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by

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Abstract

We analyze the regulatory procurement of electricity infrastructure that can take the form of either a traditional core investment or non-traditional distributed energy resources (DERs). We identify conditions under which a regulated utility will engage in self-sabotage (i.e., intentionally increase its own costs) in order to elicit more favorable procurement terms. We also demonstrate how the implementation of standard policies (e.g., cost reimbursement or a simple cost-sharing plan) or the adoption of a traditional core project rather than a potentially less-costly DER project can reduce procurement costs by deterring self-sabotage.

Keywords: self-sabotage, distributed energy resources, regulation, procurement

JEL Codes: L51, L94, Q28, Q40

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1 Introduction

Distributed energy resources (DERs) continue to play an ever-increasing role in electricity sectors throughout the world.[1] In the U.S., thirty-six states are actively exploring the expansion of advanced grid technologies that facilitate widespread DER deployment (NC-CETC, 2017). Regulators in California, Illinois, Minnesota, and New York have proposed or instituted new policies to motivate electricity distribution companies to identify cost-effective DERs and integrate them into their distribution networks.[2]

Ownership issues have garnered considerable attention in policy discussions about how to foster efficient DER deployment. Regulators are aware that if a utility is permitted to own DERs, the utility may create artificial competitive advantages for its own DERs by "sabotaging" the operations of competing suppliers of DERs. For instance, the utility might withhold vital network information from rival suppliers or otherwise impede the suppliers' access to the utility's network (Carson and Davis, 2015; Neuhauser, 2015). These concerns have led some regulators to limit DER ownership by distribution utilities, requiring the utilities instead to function primarily as platforms that facilitate grid access for independent suppliers of DER products and services (NYPSC, 2014a, 2015, 2016).

Potential utility sabotage of the operations of independent suppliers of DERs is a legitimate concern. There is a related, perhaps more subtle, concern that has received less attention in both policy discussions and academic research.[3] We label this concern "utility self-sabotage." Such sabotage arises when the utility intentionally increases the cost of either a DER project that it owns or a traditional core network project that it operates (e.g., capital investment that expands network capacity). Self-sabotage can take many forms. For

[1]See Ruester et al. (2014) and Jenkins and Perez-Arriaga (2017), for example. DERs can entail the "generation of electricity from sources that are near the point of consumption, as opposed to centralized generation sources such as large utility-owned power plants" (American Council for an Energy-Efficient Economy, 2017) and activities that reduce the need for electricity generation by fostering reduced electricity consumption.

[2]See, for example, e21 Initiative (2014), NYPSC (2015), CPUC (2016a), MIT Energy Initiative (2016), Illinois Commerce Commission (2017), and Jenkins and Perez-Arriaga (2017).

[3]Brown and Sappington (2017a) and Jenkins and Perez-Arriaga (2017), among others, examine the design of policies to promote DER deployment. These studies do not consider the possibility of self-sabotage.

example, the utility might fail to pursue or even suppress information about the most cost-effective potential DER projects. Alternatively, the utility might frustrate or even actively discourage cost-containment efforts by its managers.

We find that self-sabotage can increase a utility's profit by inducing the regulator to implement a procurement policy that generates greater rent for the utility. Utility self-sabotage can assume different forms and have varied effects in our model. Self-sabotage can affect the project that is undertaken, the terms of the procurement policy that is implemented, and the utility's efforts to contain project costs.

In addition to identifying types of self-sabotage that a utility may find profitable under a regulatory policy that minimizes expected procurement cost, we identify alternative policies that can enhance welfare by limiting self-sabotage. We show, for instance, that procurement cost can decline when the utility is effectively awarded in the form of a lump-sum bonus the rent it could otherwise secure by undertaking self-sabotage. Procurement costs can also be reduced by systematically implementing standard compensation policies that are not finely-tuned to the environment in which they are implemented. Such policies include full cost reimbursement and a cost-sharing policy under which a fixed portion of the cost savings that the utility secures are awarded to its customers.

Incentives for self-sabotage arise in our model because of the regulator's limited knowledge of the technologies the utility can employ to control project costs. Therefore, ongoing regulatory efforts to reduce relevant information asymmetries are well-advised.[4] Our findings suggest, though, that until the asymmetries are eliminated, the potential for utility self-sabotage merits active consideration.

We develop and explain our findings as follows. Section 2 identifies the key elements of our model, including the different forms of self-sabotage in which a utility might engage. Section 3 identifies conditions under which a utility will find the various forms of self-sabotage to be profitable and the effects of the self-sabotage. Section 4 explains how a regulator might

[4] Ongoing efforts include the development of integrated distribution network planning models to help guide the efficient deployment of DERs (CPUC, 2014; ICF International, 2016).

alter her policy to limit the detrimental consequences of self-sabotage. Section 5 reviews the policy implications of our analysis and discusses extensions of our model. The Appendix contains the proofs of all formal conclusions.

Before proceeding, we explain how our analysis contributes to the literature on sabotage and self-sabotage.[5] Many studies demonstrate that a firm can increase its profit by sabotaging the operations of its rivals.[6] Some studies also show that a firm can benefit from self-sabotage if the resulting increase in the firm's own operating cost is outweighed by the associated increase in rivals' costs.[7] The self-sabotage that we analyze is profitable for a different reason: it can induce the regulator to implement a more favorable procurement policy. This benefit of self-sabotage bears some resemblance to corresponding benefits that have been identified in unregulated market settings. For instance, self-sabotage in the form of choosing inefficient locations and/or transport costs (e.g., Gupta et al., 1994, 1995), reducing one's ability to expand output (e.g., Gelman and Salop, 1983), or limiting one's ability to secure cost reductions (Pal et al., 2012) can benefit a firm by eliciting more accommodating behavior from rivals.[8] The self-sabotage that we analyze is distinct in part because it arises under different circumstances, serves different purposes, and assumes different forms. In addition, we examine changes in procurement policy that can help to limit the detrimental consequences of self-sabotage.

[5] The incentives for self-sabotage that we analyze are not specific to DER procurement. Corresponding incentives can arise in any setting where a buyer seeks to procure a good from a supplier that can sabotage the technologies it employs to produce the good.

[6] See Salop and Scheffman (1983, 1987), Economides (1998), Beard et al. (2001), and Weisman and Kang (2001), for instance.

[7] Williamson (1968) demonstrates that a firm may gladly concede to a labor union's demand for a pronounced industry-wide wage increase if the increase elevates a rival's marginal cost more than it elevates the firm's own marginal cost. Similarly, Sappington and Weisman (2005) observe that a vertically-integrated producer can find it profitable to intentionally increase its upstream cost when doing so differentially disadvantages downstream competitors.

[8] Similarly, it has been shown that a firm may secure a higher market price for its product by intentionally limiting the amount of output it can produce (e.g., Joskow and Kahn, 2002; Kwoka and Sabodash, 2011).

2 The Model

We analyze a setting in which a utility must deliver a specified level of service to its customers. The utility can do so by undertaking one of two possible projects, labeled project 1 and project 2. Project 1 might be viewed as a traditional core project (e.g., capital investment that increases core network distribution capacity) whereas project 2 might be viewed as a new DER project (e.g., increased distributed solar capacity or a demand-side management program). For simplicity and to facilitate a complete characterization of optimal procurement policies, we assume the final cost of project $i \in \{1, 2\}$ is either low ($\underline{c}_i$) or high ($\overline{c}_i$). If the utility refrains from cost management of project i, then the project's low cost is realized with probability $p_{iH} \in (0, 1)$ and the high cost is realized with probability $1 - p_{iH}$.

The utility can exercise cost management on project i by undertaking personally costly effort (k_i) to reduce the expected cost of the project. The effort cost is either low ($\underline{k}_i$) or high ($\overline{k}_i$). In the absence of self-sabotage by the utility, $\phi_i \in (0, 1)$ is the probability that $k_i = \underline{k}_i$. When the utility undertakes cost management of project i (at personal cost k_i), the likelihood of the low cost realization increases from p_{iH} to $p_{iL} \in (0, 1)$. Consequently, in the absence of self-sabotage, the expected cost of the project declines from $c^e_{iH} \equiv p_{iH} \underline{c}_i + [1 - p_{iH}] \overline{c}_i$ to $c^e_{iL} \equiv p_{iL} \underline{c}_i + [1 - p_{iL}] \overline{c}_i$. Cost management of each project is assumed to be efficient when the management can be performed at relatively low cost, i.e., $c^e_{iL} + \underline{k}_i < c^e_{iH}$ for $i = 1, 2$.

The regulator cannot observe how onerous cost management is for the utility (i.e., she cannot observe k_i) or whether the utility has undertaken cost management. The regulator can only observe the realized cost of the project that is undertaken. The regulator seeks to minimize the expected cost of securing the requisite level of service. She does so by specifying the payment that will be made to the utility, depending on the project it undertakes and the realized production cost. When the utility undertakes project i, it receives payment $\underline{r}_i$ if cost $\underline{c}_i$ is realized, and payment $\overline{r}_i$ if cost $\overline{c}_i$ is realized.

We consider two main types of self-sabotage the utility might undertake.[9] First, the util-

[9]Additional forms of self-sabotage are discussed in section 6.

ity might increase its expected cost of exercising cost management on project i by increasing the likelihood that $k_i = \overline{k}_i$. Formally, this form of self-sabotage, $s_{i\phi} \in [\,0, \phi_i\,]$, increases the likelihood that $k_i = \overline{k}_i$ from $1 - \phi_i$ to $1 - \phi_i + s_{i\phi}$. In practice, a utility might increase its expected cost of exercising cost management by failing to promote, or even frustrating, managerial efforts to contain costs (by imposing cumbersome approval procedures, for example), or by failing to hire managers with proven ability to control the costs of complex energy projects.

Second, the utility might increase the expected cost of project i by increasing the likelihood that $c_i = \overline{c}_i$. Formally, this form of self-sabotage, $s_{iH} \in [\,0, p_{iH}\,]$, increases the likelihood that $c_i = \overline{c}_i$ from $1 - p_{iH}$ to $1 - p_{iH} + s_{iH}$ in the absence of cost management. Similarly, self-sabotage $s_{iL} \in [\,0, p_{iL}\,]$ increases the likelihood that $c_i = \overline{c}_i$ from $1 - p_{iL}$ to $1 - p_{iL} + s_{iL}$ in the presence of cost management. Such self-sabotage can take many forms in practice. For instance, a utility might fail to search diligently for the most promising alternatives to standard core projects.[10] Alternatively, a utility might decline to reveal technological information that would enable project partners to lower their operating costs. A utility also might fail to bargain intensely with subcontractors, or it might simply purchase unnecessary inputs (e.g., managerial perquisites).[11]

$C(s_{1\phi}, s_{2\phi}, s_{1L}, s_{2L}, s_{1H}, s_{2H})$ will denote the utility's personal cost of exercising these forms of self-sabotage. This cost could be positive if, for example, the utility faces severe financial penalties if it is found to have deliberately inflated its costs.[12] In principle, this cost

[10] Regulators often require utilities to identify all potentially cost-effective DER alternatives to traditional utility investments. See, for example, CPUC (2014, 2016b). California Assembly Bill No. 327 (https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140AB327) also requires utilities to identify and report the most promising locations for the deployment of DER projects.

[11] A utility's ability to increase the expected cost of DER projects can vary with the sophistication (and the regulator's understanding) of the distributed energy resource management system (DERMS) it implements. A DERMS can help to: (i) improve voltage regulation functions to handle two-way electricity flows; (ii) gather and utilize information about the conditions of individual network feeders and loads to improve interconnections of DERs; (iii) actively monitor the network in order to optimally dispatch DERs to meet loads; and (iv) enhance ancillary services and communication infrastructure that provides reactive power, voltage support, and other services to manage DERs (Sheaffer, 2011).

[12] The utility's managers also may find self-sabotage to be personally costly if the resulting increased expected cost diminishes their perceived skills as effective managers.

could be negative when, for instance, self-sabotage takes the form of managerial perquisites. It is apparent that a utility might engage in self-sabotage that delivers direct benefits to the utility (by reducing $C(\cdot)$). To abstract from this obvious rationale for self-sabotage, we assume that $C(\cdot) = 0$ when each of its arguments is 0 and that $C(\cdot)$ is non-decreasing in each of its arguments. For expositional ease, we also assume that the utility will refrain from self-sabotage when it is indifferent between undertaking and refraining from the self-sabotage.

The utility will operate as long as it anticipates nonnegative profit from doing so. The utility's expected profit when it undertakes project i, implements self-sabotage s_{iH}, and exercises no cost management is:

$$\pi_{iH} \;=\; [\, p_{iH} - s_{iH} \,] \, [\, \underline{r}_i - \underline{c}_i \,] + [\, 1 - p_{iH} + s_{iH} \,] \, [\, \overline{r}_i - \overline{c}_i \,] - C(\cdot)\,.$$

The utility's expected profit when it undertakes project i, implements self-sabotage s_{iL}, and exercises cost management at personal cost k_i is:

$$\pi_{iL} \;=\; [\, p_{iL} - s_{iL} \,] \, [\, \underline{r}_i - \underline{c}_i \,] + [\, 1 - p_{iL} + s_{iL} \,] \, [\, \overline{r}_i - \overline{c}_i \,] - k_i - C(\cdot)\,.$$

The utility is said to exercise *consistent* cost management of project i if it always implements this management, regardless of the personal cost ($k_i \in \{\underline{k}_i, \overline{k}_i\}$) of doing so. The utility is said to exercise *selective* cost management of project i if it implements the management only when the associated personal cost is relatively low (i.e., when $k_i = \underline{k}_i$).

The interaction between the regulator and the utility proceeds as follows. First, the utility implements its preferred levels of self-sabotage, which can alter the expected costs of operating and managing the projects. Then the regulator announces the compensation structure ($(\underline{r}_i, \overline{r}_i)$ for $i = 1, 2$) that minimizes expected procurement cost, given the prevailing cost structures.[13] Next, the utility learns its personal cost of exercising cost management (k_1

[13]In the analysis in section 3, the regulator is presumed to be unable to commit to a compensation structure before the utility has had an opportunity to influence industry costs and thus the regulator's (accurate) beliefs about these costs. (Section 4 considers an alternative presumption.) The timing considered in section 3 reflects in part: (i) the limited ability that current regulators typically have in practice to constrain the actions of future regulators (e.g., Laffont and Tirole, 1993, chapters 1 and 9); (ii) the practical difficulty of determining best practices for utility cost management, particularly in rapidly changing environments; and (iii) a regulator's legal obligation to allow the utility a reasonable opportunity to earn a fair return on capital investments under prevailing industry conditions (e.g., Sidak and Spulber, 1997).

and k_2). The utility then decides which project to undertake and whether to exercise cost management of the project. Finally, the project cost is realized and the regulator delivers the promised payment to the utility.

3 Findings

The regulatory policy that minimizes expected procurement cost varies with the prevailing environment. To illustrate, when $c^e_{1L} + \overline{k}_1 < c^e_{1H} < \min\{c^e_{2L} + \overline{k}_2, c^e_{2H}\}$, the regulator may optimally induce the utility to undertake project 1 and implement consistent cost management. Alternatively, when $c^e_{2H} < c^e_{2L} + \overline{k}_2 < c^e_{1L} + \underline{k}_1$ and ϕ_2 is large, the regulator may induce the utility to undertake project 2 and implement selective cost management. Lemma 1 characterizes the utility's expected profit in the absence of self-sabotage under the different actions the regulator might induce. The lemma refers to Assumption 1, which ensures that cost management is efficient even when it is relatively onerous for the utility.[14]

Assumption 1. $c^e_{iL} + \overline{k}_i \leq c^e_{iH}$ for $i = 1, 2$.

Lemma 1. *Suppose Assumption 1 holds and self-sabotage is prohibitively costly for the utility. Then if the utility is induced to undertake consistent cost management of project i, its expected profit is $\phi_i\left[\overline{k}_i - \underline{k}_i\right]$.*[15] *The utility's expected profit is 0 under any regulatory policy that minimizes expected procurement cost but does not induce consistent cost management.*

Lemma 1 reflects the fact that the key constraint the regulator faces is her limited knowledge of k_i. If the regulator wishes to ensure that the utility undertakes consistent cost management of project i, she must promise to fully compensate the utility for its cost management efforts, even when these efforts are onerous (i.e., when $k_i = \overline{k}_i$). Such compensation provides rent to the utility when cost management is less onerous (i.e., when $k_i = \underline{k}_i$), which is the case with probability ϕ_i.

[14] Assumption 1 simplifies the ensuing analysis by reducing the number of policies that could conceivably minimize expected procurement cost. The key qualitative conclusions drawn below continue to hold when Assumption 1 is not imposed.

[15] Expectations here are those that prevail before the utility learns the values of k_1 and k_2.

