The Economics of Financial and Operational Hedging: Insights from U.S. Power Plants *

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Abstract

We examine how financial and operational hedging interact under financing frictions. Financial hedging weakens operational hedging incentives by reducing residual risk exposure (induces hedging overhang) but strengthens them by lowering risky-debt financing costs (mitigates debt overhang). These competing forces yield complementarity when financing frictions are severe, substitution otherwise. Using U.S. electric utilities, we document financial hedging overhang: firms using derivatives subsequently reduce inventory and capacity investments. Consistent with our mechanism, this substitution weakens when financing constraints tighten or when financial hedging more effectively reduces debt overhang.

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1 Introduction

Climate change has increased the frequency and intensity of extreme weather events—floods, droughts, heat waves, wildfires, hurricanes, and blizzards—all of which adversely affect firm performance (e.g., Acharya et al. 2023, Pankratz and Schiller 2024). These events motivate firms to find ways to mitigate the effects of increased weather-related risks. The literature highlights two main approaches to risk management. Financial hedges—long-term contracts, off-taker agreements, and derivative positions—transfer the firm's risk to other market participants, lowering cash flow volatility and financing costs (e.g., Froot et al. 1993, Campello et al. 2011, Gilje and Taillard 2017, Almeida et al. 2017). Operational hedges—inventory buffers (West 1990, Dasgupta et al. 2019), excess capacity (Acharya et al. 2025), and robust supply chains (Brusset and Bertrand 2018)—physically reduce the firm's exposure to risks. This paper argues that whether these hedging strategies are substitutes or complements depends critically on the financial frictions that firms face.

We develop a parsimonious model of financial and operational hedging that features a financing friction, creating demand for risk management. A risk-neutral entrepreneur operates a project requiring external financing at $t = 0$ that delivers uncertain payoffs at $t = 2$. Investors have limited risk-bearing capacity—arising from regulatory constraints, contractual restrictions, or agency problems—making financing expensive when project cash flows are risky. At $t = 0$, before arranging financing, the entrepreneur can hedge financially by entering into an agreement with an off-taker to exchange a fraction of the project's uncertain payoff for a fixed transfer price. At $t = 1$, after financing is arranged, the entrepreneur can hedge operationally through costly effort that shifts the cash flow distribution toward favorable states. The timing reflects the uncertain arrival of operational hedging opportunities, such as technological innovations or supplier relationships that emerge after financing. At $t = 2$, uncertainty resolves, the off-taker agreement is settled, and investors are repaid.

The model highlights a tension between two economic forces. First, financial hedging in-

duces a *hedging overhang* problem—analogous to moral hazard in insurance. By reducing the entrepreneur's residual exposure to adverse events, financial hedging directly weakens incentives for costly operational hedging effort. Second, the limited risk-bearing capacity of investors makes debt the optimal financing contract, creating a conventional debt overhang problem (Myers 1977). Financial hedging reduces cash flow volatility, lowers financing costs, and mitigates debt overhang, thereby indirectly strengthening incentives for costly operational hedging. Financial and operational hedging are substitutes when the first effect dominates; they are complements when the second effect dominates. Crucially, financial frictions that raise the cost of risky debt magnify the second effect, increasing the likelihood of complementarity.

This framework generates many testable implications. First, financial hedging reduces payoff uncertainty, lowering debt financing costs. The model predicts a positive relationship between financial hedging and debt issuance, and a negative relationship between financial hedging and the cost of borrowing. Second, the sensitivity of operational hedging to financial hedging decreases when either instrument is more efficient. More efficient financial hedging reduces debt financing costs more sharply, mitigating debt overhang; more efficient operational hedging relaxes the incentive compatibility constraint directly. Third, because the complementarity between hedging types stems from the mitigation of financial frictions, the model predicts a positive correlation between financial and operational hedging among firms facing severe financing constraints.

We test these predictions using the U.S. electric utilities industry as an empirical laboratory because this setting offers several advantages. First, this industry is heavily exposed to weather risks. Both the demand for electricity and the supply of input required for its generation (particularly natural gas) are affected by weather. The Climate Central Report attributes 83% of the 1,858 major power outages in the United States from 2000 to 2021 to weather-related events. The associated economic stakes are substantial: the U.S. Department of Energy estimates that blackouts cost the U.S. economy $150 billion annually. A notable example is the 2021 Texas

Power Crisis, which caused 4.4 million household power outages, 210 deaths, and estimated losses between $80 and $130 billion. Understanding how power producers hedge their risks potentially provides insights into potential avenues for enhancing the power grid's resilience.

