2H} \;\le\; 0\,;$$

$$p_{1H}[\underline{r}_1 - \underline{c}_1] + [1-p_{1H}][\overline{r}_1 - \overline{c}_1] \;=$$

$$= \frac{p_{1H}[1-p_{1H}] - [1-p_{1H}]\,p_{1H}}{p_{1L}-p_{1H}} \left[\underline{k}_1 + \overline{k}_2 - \underline{k}_2\right] \;=\; 0\,;$$

$$p_{1L}[\underline{r}_1 - \underline{c}_1] + [1-p_{1L}][\overline{r}_1 - \overline{c}_1] - \overline{k}_1$$

$$= \frac{p_{1L}[1-p_{1H}] - [1-p_{1L}]\,p_{1H}}{p_{1L}-p_{1H}} \left[\underline{k}_1 + \overline{k}_2 - \underline{k}_2\right] - \overline{k}_1 \;=\; \overline{k}_2 - \underline{k}_2 - \left(\overline{k}_1 - \underline{k}_1\right) \;\le\; 0\,.$$

Therefore, the utility's expected profit is $[\,\phi_1 + \phi_2(1-\phi_1)\,]\left[\overline{k}_2 - \underline{k}_2\right]$ and it has no incentive to deviate from the behavior specified in Case 7. It is readily verified that the regulator's expected procurement cost is $[\,1-\phi_1\,]\left[\,c^e_{2L} + \overline{k}_2\,\right] + \phi_1\left[\,c^e_{1L} + \underline{k}_1 + \overline{k}_2 - \underline{k}_2\,\right].$ ■

<u>**Case 8**</u>. The regulator induces the utility to: (i) undertake project 2 and implement cost structure L when $k_2 = \underline{k}_2$; and (ii) undertake project 1 and implement cost structure H otherwise.

Conclusion 8. *In Case 8, the regulator's minimum expected procurement cost is* $\phi_2\,[\,c^e_{2L} + \underline{k}_2\,]$ $+\,[\,1-\phi_2\,]\,c^e_{1H}$*, and the utility's corresponding expected profit is* 0*.*

<u>Proof</u>. When $k_2 = \underline{k}_2$ and the utility undertakes project 2 and implements cost structure L, its expected cost is $c^e_{2L} + \underline{k}_2$. When the utility undertakes project 1 and implements cost structure H, its expected cost is c^e_{1H}. Therefore, the minimum possible expected procurement cost in Case 8 is $\phi_2\,[\,c^e_{2L} + \underline{k}_2\,] + [\,1-\phi_2\,]\,c^e_{1H}$. The regulator can secure this cost by setting $\underline{r}_1 = \underline{c}_1 + \left[\frac{1-p_{1H}}{p_{1L}-p_{1H}}\right]\underline{k}_1$, $\overline{r}_1 = \overline{c}_1 - \left[\frac{p_{1H}}{p_{1L}-p_{1H}}\right]\underline{k}_1$, and $\underline{r}_2 = \overline{r}_2 = c^e_{2L} + \underline{k}_2$. This compensation policy ensures that the utility secures 0 expected profit when it undertakes the specified behavior and negative expected profit when it undertakes different behavior. Specifically:

$$p_{2L}[\underline{r}_2 - \underline{c}_2] + [1-p_{2L}][\overline{r}_2 - \overline{c}_2] - \underline{k}_2 \;=\; c^e_{2L} + \underline{k}_2 - c^e_{2L} - \underline{k}_2 \;=\; 0\,;$$

$$p_{1L}[\underline{r}_1 - \underline{c}_1] + [1-p_{1L}][\overline{r}_1 - \overline{c}_1] - \underline{k}_1$$

$$= \; p_{1L}\left[\frac{1-p_{1H}}{p_{1L}-p_{1H}}\right]\underline{k}_1 - [1-p_{1L}]\left[\frac{p_{1H}}{p_{1L}-p_{1H}}\right]\underline{k}_1 - \underline{k}_1 \;=\; \underline{k}_1 - \underline{k}_1 \;=\; 0\,;$$

$$p_{1H}[\underline{r}_1 - \underline{c}_1] + [1-p_{1H}][\overline{r}_1 - \overline{c}_1]$$

$$= p_{1H}\left[\frac{1-p_{1H}}{p_{1L}-p_{1H}}\right]\underline{k}_1 - [1-p_{1H}]\left[\frac{p_{1H}}{p_{1L}-p_{1H}}\right]\underline{k} = 0\,;$$

$$p_{2H}[\underline{r}_2 - \underline{c}_2] + [1-p_{2H}][\overline{r}_2 - \overline{c}_2] = c^e_{2L} + \underline{k}_2 - c^e_{2H} < 0\,;$$

$$p_{1L}[\underline{r}_1 - \underline{c}_1] + [1-p_{1L}][\overline{r}_1 - \overline{c}_1] - \overline{k}_1$$

$$p_{1L}\left[\frac{1-p_{1H}}{p_{1L}-p_{1H}}\right]\underline{k}_1 - [1-p_{1L}]\left[\frac{p_{1H}}{p_{1L}-p_{1H}}\right]\underline{k}_1 - \overline{k}_1 = \underline{k}_1 - \overline{k}_1 < 0\,;$$

$$p_{2L}[\underline{r}_2 - \underline{c}_2] + [1-p_{2L}][\overline{r}_2 - \overline{c}_2] - \overline{k}_2 = c^e_{2L} + \underline{k}_2 - c^e_{2L} - \overline{k}_2 = \underline{k}_2 - \overline{k}_2 < 0\,.$$

Therefore, the utility's expected profit is 0 and it has no incentive to deviate from the behavior specified in Case 8. It is readily verified that the regulator's expected procurement cost is $\phi_2[c^e_{2L} + \underline{k}_2] + [1-\phi_2]c^e_{1H}$. ■

<u>**Case 9**</u>. The regulator induces the utility to: (i) undertake project 1 and implement cost structure L when $k_1 = \underline{k}_1$; and (ii) undertake project 2 and implement cost structure H otherwise.

Conclusion 9. *In Case 9, the regulator's minimum expected procurement cost is* $\phi_1[c^e_{1L} + \underline{k}_1] + [1-\phi_1]c^e_{2H}$, *and the utility's corresponding expected profit is* 0.