We now employ Lemma 1 to illustrate the types of self-sabotage that the utility may undertake in three distinct settings. In each of the three settings, some DER (project 2) procurement is efficient, as is often the case in practice (NYPSC, 2014b; MIT Energy Initiative, 2016).[16]

A. A Setting where Consistent Cost Management of Project 2 is Efficient.

First consider a setting where, in the absence of utility self-sabotage: (i) project 2 entails lower expected cost than project 1 for any given level of cost management; and (ii) consistent cost management of project 2 is efficient. If the utility refrains from self-sabotage in this setting, the regulator will induce the utility to undertake project 2 with consistent cost management by promising the utility a fixed payment that reflects the sum of expected operating cost (c^e_{2L}) and the high management cost ($\overline{k}_2$).[17] Lemma 1 implies that the utility's expected profit will be $\phi_2 \left[\overline{k}_2 - \underline{k}_2 \right]$. Utility self-sabotage that renders cost management of project 2 more onerous (i.e., $s_{2\phi} > 0$) will reduce this rent (to at most $\left[\phi_2 - s_{2\phi} \right] \left[\overline{k}_2 - \underline{k}_2 \right]$) if the self-sabotage does not lead the regulator to induce the utility to undertake a different action. Lemma 1 also implies that the self-sabotage would eliminate the utility's rent if it led the regulator to induce the utility to undertake an action other than consistent cost management of project 1 or project 2. Furthermore, self-sabotage that renders cost management of project 2 more onerous will not lead the regulator to induce the utility to undertake consistent cost management of project 1 when consistent cost management of project 2 entails lower expected cost than consistent cost management of project 1. Therefore, as Proposition 1 reports, the utility will refrain from self-sabotage that makes cost management more onerous in this setting.[18]

[16] The focus on settings where procurement of project 2 is efficient leads to a corresponding focus on incentives for self-sabotage of project 2. Parallel incentives to self-sabotage project 1 arise in settings where procurement of project 1 is efficient. Furthermore, as demonstarted below, self-sabotage of either project or both projects can arise regardless of the project that entails the lowest expected cost in the absence of self-sabotage.

[17] When the utility's compensation does not vary with the realized cost, the utility will act to minimize expected cost. Cost minimization entails consistent cost management when Assumption 1 holds.

[18] Self-sabotage that renders cost management of project 1 more onerous ($s_{1\phi} > 0$) will not alter the optimal procurement policy in this setting. Consequently, such self-sabotage is not profitable for the utility.

Proposition 1. *Suppose Assumption 1 holds,* $c^e_{2L} + \overline{k}_2 < c^e_{1L} + \overline{k}_1$*,* $c^e_{1L} + \underline{k}_1 < c^e_{2H} < c^e_{1H}$*, and* $\phi_2 < \widetilde{\phi}^A_2 \equiv \frac{c^e_{1L}+\underline{k}_1-(c^e_{2L}+\overline{k}_2)}{c^e_{1L}+\underline{k}_1-(c^e_{2L}+\underline{k}_2)}$.[19] *Then the regulator will implement fixed payments* $\underline{r}_2 = \overline{r}_2 = c^e_{2L} + \overline{k}_2$ *and* $\underline{r}_1 = \overline{r}_1 < \underline{c}_1$ *that induce the utility to undertake project 2 with consistent cost management.*[20] *The utility will set* $s_{1\phi} = s_{2\phi} = 0$*.*

Even though the utility will not engage in self-sabotage that renders cost management more onerous in this setting, it may undertake self-sabotage ($s_{2L} > 0$ and/or $s_{2H} > 0$) that increases the managed or unmanaged cost of project 2. Doing so can lead the regulator to induce the utility to undertake project 1 rather than project 2. The switch to project 1 can be profitable for the utility if its expected rent in the presence of consistent cost management is higher under project 1 than under project 2.

Proposition 2. *Suppose the conditions of Proposition 1 hold and* $\phi_1 \left[\overline{k}_1 - \underline{k}_1\right] > \phi_2 \left[\overline{k}_2 - \underline{k}_2\right]$. *Then the utility will set* $s_{2L} > 0$ *and/or* $s_{2H} > 0$ *if the associated personal cost* $C(\cdot)$ *is sufficiently small.*

Proposition 2 indicates that a utility may find it profitable to undertake self-sabotage that effectively eliminates from serious consideration a new DER project that threatens to reduce the rent the utility commands from a standard core project. In practice, a new DER project could offer less rent to the utility if, for example, the project is quite likely to be onerous to manage (so ϕ_2 is small) and/or if the potential variation in the difficulty of managing the cost of the project is limited (so $\overline{k}_2 - \underline{k}_2$ is small).

Alternatively, a utility could find it profitable to undertake self-sabotage of a core project ($s_{1L} > 0$ and/or $s_{1H} > 0$) rather than a new DER project. The same logic that underlies Proposition 2 explains why this can be the case if, in the absence of self-sabotage: (i) expected cost is lowest when the utility undertakes the core project (project 1) and exercises

[19] If $\phi_2 < \widetilde{\phi}^A_2$ under the identified conditions, then in the absence of sabotage, expected procurement cost is minimized when the utility is induced to undertake project 2 and exercise consistent cost management.

[20] The identified $\underline{r}_1$ and $\overline{r}_1$ payments are not unique. A wide variety of payments can ensure the utility will not undertake project 1.

consistent cost management; and (ii) the utility's rent is higher under the new DER project (project 2) than under the core project, so $\phi_2 \left[\overline{k}_2 - \underline{k}_2 \right] > \phi_1 \left[\overline{k}_1 - \underline{k}_1 \right]$. This pattern of rent can prevail, for example, when the potential variation in the difficulty of managing the cost of the new DER project is relatively pronounced (i.e., $\overline{k}_2 - \underline{k}_2 >> \overline{k}_1 - \underline{k}_1$).

B. A Setting where Selective Cost Management of Project 2 is Efficient.

Now consider a setting where, in the absence of self-sabotage, the regulator would induce the utility to undertake project 2 with selective cost management. Lemma 2 identifies conditions under which this outcome will arise.

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* $\phi_2 > \widetilde{\phi}^B_2 \equiv \frac{c^e_{2H} - (c^e_{2L} + \overline{k}_2)}{c^e_{2H} - (c^e_{2L} + \underline{k}_2)}$.[21] *Then in the absence of self-sabotage, the regulator will induce the utility to undertake project 2 and exercise 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* $\underline{r}_1 = \overline{r}_1 < \underline{c}_1$.[22]

The $(\underline{r}_2, \overline{r}_2)$ payments identified in Lemma 2 provide the utility with an incremental profit for realizing $\underline{c}_2$ rather than $\overline{c}_2$ under project 2 that is large enough to induce the utility to exercise cost management when $k_2 = \underline{k}_2$, but not when $k_2 = \overline{k}_2$. Recall from Lemma 1 that the utility secures no rent when it is induced to undertake selective cost management. In contrast, the utility would secure rent if the regulator decided to induce the utility to undertake project 2 with consistent cost management. The utility can ensure this more profitable outcome by increasing the likelihood that cost management is onerous under project 2 (i.e., by setting $s_{2\phi} > 0$), as Proposition 3 reports.

Proposition 3. *Suppose the conditions of Lemma 2 hold. Further suppose that self-sabotage* $s_{2\phi}$ *entails no personal cost for the utility whereas self-sabotage* $s_{2L} > 0$ *and* $s_{2H} > 0$ *are prohibitively costly for the utility.*[23] *Then the utility will set* $s_{2\phi} = \phi_2 - \widetilde{\phi}^B_2$, *and thereby*

[21] $\widetilde{\phi}^B_2$ is the value of ϕ_2 at which the expected cost of project 2 is the same under consistent and selective cost management.

[22] Again, the identified $\underline{r}_1$ and $\overline{r}_1$ payments are not unique.

[23] In practice, management of project costs can entail activities that are difficult to monitor accurately. In

secure expected profit $\widetilde{\phi}_2^B \left[\overline{k}_2 - \underline{k}_2 \right]$.

By increasing the likelihood that cost management of project 2 is onerous (i.e., that $k_2 = \overline{k}_2$) in this setting, the utility ensures that expected procurement cost is minimized when the utility is induced to undertake project 2 with consistent cost management.[24] To maximize the expected profit it derives from this form of self-sabotage, the utility will increase the likelihood that $k_2 = \overline{k}_2$ to the minimum level required to make consistent cost management of project 2 more efficient than selective cost management of the project. A further increase in this likelihood would reduce the likelihood that $k_2 = \underline{k}_2$, which is when the utility secures rent.

Proposition 4 illustrates an additional form of self-sabotage the utility may undertake in the present setting.[25] Lemma 1 implies that the utility would secure no rent if the regulator implemented a cost-reimbursement policy ($\underline{r}_i = \underline{c}_i$ and $\overline{r}_i = \overline{c}_i$) that induced the utility to undertake project i with no cost management. To render this policy less attractive to the regulator than a fixed payment ($\underline{r}_i = \overline{r}_i = c_{iL}^e + \overline{k}_i$) that induces consistent cost management, the utility can inflate expected unmanaged costs. Proposition 4 identifies conditions under which the utility will engage in this form of self-sabotage.

Proposition 4. *Suppose: (i) the conditions in Lemma 2 hold; (ii)* $\overline{c}_2 \leq c_{1L}^e + \underline{k}_1$*; (iii)* $\phi_2 \left[\overline{k}_2 - \underline{k}_2 \right] \geq \phi_1 \left[\overline{k}_1 - \underline{k}_1 \right]$*; and (iv)* $c_{2L}^e + \overline{k}_2 < \phi_2 \left[c_{2L}^e + \underline{k}_2 \right] + \left[1 - \phi_2 \right] \min\{ \overline{c}_1, \overline{c}_2 \}$.[26]

addition, many factors can affect the efficacy of cost management activities (including, for example, the personalities of project managers and their subordinates). Therefore, regulators may have relatively limited ability to detect utility self-sabotage of cost management activities. Consequently, such self-sabotage may entail relatively limited cost for a utility.

[24]When it is sufficiently likely that cost management of project 2 is not onerous (i.e., when $\phi_2 > \widetilde{\phi}_2^B$), the regulator will minimize expected procurement cost by inducing the utility to exercise cost management only when $k_2 = \underline{k}_2$.

[25]As in Proposition 2, self-sabotage $s_{2L} > 0$ and/or $s_{2H} > 0$ also can be profitable for the utility in the present setting. This will be the case if the self-sabotage entails sufficiently little personal cost for the utility and $\phi_1 \left[\overline{k}_1 - \underline{k}_1 \right] > \phi_2 \left[\overline{k}_2 - \underline{k}_2 \right]$, so the utility secures higher expected profit from consistent cost management under project 1 than under project 2.

[26]This condition ensures that if the utility undertakes sufficient sabotage of unmanaged costs to ensure that $c_{1H}^e = \overline{c}_1$ and $c_{2H}^e = \overline{c}_2$, then expected procurement cost is lower when the utility is induced to undertake project 2 with consistent cost management than when the utility is induced to undertake: (i) project 2 with cost management when $k_2 = \underline{k}_2$; and (ii) either project 1 or project 2 with no cost management when

Then the utility will set $s_{1H} > 0$ and/or $s_{2H} > 0$ if such self-sabotage entails no personal cost for the utility.[27]

Corollary 1. *Suppose: (i) the conditions specified in Proposition 4 hold; and (ii) self-sabotage that increases unmanaged costs ($s_{1H} > 0$ and/or $s_{2H} > 0$) and self-sabotage that increases the difficulty of cost management ($s_{1\phi} > 0$ and/or $s_{2\phi} > 0$) both entail no personal cost for the utility. Then the utility can secure a strictly higher level of expected profit ($\phi_2 \left[\overline{k}_2 - \underline{k}_2 \right] > \widetilde{\phi}_2^B \left[\overline{k}_2 - \underline{k}_2 \right]$) by undertaking self-sabotage that increases unmanaged costs than by undertaking self-sabotage that increases the difficulty of cost-management.*

The reason why self-sabotage that increases unmanaged costs can be more profitable than self-sabotage that increases the difficulty of cost management is straightforward. Only the latter type of self-sabotage increases the utility's equilibrium expected cost in the setting of Corollary 1. The former type of self-sabotage increases the cost the utility would incur if it were induced to operate without managing costs. However, such operation is not induced in equilibrium under the specified conditions.

C. A Setting where Both Projects May be Undertaken.

The third setting we examine is one where, in the absence of self-sabotage, expected procurement cost is minimized by inducing the utility to undertake: (i) project 1 with cost management when $k_1 = \underline{k}_1$ and $k_2 = \overline{k}_2$; and (ii) project 2 with selective cost management otherwise. Lemma 3 identifies conditions under which this setting prevails. The lemma refers to $\widetilde{\phi}_2^C \equiv \frac{\phi_1 \left[c_{1L}^e + \underline{k}_1 \right] + [1 - \phi_1] c_{2H}^e - \left(c_{2L}^e + \overline{k}_2 \right)}{\phi_1 \left[c_{1L}^e + \underline{k}_1 \right] + [1 - \phi_1] c_{2H}^e - \left(c_{2L}^e + \underline{k}_2 \right)}$.[28]

$k_2 = \overline{k}_2$.

[27] The assumption that self-sabotage $s_{1H} > 0$ and/or $s_{2H} > 0$ entails no personal cost for the utility is introduced (here and elsewhere in the analysis) for expositional convenience. The conclusion in Proposition 4 holds if the personal cost for the utility is strictly positive but sufficiently small.

[28] $\widetilde{\phi}_2^C$ is the value of ϕ_2 at which, in the absence of self-sabotage, the expected cost of project 2 with consistent cost management is equal to the expected cost under the utility actions identified in Lemma 3.

Lemma 3. *Suppose Assumption 1 holds,* $c_{2L}^e + \underline{k}_2 < c_{1L}^e + \underline{k}_1 < c_{2H}^e \leq c_{1H}^e$*,* $c_{1L}^e + \overline{k}_1 > c_{2L}^e + \overline{k}_2$*, and* $\phi_2 > \widetilde{\phi}_2^C$*. Then in the absence of self-sabotage, expected procurement cost is minimized when the regulator implements: (i) a fixed payment,* $\underline{r}_1 = \overline{r}_1 = c_{1L}^e + \underline{k}_1$*, if the utility undertakes project 1; and (ii) a cost-sharing policy,*[29] $\underline{r}_2 = \underline{c}_2 + \left[\frac{1-p_{2H}}{p_{2L}-p_{2H}}\right]\underline{k}_2$ *and* $\overline{r}_2 = \overline{c}_2 - \left[\frac{p_{2H}}{p_{2L}-p_{2H}}\right]\underline{k}_2$*, if the utility undertakes project 2. This compensation policy induces the utility to undertake project 1 and exercise cost management when* $k_1 = \underline{k}_1$ *and* $k_2 = \overline{k}_2$ *and to undertake project 2 and exercise selective cost management otherwise.*

The cost-sharing policy identified in Lemma 3 provides an incremental profit for realizing $\underline{c}_2$ that induces the utility to manage the cost of project 2 if and only if $k_2 = \underline{k}_2$. Lemma 1 implies that the utility secures 0 expected profit under the policy identified in Lemma 3 if it refrains from self-sabotage. As in the setting of Proposition 3, the utility can secure positive expected profit by increasing the likelihood that cost management of project 2 will be onerous (i.e., that $k_2 = \overline{k}_2$) to the point where the expected procurement cost is lower under project 2 with consistent cost management than under the utility actions identified in Lemma 3.[30] This conclusion is recorded formally in Proposition 5.

Proposition 5. *Suppose: (i) the conditions in Lemma 3 hold; (ii) self-sabotage* $s_{2\phi} > 0$ *entails no personal cost for the utility; and (iii) self-sabotage* $s_{iL} > 0$ *or* $s_{iH} > 0$ *is prohibitively costly for the utility. Then the utility will set* $s_{1\phi} = 0$ *and* $s_{2\phi} = \phi_2 - \widetilde{\phi}_2^C > 0$*.*

For expositional ease, Proposition 5 presumes that self-sabotage $s_{2\phi} > 0$ entails no personal cost for the utility. When such self-sabotage of the DER project (project 2) is more

[29] A cost-sharing policy is one in which the utility's incremental profit when $\underline{c}_i$ rather than $\overline{c}_i$ is realized exceeds 0 but is less than $\overline{c}_i - \underline{c}_i$.