Second, there is limited variation in the production technology across different power producers in the same category, which ensures that the investment and hedging policies we analyze are comparable across our sample firms. Electric utilities require financing for their investments, which generate uncertain cash flows. Fluctuations in input and output prices are plausibly exogenous to individual firms, creating clear hedging motives. The operational hedges available—such as, the fuel inventory buffers that firms can draw down when costs spike or supply is disrupted (e.g., West 1990, Dasgupta et al. 2019)—are well-defined and measurable. Relatedly, there are industry standards for available financial hedging products. Most electric utilities actively use exchange-traded and over-the-counter financial contracts, long-term forward agreements involving physical delivery, and weather products to manage their risk. These features match closely with our model's setup.

Third, detailed regulatory filings provide comprehensive data on derivative positions, natural gas storage, and operational capacity. We measure operational hedging using the current-asset portion of natural gas and liquefied natural gas (LNG) stored on-site, as these inventories can be readily withdrawn in adverse states. We also examine excess capacity when generation data are available. For financial hedging, we follow prior literature (e.g., Haushalter 2002, Campello et al. 2011, Acharya et al. 2013, Pérez-González and Yun 2013, Gilje and Taillard 2017) and create a financial hedging dummy to capture any traded derivative assets or liabilities firms held for hedging purposes in a specific year.[1]

Our empirical analysis reveals several key findings consistent with the model's predictions. First, we show that firms' incentive to reduce borrowing costs indeed drives their use of financial hedges. Using firms' refinancing needs as a proxy for the unobserved total external

[1]The rationale for using the dummy is that firms are required to recognize their derivative positions based on fair value accounting. As such, the amount reported in the statements reflects changes in fair value rather than the notional value. We discuss the measurement of financial hedging in more detail in Section 4.2.

financing deficit, we show that financial hedging increases when the need to retire existing long-term debt is greater. Moreover, the use of financial hedges, such as derivative contracts, reduces firms' subsequent borrowing costs, measured by the interest rates on long-term debt. These results are consistent with the feature of our model that financial hedging lowers firms' borrowing costs by reducing payoff uncertainty. They are also in line with insights and evidence in earlier work such as Smith and Stulz (1985), Froot et al. (1993), Haushalter (2002), Campello et al. (2011), Gilje and Taillard (2017), Babenko et al. (2024), showing that financial derivatives can improve firm value by reducing external financing costs. Our test exploits the variation in firms' refinancing needs arising from the maturity structure of outstanding debt, which is shaped by past issuance decisions and contractual debt schedules. This predetermined structure allows us to isolate variation in financial hedging driven by refinancing pressure, rather than by confounding changes in firms' unobserved risk exposure or managerial discretion.

Second, we provide evidence of the financial hedging overhang suggested by our model. We find that firms that hedge via financial derivatives subsequently engage in less operational hedging, measured by the current-asset portion of natural gas stored underground, LNG stored, and excess capacity. The economic magnitude is considerable. For example, when entering into a financial contract, firms reduce their subsequent on-site natural gas storage (scaled by the beginning-of-period assets) by 0.3 percentage points, which represents 25% of the average gas inventory-to-asset ratio in our model. To ensure that we do capture inventory and capacity decisions that are only relevant for hedging purposes, we perform a falsification test using natural gas reserved for long-term purposes and LNG held for processing as two placebos, and we show that the substitution effect does not exist when the reserve is not used for operational hedging. These findings are consistent with our model's prediction that, as financial hedging reduces their exposure to adverse shocks, the direct effect of financial hedging decreases firms' incentive to pursue costly operational hedging.