<u>Proof</u>. When $k_1 = \underline{k}_1$ and the utility undertakes project 1 and implements cost structure L, its expected cost is $c^e_{1L} + \underline{k}_1$. When the utility undertakes project 2 and implements cost structure H, its expected cost is c^e_{2H}. Therefore, the minimum possible expected procurement cost in Case 9 is $\phi_1[c^e_{1L} + \underline{k}_1] + [1-\phi_1]c^e_{2H}$. The regulator can secure this cost by setting $\underline{r}_1 = \overline{r}_1 = c^e_{1L} + \underline{k}_1$, $\underline{r}_2 = \underline{c}_2 + \left[\frac{1-p_{2H}}{p_{2L}-p_{2H}}\right]\underline{k}_2$, and $\overline{r}_2 = \overline{c}_2 - \left[\frac{p_{2H}}{p_{2L}-p_{2H}}\right]\underline{k}_2$. This compensation policy ensures that the utility secures 0 expected profit when it undertakes the specified behavior and negative expected profit when it undertakes different behavior. Specifically:

$$p_{1L}[\underline{r}_1 - \underline{c}_1] + [1-p_{1L}][\overline{r}_1 - \overline{c}_1] - \underline{k}_1 = c^e_{1L} + \underline{k}_1 - c^e_{1L} - \underline{k}_1 = 0\,;$$

$$p_{2L}[\underline{r}_2 - \underline{c}_2] + [1-p_{2L}][\overline{r}_2 - \overline{c}_2] - \underline{k}_2$$

$$= p_{2L}\left[\frac{1-p_{2H}}{p_{2L}-p_{2H}}\right]\underline{k}_2 - [1-p_{2L}]\left[\frac{p_{2H}}{p_{2L}-p_{2H}}\right]\underline{k}_2 - \underline{k}_2 = \underline{k}_2 - \underline{k}_2 = 0\,;$$

$$p_{2H}[\underline{r}_2 - \underline{c}_2] + [1-p_{2H}][\overline{r}_2 - \overline{c}_2]$$

$$= p_{2H}\left[\frac{1-p_{2H}}{p_{2L}-p_{2H}}\right]\underline{k}_2 - [1-p_{2H}]\left[\frac{p_{2H}}{p_{2L}-p_{2H}}\right]\underline{k}_2 = 0\,;$$

$$p_{1H}[\underline{r}_1 - \underline{c}_1] + [1-p_{1H}][\overline{r}_1 - \overline{c}_1] = c^e_{1L} + \underline{k}_1 - c^e_{1H} < 0\,;$$

$$p_{2L}\,[\,\underline{r}_2 - \underline{c}_2\,] + [\,1 - p_{2L}\,]\,[\,\overline{r}_2 - \overline{c}_2\,] - \overline{k}_2$$
$$= \; p_{2L}\left[\frac{1 \,-\, p_{2H}}{p_{2L} \,-\, p_{2H}}\right]\underline{k}_2 - [\,1 - p_{2L}\,]\left[\frac{p_{2H}}{p_{2L} \,-\, p_{2H}}\right]\underline{k}_2 - \overline{k}_2 \;=\; \underline{k}_2 - \overline{k}_2 \;<\; 0\,;$$
$$p_{1L}\,[\,\underline{r}_1 - \underline{c}_1\,] + [\,1 - p_{1L}\,]\,[\,\overline{r}_1 - \overline{c}_1\,] - \overline{k}_1 \;=\; c^e_{1L} + \underline{k}_1 - c^e_{1L} - \overline{k}_1 \;=\; \underline{k}_1 - \overline{k}_1 \;<\; 0\,.$$

Therefore, the utility's expected profit is 0 and it has no incentive to deviate from the behavior specified in Case 9. It is readily verified that the regulator's expected procurement cost is $\phi_1\,[\,c^e_{1L} + \underline{k}_1\,] + [\,1 - \phi_1\,]\,c^e_{2H}$. ■

__Case 10__. The regulator induces the utility to: (i) undertake project 2 and implement cost structure L when $k_2 = \underline{k}_2$; (ii) undertake project 1 and implement cost structure L when $k_1 = \underline{k}_1$ and $k_2 = \overline{k}_2$; and (iii) undertake project 2 and implement cost structure H when $k_1 = \overline{k}_1$ and $k_2 = \overline{k}_2$.

Conclusion 10. *In Case 10, the regulator's minimum expected procurement cost is* $\phi_2\,[\,c^e_{2L} + \underline{k}_2\,] + \phi_1\,[\,1 - \phi_2\,]\,[\,c^e_{1L} + \underline{k}_1\,] + [\,1 - \phi_1\,]\;[\,1 - \phi_2\,]\,c^e_{2H}$, *and the utility's corresponding expected profit is* 0.

__Proof__. When $k_2 = \underline{k}_2$ the utility's expected cost under the identified behavior is $c^e_{2L} + \underline{k}_2$. When $k_2 = \overline{k}_2$ in Case 10, the utility's expected cost is c^e_{2H} when $k_1 = \overline{k}_1$, and $c^e_{1L} + \underline{k}_1$ when $k_1 = \underline{k}_1$. Therefore, the lowest possible expected procurement cost the regulator can achieve in Case 10 is $\phi_2\,[\,c^e_{2L} + \underline{k}_2\,] + \phi_1\,[\,1 - \phi_2\,]\,[\,c^e_{1L} + \underline{k}_1\,] + [\,1 - \phi_1\,]\,[\,1 - \phi_2\,]\,c^e_{2H}$.

The regulator can secure this cost by setting $\underline{r}_2 = \underline{c}_2 + \left[\frac{1 - p_{2H}}{p_{2L} - p_{2H}}\right]\underline{k}_2$, $\overline{r}_2 = \overline{c}_2 - \left[\frac{p_{2H}}{p_{2L} - p_{2H}}\right]\underline{k}_2$, and $\underline{r}_1 = \overline{r}_1 = c^e_{1L} + \underline{k}_1$. This compensation structure ensures that the utility secures 0 expected profit when it undertakes the specified behavior and negative expected profit when it undertakes different behavior. Specifically:

$$p_{2H}\,[\,\underline{r}_2 - \underline{c}_2\,] + [\,1 - p_{2H}\,]\,[\,\overline{r}_2 - \overline{c}_2\,]$$
$$= \; p_{2H}\left[\frac{1 - p_{2H}}{p_{2L} - p_{2H}}\right]\underline{k}_2 - [\,1 - p_{2H}\,]\left[\frac{p_{2H}}{p_{2L} - p_{2H}}\right]\underline{k}_2 \;=\; 0\,;$$
$$p_{2L}\,[\,\underline{r}_2 - \underline{c}_2\,] + [\,1 - p_{2L}\,]\,[\,\overline{r}_2 - \overline{c}_2\,] - \underline{k}_2$$
$$= \; p_{2L}\left[\frac{1 - p_{2H}}{p_{2L} - p_{2H}}\right]\underline{k}_2 - [\,1 - p_{2L}\,]\left[\frac{p_{2H}}{p_{2L} - p_{2H}}\right]\underline{k}_2 - \underline{k}_2 \;=\; \underline{k}_2 - \underline{k}_2 \;=\; 0\,;$$
$$p_{1L}\,[\,\underline{r}_1 - \underline{c}_1\,] + [\,1 - p_{1L}\,]\,[\,\overline{r}_1 - \overline{c}_1\,] - \underline{k}_1 \;=\; c^e_{1L} + \underline{k}_1 - (c^e_{1L} + \underline{k}_1) \;=\; 0\,;$$
$$p_{1H}\,[\,\underline{r}_1 - \underline{c}_1\,] + [\,1 - p_{1H}\,]\,[\,\overline{r}_1 - \overline{c}_1\,] \;=\; c^e_{1L} + \underline{k}_1 - c^e_{1H} \;<\; 0\,;$$
$$p_{1L}\,[\,\underline{r}_1 - \underline{c}_1\,] + [\,1 - p_{1L}\,]\,[\,\overline{r}_1 - \overline{c}_1\,] - \overline{k}_1 \;=\; c^e_{1L} + \underline{k}_1 - \left(c^e_{1L} + \overline{k}_1\right) \;=\; \underline{k}_1 - \overline{k}_1 \;<\; 0\,;$$

$$p_{2L}\,[\,\underline{r}_2 - \underline{c}_2\,] + [\,1 - p_{2L}\,]\,[\,\overline{r}_2 - \overline{c}_2\,] - \overline{k}_2$$

$$= \; p_{2L} \left[\frac{1 - p_{2H}}{p_{2L} - p_{2H}} \right] \underline{k}_2 - [\,1 - p_{2L}\,] \left[\frac{p_{2H}}{p_{2L} - p_{2H}} \right] \underline{k}_2 - \overline{k}_2 \;=\; \underline{k}_2 - \overline{k}_2 \;<\; 0\,.$$

Therefore, the utility's expected profit is 0 and the utility has no incentive to deviate from the behavior specified in Case 10. It is readily verified that the regulator's expected procurement cost is $\phi_2\,[\,c^e_{2L} + \underline{k}_2\,] + \phi_1\,[\,1 - \phi_2\,]\,[\,c^e_{1L} + \underline{k}_1\,] + [\,1 - \phi_1\,]\,[\,1 - \phi_2\,]\,c^e_{2H}$. ■

<u>**Case 11**</u>. The regulator induces the utility to: (i) undertake project 1 and implement cost structure L when $k_1 = \underline{k}_1$; (ii) undertake project 2 and implement cost structure L when $k_2 = \underline{k}_2$ and $k_1 = \overline{k}_1$; and (iii) undertake project 1 and implement cost structure H when $k_1 = \overline{k}_1$ and $k_2 = \overline{k}_2$.

Conclusion 11. *In Case 11, the regulator's minimum expected procurement cost is* $\phi_1\,[\,c^e_{1L} + \underline{k}_1\,] + \phi_2\,[\,1 - \phi_1\,]\,[\,c^e_{2L} + \underline{k}_2\,] + [\,1 - \phi_1\,]\,[\,1 - \phi_2\,]\,c^e_{1H}$, *and the utility's corresponding expected profit is* 0.

<u>Proof</u>. When $k_1 = \underline{k}_1$ the utility's expected cost under the identified behavior is $c^e_{1L} + \underline{k}_1$. When $k_1 = \overline{k}_1$ in Case 11, the utility's expected cost is c^e_{1H} when $k_2 = \overline{k}_2$, and $c^e_{2L} + \underline{k}_2$ when $k_2 = \underline{k}_2$. Therefore, the lowest possible expected procurement cost the regulator can achieve in Case 11 is $\phi_1\,[\,c^e_{1L} + \underline{k}_1\,] + \phi_2\,[\,1 - \phi_1\,]\,[\,c^e_{2L} + \underline{k}_2\,] + [\,1 - \phi_1\,]\,[\,1 - \phi_2\,]\,c^e_{1H}$.

The regulator can secure this cost by setting $\underline{r}_1 = \underline{c}_1 + \left[\frac{1 - p_{1H}}{p_{1L} - p_{1H}} \right] \underline{k}_1$, $\overline{r}_1 = \overline{c}_1 - \left[\frac{p_{1H}}{p_{1L} - p_{1H}} \right] \underline{k}_1$, and $\underline{r}_2 = \overline{r}_2 = c^e_{2L} + \underline{k}_2$. This compensation structure ensures that the utility secures 0 expected profit when it undertakes the specified behavior and negative expected profit when it undertakes different behavior. Specifically:

$$p_{1H}\,[\,\underline{r}_1 - \underline{c}_1\,] + [\,1 - p_{1H}\,]\,[\,\overline{r}_1 - \overline{c}_1\,]$$

$$= \; p_{1H} \left[\frac{1 - p_{1H}}{p_{1L} - p_{1H}} \right] \underline{k}_1 - [\,1 - p_{1H}\,] \left[\frac{p_{1H}}{p_{1L} - p_{1H}} \right] \underline{k}_1 \;=\; 0\,;$$

$$p_{1L}\,[\,\underline{r}_1 - \underline{c}_1\,] + [\,1 - p_{1L}\,]\,[\,\overline{r}_1 - \overline{c}_1\,] - \underline{k}_1$$

$$= \; p_{1L} \left[\frac{1 - p_{1H}}{p_{1L} - p_{1H}} \right] \underline{k}_1 - [\,1 - p_{1L}\,] \left[\frac{p_{1H}}{p_{1L} - p_{1H}} \right] \underline{k}_1 - \underline{k}_1 \;=\; \underline{k}_1 - \underline{k}_1 \;=\; 0\,;$$

$$p_{2L}\,[\,\underline{r}_2 - \underline{c}_2\,] + [\,1 - p_{2L}\,]\,[\,\overline{r}_2 - \overline{c}_2\,] - \underline{k}_2 \;=\; c^e_{2L} + \underline{k}_2 - (c^e_{2L} + \underline{k}_2) \;=\; 0\,;$$