[30] As in Proposition 4, the utility can also secure rent in the present setting by setting $s_{1H} > 0$ or $s_{2H} > 0$ if such self-sabotage entails sufficiently small cost for the utility. The increase in the expected unmanaged cost of the projects can lead the regulator to induce the utility to always undertake project 2 with consistent cost management. Formally, it can be shown that the utility will set $s_{1H} > 0$ or $s_{2H} > 0$ and thereby secure rent $\phi_2\left[\overline{k}_2 - \underline{k}_2\right]$ if: (i) the conditions in Lemma 3 hold; (ii) $\phi_2\left[c_{2L}^e + \underline{k}_2\right] + \left[1-\phi_2\right]\left[\phi_1\left(c_{1L}^e + \underline{k}_1\right) + (1-\phi_1)\min\{\overline{c}_1, \overline{c}_2\}\right] > c_{2L}^e + \overline{k}_2$; (iii) $\phi_2\left[\overline{k}_2 - \underline{k}_2\right] \geq \phi_1\left[\overline{k}_1 - \underline{k}_1\right]$; and (iv) self-sabotage $s_{1H} > 0$ and $s_{2H} > 0$ entails no personal cost for the utility.

costly for the utility than the corresponding self-sabotage of the core project (project 1), the utility may find it profitable to implement self-sabotage of both projects. The self-sabotage of project 1 reduces its attraction to the regulator, and thereby reduces the amount of (the relatively costly) self-sabotage of project 2 the utility must undertake to convince the regulator to implement consistent cost management of project 2. This conclusion is recorded formally in Proposition 6, which refers to $\widetilde{\phi}_2^C(s_{1\phi}) \equiv \frac{\left[\phi_1 - s_{1\phi}\right]\left[c_{1L}^e + \underline{k}_1\right] + \left[1 - \phi_1 + s_{1\phi}\right] c_{2H}^e - \left(c_{2L}^e + \overline{k}_2\right)}{\left[\phi_1 - s_{1\phi}\right]\left[c_{1L}^e + \underline{k}_1\right] + \left[1 - \phi_1 + s_{1\phi}\right] c_{2H}^e - \left(c_{2L}^e + \underline{k}_2\right)}$.[31]

Proposition 6. *Suppose: (i) the conditions in Lemma 3 hold; (ii) $\phi_2 > \widetilde{\phi}_2^C(\phi_1)$; (iii) self-sabotage $s_{iL} > 0$ or $s_{iH} > 0$ is prohibitively costly for the utility; (iv) self-sabotage $s_{1\phi} > 0$ entails no personal cost for the utility; and (v) self-sabotage $s_{2\phi} > 0$ entails personal cost for the utility that is strictly positive but sufficiently small.*[32] *Then the utility will set $s_{1\phi} = \phi_1 > 0$ and $s_{2\phi} = \phi_2 - \widetilde{\phi}_2^C(\phi_1) > 0$.*

Together, the preceding findings reveal that several different patterns of self-sabotage can arise even in the relatively simple environment under consideration. The utility may find it profitable to increase unmanaged costs, managed costs, or the difficulty of project cost management. Furthermore, the utility may benefit by engaging in self-sabotage of a traditional network project, a non-traditional (DER) project, or both. The most profitable pattern of self-sabotage varies with the costs of the different types of sabotage and prevailing project cost structures. These findings suggest that, in practice, it may be difficult for regulators to anticipate and successfully limit all relevant patterns of self-sabotage.

4 Policy Changes to Limit Self-Sabotage

The preceding analysis assumes that the regulator acts to minimize expected procurement cost, taking as given prevailing industry costs. We now consider the possibility that the regulator might anticipate the utility's self-sabotage and modify her procurement policy

[31] $\widetilde{\phi}_2^C(s_{1\phi})$ is the value of ϕ_2 at which the expected cost of project 2 with consistent cost management is equal to the expected cost under the utility actions identified in Lemma 3 when the utility implements self-sabotage $s_{1\phi}$.

[32] Condition (v) can be stated more precisely as $C(\phi_1, \phi_2 - \widetilde{\phi}_2^C(\phi_1), 0, 0, 0, 0) < \widetilde{\phi}_2^C(\phi_1)\left[\overline{k}_2 - \underline{k}_2\right]$.

accordingly.[33] We consider four distinct types of policy modifications.

First, the regulator may direct the utility to undertake a relatively high-cost project because it is less prone to self-sabotage. For example, suppose that in the absence of self-sabotage, expected procurement cost is minimized when the utility is induced to undertake project 2 and exercise selective cost management. Further suppose that the utility can readily increase the expected cost of project 2 but cannot inflate the expected cost of project 1.[34] Then, as Proposition 7 reports, the regulator may reduce expected procurement cost by inducing the utility to undertake the more costly (but less manipulable) project 1 rather than project 2.

Proposition 7. *Suppose: (i)* $\phi_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 \,] \, c^e_{2H} < \phi_1 \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \, c^e_{1H} < \min \{ \, c^e_{1L} + \overline{k}_1, c^e_{2L} + \overline{k}_2 \, \}$*; (ii) self-sabotage other than* $s_{2\phi} > 0$ *is prohibitively costly for the utility; and (iii) self-sabotage* $s_{2\phi} > 0$ *entails no personal cost for the utility. Then the regulator can reduce expected procurement cost by implementing the policy that minimizes expected procurement cost under project 1 than by implementing the policy that minimizes expected procurement cost under project 2.*

Second, the regulator may alter the extent of cost management that is exercised on the chosen project. To illustrate, suppose for simplicity that project 1 is prohibitively costly to operate.[35] Further suppose that in the absence of self-sabotage, expected procurement cost under project 2 is lowest under selective cost management and highest under consistent cost management. Then as Proposition 8 reports, if self-sabotage of project 2 entails sufficiently

[33] We continue to focus on policies that provide nonnegative expected profit for the utility even if it undertakes self-sabotage. Specifically, we do not consider policies that threaten to impose large penalties on the utility if actual expected project costs exceed their minimum possible levels. Such policies would render the present analysis uninteresting by effectively enabling the regulator to (costlessly) preclude self-sabotage. Such policies would be difficult to implement in practice, in part due to the difficulty of documenting conclusively in a court of law expectations about prevailing costs and about minimum possible costs.

[34] In practice, a utility may have considerable leeway to increase the expected cost of a novel, untested DER project, but have limited ability to inflate the expected cost of a more standard, relatively well-understood core project.

[35] This strong assumption is adopted here (and below) to simplify the conditions under which the identified policy change reduces procurement costs. The assumption is not required for the identified change to reduce procurement costs.

low personal cost for the utility, the regulator will minimize expected procurement cost by implementing a cost-reimbursement policy that induces no cost management of project 2. Doing so eliminates the utility's potential gain from self-sabotage, thereby ensuring that consistent cost management of project 2 is not implemented.

Proposition 8. *Suppose* $\phi_2 \left[c_{2L}^e + \underline{k}_2 \right] + \left[1 - \phi_2 \right] c_{2H}^e < c_{2L}^e + \overline{k}_2 < c_{2H}^e < c_{2L}^e + \overline{k}_2$ *and project 1 is prohibitively costly to operate. Then if self-sabotage* $s_{2\phi} > 0$ *or* $s_{2H} > 0$ *is prohibitively costly for the utility, expected procurement cost is minimized when the utility is induced to undertake project 2 with selective cost management. In contrast, if such self-sabotage entails no personal cost for the utility, then expected procurement cost will be lower if the utility is induced to undertake project 2 with no cost management.*

Third, the regulator may optimally modify the terms of the procurement contract without altering the project that is undertaken or the extent of cost management that is exercised. To illustrate, suppose that project 1 is prohibitively costly to operate. Further suppose that in the absence of self-sabotage, expected procurement cost under project 2 is lowest when selective cost management is exercised and highest when no cost management is undertaken. The compensation policy identified in Lemma 2 would minimize expected procurement cost in this setting in the absence of self-sabotage. When self-sabotage of project 2 entails no personal cost for the utility, the regulator can increase both $\underline{r}_2$ and $\overline{r}_2$ by $\phi_2 \left[\overline{k}_2 - \underline{k}_2 \right]$. Doing so effectively awards to the utility a guaranteed "bonus" equal to the rent it could secure by undertaking the self-sabotage that would lead the regulator to induce consistent, rather than selective, cost management. The award thereby eliminates the utility's incentive to undertake self-sabotage. As Proposition 9 reports, implementing this award can reduce expected procurement cost by inducing selective cost management rather than consistent cost management without altering the utility's rent.[36]

[36] In practice, regulators provide financial bonuses (in the form of payments above the standard rate of return on capital) to induce utilities to replace standard core projects with new DER projects. See, for example, CPUC (2016b).

Proposition 9. *Suppose: (i)* $\phi_2 [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 \,]\, c^e_{2H} + \phi_2 \left[\, \overline{k}_2 - \underline{k}_2 \,\right] < c^e_{2L} + \overline{k}_2 < c^e_{2H}$*; (ii) project 1 is prohibitively costly relative to operate; and (iii) self-sabotage of project 2 entails no personal cost for the utility. Then the regulator can secure the lowest feasible expected procurement cost by setting* $\underline{r}_2 \;=\; \underline{c}_2 + \left[\, \frac{1 - p_{2H}}{p_{2L} - p_{2H}} \,\right] \underline{k}_2 + \phi_2 \left[\, \overline{k}_2 - \underline{k}_2 \,\right]$, $\overline{r}_2 \;=\; \overline{c}_2 - \left[\, \frac{p_{2H}}{p_{2L} - p_{2H}} \,\right] \underline{k}_2 + \phi_2 \left[\, \overline{k}_2 - \underline{k}_2 \,\right]$*, and* $\underline{r}_1 \;=\; \overline{r}_1 < \underline{c}_1$*. This policy induces the utility to undertake project 2 with selective cost management, while refraining from self-sabotage.*

Fourth, the regulator may implement standard procurement policies that do not vary with the prevailing environment. These policies include cost-reimbursement policies and exogenous cost-sharing policies.[37] Exogenous cost-sharing policies include policies of the form:

$$\underline{r}_i \;=\; \underline{c}_i + \alpha \, [\, \overline{c}_i - \underline{c}_i \,] \quad \text{and} \quad \overline{r}_i \;=\; \overline{c}_i \;\; \text{for } i \in \{1, 2\}, \tag{1}$$

where $\alpha \in (0, 1)$ is a parameter that does not vary with the prevailing environment. The cost-sharing policy in expression (1) reimburses the utility for its realized cost under project i and provides as a financial bonus a fixed fraction (α) of the cost saving ($[\, \overline{c}_i - \underline{c}_i \,]$) that is achieved when the low project cost ($\underline{c}_i$) is realized.[38] By systematically implementing such a policy, the regulator can eliminate the utility's incentive to undertake self-sabotage designed to induce the regulator to implement a more favorable procurement policy.[39] By precluding self-sabotage, such systematic policy implementation can reduce expected procurement cost, as Proposition 10 reports.

Proposition 10. *Suppose: (i)* $\alpha \, [\, p_{2L} - p_{2H} \,] \, [\, \overline{c}_2 - \underline{c}_2 \,] \in (\underline{k}_2, \overline{k}_2)$*; (ii)* $\phi_2 [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 \,] \, c^e_{2H} \;<\; \phi_2 \{\, c^e_{2L} + \alpha \, p_{2L} \, [\, \overline{c}_2 - \underline{c}_2 \,] \,\} + [\, 1 - \phi_2 \,] \{\, c^e_{2H} + \alpha \, p_{2H} \, [\, \overline{c}_2 - \underline{c}_2 \,] \,\} \;<\; c^e_{2H} \;<\; c^e_{2L} + \overline{k}_2$*; (iii) project 1 is prohibitively costly to operate; and (iv) self-sabotage* $s_{2H} > 0$ *entails no personal cost for the utility. Then expected procurement cost is lower under the cost-sharing plan*

[37] Policymakers and academic scholars alike have noted the potential benefits of cost-sharing policies. See, for example, NYPSC (2014a) and Jenkins and Perez-Arriaga (2017).

[38] This cost-sharing policy reflects elements of the NYPSC's Con Edison Demand Side-Management Project compensation policy which provides cost-reimbursement and an incentive payment if certain benchmarks are obtained (NYPSC, 2014b).

[39] See Lemma 7 in the Appendix.

in expression (1) than under a cost-reimbursement policy or the policy that minimizes the regulator's expected procurement cost, given prevailing industry costs.

The first two conditions in Proposition 10 hold when: (i) α and $\underline{k}_2$ are sufficiently small; and (ii) $\overline{k}_2$ and ϕ_2 are sufficiently large. When ϕ_2 is large and $\underline{k}_2$ is small relative to $\overline{k}_2$, expected cost is lower under selective cost management than under consistent cost management. When α is small, the regulator effectively retains for consumers a large fraction of the cost reduction that is secured via selective cost management.

In summary, by committing to implement a policy that does not minimize expected procurement cost under the industry conditions that prevail, a regulator may be able to reduce realized procurement costs. The cost-reduction arises when the long-term commitment limits a utility's ability to influence the prevailing procurement policy by engaging in self-sabotage. Therefore, even though a policy like cost reimbursement has many well-known drawbacks,[40] there are settings in which such a policy can reduce procurement costs by deterring strategic cost inflation in the form of self-sabotage.

5 Conclusions

Regulators are well aware that a utility may be motivated to sabotage the DER projects of independent suppliers in order to secure a competitive advantage for the utility's own DER projects. Regulators seem less aware of the fact that a utility may find it profitable to sabotage its own operations if policies designed to foster efficient DER deployment are not carefully designed to limit such self-sabotage.

We have shown that a utility can benefit from self-sabotage that increases managed costs, unmanaged costs, and/or the difficulty of managing project costs. Furthermore, the utility may benefit by sabotaging a DER project it owns, a traditional network project it operates, or both. We have also identified policy changes that can reduce procurement costs by limiting a utility's incentive to engage in self-sabotage. For example, a regulator might

[40]Most importantly, a cost-reimbursement policy provides no incentives to reduce costs.

require a utility to undertake a project that does not have the lowest expected cost, but is relatively immune to strategic cost inflation. In particular, a regulator might mandate the adoption of a standard, well-understood core network project even though a new DER project might entail lower expected cost in the absence of self-sabotage.

A regulator might also systematically implement standard procurement policies (e.g., cost reimbursement or a simple cost-sharing plan) rather than adopt policies that are finely-tuned to prevailing project cost structures. Such systematic implementation can eliminate a utility's ability to influence the procurement policy that is implemented, and can thereby eliminate the utility's incentive to engage in self-sabotage. Alternatively, the regulator might add a lump-sum bonus to a cost-sharing policy that eliminates the utility's incentive for self-sabotage while preserving its incentive to exercise selective cost management of the project it operates. Although such a bonus will increase procurement costs by delivering rent to the utility, its overall impact can be to reduce procurement costs by precluding utility self-sabotage.

Of course, a utility typically would be able to secure gains in excess of the gains we have identified if the utility could convince the regulator that project operating and management costs are relatively high when, in fact, they are relatively low. Our analysis documents the less apparent conclusion that even when a regulator always assesses prevailing cost accurately, a utility may find it profitable to implement the welfare-reducing cost increases required to convince the regulator that costs are relatively high.

For brevity, the foregoing analysis has not considered all potential forms of self-sabotage. For instance, although we allowed the utility to increase the likelihood that project costs are onerous to manage (i.e., that $k_i = \overline{k}_i$), we did not allow the utility to increase the magnitude of potential project management costs ($\underline{k}_i$ and/or $\overline{k}_i$). It can be shown, though, that the same basic considerations and incentives identified above persist in the presence of this alternative form of self-sabotage.[41]

[41]Conceivably, the utility might also increase $\underline{c}_i$ or $\overline{c}_i$ rather than increase the probability that $c_i = \overline{c}_i$. In our binary model, though, the realized cost might then provide definitive proof that the utility engaged

We analyzed a relatively simple, stylized model in order to illustrate most clearly the incentives for self-sabotage that can arise and how these incentives can be mitigated. The basic forces that arise in our streamlined model will persist in more general settings where, for instance, realized project costs and project management costs are not binary.[42] The critical feature of the analysis is that the utility has better information than the regulator about the difficulty of managing project costs and the effort the utility has devoted to controlling project costs. As long as such information asymmetries persist, the utility often will find ways to alter prevailing cost structures in order to induce the implementation of more profitable procurement policies.[43] Thus, our analysis supports ongoing regulatory initiatives to reduce relevant information asymmetry by, for example, developing network planning models that reflect the best available information about the benefits and costs of deploying DER projects (CPUC, 2014; ICF International, 2016).

The manner in which the optimal procurement policy changes over time as critical information asymmetries evolve remains to be determined. For instance, the optimal policy might entail the adoption of relatively simple, standard policies (e.g., cost reimbursement) initially, when the regulator's knowledge of the costs of non-traditional DER projects and the utility's ability to influence these costs is particularly limited. Then later, as more objective information becomes available that limits the ability of utilities to strategically influence the expected costs of DER projects, the regulator might implement policies that are more finely tailored to the prevailing environment. The optimal management of relevant information asymmetries and the associated evolution of optimal policy merits further study.

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in self-sabotage. In principle, a regulator might be able to preclude such self-sabotage by threatening to impose a large financial penalty on the utility if "inflated" costs are realized.

[42] For example, $G_i(c_i, s_i)$ might be the distribution function for the cost of project i, $c_i \in [\underline{c}_i, \overline{c}_i]$, where $s_i \in [\underline{s}_i, \overline{s}_i]$ is the amount of self-sabotage the utility undertakes to increase this cost. Increases in s_i might increase the distribution of c_i in the sense of first-order stochastic dominance.

[43] A more general formulation like the one identified in the preceding footnote would complicate the analysis in part by admitting a greater variety of cost-minimizing procurement policies and associated induced utility actions, as well as a wider array of profit-maximizing patterns of self-sabotage. However, self-sabotage would continue to serve the same purpose it serves in the binary model. Specifically, the self-sabotage would alter the optimal procurement policy in a manner that generates increased rent for the utility.

Appendix

Proof of Lemma 1

The proof proceeds by identifying all outcomes the regulator might conceivably implement in order to minimize the expected cost of inducing the utility to undertake one of the projects, and determining the utility's expected profit in each case. These outcomes and associated levels of expected profit are reported in the following Conclusions.[44] The Conclusions identify eleven potentially relevant cases.

Conclusion 2. *In Case 1, the regulator always induces the utility to undertake one project (project i) without exercising any cost management. The regulator's minimum expected procurement cost in this case is* c^e_{iH} *and the utility's corresponding profit is* 0.