Finally, we test our model's novel prediction on the indirect effect of financial hedging in

encouraging operational hedging through mitigating debt overhang. We first explore the variation in the severity of financing frictions. Using the BBB credit spreads as a proxy for aggregate financing frictions in the utility sector, we find that the substitution effect of financial hedging on operational hedging is less pronounced when financing frictions are more severe. We then examine the heterogeneity of our results with respect to the efficiency of financial hedging. In our model, the efficiency of financial hedging depends on the firm's payoff from its financial hedging contract and its external financing need. We proxy the former by speculators' ease of access to capital following Acharya et al. (2013) and the latter by the firm's refinancing needs. Our model hypothesizes that, when broker-dealers have ample capital, or when the firm's refinancing need is lower, the firm does not have to hedge a large fraction of the project's payoff to make the debt safe. This makes their incentive compatibility condition to pursue operational hedging more likely to be satisfied and that financial and operational hedges are more likely to occur together. Consistent with these predictions, we find that the substitution effect of operational hedging by financial hedging is weaker when the efficiency of financial hedging to reduce debt overhang is higher.

Our paper connects to three areas in the literature. First, it extends the literature on financial frictions and corporate hedging. Absent frictions, well-diversified shareholders can adjust portfolio risk themselves, making corporate hedging irrelevant (Modigliani and Miller 1958). Prior studies (e.g., Smith and Stulz 1985, Froot et al. 1993) focused on the role of financial frictions, such as bankruptcy costs and external financing costs, in explaining how financial hedging can add firm value, with supportive evidence across different settings (Haushalter 2002, Adam 2002, Campello et al. 2011, Gilje and Taillard 2017, Babenko et al. (2024)).[2] We connect these insights by jointly modeling financial hedging and financing decisions, highlighting how friction severity determines the interaction between financial and operational hedging.

[2]Other motives for hedging include managers' career concerns (DeMarzo and Duffie 1995), industry competition (Adam et al. 2007), etc.

Second, we contribute to the emerging literature on operational hedging. Several studies provide evidence that operational decisions, such as acquisitions (Hankins 2011), offshore transactions (Hoberg and Moon 2017), inventory (West 1990, Dasgupta et al. 2019), and robust supply chains (Brusset and Bertrand 2018), are widely used in risk management. Recent work by Acharya et al. (2025) shows that financially constrained firms reduce operational hedging in favor of cash holding, emphasizing *resource reallocation*. Our paper offers a complementary perspective, modeling financial and operational hedging as interacting through *incentive channels*. We show that financial hedging—risk management approaches that transfer the firm's risk to other market participants—can either crowd out or encourage operational hedging, depending on the severity of financing frictions. The hedging overhang mechanism and its interaction with debt overhang are new to the literature.

Finally, our paper contributes to the ongoing policy discussion on improving power grid resilience. As energy systems globally confront both decarbonization imperatives and increased volatility, understanding how firms hedge against operational disruptions becomes critical. Our results highlight both benefits and costs of financial hedging: while it reduces financing costs, it can also weaken incentives for real operational improvements. These mechanisms extend beyond utilities to other capital-intensive sectors facing adaptation challenges.

The rest of the paper is organized as follows. Section 2 describes our model's setup. Section 3 solves for the optimal hedging policies and develops the hypotheses. Section 4 describes the data and variable constructions. Section 5 tests our model's predictions and presents the empirical results. Section 6 concludes.

2 Model

To illustrate our hypotheses, we develop a parsimonious model of financial and operational hedging. It features three dates ($t = 0, t = 1, t = 2$), two types of hedging instruments with distinct characteristics, and a financing friction that creates a role for risk management.

Production Technology. At $t = 0$, a risk-neutral entrepreneur has a project that requires $I > 0$ in investment. The entrepreneur has no internal funds and must therefore raise the full investment amount from external investors. The project generates a payoff at $t = 2$ that can be high (y_H) or low ($y_L < y_H$) with probabilities $1 - p$ and $p < \frac{1}{2}$, respectively. We interpret p as the probability of an adverse shock (e.g., production disruption, input cost spike, demand shortfall) and $\Delta_y = y_H - y_L$ as the magnitude of the exposure. We assume that the project is $NPV > 0$: $y_H - p\Delta_y > I$. We also assume that $I > y_L$ so that the financing friction becomes a binding constraint.