$$p_{2H}\,[\,\underline{r}_2 - \underline{c}_2\,] + [\,1 - p_{2H}\,]\,[\,\overline{r}_2 - \overline{c}_2\,] \;=\; c^e_{2L} + \underline{k}_2 - c^e_{2H} \;<\; 0\,;$$

$$p_{2L}\,[\,\underline{r}_2 - \underline{c}_2\,] + [\,1 - p_{2L}\,]\,[\,\overline{r}_2 - \overline{c}_2\,] - \overline{k}_2 \;=\; c^e_{2L} + \underline{k}_2 - \left(c^e_{2L} + \overline{k}_2\right) \;=\; \underline{k}_2 - \overline{k}_2 \;<\; 0\,;$$

$$p_{1L}\,[\,\underline{r}_1 - \underline{c}_1\,] + [\,1 - p_{1L}\,]\,[\,\overline{r}_1 - \overline{c}_1\,] - \overline{k}_1$$

$$= p_{1L}\left[\frac{1-p_{1H}}{p_{1L}-p_{1H}}\right]\underline{k}_1 - [\,1-p_{1L}\,]\left[\frac{p_{1H}}{p_{1L}-p_{1H}}\right]\underline{k}_1 - \overline{k}_1 \;=\; \underline{k}_1 - \overline{k}_1 \;<\; 0\,.$$

Therefore, the utility's expected profit is 0 and the utility has no incentive to deviate from the behavior specified in Case 11. It is readily verified that the regulator's expected procurement cost is $\phi_1\,[\,c^e_{1L} + \underline{k}_1\,] + \phi_2\,[\,1-\phi_1\,]\,[\,c^e_{2L} + \underline{k}_2\,] + [\,1-\phi_1\,]\;[\,1-\phi_2\,]\,c^e_{1H}$. ■

We now state and prove the additional conclusions that were not proved fully in the paper.

Lemma 2. *Suppose Assumption 1 holds,* $c^e_{2H} < c^e_{1L} + \underline{k}_1$*,* $c^e_{1L} + \overline{k}_1 > c^e_{2L} + \overline{k}_2$*, and* $\phi_2 > \widetilde{\phi}_2^{\,B} \equiv \frac{c^e_{2H} - (c^e_{2L} + \overline{k}_2)}{c^e_{2H} - (c^e_{2L} + \underline{k}_2)}$*. Then in the absence of self-sabotage, the regulator will induce the utility to undertake project 2 and implement selective cost management by setting* $\underline{r}_2 = \underline{c}_2 + \left[\frac{1-p_{2H}}{p_{2L}-p_{2H}}\right]\underline{k}_2\,,\; \overline{r}_2 = \overline{c}_2 - \left[\frac{p_{2H}}{p_{2L}-p_{2H}}\right]\underline{k}_2\,,$ *and* $\underline{r}_1 = \overline{r}_1 < \underline{c}_1$.

<u>Proof</u>. The proof proceeds by demonstrating that expected procurement cost is lower under the identified outcome (i.e., the outcome in Case 3 with $i = 2$) than under the outcome in any of the other relevant cases when Assumption 1 holds.

Because $\phi_2\,[\,c^e_{2L} + \underline{k}_2\,] + [\,1-\phi_2\,]\,c^e_{2H} < c^e_{2H} < c^e_{1L} + \underline{k}_1 < c^e_{1H}$, Conclusions 1 and 3 imply that expected procurement cost is lower under the identified outcome than under the outcome in Case 1 with $i = 1$ and under the outcome in Case 1 with $i = 2$.

Conclusions 2 and 3 imply the expected procurement cost is lower under the identified outcome than under the outcome in Case 2 with $i = 1$ because:

$$\phi_2\,[\,c^e_{2L} + \underline{k}_2\,] + [\,1-\phi_2\,]\,c^e_{2H} - (\,c^e_{1L} + \overline{k}_1\,) \;<\; 0$$

$$\Leftrightarrow\quad c^e_{2H} - (c^e_{1L} + \overline{k}_1) \;<\; \phi_2\,[\,c^e_{2H} - (c^e_{2L} + \underline{k}_2)\,]\,.$$

This inequality holds because $c^e_{2L} + \underline{k}_2 < c^e_{2H} < c^e_{1L} + \underline{k}_1 < c^e_{1L} + \overline{k}_1$.

Conclusions 2 and 3 imply the expected procurement cost is lower under the identified outcome than under the outcome in Case 2 with $i = 2$ because:

$$\phi_2\,[\,c^e_{2L} + \underline{k}_2\,] + [\,1-\phi_2\,]\,c^e_{2H} - (\,c^e_{2L} + \overline{k}_2\,) \;<\; 0$$

$$\Leftrightarrow\quad [\,1-\phi_2\,]\,[\,c^e_{2H} - c^e_{2L}\,] < \overline{k}_2 - \phi_2\,\underline{k}_2 \;=\; [\,1-\phi_2\,]\,\underline{k}_2 + \overline{k}_2 - \underline{k}_2$$

$$\Leftrightarrow\quad c^e_{2H} - c^e_{2L} \;<\; \underline{k}_2 + \frac{\overline{k}_2 - \underline{k}_2}{1-\phi_2} \quad\Leftrightarrow\quad 1-\phi_2 \;<\; \frac{\overline{k}_2 - \underline{k}_2}{c^e_{2H} - (c^e_{2L} + \underline{k}_2)}$$

$$\Leftrightarrow\quad \phi_2 \;>\; \frac{c^e_{2H} - (c^e_{2L} + \underline{k}_2) - \left(\overline{k}_2 - \underline{k}_2\right)}{c^e_{2H} - (c^e_{2L} + \underline{k}_2)} \;=\; \frac{c^e_{2H} - (c^e_{2L} + \overline{k}_2)}{c^e_{2H} - (c^e_{2L} + \underline{k}_2)} \;=\; \widetilde{\phi}_2^{\,B}\,. \tag{1}$$

Conclusion 3 implies that expected procurement cost is lower under the identified outcome than under the outcome in Case 3 with $i = 1$ if:

$$\begin{aligned} & \phi_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 \,] \, c^e_{2H} - (\, \phi_1 \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \, c^e_{1H} \,) \;\; < \;\; 0 \\ \Leftrightarrow \quad & c^e_{1H} - c^e_{2H} \;\; > \;\; \phi_1 \, [\, c^e_{1H} - (c^e_{1L} + \underline{k}_1) \,] - \phi_2 \, [\, c^e_{2H} - (c^e_{2L} + \underline{k}_2) \,] \, . \end{aligned} \tag{2}$$