Conclusion 3. *In Case 2, the regulator induces the utility to always undertake one project (project i) and implement consistent cost management. If* $c^e_{iH} - c^e_{iL} \geq \overline{k}_i$*, 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* $k_i = \underline{k}_i$.

Conclusion 4. *In Case 3, the regulator induces the utility to always undertake one project (project i) and implement selective cost management. The regulator's minimum expected procurement cost in this case is* $\phi_i \left[c^e_{iL} + \underline{k}_i \right] + \left[1 - \phi_i \right] c^e_{iH}$ *and the utility's corresponding expected profit is* 0.

Conclusion 5. *In Case 4, the regulator induces the utility to: (i) undertake project* 1 *and exercise cost management when* $k_1 = \underline{k}_1$ *and* $k_2 = \overline{k}_2$*; (ii) undertake project* 1 *without exercising cost management when* $k_1 = \overline{k}_1$ *and* $k_2 = \overline{k}_2$*; and (iii) undertake project* 2 *and exercise cost management when* $k_2 = \underline{k}_2$*. The regulator's minimum expected procurement cost in this case is* $\phi_2 \left[c^e_{2L} + \underline{k}_2 \right] + \phi_1 \left[1 - \phi_2 \right] \left[c^e_{1L} + \underline{k}_1 \right] + \left[1 - \phi_1 \right] \left[1 - \phi_2 \right] c^e_{1H}$*, and the utility's corresponding expected profit is* 0.

Conclusion 6. *In Case 5, the regulator induces the utility to: (i) undertake project* 1 *and exercise cost management when* $k_1 = \underline{k}_1$*; (ii) undertake project* 2 *and exercise cost management when* $k_1 = \overline{k}_1$ *and* $k_2 = \underline{k}_2$*; and (iii) undertake project* 2 *with no cost management when* $k_1 = \overline{k}_1$ *and* $k_2 = \overline{k}_2$*. The regulator's minimum expected procurement cost in this case is* $\phi_1 \left[c^e_{1L} + \underline{k}_1 \right] + \left[1 - \phi_1 \right] \phi_2 \left[c^e_{2L} + \underline{k}_2 \right] + \left[1 - \phi_1 \right] \left[1 - \phi_2 \right] c^e_{2H}$*, and the utility's corresponding expected profit is* 0.

[44] Brown and Sappington (2017b) provides the proofs of these Conclusions. The Conclusions also report the relevant expected procurement costs, which are employed in the proofs of subsequent lemmas and propositions.

Conclusion 7. *In Case 6, the regulator induces the utility to: (i) undertake project* 1 *and exercise consistent cost management when* $k_2 = \overline{k}_2$*; and (ii) undertake project* 2 *and exercise cost management when* $k_2 = \underline{k}_2$*. If* $c^e_{1H} - c^e_{1L} \geq \overline{k}_1$ *and* $\overline{k}_2 - \underline{k}_2 \geq \overline{k}_1 - \underline{k}_1$*, then the regulator's minimum expected procurement cost in this case 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* $[\phi_2 + (1 - \phi_2)\phi_1] \left[\overline{k}_1 - \underline{k}_1 \right]$.

Conclusion 8. *In Case 7, the regulator induces the utility to: (i) undertake project* 2 *and exercise consistent cost management when* $k_1 = \overline{k}_1$*; and (ii) undertake project* 1 *and exercise cost management when* $k_1 = \underline{k}_1$*. If* $c^e_{2H} - c^e_{2L} \geq \overline{k}_2$ *and* $\overline{k}_1 - \underline{k}_1 \geq \overline{k}_2 - \underline{k}_2$*, then the regulator's minimum expected procurement cost in this case 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* $[\phi_1 + \phi_2 (1 - \phi_1)] \left[\overline{k}_2 - \underline{k}_2 \right]$.

Conclusion 9. *In Case 8, the regulator induces the utility to: (i) undertake project* 2 *and exercise cost management when* $k_2 = \underline{k}_2$*; and (ii) undertake project* 1 *with no cost management when* $k_2 = \overline{k}_2$*. The regulator's minimum expected procurement cost in this case is* $\phi_2 [c^e_{2L} + \underline{k}_2] + [1 - \phi_2] c^e_{1H}$*, and the utility's corresponding expected profit is* 0.

Conclusion 10. *In Case 9, the regulator induces the utility to: (i) undertake project* 1 *and exercise cost management when* $k_1 = \underline{k}_1$*; and (ii) undertake project* 2 *with no cost management when* $k_1 = \overline{k}_1$*. The regulator's minimum expected procurement cost in this case is* $\phi_1 [c^e_{1L} + \underline{k}_1] + [1 - \phi_1] c^e_{2H}$*, and the utility's corresponding expected profit is* 0.

Conclusion 11. *In Case 10, the regulator induces the utility to: (i) undertake project* 2 *and exercise cost management when* $k_2 = \underline{k}_2$*; (ii) undertake project* 1 *and exercise cost management when* $k_1 = \underline{k}_1$ *and* $k_2 = \overline{k}_2$*; and (iii) undertake project* 2 *with no cost management when* $k_1 = \overline{k}_1$ *and* $k_2 = \overline{k}_2$*. The regulator's minimum expected procurement cost in this case 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.

Conclusion 12. *In Case 11, the regulator induces the utility to: (i) undertake project* 1 *and exercise cost management when* $k_1 = \underline{k}_1$*; (ii) undertake project* 2 *and exercise cost management when* $k_2 = \underline{k}_2$ *and* $k_1 = \overline{k}_1$*; and (iii) undertake project* 1 *with no cost management when* $k_1 = \overline{k}_1$ *and* $k_2 = \overline{k}_2$*. The regulator's minimum expected procurement cost in this case 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.

Cases other than Cases 1 – 11 are conceivable. However, expected procurement cost will always be lower in one of Cases 1 – 11 than in any of these additional cases. Furthermore, the following lemmas imply that when Assumption 1 holds and in the absence of self-sabotage, expected procurement cost is minimized in one of Cases 1 – 5 and 8 – 11.

Lemma 4. *Suppose Assumption 1 holds,* $c_{1L}^e + \underline{k}_1 \ \le \ c_{2L}^e + \underline{k}_2$*, and* $\overline{k}_1 - \underline{k}_1 \ \le \ \overline{k}_2 - \underline{k}_2$*. Then expected procurement cost is at least as low under the outcome in Case 2 with* $i = 1$ *as under the outcome in Case 6.*

Proof. Conclusions 3 and 7 imply that the conclusion in the lemma holds if:

$$c_{1L}^e + \overline{k}_1 \ \le \ \phi_2 \left[c_{2L}^e + \underline{k}_2 + \overline{k}_1 - \underline{k}_1 \right] + \left[1 - \phi_2 \right] \left[c_{1L}^e + \overline{k}_1 \right]$$

$$\Leftrightarrow \quad \phi_2 \left[c_{2L}^e + \underline{k}_2 + \overline{k}_1 - \underline{k}_1 - \left(c_{1L}^e + \overline{k}_1 \right) \right] \ \ge \ 0 \quad \Leftrightarrow \quad c_{2L}^e + \underline{k}_2 \ \ge \ c_{1L}^e + \underline{k}_1 \, . \quad \square$$

Lemma 5. *Suppose Assumption 1 holds,* $c_{2L}^e + \underline{k}_2 \ \le \ c_{1L}^e + \underline{k}_1$*, and* $\overline{k}_2 - \underline{k}_2 \ \le \ \overline{k}_1 - \underline{k}_1$*. Then expected procurement cost is at least as low under the outcome in Case 2 with* $i = 2$ *as under the outcome in Case 7.*

Proof. Conclusions 3 and 8 imply that the conclusion in the lemma holds if:

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

$$\Leftrightarrow \quad \phi_1 \left[c_{1L}^e + \underline{k}_1 + \overline{k}_2 - \underline{k}_2 - \left(c_{2L}^e + \overline{k}_2 \right) \right] \ \ge \ 0 \quad \Leftrightarrow \quad c_{2L}^e + \underline{k}_1 \ \ge \ c_{2L}^e + \underline{k}_2 \, . \quad \square$$

Lemma 6. *Suppose Assumption 1 holds. Then expected procurement cost is never strictly lower under the outcome in Case 6 or the outcome in Case 7 than under all of the outcomes in Cases 1 – 5 and 8 – 11.*

Proof. First suppose the two inequalities identified in Lemma 4 hold. Then the conclusion in Lemma 6 follows from Lemma 4.

Next suppose $c_{1L}^e + \underline{k}_1 \ \le \ c_{2L}^e + \underline{k}_2$ and $\overline{k}_1 - \underline{k}_1 \ > \ \overline{k}_2 - \underline{k}_2$. Then the proof of Lemma 4 implies that expected procurement cost under the outcome in Case 2 with $i = 1$ (EC_{21}) is no greater than EC_6, the lowest expected procurement cost that can be secured under the outcome in Case 6 when $\overline{k}_1 - \underline{k}_1 \ \le \ \overline{k}_2 - \underline{k}_2$. This assumption ensures that expected procurement cost achieves its lowest possible level under the outcome in Case 6. Therefore, the lowest expected procurement cost that can be secured under the outcome in Case 6 is at least EC_6, which exceeds EC_{21}.

Now suppose the two inequalities identified in Lemma 5 hold. Then the conclusion in Lemma 6 follows from Lemma 5.

Finally, suppose $c_{2L}^e + \underline{k}_2 \ \le \ c_{1L}^e + \underline{k}_1$ and $\overline{k}_2 - \underline{k}_2 \ > \ \overline{k}_1 - \underline{k}_1$. Then the proof of Lemma 5 implies that expected procurement cost under the outcome in Case 2 with $i = 2$ (EC_{22}) is no greater than EC_7, the lowest expected procurement cost that can be secured under the outcome in Case 7 when $\overline{k}_2 - \underline{k}_2 \ \le \ \overline{k}_1 - \underline{k}_1$. This assumption ensures that expected procurement cost achieves its lowest possible level under the outcome in Case 7. Therefore, the lowest expected procurement cost that can be secured under the outcome in Case 7 is at least EC_7, which exceeds EC_{22}. $\square$ $\blacksquare$

Proof of Proposition 1

The proof proceeds initially by demonstrating that when Assumption 1 holds and in the absence of self-sabotage, expected procurement cost is lower under the identified outcome (i.e., the outcome in Case 2 with $i = 2$) than under the outcome in any of the other relevant cases.

Because $c_{2L}^e + \overline{k}_2 < c_{2H}^e$, Conclusions 2 and 3 imply that expected procurement cost is lower under the identified outcome than under the outcome in Case 1 with $i = 2$.

Because $c_{1H}^e > c_{2H}^e$, expected procurement cost is lower under the outcome in Case 1 with $i = 2$ than under the outcome in Case 1 with $i = 1$.

Because $c_{2L}^e + \overline{k}_2 < c_{1L}^e + \overline{k}_1$, Conclusion 3 implies that expected procurement cost is lower under the identified outcome than under the outcome in Case 2 with $i = 1$.

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

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

$$\Leftrightarrow \quad [\, 1 - \phi_2 \,]\,[\, c_{2H}^e - c_{2L}^e \,] \;>\; \overline{k}_2 - \phi_2 \, \underline{k}_2 \;=\; [\, 1 - \phi_2 \,]\, \underline{k}_2 + \overline{k}_2 - \underline{k}_2$$

$$\Leftrightarrow \quad c_{2H}^e - c_{2L}^e \;>\; \underline{k}_2 + \frac{\overline{k}_2 - \underline{k}_2}{1 - \phi_2}\,. \tag{2}$$

Expected procurement cost is lower under the identified outcome than under the outcome in Case 3 with $i = 1$ if:

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

$$\Leftrightarrow \quad c_{1H}^e - (c_{2L}^e + \overline{k}_2) \;>\; \phi_1 \,[\, c_{1H}^e - (c_{1L}^e + \underline{k}_1) \,]. \tag{3}$$

Conclusions 3 and 5 imply that expected procurement cost is lower under the identified outcome than under the outcome in Case 4 if:

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

$$\Leftrightarrow \quad c_{2L}^e + \overline{k}_2 - \phi_2 \,[\, c_{2L}^e + \underline{k}_2 \,] - \phi_1 \,[\, 1 - \phi_2 \,]\,[\, c_{1L}^e + \underline{k}_1 \,]$$

$$- \; c_{1H}^e + \phi_1 \,[\, 1 - \phi_2 \,]\, c_{1H}^e + \phi_2 \, c_{1H}^e \;<\; 0$$

$$\Leftrightarrow \quad c_{1H}^e - \big(c_{2L}^e + \overline{k}_2 \big) \;>\; \phi_2 \,[\, c_{1H}^e - (c_{2L}^e + \underline{k}_2) \,] + \phi_1 \,[\, 1 - \phi_2 \,]\,[\, c_{1H}^e - (c_{1L}^e + \underline{k}_1) \,]\,. \tag{4}$$

Conclusions 3 and 6 imply that expected procurement cost is lower under the identified outcome than under the outcome in Case 5 if:

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

$$\Leftrightarrow \quad c_{2L}^e + \overline{k}_2 - \phi_1 \,[\, c_{1L}^e + \underline{k}_1 \,] - [\, 1 - \phi_1 \,]\, \phi_2 \,[\, c_{2L}^e + \underline{k}_2 \,]$$

$$- \; c^e_{2H} + \phi_2 \, [\, 1 - \phi_1 \,] \, c^e_{2H} + \phi_1 \, c^e_{2H} \;<\; 0$$

$$\Leftrightarrow \quad c^e_{2H} - \big(c^e_{2L} + \overline{k}_2 \big) \;>\; \phi_1 \, [\, c^e_{2H} - (c^e_{1L} + \underline{k}_1) \,] + \phi_2 \, [\, 1 - \phi_1 \,] \, [\, c^e_{2H} - (c^e_{2L} + \underline{k}_2) \,] \, . \tag{5}$$

Conclusions 3 and 9 imply that expected procurement cost is lower under the identified outcome than under the outcome in Case 8 if:

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

$$\Leftrightarrow \quad c^e_{1H} - \big(c^e_{2L} + \overline{k}_2 \big) \;>\; \phi_2 \, [\, c^e_{1H} - (c^e_{2L} + \underline{k}_2) \,] \, . \tag{6}$$

Conclusions 3 and 10 imply that expected procurement cost is lower under the identified outcome than under the outcome in Case 9 if:

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

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

Conclusions 3 and 11 imply that expected procurement cost is lower under the identified outcome than under the outcome in Case 10 if:

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

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

$$- \; c^e_{2H} + \phi_1 \, [\, 1 - \phi_2 \,] \, c^e_{2H} + \phi_2 \, c^e_{2H} \;<\; 0$$

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

Conclusions 3 and 12 imply that expected procurement cost is lower under the identified outcome than under the outcome in Case 11 if:

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

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

$$- \; c^e_{1H} + \phi_2 \, [\, 1 - \phi_1 \,] \, c^e_{1H} + \phi_1 \, c^e_{1H} \;<\; 0$$

$$\Leftrightarrow \quad c^e_{1H} - \big(c^e_{2L} + \overline{k}_2 \big) \;>\; \phi_1 \, [\, c^e_{1H} - (c^e_{1L} + \underline{k}_1) \,] + \phi_2 \, [\, 1 - \phi_1 \,] \, [\, c^e_{1H} - (c^e_{2L} + \underline{k}_2) \,] \, . \tag{9}$$

(3), (4), (6), and (9) imply that expected procurement cost is lower under the identified outcome than under the outcomes in Case 3 with $i = 1$, Case 4, Case 8, and Case 11 if:

$$\begin{aligned} c^e_{1H} - (c^e_{2L} + \overline{k}_2) \;>\; \max \{ \, & \phi_1 \, [\, c^e_{1H} - (c^e_{1L} + \underline{k}_1) \,] \, , \; \phi_2 \, [\, c^e_{1H} - (c^e_{2L} + \underline{k}_2) \,] \, , \\ & \phi_2 \, [\, c^e_{1H} - (c^e_{2L} + \underline{k}_2) \,] + \phi_1 \, [\, 1 - \phi_2 \,] \, [\, c^e_{1H} - (c^e_{1L} + \underline{k}_1) \,] \, , \\ & \phi_1 \, [\, c^e_{1H} - (c^e_{1L} + \underline{k}_1) \,] + \phi_2 \, [\, 1 - \phi_1 \,] \, [\, c^e_{1H} - (c^e_{2L} + \underline{k}_2) \,] \, \} \, . \end{aligned} \tag{10}$$

Observe that:

$$\begin{aligned}
&\phi_2\,[\,c^e_{1H} - (c^e_{2L} + \underline{k}_2)\,] + \phi_1\,[\,1 - \phi_2\,]\,[\,c^e_{1H} - (c^e_{1L} + \underline{k}_1)\,] \\
&\qquad\qquad > \ \phi_1\,[\,c^e_{1H} - (c^e_{1L} + \underline{k}_1)\,] + \phi_2\,[\,1 - \phi_1\,]\,[\,c^e_{1H} - (c^e_{2L} + \underline{k}_2)\,] \\
\Leftrightarrow \quad &\phi_1\,\phi_2\,[\,c^e_{1H} - (c^e_{2L} + \underline{k}_2)\,] \ > \ \phi_1\,\phi_2\,[\,c^e_{1H} - (c^e_{1L} + \underline{k}_1)\,] \\
\Leftrightarrow \quad &\phi_1\,\phi_2\,[\,c^e_{1L} + \underline{k}_1 - (c^e_{2L} + \underline{k}_2)\,] \ > \ 0\,. \qquad (11)
\end{aligned}$$

The inequality in (11) holds because $c^e_{1L} + \underline{k}_1 \ > \ c^e_{2L} + \overline{k}_2 \ > \ c^e_{2L} + \underline{k}_2$.

Also observe that:

$$\phi_2\,[\,c^e_{1H} - (c^e_{2L} + \underline{k}_2)\,] + \phi_1\,[\,1 - \phi_2\,]\,[\,c^e_{1H} - (c^e_{1L} + \underline{k}_1)\,] \ > \ \phi_2\,[\,c^e_{1H} - (c^e_{2L} + \underline{k}_2)\,] \qquad (12)$$

because $c^e_{1H} > c^e_{1L} + \underline{k}_1$.

Furthermore:

$$\begin{aligned}
&\phi_2\,[\,c^e_{1H} - (c^e_{2L} + \underline{k}_2)\,] + \phi_1\,[\,1 - \phi_2\,]\,[\,c^e_{1H} - (c^e_{1L} + \underline{k}_1)\,] \ > \ \phi_1\,[\,c^e_{1H} - (c^e_{1L} + \underline{k}_1)\,] \\
&\qquad \Leftrightarrow \quad \phi_2\,\{\,c^e_{1H} - (c^e_{2L} + \underline{k}_2) - \phi_1\,[\,c^e_{1H} - (c^e_{1L} + \underline{k}_1)\,]\,\} \ > \ 0\,. \qquad (13)
\end{aligned}$$

The inequality in (13) holds because $c^e_{1H} - (c^e_{2L} + \underline{k}_2) \ > \ c^e_{1H} - (c^e_{1L} + \underline{k}_1)$, since $c^e_{1L} + \underline{k}_1 \ > \ c^e_{2L} + \overline{k}_2 \ > \ c^e_{2L} + \underline{k}_2$.

(11), (12), and (13) imply that (10) holds if:

$$c^e_{1H} - \left(c^e_{2L} + \overline{k}_2\right) \ > \ \phi_2\,[\,c^e_{1H} - (c^e_{2L} + \underline{k}_2)\,] + \phi_1\,[\,1 - \phi_2\,]\,[\,c^e_{1H} - (c^e_{1L} + \underline{k}_1)\,]\,. \qquad (14)$$

(5), (7), and (8) imply that expected procurement cost is lower under the identified outcome than under the outcomes in Case 5, Case 9, and Case 10 if:

$$\begin{aligned}
c^e_{2H} - \left(c^e_{2L} + \overline{k}_2\right) \ > \ \max\{\,&\phi_1\,[\,c^e_{2H} - (c^e_{1L} + \underline{k}_1)\,] + \phi_2\,[\,1 - \phi_1\,]\,[\,c^e_{2H} - (c^e_{2L} + \underline{k}_2)\,]\,, \\
&\phi_2\,[\,c^e_{2H} - (c^e_{2L} + \underline{k}_2)\,] + \phi_1\,[\,1 - \phi_2\,]\,[\,c^e_{2H} - (c^e_{1L} + \underline{k}_1)\,]\,, \\
&\phi_1\,[\,c^e_{2H} - (c^e_{1L} + \underline{k}_1)\,]\,\}. \qquad (15)
\end{aligned}$$

Observe that:

$$\begin{aligned}
&\phi_2\,[\,c^e_{2H} - (c^e_{2L} + \underline{k}_2)\,] + \phi_1\,[\,1 - \phi_2\,]\,[\,c^e_{2H} - (c^e_{1L} + \underline{k}_1)\,] \\
&\qquad\qquad > \ \phi_1\,[\,c^e_{2H} - (c^e_{1L} + \underline{k}_1)\,] + \phi_2\,[\,1 - \phi_1\,]\,[\,c^e_{2H} - (c^e_{2L} + \underline{k}_2)\,] \\
\Leftrightarrow \quad &\phi_1\,\phi_2\,[\,c^e_{2H} - (c^e_{2L} + \underline{k}_2)\,] \ > \ \phi_1\,\phi_2\,[\,c^e_{2H} - (c^e_{1L} + \underline{k}_1)\,] \\
\Leftrightarrow \quad &\phi_1\,\phi_2\,[\,c^e_{1L} + \underline{k}_1 - (c^e_{2L} + \underline{k}_2)\,] \ > \ 0\,. \qquad (16)
\end{aligned}$$

The inequality in (16) holds because $c^e_{1L} + \underline{k}_1 \ > \ c^e_{2L} + \overline{k}_2 \ > \ c^e_{2L} + \underline{k}_2$.

Also observe that:

$$\phi_2 \left[\, c^e_{2H} - (c^e_{2L} + \underline{k}_2) \,\right] + \phi_1 \left[\, 1 - \phi_2 \,\right] \left[\, c^e_{2H} - (c^e_{1L} + \underline{k}_1) \,\right] \;>\; \phi_1 \left[\, c^e_{2H} - (c^e_{1L} + \underline{k}_1) \,\right]$$

$$\Leftrightarrow \quad \phi_2 \left\{\, c^e_{2H} - (c^e_{2L} + \underline{k}_2) - \phi_1 \left[\, c^e_{2H} - (c^e_{1L} + \underline{k}_1) \,\right] \right\} \;>\; 0\,. \tag{17}$$

The inequality in (17) holds because because $c^e_{2H} - (c^e_{2L} + \underline{k}_2) \;>\; c^e_{2H} - (c^e_{1L} + \underline{k}_1)$, since $c^e_{1L} + \underline{k}_1 \;>\; c^e_{2L} + \overline{k}_2 \;>\; c^e_{2L} + \underline{k}_2$.

(16) and (17) imply that (15) holds if:

$$c^e_{2H} - \left(c^e_{2L} + \overline{k}_2\right) \;>\; \phi_2 \left[\, c^e_{2H} - (c^e_{2L} + \underline{k}_2) \,\right] + \phi_1 \left[\, 1 - \phi_2 \,\right] \left[\, c^e_{2H} - (c^e_{1L} + \underline{k}_1) \,\right]. \tag{18}$$

Let $\widehat{\phi}^A_1$ and $\widehat{\phi}^A_2$ denote the values of ϕ_1 and ϕ_2 at which (14) and (18) hold as equalities. Because $c^e_{1H} > c^e_{2H} > c^e_{1L} + \underline{k}_1 > c^e_{2L} + \underline{k}_2$, it is readily verified that the right hand side of each of these inequalities increases as ϕ_1 increases or ϕ_2 increases. Therefore, the inequalities will be satisfied if $\phi_1 < \widehat{\phi}^A_1$ and $\phi_2 < \widehat{\phi}^A_2$.

From (18):

$$c^e_{2H} - \left(c^e_{2L} + \overline{k}_2\right) \;=\; \widehat{\phi}^A_2 \left[\, c^e_{2H} - (c^e_{2L} + \underline{k}_2) \,\right] + \widehat{\phi}^A_1 \left[\, 1 - \widetilde{\phi}^A_2 \,\right] \left[\, c^e_{2H} - (c^e_{1L} + \underline{k}_1) \,\right]$$

$$\Leftrightarrow \quad \widehat{\phi}^A_1 \;=\; \frac{c^e_{2H} - \left(c^e_{2L} + \overline{k}_2\right) - \widehat{\phi}^A_2 \left[\, c^e_{2H} - (c^e_{2L} + \underline{k}_2) \,\right]}{\left[\, 1 - \widetilde{\phi}^A_2 \,\right] \left[\, c^e_{2H} - (c^e_{1L} + \underline{k}_1) \,\right]}\,. \tag{19}$$

(14) and (19) imply:

$$c^e_{1H} - \left(c^e_{2L} + \overline{k}_2\right) \;=\; \widehat{\phi}^A_2 \left[\, c^e_{1H} - (c^e_{2L} + \underline{k}_2) \,\right] + \widehat{\phi}^A_1 \left[\, 1 - \widehat{\phi}^A_2 \,\right] \left[\, c^e_{1H} - (c^e_{1L} + \underline{k}_1) \,\right]$$

$$\Leftrightarrow \quad c^e_{1H} - (c^e_{2L} + \overline{k}_2) \;=\; \widehat{\phi}^A_2 \left[\, c^e_{1H} - (c^e_{2L} + \underline{k}_2) \,\right]$$

$$+ \; \frac{\left[\, c^e_{2H} - \left(c^e_{2L} + \overline{k}_2\right) - \widehat{\phi}^A_2 \left(\, c^e_{2H} - \left[\, c^e_{2L} + \underline{k}_2 \,\right] \right) \right] \left[\, c^e_{1H} - (c^e_{1L} + \underline{k}_1) \,\right]}{c^e_{2H} - (c^e_{1L} + \underline{k}_1)}$$

$$\Leftrightarrow \quad \left[\, c^e_{1H} - \left(c^e_{2L} + \overline{k}_2\right) \right] \left[\, c^e_{2H} - (c^e_{1L} + \underline{k}_1) \,\right] \;=\; \widehat{\phi}^A_2 \left[\, c^e_{1H} - (c^e_{2L} + \underline{k}_2) \,\right] \left[\, c^e_{2H} - (c^e_{1L} + \underline{k}_1) \,\right]$$

$$+ \left\{\, c^e_{2H} - \left(c^e_{2L} + \overline{k}_2\right) - \widehat{\phi}^A_2 \left[\, c^e_{2H} - (c^e_{2L} + \underline{k}_2) \,\right] \right\} \left[\, c^e_{1H} - (c^e_{1L} + \underline{k}_1) \,\right]$$

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

$$= \; \widehat{\phi}^A_2 \left\{ \left[\, c^e_{1H} - (c^e_{2L} + \underline{k}_2) \,\right] \left[\, c^e_{2H} - (c^e_{1L} + \underline{k}_1) \,\right] - \left[\, c^e_{2H} - (c^e_{2L} + \underline{k}_2) \,\right] \left[\, c^e_{1H} - (c^e_{1L} + \underline{k}_1) \,\right] \right\}$$

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

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

$$= \; \widehat{\phi}^A_2 \left\{\, c^e_{1H}\, c^e_{2H} - c^e_{1H} \left[\, c^e_{1L} + \underline{k}_1 \,\right] - c^e_{2H} \left[\, c^e_{2L} + \underline{k}_2 \,\right] + \left[\, c^e_{1L} + \underline{k}_1 \,\right] \left[\, c^e_{2L} + \underline{k}_2 \,\right] \right\}$$

$$- \ \widehat{\phi}_2^A \{ c_{1H}^e c_{2H}^e - c_{1H}^e [c_{2L}^e + \underline{k}_2] - c_{2H}^e [c_{1L}^e + \underline{k}_1] + [c_{1L}^e + \underline{k}_1] [c_{2L}^e + \underline{k}_2] \}$$

$$\Leftrightarrow \quad [c_{1H}^e - c_{2H}^e] \left[c_{2L}^e + \overline{k}_2 - (c_{1L}^e + \underline{k}_1) \right] \ = \ \widehat{\phi}_2^A [c_{1H}^e - c_{2H}^e] [c_{2L}^e + \underline{k}_2 - (c_{1L}^e + \underline{k}_1)]$$

$$\Leftrightarrow \quad \widehat{\phi}_2^A \ = \ \frac{c_{1L}^e + \underline{k}_1 - (c_{2L}^e + \overline{k}_2)}{c_{1L}^e + \underline{k}_1 - (c_{2L}^e + \underline{k}_2)} = \ \widetilde{\phi}_2^A \, . \tag{20}$$

(20) implies:

$$1 - \widetilde{\phi}_2^A \ = \ \frac{c_{1L}^e + \underline{k}_1 - (c_{2L}^e + \underline{k}_2) - \left\{ c_{1L}^e + \underline{k}_1 - \left(c_{2L}^e + \overline{k}_2 \right) \right\}}{c_{1L}^e + \underline{k}_1 - (c_{2L}^e + \underline{k}_2)}$$

$$= \ \frac{\overline{k}_2 - \underline{k}_2}{c_{1L}^e + \underline{k}_1 - (c_{2L}^e + \underline{k}_2)} \, . \tag{21}$$

(19) – (21) imply:

$$\widehat{\phi}_1^A \ = \ \frac{c_{1L}^e + \underline{k}_1 - (c_{2L}^e + \underline{k}_2)}{\left[\overline{k}_2 - \underline{k}_2 \right] [c_{2H}^e - (c_{1L}^e + \underline{k}_1)]} \left\{ c_{2H}^e - \left(c_{2L}^e + \overline{k}_2 \right) - \widetilde{\phi}_2^A [c_{2H}^e - (c_{2L}^e + \underline{k}_2)] \right\}$$

$$= \ \frac{c_{1L}^e + \underline{k}_1 - (c_{2L}^e + \underline{k}_2)}{\left[\overline{k}_2 - \underline{k}_2 \right] [c_{2H}^e - (c_{1L}^e + \underline{k}_1)]} \times$$

$$\left\{ \frac{\left[c_{2H}^e - \left(c_{2L}^e + \overline{k}_2 \right) \right] [c_{1L}^e + \underline{k}_1 - (c_{2L}^e + \underline{k}_2)] - \left[c_{1L}^e + \underline{k}_1 - \left(c_{2L}^e + \overline{k}_2 \right) \right] [c_{2H}^e - (c_{2L}^e + \underline{k}_2)]}{c_{1L}^e + \underline{k}_1 - (c_{2L}^e + \underline{k}_2)} \right\}$$

$$= \ \frac{1}{\left[\overline{k}_2 - \underline{k}_2 \right] [c_{2H}^e - (c_{1L}^e + \underline{k}_1)]} \{ \left[c_{2H}^e - \left(c_{2L}^e + \overline{k}_2 \right) \right] [c_{1L}^e + \underline{k}_1 - (c_{2L}^e + \underline{k}_2)]$$

$$- \ \left[c_{1L}^e + \underline{k}_1 - \left(c_{2L}^e + \overline{k}_2 \right) \right] [c_{2H}^e - (c_{2L}^e + \underline{k}_2)] \}$$

$$= \ \frac{1}{\left[\overline{k}_2 - \underline{k}_2 \right] [c_{2H}^e - (c_{1L}^e + \underline{k}_1)]} \{ - c_{2H}^e [c_{2L}^e + \underline{k}_2] - [c_{1L}^e + \underline{k}_1] \left[c_{2L}^e + \overline{k}_2 \right]$$

$$+ \ c_{2H}^e \left[c_{2L}^e + \overline{k}_2 \right] + [c_{1L}^e + \underline{k}_1] [c_{2L}^e + \underline{k}_2] \}$$

$$= \ \frac{\left[\overline{k}_2 - \underline{k}_2 \right] [c_{2H}^e - (c_{1L}^e + \underline{k}_1)]}{\left[\overline{k}_2 - \underline{k}_2 \right] [c_{2H}^e - (c_{1L}^e + \underline{k}_1)]} \ = \ 1 \, . \tag{22}$$

(20) and (22) imply that inequalities (3) – (9) hold if $\phi_2 < \widetilde{\phi}_2^A$ and $\phi_1 < \widehat{\phi}_1^A = 1$.

It remains to verify that inequality (2) holds when $\phi_2 < \widetilde{\phi}_2^A$. From (2):

$$c_{2H}^e - c_{2L}^e \ > \ \underline{k}_2 + \frac{\overline{k}_2 \ - \ \underline{k}_2}{1 \ - \ \phi_2} \quad \Leftrightarrow \quad 1 - \phi_2 \ > \ \frac{\overline{k}_2 \ - \ \underline{k}_2}{c_{2H}^e - (c_{2L}^e + \underline{k}_2)} \, . \tag{23}$$

Because $1 - \phi_2$ is decreasing in ϕ_2, if the inequality in (23) holds at $\phi_2 = \widetilde{\phi}_2^A$, then it holds for all $\phi_2 < \widetilde{\phi}_2^A$. (21) implies that when $\phi_2 = \widetilde{\phi}_2^A$, (23) can be written as:

$$\frac{\overline{k}_2 - \underline{k}_2}{c_{1L}^e + \underline{k}_1 - (c_{2L}^e + \underline{k}_2)} > \frac{\overline{k}_2 - \underline{k}_2}{c_{2H}^e - (c_{2L}^e + \underline{k}_2)}$$

$$\Leftrightarrow \quad c_{2H}^e - (c_{2L}^e + \underline{k}_2) > c_{1L}^e + \underline{k}_1 - (c_{2L}^e + \underline{k}_2) \quad \Leftrightarrow \quad c_{2H}^e > c_{1L}^e + \underline{k}_1 \,.$$

These findings imply that in the absence of self-sabotage under the specified conditions, the regulator will induce the utility to undertake project 2 with consistent cost management (i.e., induce the outcome in Case 2 with $i = 2$).