Conclusions 3 and 4 imply that expected procurement cost is lower under the identified outcome than under the outcome in Case 4 because:

$$\begin{aligned} & \phi_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 \,] \, c^e_{2H} \\ & \quad - \, (\, \phi_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + \, \phi_1 \, [\, 1 - \phi_2 \,] \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \, [\, 1 - \phi_2 \,] \, c^e_{1H} \,) \;\; < \;\; 0 \\ \Leftrightarrow \quad & c^e_{1H} - c^e_{2H} \;\; > \;\; \phi_1 \, [\, 1 - \phi_2 \,] \, [\, c^e_{1H} - (c^e_{1L} + \underline{k}_1) \,] + \phi_2 \, [\, c^e_{1H} - c^e_{2H} \,] \qquad (3) \\ \Leftrightarrow \quad & \phi_1 \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \, c^e_{1H} - c^e_{2H} \;\; > \;\; 0 \, . \end{aligned}$$

The last inequality here holds because $c^e_{2H} < c^e_{1L} + \underline{k}_1 < c^e_{1H}$.

Observe that:

$$\begin{aligned} & \phi_1 \, [\, 1 - \phi_2 \,] \, [\, c^e_{1H} - (c^e_{1L} + \underline{k}_1) \,] + \phi_2 \, [\, c^e_{1H} - c^e_{2H} \,] \\ & \quad > \;\; \phi_1 \, [\, c^e_{1H} - (c^e_{1L} + \underline{k}_1) \,] - \phi_2 [\, c^e_{2H} - (c^e_{2L} + \underline{k}_2) \,] \\ \Leftrightarrow \quad & - \, \phi_1 \, \phi_2 \, [\, c^e_{1H} - (c^e_{1L} + \underline{k}_1) \,] + \phi_2 \, [\, c^e_{1H} - (c^e_{2L} + \underline{k}_2) \,] \;\; > \;\; 0 \\ \Leftrightarrow \quad & \phi_2 \, [\, \phi_1 \, (c^e_{1L} + \underline{k}_1) + (1 - \phi_1) \, c^e_{1H} - (c^e_{2L} + \underline{k}_2) \,] \;\; > \;\; 0 \, . \qquad (4) \end{aligned}$$

The inequality in (4) holds because $c^e_{1H} > c^e_{1L} + \underline{k}_1 > c^e_{2H} > c^e_{2L} + \underline{k}_2$.

(2) holds because (3) and (4) hold.

Conclusions 3 and 5 imply that expected procurement cost is lower under the identified outcome than under the outcome in Case 5 because:

$$\begin{aligned} & \phi_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 \,] \, c^e_{2H} \\ & \quad - \, (\, \phi_1 \, [\, c^e_{1L} + \underline{k}_1 \,] + \, [\, 1 - \phi_1 \,] \, \phi_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_1 \,] \, [\, 1 - \phi_2 \,] \, c^e_{2H} \,) \;\; < \;\; 0 \\ \Leftrightarrow \quad & - \phi_1 \, [\, c^e_{1L} + \underline{k}_1 \,] + \phi_1 \, \phi_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + \phi_1 \, [\, 1 - \phi_2 \,] \, c^e_{2H} \;\; < \;\; 0 \\ \Leftrightarrow \quad & \phi_1 \, \{\, \phi_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 \,] \, c^e_{2H} - (\, c^e_{1L} + \underline{k}_1 \,) \,\} \;\; < \;\; 0 \, . \end{aligned}$$

This inequality holds because $c^e_{1L} + \underline{k}_1 > c^e_{2H} > c^e_{2L} + \underline{k}_2$.

Conclusions 3 and 6 imply that expected procurement cost is lower under the identified outcome than under the outcome in Case 6 because:

$$\phi_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 \,] \, c^e_{2H} \;\; < \;\; \phi_2 \, \left[\, c^e_{2L} + \underline{k}_2 + \overline{k}_1 - \underline{k}_1 \,\right] + [\, 1 - \phi_2 \,] \, \left[\, c^e_{1L} + \overline{k}_1 \,\right]$$

$$\Leftrightarrow \quad [\,1-\phi_2\,]\, c_{2H}^e \;<\; \phi_2 \left[\, \overline{k}_1 - \underline{k}_1 \,\right] + [\,1-\phi_2\,] \left[\, c_{1L}^e + \overline{k}_1 \,\right]$$

$$\Leftrightarrow \quad [\,1-\phi_2\,] \left[\, c_{2H}^e - \left(c_{1L}^e + \overline{k}_1 \,\right) \right] \;<\; \phi_2 \left[\, \overline{k}_1 - \underline{k}_1 \,\right] .$$

This inequality holds because $c_{2H}^e < c_{1L}^e + \underline{k}_1 < c_{1L}^e + \overline{k}_1$.

Conclusions 3 and 7 imply that expected procurement cost is lower under the identified outcome than under the outcome in Case 7 if:

$$\phi_2\,[\,c_{2L}^e + \underline{k}_2\,] + [\,1-\phi_2\,]\, c_{2H}^e \;<\; \phi_1 \left[\, c_{1L}^e + \underline{k}_1 + \overline{k}_2 - \underline{k}_2 \,\right] + [\,1-\phi_1\,] \left[\, c_{2L}^e + \overline{k}_2 \,\right] . \qquad (5)$$

Because $c_{2L}^e + \underline{k}_2 < c_{1L}^e + \underline{k}_1$ and $c_{2H}^e < c_{1L}^e + \underline{k}_1$, the inequality in (5) holds, since:

$$c_{1L}^e + \underline{k}_1 \;<\; \phi_1 \left[\, c_{1L}^e + \underline{k}_1 + \overline{k}_2 - \underline{k}_2 \,\right] + [\,1-\phi_1\,] \left[\, c_{2L}^e + \overline{k}_2 \,\right] .$$

$$\Leftrightarrow \quad [\,1-\phi_1\,] \left[\, c_{1L}^e + \underline{k}_1 - \left(c_{2L}^e + \overline{k}_2 \right) \right] < \; \phi_1 \left[\, \overline{k}_2 - \underline{k}_2 \,\right]$$

$$\Leftrightarrow \quad \overline{k}_2 - \underline{k}_2 \;>\; \left[\frac{1-\phi_1}{\phi_1} \right] \left[\, c_{1L}^e + \underline{k}_1 - \left(c_{2L}^e + \overline{k}_2 \right) \right] .$$

Conclusions 3 and 8 imply that expected procurement cost is lower under the identified outcome than under the outcome in Case 8 because:

$$\phi_2\,[\,c_{2L}^e + \underline{k}_2\,] + [\,1-\phi_2\,]\, c_{2H}^e - \{\, \phi_2\,[\,c_{2L}^e + \underline{k}_2\,] + [\,1-\phi_2\,]\, c_{1H}^e \,\} \;=\; [\,1-\phi_2\,]\,[\,c_{2H}^e - c_{1H}^e\,] \;<\; 0 .$$

This inequality holds because $c_{2H}^e < c_{1L}^e + \underline{k}_1 < c_{1H}^e$.

Conclusions 3 and 9 imply that expected procurement cost is lower under the identified outcome than under the outcome in Case 9 because:

$$\phi_2\,[\,c_{2L}^e + \underline{k}_2\,] + [\,1-\phi_2\,]\, c_{2H}^e - (\, \phi_1\,[\,c_{1L}^e + \underline{k}_1\,] + [\,1-\phi_1\,]\, c_{2H}^e \,) \;<\; 0$$

$$\Leftrightarrow \quad \phi_2\,[\,c_{2L}^e + \underline{k}_2 - c_{2H}^e\,] + \phi_1\,[\,c_{2H}^e - (c_{1L}^e + \underline{k}_1)\,] \;<\; 0 .$$

This inequality holds because $c_{2L}^e + \underline{k}_2 < c_{2H}^e < c_{1L}^e + \underline{k}_1$.

Conclusions 3 and 10 imply that expected procurement cost is lower under the identified outcome than under the outcome in Case 10 because:

$$\begin{aligned}
& \phi_2\,[\,c_{2L}^e + \underline{k}_2\,] + [\,1-\phi_2\,]\, c_{2H}^e \\
& \qquad - (\, \phi_2\,[\,c_{2L}^e + \underline{k}_2\,] + \phi_1\,[\,1-\phi_2\,]\,[\,c_{1L}^e + \underline{k}_1\,] + [\,1-\phi_1\,]\;[\,1-\phi_2\,]\, c_{2H}^e \,) \\
= \;& [\,1-\phi_2\,]\,\{\, c_{2H}^e - \phi_1\,[\,c_{1L}^e + \underline{k}_1\,] - [\,1-\phi_1\,]\, c_{2H}^e \,\} \\
= \;& \phi_1\,[\,1-\phi_2\,]\,[\,c_{2H}^e - (\,c_{1L}^e + \underline{k}_1\,)\,] \;<\; 0 .
\end{aligned}$$

Conclusions 3 and 11 imply that expected procurement cost is lower under the identified outcome than under the outcome in Case 11 because:

$$
\begin{aligned}
&\phi_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 \,] \, c^e_{2H} \\
&\qquad - \big(\, \phi_1 \, [\, c^e_{1L} + \underline{k}_1 \,] + \phi_2 \, [\, 1 - \phi_1 \,] \, [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_1 \,] \, [\, 1 - \phi_2 \,] \, c^e_{1H} \, \big) \\
&= \; [\, 1 - \phi_2 \,] \, c^e_{2H} - \; \phi_1 \, [\, c^e_{1L} + \underline{k}_1 \,] + \phi_1 \, \phi_2 \, [\, c^e_{2L} + \underline{k}_2 \,] - [\, 1 - \phi_1 \,] \, [\, 1 - \phi_2 \,] \, c^e_{1H} \\
&< \; [\, 1 - \phi_2 \,] \, c^e_{2H} - \; \phi_1 \, [\, 1 - \phi_2 \,] \, [\, c^e_{2L} + \underline{k}_2 \,] - [\, 1 - \phi_1 \,] \, [\, 1 - \phi_2 \,] \, [\, c^e_{1L} + \underline{k}_1 \,] \\
&= \; [\, 1 - \phi_2 \,] \, \{ \, c^e_{2H} - \; \phi_1 \, [\, c^e_{2L} + \underline{k}_2 \,] - [\, 1 - \phi_1 \,] \, [\, c^e_{1L} + \underline{k}_1 \,] \, \} \\
&\; < \; [\, 1 - \phi_2 \,] \, [\, c^e_{2H} - (\, c^e_{2L} + \underline{k}_2 \,) \,] \; < \; 0 \, . \qquad (6)
\end{aligned}
$$

The first inequality in (6) holds because $c^e_{2L} + \underline{k}_2 \, < \, c^e_{2H} \, \leq \, c^e_{1L} + \underline{k}_1$ and $c^e_{1L} + \underline{k}_1 \, < \, c^e_{1H}$. The last inequality in (6) holds because $c^e_{2L} + \underline{k}_2 \, < \, c^e_{2L} + \overline{k}_2 \, < \, c^e_{1L} + \underline{k}_1$. ■

Lemma 3. *Suppose Assumption 1 holds,* $c^e_{2L} + \underline{k}_2 \, < \, c^e_{1L} + \underline{k}_1 \, < \, c^e_{2H} \, \leq \, c^e_{1H}$, $c^e_{1L} + \overline{k}_1 \, > \, c^e_{2L} + \overline{k}_2$, *and* $\phi_2 \, > \, \widetilde{\phi}^{C}_2$. *Then in the absence of self-sabotage, expected procurement cost is minimized when the regulator implements: (i) a fixed payment (* $\underline{r}_1 \, = \, \overline{r}_1 \, = \, c^e_{1L} + \underline{k}_1$*) that induces the utility to undertake project 1 and exercise cost management when* $k_1 = \underline{k}_1$*; and (ii) a cost-sharing policy (* $\underline{r}_2 \, = \, \underline{c}_2 + \left[\frac{1 - p_{2H}}{p_{2L} - p_{2H}} \right] \underline{k}_2$ *and* $\overline{r}_2 \, = \, \overline{c}_2 - \left[\frac{p_{2H}}{p_{2L} - p_{2H}} \right] \underline{k}_2$*) that induces the utility to undertake project 2 and exercise selective cost management when* $k_1 = \overline{k}_1$.

<u>Proof</u>. The proof proceeds by demonstrating that expected procurement cost is lower under the identified outcome (i.e., the outcome in Case 10) than under the outcome in any of the other relevant cases when Assumption 1 holds.