It remains to demonstrate that the utility will not undertake self-sabotage of its cost management activities. First suppose $\phi_2 \left[\overline{k}_2 - \underline{k}_2 \right] \geq \phi_1 \left[\overline{k}_1 - \underline{k}_1 \right]$. Then Lemma 1 implies that the utility secures the maximum feasible level of profit in the absence of self-sabotage. If self-sabotage does not affect the regulator's decision to induce the outcome in Case 2 with $i = 2$, Conclusion 3 implies that the utility's expected profit given self-sabotage $s_{1\phi}$ and $s_{2\phi}$ is:

$$\pi(s_{1\phi}, s_{2\phi}) = [\phi_2 - s_{2\phi}] \left[\overline{k}_2 - \underline{k}_2 \right] - C_\phi(s_{1\phi}, s_{2\phi})$$

$$\Rightarrow \quad \frac{\partial \pi(\cdot)}{\partial s_{1\phi}} = -\frac{\partial C_\phi(\cdot)}{\partial s_{1\phi}} \leq 0 \text{ and } \frac{\partial \pi(\cdot)}{\partial s_{2\phi}} = -\left[\overline{k}_2 - \underline{k}_2 \right] - \frac{\partial C_\phi(\cdot)}{\partial s_{2\phi}} < 0 \,.$$

Therefore, the utility will set $s_{1\phi} = s_{2\phi} = 0$ if self-sabotage does not affect the regulator's decision to induce the outcome in Case 2 with $i = 2$. Furthermore, Lemma 1 implies that when $\phi_2 \left[\overline{k}_2 - \underline{k}_2 \right] \geq \phi_1 \left[\overline{k}_1 - \underline{k}_1 \right]$, if self-sabotage leads the regulator to induce an outcome other than the outcome in Case 2 with $i = 2$, then the utility's rent will not exceed the rent it secures by setting $s_{1\phi} = s_{2\phi} = 0$.

Now suppose $\phi_1 \left[\overline{k}_1 - \underline{k}_1 \right] > \phi_2 \left[\overline{k}_2 - \underline{k}_2 \right]$. Lemma 1 implies that self-sabotage (of cost management) can only increase the utility's expected profit if the self-sabotage causes the regulator to induce the utility to always undertake project 1 and exercise consistent cost management. Such self-sabotage cannot do so when the identified conditions hold because $c_{1L}^e + \overline{k}_1 > c_{2L}^e + \overline{k}_2$. Therefore, from Conclusion 3, the regulator's expected procurement cost would be higher if she induced the outcome in Case 2 with $i = 1$ than if she induced the outcome in Case 2 with $i = 2$. Consequently, $s_{1\phi} > 0$ or $s_{2\phi} > 0$ would not increase the utility's expected profit. ■

Proof of Proposition 2

Proposition 1 implies that in the absence of self-sabotage under the specified conditions, the regulator will induce the utility to always undertake project 2 and exercise consistent cost management (i.e., induce the outcome in Case 2 with $i = 2$). Consequently, from Lemma 1, the utility's expected profit will be $\phi_2 \left[\overline{k}_2 - \underline{k}_2 \right]$.

Now suppose the utility sets s_{2H} and s_{2L} at levels that ensure the regulator's expected procurement cost exceeds $c_{1L}^e + \overline{k}_1$ whenever the utility is induced to undertake project 2 with positive probability. Therefore, because $c_{1L}^e + \overline{k}_1 \leq c_{1H}^e$ from Assumption 1, the regulator will optimally induce the utility to always undertake project 1 and exercise consistent cost management. Lemma 1 implies that in this event, the utility secures the maximum possible expected profit, $\phi_1 \left[\overline{k}_1 - \underline{k}_1 \right] > \phi_2 \left[\overline{k}_2 - \underline{k}_2 \right]$, when the identified self-sabotage entails no personal cost for the utility. Therefore, the utility will set $s_{2L} > 0$ and/or $s_{2H} > 0$ if the associated personal cost $C(\cdot)$ is sufficiently small. ■

Proof of Lemma 2

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. The proof parallels the proof of Proposition 1, and so is omitted.[45]

Proof of Proposition 3

Lemma 2 implies that in the absence of self-sabotage in this setting, the regulator will induce the outcome in Case 3 with $i = 2$. Lemma 1 implies that the utility's expected profit is 0 in this case.

Lemma 1 also implies that self-sabotage will only increase the utility's expected profit if it leads the regulator to induce the outcome in Case 2. Conclusions 3 and 4 imply that self-sabotage will lead the regulator to induce the outcome in Case 2 with $i = 2$ rather than the outcome in Case 3 with $i = 2$ if:

$$
\begin{aligned}
& c^e_{2L} + \overline{k}_2 \ \leq \ [\, \phi_2 - s_{2\phi} \,] \, [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 + s_{2\phi} \,] \, c^e_{2H} \\
\Leftrightarrow \quad & c^e_{2H} - \left(c^e_{2L} + \overline{k}_2 \right) \ \geq \ [\, \phi_2 - s_{2\phi} \,] \, [\, c^e_{2H} - (c^e_{2L} + \underline{k}_2) \,] \\
\Leftrightarrow \quad & \phi_2 - s_{2\phi} \ \leq \ \frac{c^e_{2H} - \left(c^e_{2L} + \overline{k}_2 \right)}{c^e_{2H} - \left(c^e_{2L} + \underline{k}_2 \right)} \ = \ \widetilde{\phi}^B_2 \quad \Leftrightarrow \quad s_{2\phi} \ \geq \ \phi_2 - \widetilde{\phi}^B_2 \, .
\end{aligned}
$$

Lemma 1 implies that when the utility sets $s_{2\phi} \geq \phi_2 - \widetilde{\phi}^B_2$, its expected profit under the outcome in Case 2 with $i = 2$ is $[\, \phi_2 - s_{2\phi} \,] \left[\overline{k}_2 - \underline{k}_2 \right]$. Therefore, when: (i) $s_{2\phi} > 0$ entails no personal cost for the utility; and (ii) the utility sets $s_{2\phi} \geq \phi_2 - \widetilde{\phi}^B_2$ to induce the regulator to implement the outcome in Case 2 with $i = 2$, the utility will maximize its profit by setting $s_{2\phi} = \phi_2 - \widetilde{\phi}^B_2 > 0$.

$c^e_{1L} + \overline{k}_1 > c^e_{2L} + \overline{k}_2$ when the conditions in Lemma 2 hold. Therefore, self-sabotage $s_{1\phi} > 0$ would not induce the regulator to implement the outcome in Case 2 with $i = 1$. Furthermore, $s_{1\phi} > 0$ would not increase the utility's rent when $k_2 = \underline{k}_2$, increase the likelihood that $k_2 = \underline{k}_2$, or cause the regulator to induce the utility to undertake project 1. Also, as demonstrated below, $s_{1\phi} > 0$ is not required to ensure the regulator will induce the outcome in Case 2 with $i = 2$ when $s_{2\phi} = \phi_2 - \widetilde{\phi}^B_2$. Therefore, self-sabotage $s_{1\phi} > 0$ would not increase the utility's expected profit.

It remains to verify that the regulator's expected procurement cost is minimized by inducing the outcome in Case 2 with $i = 2$ when $s_{2\phi} = \phi_2 - \widetilde{\phi}^B_2$ and $s_{1\phi} = 0$. The regulator's expected procurement cost in this event is:

[45] The proof is provided in Brown and Sappington (2017b).

$$c^e_{2L} + \overline{k}_2 \;=\; \widetilde{\phi}^B_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + \left[\, 1 - \widetilde{\phi}^B_2 \,\right] c^e_{2H} \,. \tag{24}$$

Lemmas 4 and 5 hold for all values of ϕ_2. Therefore, Lemma 6 continues to hold when $s_{2\phi} > 0$. Consequently, it only needs to be shown that $c^e_{2L} + \overline{k}_2 \;\leq\; \min\limits_i \{EP_i\}$ for $i \in \{1, 2, 3, 4, 5, 8, 9, 10, 11\}$, where EP_i denotes the minimum possible expected procurement costs under the outcome in Case i.

When the conditions in Lemma 2 hold:

$$c^e_{2L} + \overline{k}_2 \;<\; c^e_{1L} + \overline{k}_1 \;\leq\; c^e_{1H} \;\text{ and }\; c^e_{2L} + \overline{k}_2 \;\leq\; c^e_{2H} \;<\; c^e_{1L} + \underline{k}_1 \;<\; c^e_{1H} \,. \tag{25}$$

It is apparent from (24), (25), and Conclusions 2, 3, 4, and 10 that $\min\{EP_1, EP_2, EP_3, EP_9\} \geq c^e_{2L} + \overline{k}_2$.

(24), (25), and Conclusion 5 imply:

$$\begin{aligned} EP_4 \;&=\; \widetilde{\phi}^B_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + \left[\, 1 - \widetilde{\phi}^B_2 \,\right] \{\, \phi_1 \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \, c^e_{1H} \,\} \\ &\geq\; \widetilde{\phi}^B_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + \left[\, 1 - \widetilde{\phi}^B_2 \,\right] [\, c^e_{1L} + \underline{k}_1 \,] \\ &>\; \widetilde{\phi}^B_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + \left[\, 1 - \widetilde{\phi}^B_2 \,\right] c^e_{2H} \;=\; c^e_{2L} + \overline{k}_2 \,. \end{aligned}$$

(24), (25), and Conclusion 6 imply:

$$\begin{aligned} EP_5 \;&=\; \phi_1 \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \left\{ \widetilde{\phi}^B_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + \left[\, 1 - \widetilde{\phi}^B_2 \,\right] c^e_{2H} \right\} \\ &>\; \phi_1 \left[\, c^e_{2L} + \overline{k}_2 \,\right] + [\, 1 - \phi_1 \,] \left[\, c^e_{2L} + \overline{k}_2 \,\right] \;=\; c^e_{2L} + \overline{k}_2 \,. \end{aligned}$$

(24) and Conclusion 9 imply:

$$\begin{aligned} EP_8 \;&=\; \widetilde{\phi}^B_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + \left[\, 1 - \widetilde{\phi}^B_2 \,\right] c^e_{1H} \\ &>\; \widetilde{\phi}^B_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + \left[\, 1 - \widetilde{\phi}^B_2 \,\right] c^e_{2H} \;=\; c^e_{2L} + \overline{k}_2 \,. \end{aligned}$$

(24), (25), and Conclusion 11 imply:

$$\begin{aligned} EP_{10} \;&=\; \widetilde{\phi}^B_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + \left[\, 1 - \widetilde{\phi}^B_2 \,\right] \{\, \phi_1 \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \, c^e_{2H} \,\} \\ &>\; \widetilde{\phi}^B_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + \left[\, 1 - \widetilde{\phi}^B_2 \,\right] c^e_{2H} \;=\; c^e_{2L} + \overline{k}_2 \,. \end{aligned}$$

(24), (25), and Conclusion 12 imply:

$$\begin{aligned} EP_{11} \;&=\; \phi_1 \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \left\{ \widetilde{\phi}^B_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + \left[\, 1 - \widetilde{\phi}^B_2 \,\right] c^e_{1H} \right\} \\ &>\; \phi_1 \, [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \left\{ \widetilde{\phi}^B_2 \, [\, c^e_{2L} + \underline{k}_2 \,] + \left[\, 1 - \widetilde{\phi}^B_2 \,\right] c^e_{2H} \right\} \end{aligned}$$

$$= \phi_1 [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \left[\, c^e_{2L} + \overline{k}_2 \,\right] \; > \; c^e_{2L} + \overline{k}_2 \, . \quad \blacksquare$$

Proof of Proposition 4

Lemma 2 implies that in the absence of self-sabotage in this setting, the regulator will induce the outcome in Case 3 with $i = 2$. Lemma 1 implies that the utility's expected profit is 0 in this case. Lemma 1 also implies that self-sabotage $s_{1H} > 0$ and/or $s_{2H} > 0$ will increase the utility's expected profit to its highest possible level if the self-sabotage leads the regulator to induce the outcome in Case 2 with $i = 2$.

Define $\widetilde{c}^e_{iH} \equiv [\, p_{iH} - s_{iH} \,] \, \underline{c}_i + [\, 1 - p_{iH} + s_{iH} \,] \, \overline{c}_i$. Lemmas 4 and 5 hold for all values of $\widetilde{c}^e_{iH} \geq c^e_{iH}$ for $i \in \{1, 2\}$. Therefore, Lemma 6 continues to hold when $s_{1H} > 0$ and/or $s_{2H} > 0$. Consequently, to ensure the regulator minimizes expected procurement cost by inducing the outcome in Case 2 with $i = 2$, it only needs to be shown that $c^e_{2L} + \overline{k}_2 \; \leq \; \min\limits_i \{ EP_i \}$ for $i \in \{1, 2, 3, 4, 5, 8, 9, 10, 11\}$.

When the conditions in Lemma 2 hold:

$$c^e_{2L} + \overline{k}_2 \; < \; c^e_{1L} + \overline{k}_1 \; \leq \; c^e_{1H} \; \leq \; \widetilde{c}^e_{1H} \; ; \quad c^e_{2H} \; \leq \; \widetilde{c}^e_{2H}; \quad \text{and}$$

$$c^e_{2L} + \overline{k}_2 \; \leq \; c^e_{2H} \; < \; c^e_{1L} + \underline{k}_1 \; < \; c^e_{1H} \; \leq \; \widetilde{c}^e_{1H} \, . \tag{26}$$

It is apparent from (26) and Conclusions 2, 3, 4, and 10 that $\min \{ EP_1, EP_2, EP_3 \big|_{i=1}, EP_9 \} \geq c^e_{2L} + \overline{k}_2$. Furthermore, (26) and Conclusions 5 and 9 imply that $EP_4 < EP_8$. Therefore, the regulator will minimize expected procurement cost by inducing the outcome in Case 2 with $i = 2$ if $c^e_{2L} + \overline{k}_2 \; \leq \; \min \{ EP_3 \big|_{i=2}, EP_4, EP_5, EP_{10}, EP_{11} \}$.

Conclusion 4 implies that when $s_{2H} = p_{2H}$ (so $\widetilde{c}^e_{2H} = \overline{c}_2$):

$$EP_3 \big|_{i=2} \; = \; \phi_2 [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 \,] \, \overline{c}_2 \; > \; c^e_{2L} + \overline{k}_2 \, .$$

Conclusion 5 implies that when $s_{1H} = p_{1H}$ (so $\widetilde{c}^e_{1H} = \overline{c}_1$):

$$\begin{aligned} EP_4 \; &= \; \phi_2 [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 \,] \{ \, \phi_1 [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \, \overline{c}_1 \, \} \\ &\geq \; \phi_2 [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 \,] \{ \, \phi_1 \, \overline{c}_2 + [\, 1 - \phi_1 \,] \, \overline{c}_1 \, \} \\ &\geq \; \phi_2 [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 \,] \min \{ \, \overline{c}_1, \overline{c}_2 \, \} \; > \; c^e_{2L} + \overline{k}_2 \, . \end{aligned}$$

Conclusion 6 implies that when $s_{2H} = p_{2H}$ (so $\widetilde{c}^e_{2H} = \overline{c}_2$):

$$\begin{aligned} EP_5 \; &= \; \phi_1 [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \{ \, \phi_2 [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 \,] \, \overline{c}_2 \, \} \\ &= \; \phi_2 [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 \,] \, \overline{c}_2 \\ &\qquad + \; \phi_1 [\, c^e_{1L} + \underline{k}_1 - \{ \, \phi_2 [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 \,] \, \overline{c}_2 \, \} \,] \\ &\geq \; \phi_2 [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 \,] \, \overline{c}_2 \; > \; c^e_{2L} + \overline{k}_2 \, . \end{aligned}$$

Conclusion 11 implies that when $s_{2H} = p_{2H}$ (so $\widetilde{c}^{e}_{2H} = \overline{c}_2$):

$$EP_{10} = \phi_2 [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 \,] \{\, \phi_1 [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \overline{c}_2 \,\}$$
$$\geq \phi_2 [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 \,] \overline{c}_2 \;>\; c^e_{2L} + \overline{k}_2 \,.$$

Conclusion 12 implies that when $s_{1H} = p_{1H}$ (so $\widetilde{c}^{e}_{1H} = \overline{c}_1$):

$$EP_{11} = \phi_1 [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \{\, \phi_2 [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 \,] \overline{c}_1 \,\}$$
$$> \phi_1 \left[\, c^e_{2L} + \overline{k}_2 \,\right] + [\, 1 - \phi_1 \,] \{\, \phi_2 [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 \,] \overline{c}_1 \,\}$$
$$> \phi_1 \left[\, c^e_{2L} + \overline{k}_2 \,\right] + [\, 1 - \phi_1 \,] \left[\, c^e_{2L} + \overline{k}_2 \,\right] = \; c^e_{2L} + \overline{k}_2 \,.$$

Finally, observe that even if self-sabotage $s_{1\phi} > 0$ and/or $s_{2\phi} > 0$ entailed no personal cost for the utility, such self-sabotage would not allow the utility to secure expected profit $\phi_2 \left[\, \overline{k}_2 - \underline{k}_2 \,\right]$. Proposition 3 implies that if $s_{1H} = s_{2H} = 0$, the maximum expected profit the utility can secure by setting $s_{1\phi} > 0$ and/or $s_{2\phi} > 0$ is $\widetilde{\phi}^{B}_{2} \left[\, \overline{k}_2 - \underline{k}_2 \,\right] < \phi_2 \left[\, \overline{k}_2 - \underline{k}_2 \,\right]$. ■

Proof of Corollary 1

The proof follows directly from the last paragraph in the proof of Proposition 4. ■

Proof of Lemma 3

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. This demonstration parallels the corresponding demonstration in Proposition 1, and so is omitted.[46]

Proof of Proposition 5

Lemma 3 implies that in the absence of self-sabotage, the regulator will induce the outcome in Case 10 under the specified conditions. Lemma 1 implies that the utility's expected profit is 0 in this case.