Because $c^e_{2H} \, \leq \, c^e_{1H}$, Conclusions 1 and 10 imply that expected procurement cost is lower under the outcome In Case 10 than under the outcome in Case 1 both with $i = 1$ and with $i = 2$ because:

$$
\begin{aligned}
&\phi_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + \phi_1 \, [\, 1 - \phi_2 \,] \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \; [\, 1 - \phi_2 \,] \, c^e_{2H} - c^e_{2H} \; < \; 0 \\
&\Leftrightarrow \quad \phi_2 [\, c^e_{2H} - (c^e_{2L} + \underline{k}_2) \,] + \phi_1 [\, 1 - \phi_2 \,] \, [\, c^e_{2H} - (c^e_{1L} + \underline{k}_1) \,] \; > \; 0 \, .
\end{aligned}
$$

This inequality holds because $c^e_{2H} \, > \, c^e_{1L} + \underline{k}_1 \, > \, c^e_{2L} + \underline{k}_2$.

Conclusions 2 and 10 imply that expected procurement cost is lower under the identified outcome than under the outcome in Case 2 with $i = 2$ if:

$$
\begin{aligned}
&\phi_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 \,] \, \{ \, \phi_1 \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \, c^e_{2H} \, \} - \left(c^e_{2L} + \overline{k}_2 \right) \; < \; 0 \\
&\Leftrightarrow \quad c^e_{2L} + \overline{k}_2 - \{ \, \phi_1 \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \, c^e_{2H} \, \} \\
&\qquad\qquad\qquad > \; \phi_2 \, \{ \, c^e_{2L} + \underline{k}_2 - \phi_1 \, [\, c^e_{1L} + \underline{k}_1 \,] - [\, 1 - \phi_1 \,] \, c^e_{2H} \, \} \\
&\Leftrightarrow \quad \phi_2 \, \{ \, \phi_1 \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \, c^e_{2H} - (c^e_{2L} + \underline{k}_2) \, \}
\end{aligned}
$$

$$> \ \phi_1 \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \, c^e_{2H} - \big(c^e_{2L} + \overline{k}_2 \big)$$

$$\Leftrightarrow \quad \phi_2 \ > \ \frac{\phi_1 \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \, c^e_{2H} - \big(c^e_{2L} + \overline{k}_2 \big)}{\phi_1 \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \, c^e_{2H} - (c^e_{2L} + \underline{k}_2)} \ = \ \tilde{\phi}^C_2 \, . \tag{7}$$

Conclusions 2 and 10 imply that expected procurement cost is lower under the outcome in Case 10 than under the outcome in Case 2 with $i = 1$ because:

$$\phi_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + \phi_1 \, [\, 1 - \phi_2 \,] \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \, [\, 1 - \phi_2 \,] \, c^e_{2H} - (c^e_{1L} + \overline{k}_1) \ < \ 0$$

$$\Leftrightarrow \quad c^e_{2H} - \big(c^e_{1L} + \overline{k}_1 \big) \ < \ \phi_2 \, [\, c^e_{2H} - (c^e_{2L} + \underline{k}_2) \,] + \phi_1 [\, 1 - \phi_2 \,] [\, c^e_{2H} - (c^e_{1L} + \underline{k}_1) \,]. \tag{8}$$

The inequality in (8) holds because the inequality in (7) holds and $c^e_{1L} + \overline{k}_1 \geq c^e_{2L} + \overline{k}_2$.

Conclusions 3 and 10 imply that expected procurement cost is lower under the outcome in Case 10 than under the outcome in Case 3 both with $i = 1$ and with $i = 2$ because:

$$\begin{aligned}
& \phi_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + \phi_1 \, [\, 1 - \phi_2 \,] \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \ [\, 1 - \phi_2 \,] \, c^e_{2H} \\
& \qquad - \big(\, \phi_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 \,] \, c^e_{2H} \, \big) \\
& \quad = \ [\, 1 - \phi_2 \,] \, \{ \, \phi_1 \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \, c^e_{2H} - c^e_{2H} \, \} \\
& \quad = \ \phi_1 \, [\, 1 - \phi_2 \,] \, [\, c^e_{1L} + \underline{k}_1 - c^e_{2H} \,] \ < \ 0 \, ; \ \text{ and}
\end{aligned} \tag{9}$$

$$\begin{aligned}
& \phi_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + \phi_1 \, [\, 1 - \phi_2 \,] \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \ [\, 1 - \phi_2 \,] \, c^e_{2H} \\
& \qquad - \big(\, \phi_1 \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \, c^e_{1H} \, \big) \ < \ 0 \\
\Leftrightarrow \quad & [\, 1 - \phi_1 \,] \, [\, c^e_{1H} - c^e_{2H} \,] + \phi_2 [\, c^e_{2H} - (c^e_{2L} + \underline{k}_2) - \phi_1 \, c^e_{2H} + \phi_1 \, (c^e_{1L} + \underline{k}_1) \,] \ > \ 0 \\
\Leftrightarrow \quad & [\, 1 - \phi_1 \,] \, [\, c^e_{1H} - c^e_{2H} \,] + \phi_2 \, [\, (1 - \phi_1) \, c^e_{2H} + \phi_1 \, (c^e_{1L} + \underline{k}_1) - (c^e_{2L} + \underline{k}_2) \,] \ > \ 0 \, .
\end{aligned} \tag{10}$$

The inequality in (9) holds because $c^e_{2H} > c^e_{1L} + \underline{k}_1$. The inequality in (10) holds because $c^e_{1H} \geq c^e_{2H}$ and $c^e_{2H} > c^e_{1L} + \underline{k}_1 > c^e_{2L} + \underline{k}_2$.

Conclusions 5 and 10 imply that expected procurement cost is lower under the outcome in Case 10 than under the outcome in Case 5 because:

$$\begin{aligned}
& \phi_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + \phi_1 \, [\, 1 - \phi_2 \,] \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \, [\, 1 - \phi_2 \,] \, c^e_{2H} \\
& \qquad - \big(\, \phi_1 \, [\, c^e_{1L} + \underline{k}_1 \,] + \ [\, 1 - \phi_1 \,] \, \phi_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_1 \,] \, [\, 1 - \phi_2 \,] \, c^e_{2H} \, \big) \ < \ 0 \\
\Leftrightarrow \quad & \phi_1 \, \phi_2 \, [\, c^e_{2L} + \underline{k}_2 - (c^e_{1L} + \underline{k}_1) \,] \ < \ 0 \, .
\end{aligned}$$

Conclusions 6 and 10 imply that expected procurement cost is lower under the outcome in Case 10 than under the outcome in Case 6 because:

$$\phi_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + \phi_1 \, [\, 1 - \phi_2 \,] \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \, [\, 1 - \phi_2 \,] \, c^e_{2H}$$

$$< \ \phi_2 \left[c^e_{2L} + \underline{k}_2 + \overline{k}_1 - \underline{k}_1 \right] + [1 - \phi_2] \left[c^e_{1L} + \overline{k}_1 \right]$$

$$\Leftrightarrow \quad \phi_1 [1 - \phi_2] [c^e_{1L} + \underline{k}_1] + [1 - \phi_1] [1 - \phi_2] c^e_{2H}$$

$$< \ \phi_2 \left[\overline{k}_1 - \underline{k}_1 \right] + [1 - \phi_2] \left[c^e_{1L} + \overline{k}_1 \right]$$

$$\Leftrightarrow \quad [1 - \phi_2] \{ \phi_1 [c^e_{1L} + \underline{k}_1] + [1 - \phi_1] c^e_{2H} - \left(c^e_{1L} + \overline{k}_1 \right) \} \ < \ \phi_2 \left[\overline{k}_1 - \underline{k}_1 \right].$$

This inequality holds because $c^e_{1L} + \overline{k}_1 > c^e_{2H} > c^e_{1L} + \underline{k}_1$.

Conclusions 7 and 10 imply that expected procurement cost is lower under the outcome in Case 10 than under the outcome in Case 7 because:

$$\phi_2 [c^e_{2L} + \underline{k}_2] + \phi_1 [1 - \phi_2] [c^e_{1L} + \underline{k}_1] + [1 - \phi_1] [1 - \phi_2] c^e_{2H}$$

$$< \ \phi_2 \left[c^e_{2L} + \underline{k}_2 + \overline{k}_1 - \underline{k}_1 \right] + [1 - \phi_2] \left[c^e_{1L} + \overline{k}_1 \right]$$

$$\Leftrightarrow \quad [1 - \phi_2] \{ \phi_1 [c^e_{1L} + \underline{k}_1] + [1 - \phi_1] c^e_{2H} - \left(c^e_{1L} + \overline{k}_1 \right) \} < \ \phi_2 \left[\overline{k}_1 - \underline{k}_1 \right]$$

$$\Leftrightarrow \quad [1 - \phi_2] \{ \phi_1 [c^e_{1L} + \underline{k}_1] + [1 - \phi_1] c^e_{2H} - (c^e_{1L} + \underline{k}_1) - \left(\overline{k}_1 - \underline{k}_1 \right) \} \ < \ \phi_2 \left[\overline{k}_1 - \underline{k}_1 \right]$$

$$\Leftrightarrow \quad [1 - \phi_2] [1 - \phi_1] [c^e_{2H} - (c^e_{1L} + \underline{k}_1)] \ < \ \overline{k}_1 - \underline{k}_1 .$$

Conclusions 8 and 10 imply that expected procurement cost is lower under the outcome in Case 10 than under the outcome in Case 8 because:

$$\phi_2 [c^e_{2L} + \underline{k}_2] + \phi_1 [1 - \phi_2] [c^e_{1L} + \underline{k}_1] + [1 - \phi_1] \ [1 - \phi_2] c^e_{2H}$$

$$- \ (\phi_2 [c^e_{2L} + \underline{k}_2] + [1 - \phi_2] c^e_{1H})$$

$$= \ [1 - \phi_2] \{ \phi_1 [c^e_{1L} + \underline{k}_1] + [1 - \phi_1] c^e_{2H} - c^e_{1H} \}$$

$$< \ [1 - \phi_2] [c^e_{2H} - c^e_{1H}] \ \leq \ 0 .$$

The strict inequality holds here because $c^e_{2H} > c^e_{1L} + \underline{k}_1$.

Conclusions 9 and 10 imply that expected procurement cost is lower under the outcome in Case 10 than under the outcome in Case 9 because:

$$\phi_2 [c^e_{2L} + \underline{k}_2] + \phi_1 [1 - \phi_2] [c^e_{1L} + \underline{k}_1] + [1 - \phi_1] [1 - \phi_2] c^e_{2H}$$

$$- \ (\phi_1 [c^e_{1L} + \underline{k}_1] + [1 - \phi_1] c^e_{2H}) \ < \ 0$$

$$\Leftrightarrow \quad c^e_{2H} - (c^e_{2L} + \underline{k}_2) \ > \ \phi_1 [c^e_{2H} - (c^e_{1L} + \underline{k}_1)]$$

$$\Leftrightarrow \quad [1 - \phi_1] c^e_{2H} + \phi_1 [c^e_{1L} + \underline{k}_1] - (c^e_{2L} + \underline{k}_2) \ > \ 0 .$$

This inequality holds because $c^e_{2H} > c^e_{1L} + \underline{k}_1 > c^e_{2L} + \underline{k}_2$.

Conclusions 10 and 11 imply that expected procurement cost is lower under the identified outcome than under the outcome in Case 11 because:

$$
\begin{aligned}
& \phi_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + \phi_1 \, [\, 1 - \phi_2 \,] \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \; [\, 1 - \phi_2 \,] \, c^e_{2H} \\
& \qquad - \; (\, \phi_1 \, [\, c^e_{1L} + \underline{k}_1 \,] + \phi_2 \, [\, 1 - \phi_1 \,] \, [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_1 \,] \, [\, 1 - \phi_2 \,] \, c^e_{1H} \,) \\
& = \; - \, \phi_1 \, \phi_2 \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \; [\, 1 - \phi_2 \,] \, c^e_{2H} \\
& \qquad\qquad\qquad + \; \phi_1 \, \phi_2 \, [\, c^e_{2L} + \underline{k}_2 \,] - [\, 1 - \phi_1 \,] \, [\, 1 - \phi_2 \,] \, c^e_{1H} \\
& < \; [\, 1 - \phi_1 \,] \; [\, 1 - \phi_2 \,] \, [\, c^e_{2H} - c^e_{1H} \,] \; \leq \; 0 \, .
\end{aligned}
$$

The strict inequality holds here because $c^e_{1L} + \underline{k}_1 \; > \; c^e_{2L} + \underline{k}_2$. ■