Lemma 1 also implies that self-sabotage will only increase the utility's expected profit if it leads the regulator to induce the outcome in Case 2. Conclusions 3 and 11 imply that self-sabotage $s_{2\phi}$ will lead the regulator to induce the outcome in Case 2 with $i = 2$ rather than the outcome in Case 10 if:

$$c^e_{2L} + \overline{k}_2 \;\leq\; [\, \phi_2 - s_{2\phi} \,] [\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 + s_{2\phi} \,] \{\, \phi_1 [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] c^e_{2H} \,\}$$
$$\Leftrightarrow \;\; \phi_1 [\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] c^e_{2H} - \left(c^e_{2L} + \overline{k}_2 \right)$$

[46] The proof is provided in Brown and Sappington (2017b).

$$\geq \; [\,\phi_2 - s_{2\phi}\,]\,\{\,\phi_1\,[\,c^e_{1L} + \underline{k}_1\,] + [\,1-\phi_1\,]\,c^e_{2H} - (c^e_{2L} + \underline{k}_2)\,\}$$

$$\Leftrightarrow \;\; \phi_2 - s_{2\phi} \;\leq\; \frac{\phi_1\,[\,c^e_{1L} + \underline{k}_1\,] + [\,1-\phi_1\,]\,c^e_{2H} - \left(c^e_{2L} + \overline{k}_2\right)}{\phi_1\,[\,c^e_{1L} + \underline{k}_1\,] + [\,1-\phi_1\,]\,c^e_{2H} - (c^e_{2L} + \underline{k}_2)} \;=\; \widetilde{\phi}^C_2$$

$$\Leftrightarrow \;\; s_{2\phi} \;\geq\; \phi_2 - \widetilde{\phi}^C_2\,.$$

Lemma 1 implies that when the utility sets $s_{2\phi} \geq \phi_2 - \widetilde{\phi}^C_2$, its expected profit under the outcome in Case 2 with $i = 2$ is $[\,\phi_2 - s_{2\phi}\,]\left[\,\overline{k}_2 - \underline{k}_2\,\right]$. Therefore, when: (i) $s_{2\phi} > 0$ entails no personal cost for the utility; and (ii) the utility sets $s_{2\phi} \geq \phi_2 - \widetilde{\phi}^C_2$ to induce the regulator to implement the outcome in Case 2 with $i = 2$, the utility will maximize its profit by setting $s_{2\phi} = \phi_2 - \widetilde{\phi}^C_2 > 0$.

When the conditions in Lemma 3 hold:

$$c^e_{2L} + \overline{k}_2 \;<\; c^e_{1L} + \underline{k}_1 \;<\; c^e_{2H} \;\leq\; c^e_{1H}\,. \tag{27}$$

(27) implies that $c^e_{1L} + \overline{k}_1 > c^e_{2L} + \overline{k}_2$. Therefore, self-sabotage $s_{1\phi} > 0$ would not induce the regulator to implement the outcome in Case 2 with $i = 1$. Furthermore, $s_{1\phi} > 0$ would not increase the utility's rent when $k_2 = \underline{k}_2$, increase the likelihood that $k_2 = \underline{k}_2$, or cause the regulator to induce the utility to undertake project 1. Also, as demonstrated below, $s_{1\phi} > 0$ is not required to ensure the regulator will induce the outcome in Case 2 with $i = 2$ when $s_{2\phi} = \phi_2 - \widetilde{\phi}^C_2$. Therefore, self-sabotage $s_{1\phi} > 0$ would not increase the utility's expected profit.

It remains to verify that the regulator's expected procurement cost is minimized by inducing the outcome in Case 2 with $i = 2$ when $s_{2\phi} = \phi_2 - \widetilde{\phi}^C_2$ and $s_{1\phi} = 0$. The regulator's expected procurement cost in this event is:

$$c^e_{2L} + \overline{k}_2 \;=\; \widetilde{\phi}^C_2\,[\,c^e_{2L} + \underline{k}_2\,] + \left[\,1 - \widetilde{\phi}^C_2\,\right]\{\,\phi_1\,[\,c^e_{1L} + \underline{k}_1\,] + [\,1-\phi_1\,]\,c^e_{2H}\,\}\,. \tag{28}$$

Lemmas 4 and 5 hold for all values of ϕ_2. Therefore, Lemma 6 continues to hold when $s_{2\phi} > 0$. Consequently, it only needs to be shown that $c^e_{2L} + \overline{k}_2 \leq \min_i \{EP_i\}$ for $i \in \{1, 2, 3, 4, 5, 8, 9, 10, 11\}$.

It is apparent from (27), (28), and Conclusions 2, 3, 5, 9, 10, and 11 that $c^e_{2L} + \overline{k}_2 \leq \min\{EP_1, EP_2, EP_4, EP_8, EP_9, EP_{10}\}$.

(27) and Conclusion 4 imply that when $i = 1$:

$$EP_3\big|_{i=1} \;=\; \phi_1\,[\,c^e_{1L} + \underline{k}_1\,] + [\,1-\phi_1\,]\,c^e_{1H} \;>\; c^e_{2L} + \overline{k}_2\,.$$

(27), (28), and Conclusion 4 imply that when $i = 2$:

$$EP_3\big|_{i=2} \;=\; \widetilde{\phi}^C_2\,[\,c^e_{2L} + \underline{k}_2\,] + \left[\,1 - \widetilde{\phi}^C_2\,\right] c^e_{2H}$$

$$> \; \widetilde{\phi}^C_2\,[\,c^e_{2L} + \underline{k}_2\,] + \left[\,1 - \widetilde{\phi}^C_2\,\right]\{\,\phi_1\,[\,c^e_{1L} + \underline{k}_1\,] + [\,1-\phi_1\,]\,c^e_{2H}\,\} \;=\; c^e_{2L} + \overline{k}_2\,.$$

(27), (28), and Conclusion 6 imply:

$$
\begin{aligned}
EP_5 \;&=\; \phi_1 \,[\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \left\{ \widetilde{\phi}^C_2 \,[\, c^e_{2L} + \underline{k}_2 \,] + \left[1 - \widetilde{\phi}^C_2 \right] c^e_{2H} \right\} \\
&>\; \phi_1 \left[\, c^e_{2L} + \overline{k}_2 \,\right] \\
&\quad + [\, 1 - \phi_1 \,] \left\{ \widetilde{\phi}^C_2 \,[\, c^e_{2L} + \underline{k}_2 \,] + \left[1 - \widetilde{\phi}^C_2 \right] [\, \phi_1 \,(\, c^e_{1L} + \underline{k}_1 \,) + (\, 1 - \phi_1 \,)\, c^e_{2H} \,] \right\} \\
&=\; \phi_1 \left[\, c^e_{2L} + \overline{k}_2 \,\right] + [\, 1 - \phi_1 \,] \left[\, c^e_{2L} + \overline{k}_2 \,\right] \;=\; c^e_{2L} + \overline{k}_2 \,.
\end{aligned}
$$

(27), (28), and Conclusion 12 imply:

$$
\begin{aligned}
EP_{11} \;&=\; \phi_1 \,[\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 \,] \left\{ \widetilde{\phi}^C_2 \,[\, c^e_{2L} + \underline{k}_2 \,] + \left[1 - \widetilde{\phi}^C_2 \right] c^e_{1H} \right\} \\
&>\; \phi_1 \left[\, c^e_{2L} + \overline{k}_2 \,\right] \\
&\quad + [\, 1 - \phi_1 \,] \left\{ \widetilde{\phi}^C_2 \,[\, c^e_{2L} + \underline{k}_2 \,] + \left[1 - \widetilde{\phi}^C_2 \right] [\, \phi_1 \,(\, c^e_{1L} + \underline{k}_1 \,) + (\, 1 - \phi_1 \,)\, c^e_{2H} \,] \right\} \\
&=\; \phi_1 \left[\, c^e_{2L} + \overline{k}_2 \,\right] + [\, 1 - \phi_1 \,] \left[\, c^e_{2L} + \overline{k}_2 \,\right] \;=\; c^e_{2L} + \overline{k}_2 \,. \quad \blacksquare
\end{aligned}
$$

Proof of Proposition 6

Lemma 3 implies that in the absence of self-sabotage, the regulator will induce the outcome in Case 10 under the specified conditions. Lemma 1 implies that the utility's expected profit is 0 in this case.

Lemma 1 also implies that self-sabotage will only increase the utility's expected profit if it leads the regulator to induce the outcome in Case 2. Conclusions 3 and 11 imply that self-sabotage $s_{1\phi}$ and $s_{2\phi}$ will induce the regulator to prefer the outcome in Case 2 with $i = 2$ to the outcome in Case 10 if:

$$
\begin{aligned}
& c^e_{2L} + \overline{k}_2 \;\leq\; [\, \phi_2 - s_{2\phi} \,]\,[\, c^e_{2L} + \underline{k}_2 \,] + [\, 1 - \phi_2 + s_{2\phi} \,]\,\{\, [\, \phi_1 - s_{1\phi} \,]\,[\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 + s_{1\phi} \,]\, c^e_{2H} \,\} \\
& \quad \Leftrightarrow \quad [\, \phi_1 - s_{1\phi} \,]\,[\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 + s_{1\phi} \,]\, c^e_{2H} - \left(c^e_{2L} + \overline{k}_2 \right) \\
& \qquad\quad \geq\; [\, \phi_2 - s_{2\phi} \,]\,\{\, [\, \phi_1 - s_{1\phi} \,]\,[\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 + s_{1\phi} \,]\, c^e_{2H} - (c^e_{2L} + \underline{k}_2) \,\} \\
& \quad \Leftrightarrow \quad \phi_2 - s_{2\phi} \;\leq\; \frac{[\, \phi_1 - s_{1\phi} \,]\,[\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 + s_{1\phi} \,]\, c^e_{2H} - \left(c^e_{2L} + \overline{k}_2 \right)}{[\, \phi_1 - s_{1\phi} \,]\,[\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 + s_{1\phi} \,]\, c^e_{2H} - (c^e_{2L} + \underline{k}_2)} \;=\; \widetilde{\phi}^C_2(s_{1\phi}) \\
& \quad \Leftrightarrow \quad s_{2\phi} \;\geq\; \phi_2 - \widetilde{\phi}^C_2(s_{1\phi}) \,. \qquad (29)
\end{aligned}
$$

Differentiating (29) provides:

$$
\begin{aligned}
\frac{d\widetilde{\phi}^C_2(s_{1\phi})}{ds_{1\phi}} \;&\stackrel{s}{=}\; \{\, [\, \phi_1 - s_{1\phi} \,]\,[\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 + s_{1\phi} \,]\, c^e_{2H} - (c^e_{2L} + \underline{k}_2) \,\}\,[\, c^e_{2H} - (c^e_{1L} + \underline{k}_1) \,] \\
& - \{\, [\, \phi_1 - s_{1\phi} \,]\,[\, c^e_{1L} + \underline{k}_1 \,] + [\, 1 - \phi_1 + s_{1\phi} \,]\, c^e_{2H} - \left(c^e_{2L} + \overline{k}_2 \right) \}\,[\, c^e_{2H} - (c^e_{1L} + \underline{k}_1) \,] \,\}
\end{aligned}
$$

$$= \; [\, c^e_{2H} - (c^e_{1L} + \underline{k}_1)\,]\, [\, \overline{k}_2 - \underline{k}_2 \,] \; > \; 0\,. \tag{30}$$

When the regulator induces the utility to implement the outcome in Case 2 with $i = 2$, the utility's expected profit is:

$$\pi(s_{1\phi}, s_{2\phi}) \; = \; [\, \phi_2 - s_{2\phi}\,]\, [\, \overline{k}_2 - \underline{k}_2 \,] - C_\phi(s_{1\phi}, s_{2\phi}) \tag{31}$$

$$\Rightarrow \; \frac{\partial \pi(\cdot)}{\partial s_{2\phi}} \; = \; - \, [\, \overline{k}_2 - \underline{k}_2 \,] - \frac{\partial C_\phi(\cdot)}{\partial s_{2\phi}} \; < \; 0\,. \tag{32}$$

(29) and (32) imply that the utility will optimally set $s_{2\phi} = \phi_2 - \widetilde{\phi}^C_2(s_{1\phi})$. Therefore, (31) and condition (iii) imply that the maximum level of expected profit the utility can secure, given $s_{1\phi}$, is:

$$\pi^*(s_{1\phi}) \; = \; \widetilde{\phi}^C_2(s_{1\phi})\, [\, \overline{k}_2 - \underline{k}_2 \,] - C_\phi(s_{1\phi}, \phi_2 - \widetilde{\phi}^C_2(s_{1\phi}))$$

$$\Rightarrow \; \pi^{*\prime}(s_{1\phi}) \; = \; \left[\overline{k}_2 - \underline{k}_2 + \frac{\partial C_\phi(s_{1\phi}, \phi_2 - \widetilde{\phi}^C_2(s_{1\phi}))}{\partial s_{2\phi}} \right] \frac{d\widetilde{\phi}^C_2(s_{1\phi})}{ds_{1\phi}} \; > \; 0\,. \tag{33}$$

The inequality in (33) reflects (30) and condition (iii). (33) implies that the utility will optimally set $s_{1\phi}$ at its upper bound, ϕ_1. The utility's resulting expected profit is $\widetilde{\phi}^C_2(\phi_1)\, [\, \overline{k}_2 - \underline{k}_2 \,] - C(\phi_1, \phi_2 - \widetilde{\phi}^C_2(\phi_1)) > 0$.

Recall that (27) holds when the conditions in Lemma 3 hold. (27) implies that $c^e_{1L} + \overline{k}_1 > c^e_{2L} + \overline{k}_2$. Therefore, self-sabotage $s_{1\phi} > 0$ would not induce the regulator to implement the outcome in Case 2 with $i = 1$.

It remains to verify that the regulator's expected procurement cost is minimized by inducing the outcome in Case 2 with $i = 2$ when $s_{1\phi} = \phi_1$ and $s_{2\phi} = \phi_2 - \widetilde{\phi}^C_2(\phi_1)$. The regulator's expected procurement cost in this event is:

$$c^e_{2L} + \overline{k}_2 \; = \; \widetilde{\phi}^C_2(\phi_1)\, [\, c^e_{2L} + \underline{k}_2\,] + \left[1 - \widetilde{\phi}^C_2(\phi_1) \right] c^e_{2H}\,. \tag{34}$$

Lemmas 4 and 5 hold for all values of ϕ_1 and ϕ_2. Therefore, Lemma 6 continues to hold when $s_{1\phi} > 0$ and/or $s_{2\phi} > 0$. Consequently, it only needs to be shown that $c^e_{2L} + \overline{k}_2 \leq \min_i \{EP_i\}$ for $i \in \{1, 2, 3, 4, 5, 8, 9, 10, 11\}$.

It is apparent from (27), (34), and Conclusions 2, 3, 5, 9, 10, and 11 that $c^e_{2L} + \overline{k}_2 \leq \min\{EP_1, EP_2, EP_4, EP_8, EP_9, EP_{10}\}$ when $s_{1\phi} = \phi_1$ and $s_{2\phi} = \phi_2 - \widetilde{\phi}^C_2(\phi_1)$.

(27) and Conclusion 4 imply that when $i = 1$, $s_{1\phi} = \phi_1$, and $s_{2\phi} = \phi_2 - \widetilde{\phi}^C_2(\phi_1)$:

$$EP_3\big|_{i=1} \; = \; c^e_{1H} \; > \; c^e_{2L} + \overline{k}_2\,.$$

(27), (34), and Conclusion 4 imply that when $i = 2$, $s_{1\phi} = \phi_1$, and $s_{2\phi} = \phi_2 - \widetilde{\phi}^C_2(\phi_1)$:

$$EP_3\big|_{i=2} \; = \; \widetilde{\phi}^C_2(\phi_1)\, [\, c^e_{2L} + \underline{k}_2\,] + \left[1 - \widetilde{\phi}^C_2(\phi_1) \right] c^e_{2H} \; = \; c^e_{2L} + \overline{k}_2\,.$$

(27), (34), and Conclusion 6 imply that when $s_{1\phi} = \phi_1$ and $s_{2\phi} = \phi_2 - \widetilde{\phi}^C_2(\phi_1)$:

$$EP_5 \;=\; \widetilde{\phi}_2^C(\phi_1)\,[\,c_{2L}^e + \underline{k}_2\,] + \left[1 - \widetilde{\phi}_2^C(\phi_1)\right] c_{2H}^e \;=\; c_{2L}^e + \overline{k}_2\,.$$

(27), (34), and Conclusion 12 imply that when $s_{1\phi} = \phi_1$ and $s_{2\phi} = \phi_2 - \widetilde{\phi}_2^C(\phi_1)$:

$$EP_{11} \;=\; \widetilde{\phi}_2^C(\phi_1)\,[\,c_{2L}^e + \underline{k}_2\,] + \left[1 - \widetilde{\phi}_2^C(\phi_1)\right] c_{1H}^e$$

$$\;=\; c_{2L}^e + \overline{k}_2 + \left[1 - \widetilde{\phi}_2^C(\phi_1)\right][\,c_{1H}^e - c_{2H}^e\,] \;\geq\; c_{2L}^e + \overline{k}_2\,. \quad \blacksquare$$

Proof of Proposition 7

First suppose the regulator implements the policy that minimizes expected procurement cost under project 2. If the utility refrains from self-sabotage, it will earn no rent because the regulator will induce the utility to undertake project 2 with selective cost management (because $\phi_2\,[\,c_{2L}^e + \underline{k}_2\,] + [\,1 - \phi_2\,]\,c_{2H}^e \;<\; c_{2L}^e + \overline{k}_2$, which implies $\phi_2 \;>\; \widetilde{\phi}_2^B$). By setting $s_{2\phi} \;=\; \phi_2 - \widetilde{\phi}_2^B$, the utility can secure rent $\widetilde{\phi}_2^B\left[\,\overline{k}_2 - \underline{k}_2\,\right]$ by ensuring that the regulator will induce the utility to undertake project 2 with consistent cost management (because $\widetilde{\phi}_2^B\,[\,c_{2L}^e + \underline{k}_2\,] + \left[1 - \widetilde{\phi}_2^B\right] c_{2H}^e \;=\; c_{2L}^e + \overline{k}_2\,$).

Now suppose the regulator implements the policy that minimizes expected procurement cost under project 1. The regulator will induce the utility to implement selective cost management because $\phi_1\,[\,c_{1L}^e + \underline{k}_1\,] + [\,1 - \phi_1\,]\,c_{1H}^e \;<\; c_{1L}^e + \overline{k}_1$. Expected procurement cost is $\phi_1\,[\,c_{1L}^e + \underline{k}_1\,] + [\,1 - \phi_1\,]\,c_{1H}^e \;<\; c_{2L}^e + \overline{k}_2$. $\blacksquare$

Proof of Proposition 8

First suppose the utility cannot implement self-sabotage of project 2. Then because $\phi_2\,[\,c_{2L}^e + \underline{k}_2\,] + [\,1 - \phi_2\,]\,c_{2H}^e < c_{2H}^e < c_{2L}^e + \overline{k}_2$, expected procurement cost is minimized when the regulator induces the utility to undertake project 2 with selective cost management.

Now suppose that self-sabotage $s_{2\phi} > 0$ entails no personal cost for the utility. If the regulator induces the utility to undertake project 2 with no cost management, expected procurement cost will be c_{2H}^e and the utility will secure no rent.

If $\phi_2 \;\leq\; \widetilde{\phi}_2^B$, the regulator will minimize expected procurement cost by inducing the utility to undertake project 2 with consistent cost management. The associated expected procurement cost is $c_{2L}^e + \overline{k}_2 > c_{2H}^e$.

If $\phi_2 > \widetilde{\phi}_2^B$, then to ensure the regulator does not induce the utility to undertake project 2 with selective cost management, the utility will set $s_{2\phi} \;=\; \phi_2 - \widetilde{\phi}_2^B$. This will cause the regulator to induce the utility to undertake project 2 with consistent cost management. The associated expected procurement cost is $c_{2L}^e + \overline{k}_2 > c_{2H}^e$. $\blacksquare$

Proof of Proposition 9

Because $r_1 \;<\; \underline{c}_1$ under the identified compensation policy, the utility will never undertake project 1.

Suppose initially that the utility refrains from self-sabotage of project 2. When $k_2 = \underline{k}_2$, if the utility undertakes project 2 and exercises cost management, its expected profit is:

$$
\begin{aligned}
& p_{2L} \left[\underline{r}_2 - \underline{c}_2 \right] + \left[1 - p_{2L} \right] \left[\overline{r}_2 - \overline{c}_2 \right] - \underline{k}_2 \\
& = \phi_2 \left[\overline{k}_2 - \underline{k}_2 \right] + p_{2L} \left[\frac{1 - p_{2H}}{p_{2L} - p_{2H}} \right] \underline{k}_2 - \left[1 - p_{2L} \right] \left[\frac{p_{2H}}{p_{2L} - p_{2H}} \right] \underline{k}_2 - \underline{k}_2 \\
& = \phi_2 \left[\overline{k}_2 - \underline{k}_2 \right] + \frac{\underline{k}_2}{p_{2L} - p_{2H}} \left[p_{2L} \left(1 - p_{2H} \right) - \left(1 - p_{2L} \right) p_{2H} \right] - \underline{k}_2 \;=\; \phi_2 \left[\overline{k}_2 - \underline{k}_2 \right] .
\end{aligned} \tag{35}
$$

(35) implies that when $k_2 = \overline{k}_2$, if the utility undertakes project 2 and exercises cost management, its expected profit is:

$$
\phi_2 \left[\overline{k}_2 - \underline{k}_2 \right] + \underline{k}_2 - \overline{k}_2 \;=\; - \left[1 - \phi_2 \right] \left[\overline{k}_2 - \underline{k}_2 \right] \;<\; 0 . \tag{36}
$$

The utility's expected profit when it undertakes project 2 with no cost management is:

$$
\begin{aligned}
& p_{2H} \left[\underline{r}_2 - \underline{c}_2 \right] + \left[1 - p_{2H} \right] \left[\overline{r}_2 - \overline{c}_2 \right] \\
& = \phi_2 \left[\overline{k}_2 - \underline{k}_2 \right] + p_{2H} \left[\frac{1 - p_{2H}}{p_{2L} - p_{2H}} \right] \underline{k}_2 - \left[1 - p_{2H} \right] \left[\frac{p_{2H}}{p_{2L} - p_{2H}} \right] \underline{k}_2 \\
& = \phi_2 \left[\overline{k}_2 - \underline{k}_2 \right] + \frac{\underline{k}_2}{p_{2L} - p_{2H}} \left[p_{2H} \left(1 - p_{2H} \right) - \left(1 - p_{2H} \right) p_{2H} \right] \;=\; \phi_2 \left[\overline{k}_2 - \underline{k}_2 \right] .
\end{aligned} \tag{37}
$$

(35), (36), and (37) imply that the utility will exercise selective cost management and expected procurement cost will be:

$$
\begin{aligned}
& \phi_2 \left\{ p_{2L} \, \underline{r}_2 + \left[1 - p_{2L} \right] \overline{r}_2 \right\} + \left[1 - \phi_2 \right] \left\{ p_{2H} \, \underline{r}_2 + \left[1 - p_{2H} \right] \overline{r}_2 \right\} \\
& = \phi_2 \left\{ c^e_{2L} + \phi_2 \left[\overline{k}_2 - \underline{k}_2 \right] + \frac{\underline{k}_2}{p_{2L} - p_{2H}} \left[p_{2L} \left(1 - p_{2H} \right) - \left(1 - p_{2L} \right) p_{2H} \right] \right\} \\
& \quad + \left[1 - \phi_2 \right] \left\{ c^e_{2H} + \phi_2 \left[\overline{k}_2 - \underline{k}_2 \right] + \frac{\underline{k}_2}{p_{2L} - p_{2H}} \left[p_{2H} \left(1 - p_{2H} \right) - \left(1 - p_{2H} \right) p_{2H} \right] \right\} \\
& = \phi_2 \left[c^e_{2L} + \underline{k}_2 \right] + \left[1 - \phi_2 \right] c^e_{2H} + \phi_2 \left[\overline{k}_2 - \underline{k}_2 \right] .
\end{aligned} \tag{38}
$$

The minimum expected procurement cost when the utility is induced to undertake project 2 with consistent cost management is:

$$
c^e_{2L} + \overline{k}_2 \;>\; \phi_2 \left[c^e_{2L} + \underline{k}_2 \right] + \left[1 - \phi_2 \right] c^e_{2H} + \phi_2 \left[\overline{k}_2 - \underline{k}_2 \right] . \tag{39}
$$

The minimum expected procurement cost when the utility is induced to undertake project 2 with no cost management is:

$$
c^e_{2H} \;>\; \phi_2 \left[c^e_{2L} + \underline{k}_2 \right] + \left[1 - \phi_2 \right] c^e_{2H} + \phi_2 \left[\overline{k}_2 - \underline{k}_2 \right] . \tag{40}
$$

(38), (39), and (40) imply that if the utility refrains from self-sabotage of project 2, the regulator will induce the utility to undertake project 2 and implement selective cost management. Expected procurement cost will be $\phi_2 \left[c^e_{2L} + \underline{k}_2 \right] + \left[1 - \phi_2 \right] c^e_{2H} + \phi_2 \left[\overline{k}_2 - \underline{k}_2 \right]$.

From Lemma 1, $\phi_2 \left[\overline{k}_2 - \underline{k}_2 \right]$ is the maximum rent the utility can secure by undertaking self-sabotage. The utility can secure this rent by undertaking self-sabotage that increases c^e_{2H} to the point where the regulator induces the utility to undertake project 2 with consistent cost management. Observe from (35) that this is precisely the rent the utility secures under the identified procurement policy when it refrains from self-sabotage of project 2. Therefore, the utility has no strict preference to undertake self-sabotage. (38) implies that when the utility refrains from self-sabotage, expected procurement cost declines from $c^e_{2L} + \overline{k}_2$ to $\phi_2 [c^e_{2L} + \underline{k}_2] + [1 - \phi_2] c^e_{2H} + \phi_2 \left[\overline{k}_2 - \underline{k}_2 \right]$. ■

The following lemma is employed in the proof of Proposition 10.

Lemma 7. *Suppose* $\alpha [p_{2L} - p_{2H}] [\overline{c}_2 - \underline{c}_2] \in (\underline{k}_2, \overline{k}_2)$ *and project 1 is prohibitively costly to operate. Then when the cost-sharing plan in (1) is implemented, the utility will undertake project* 2*, implement selective cost management, and refrain from self-sabotage.*

Proof. The utility's expected profit when it undertakes project 2 with no cost management is:

$$
\begin{aligned}
\pi_{2H}(s_{2H}) &\equiv [p_{2H} - s_{2H}] [\underline{r}_2 - \underline{c}_2] + [1 - p_{2H} + s_{2H}] [\overline{r}_2 - \overline{c}_2] - C(\cdot, s_{2H}) \\
&= \alpha [p_{2H} - s_{2H}] [\overline{c}_2 - \underline{c}_2] - C(s_{1H}, s_{2H}) \\
&\Rightarrow \quad \pi'_{2H}(s_{2H}) \;=\; - \alpha [\overline{c}_2 - \underline{c}_2] - \frac{\partial C(\cdot)}{\partial s_{2H}} \;<\; 0 \quad \Rightarrow \quad s_{2H} \;=\; 0 \, .
\end{aligned}
$$

The utility's expected profit when it undertakes project 2 with consistent management is:

$$
\begin{aligned}
\pi_{2L}(s_{2L}) &\equiv [p_{2L} - s_{2L}] [\underline{r}_2 - \underline{c}_2] + [1 - p_{2L} + s_{2L}] [\overline{r}_2 - \overline{c}_2] - C(\cdot, s_{2L}, \cdot) \\
&= \alpha [p_{2L} - s_{2L}] [\overline{c}_2 - \underline{c}_2] - C(\cdot) \\
&\Rightarrow \quad \pi'_{2L}(s_{2L}) \;=\; - \alpha [\overline{c}_2 - \underline{c}_2] - \frac{\partial C(\cdot)}{\partial s_{2L}} \;<\; 0 \quad \Rightarrow \quad s_{2L} \;=\; 0 \, .
\end{aligned}
$$

The utility's expected profit when it undertakes project 2 with selective cost management is:

$$
\begin{aligned}
\pi_{2\phi LH}(\cdot) \;=\; & [\phi_2 - s_{2\phi}] \{ [p_{2L} - s_{2L}] [\underline{r}_2 - \underline{c}_2] + [1 - p_{2L} + s_{2L}] [\overline{r}_2 - \overline{c}_2] - \underline{k}_2 \} \\
& + [1 - \phi_2 + s_{2\phi}] \{ [p_{2H} - s_{2H}] [\underline{r}_2 - \underline{c}_2] + [1 - p_{2H} + s_{2H}] [\overline{r}_2 - \overline{c}_2] \} - C(\cdot) \\
=\; & [\phi_2 - s_{2\phi}] \{ \alpha [p_{2L} - s_{2L}] [\overline{c}_2 - \underline{c}_2] - \underline{k}_2 \} + [1 - \phi_2 + s_{2\phi}] \{ \alpha [\overline{c}_2 - \underline{c}_2] \} - C_\phi(\cdot) \, . \qquad (41)
\end{aligned}
$$

Differentiating (41) provides:

$$
\begin{aligned}
\frac{\partial \pi_{2\phi LH}(\cdot)}{\partial s_{2\phi}} &= - \{ \alpha [p_{2L} - p_{2H}] [\overline{c}_2 - \underline{c}_2] - \underline{k}_2 \} - \frac{\partial C(\cdot)}{\partial s_{2\phi}} \;<\; 0 \, ; \\
\frac{\partial \pi_{2\phi LH}(\cdot)}{\partial s_{2L}} &= - [\phi_2 - s_{2\phi}] \, \alpha [\overline{c}_2 - \underline{c}_2] - \frac{\partial C(\cdot)}{\partial s_{2L}} \;\leq\; 0 \, ; \quad \text{and}
\end{aligned}
$$

$$\frac{\partial \pi_{2\phi LH}(\cdot)}{\partial s_{2H}} \;=\; -\,[\,1-\phi_2+s_{2\phi}\,]\,\alpha\,[\,\overline{c}_2-\underline{c}_2\,]-\frac{\partial C(\cdot)}{\partial s_{2H}} \;\leq\; 0\,.$$

Therefore, $s_{2\phi} = s_{2L} = s_{2H} = 0$. It is also apparent that increasing $s_{1\phi}$, s_{1L}, or s_{1H} above 0 will not increase the utility's expected profit.

In the absence of self-sabotage, the utility will implement project 2 with no cost management when $k_2 = \overline{k}_2$ if:

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

$$\Leftrightarrow \quad \alpha\,p_{2H}\,[\,\overline{c}_2-\underline{c}_2\,] \;>\; \alpha\,p_{2L}\,[\,\overline{c}_2-\underline{c}_2\,]-\overline{k}_2 \quad \Leftrightarrow \; \alpha\,[\,p_{2L}-p_{2H}\,]\,[\,\overline{c}_2-\underline{c}_2\,] \;<\; \overline{k}_2.$$

The utility will implement project 2 and exercise cost management when $k_2 = \underline{k}_2$ if:

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

$$\Leftrightarrow \quad \alpha\,[\,p_{2L}-p_{2H}\,]\,[\,\overline{c}_2-\underline{c}_2\,] \;>\; \underline{k}_2\,. \quad \blacksquare$$

Proof of Proposition 10

Self-sabotage will not increase the utility's expected profit under a cost-reimbursement policy. Therefore, expected procurement cost is c^e_{2H} under such a policy. Lemma 7 implies that under the cost-sharing plan in (1), expected procurement cost is:

$$\phi_2\,[\,p_{2L}\,\underline{r}_2+(1-p_{2L})\,\overline{r}_2\,]+[\,1-\phi_2\,]\,[\,p_{2H}\,\underline{r}_2+(1-p_{2H})\,\overline{r}_2\,]$$

$$=\; \phi_2\,\{\,c^e_{2L}+\alpha\,p_{2L}\,[\,\overline{c}_2-\underline{c}_2\,]\,\}+[\,1-\phi_2\,]\,\{\,c^e_{2H}+\alpha\,p_{2H}\,[\,\overline{c}_2-\underline{c}_2\,]\,\} \;<\; c^e_{2H}\,.$$

Lemma 1 implies that when the regulator implements the policy that minimizes her expected procurement cost, the utility will set s_{2H} to ensure:

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

Consequently, the regulator will induce the utility to undertake project 2 with consistent cost management. The corresponding expected procurement cost is $c^e_{2L}+\overline{k}_2 > c^e_{2H} > \phi_2\,\{\,c^e_{2L}+\alpha\,p_{2L}\,[\,\overline{c}_2-\underline{c}_2\,]\,\}+[\,1-\phi_2\,]\,\{\,c^e_{2H}+\alpha\,p_{2H}\,[\,\overline{c}_2-\underline{c}_2\,]\,\}$.

It remains to verify that conditions (i) and (ii) can hold simultaneously. It is apparent that $\alpha\,[\,p_{2L}-p_{2H}\,]\,[\,\overline{c}_2-\underline{c}_2\,] \in (\underline{k}_2, \overline{k}_2)$ and $c^e_{2H} < c^e_{2L}+\overline{k}_2$ when $\overline{k}_2$ is sufficiently large and $\underline{k}_2$ is sufficiently small. It is also apparent that when α is sufficiently small and ϕ_2 is sufficiently large:

$$\phi_2\,\{\,c^e_{2L}+\alpha\,p_{2L}\,[\,\overline{c}_2-\underline{c}_2\,]\,\}+[\,1-\phi_2\,]\,\{\,c^e_{2H}+\alpha\,p_{2H}\,[\,\overline{c}_2-\underline{c}_2\,]\,\} \;<\; c^e_{2H}\,. \quad \blacksquare$$

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