Financial Hedging. At $t = 0$, before arranging financing, the entrepreneur can contract with an off-taker to hedge a fraction $h \in [0, 1]$ of the project's payoff risk. Under this contract, the entrepreneur commits to transfer a fraction h of the project's risky payoff to the off-taker at $t = 2$ in exchange for a fixed per-unit payment P. Specifically, if the project generates y_H, the off-taker receives hy_H and pays the entrepreneur hP; similarly, if the project generates y_L, the off-taker receives hy_L and pays hP.

This hedging contract transforms the firm's payoffs in the high and low states to

$$\pi_H = (1 - h)y_H + hP \tag{1}$$

and

$$\pi_L = (1 - h)y_L + hP, \tag{2}$$

respectively. A higher financial hedge ratio (h) reduces the firm's payoff volatility without altering the probabilities of the underlying states. We assume the off-taker contract is observable to all parties and impose

$$I < P < y_H - p\Delta_y. \tag{3}$$

The first inequality ensures that the project remains $NPV > 0$ even under full financial hedg-

ing ($h = 1$). The second inequality implies that financial hedging is costly. This cost captures frictions such as market segmentation, contracting costs, or the off-taker's rents.

Financing Friction. The entrepreneur raises capital from an investor with limited risk-bearing capacity. This capacity constraint may arise from regulatory restrictions on risk exposure (e.g., risk-based capital requirements for banks or insurance companies), contractual constraints that limit portfolio diversification, or unmodeled agency problems that prevent full risk-sharing. We model this friction through a piecewise-linear utility function that transparently captures how the constraint translates into higher capital costs for risky payoffs. The investor's utility from receiving a payoff of x at $t = 2$ is

$$U(x) = \begin{cases} x & \text{if } x \leq \bar{x} \\ \bar{x} + \frac{1}{1+\gamma}(x - \bar{x}) & \text{if } x > \bar{x}, \end{cases} \tag{4}$$

where the parameters $\bar{x} > 0$ and $\gamma > 0$ capture the extensive and intensive margins of the investor's limited risk-bearing capacity, respectively. We normalize $\bar{x} = I$ in the baseline model, which simplifies algebra and exposition without loss of generality. The key economic force—that limited risk-bearing capacity increases financing costs for risky projects—arises more generally under any concave utility function that penalizes payoff risk.

A feasible financing contract specifies that the investor provides I at $t = 0$ and receives state-contingent payments (x_H, x_L) at $t = 2$, where x_H and x_L denote payments in the high and low payoff states, respectively. The entrepreneur's limited liability and wealth constraint require $x_H \leq \pi_H$ and $x_L \leq \pi_L$, where (π_H, π_L) are the firm's financially hedged payoffs. As in Innes (1990), we impose monotonicity: $x_H \geq x_L$.

Operational Hedging. At $t = 1$, after financing is arranged, the entrepreneur can exert costly effort $a \in \{0, 1\}$ to shift the distribution of project payoffs. If the entrepreneur exerts effort ($a = 1$), incurring a private cost c, the probability of the low state decreases from p to

$p - e$, where $e < p$ measures the effectiveness of the entrepreneur's effort. Without effort ($a = 0$), the probabilities remain at their baseline levels. We interpret this effort as operational hedging, such as diversifying input, holding inventory, building excess capacity, or adopting flexible production technologies.

Unlike financial hedging, which transfers risk to another party, operational hedging reduces the likelihood of adverse events, shifting the payoff distribution in a first-order stochastic dominance sense. We assume operational hedging is socially efficient: $\Delta_y e > c$. Critically, the entrepreneur's operational hedging effort at $t = 1$ is unobservable to outside investors and cannot be contracted upon at $t = 0$. The timing captures the uncertain nature of operational hedging opportunities that make it difficult for the entrepreneur to commit to implementing them. One can think of the baseline probability p as incorporating all operational hedges that are available and the entrepreneur can commit to implement at $t = 0$.

Timeline and Equilibrium. The sequence of events is as follows. At $t = 0$, the entrepreneur chooses a financial hedge ratio (h) and proposes a financing contract (x_H, x_L) to the investor. The investor accepts or rejects the contract. At $t = 1$, the entrepreneur chooses operational hedging effort (a). At $t = 2$, the project payoff is realized, and accounts are settled. The entrepreneur makes a take-it-or-leave-it offer to the investor, choosing (h, x_H, x_L) to maximize her expected payoff, subject to the investor's participation constraint:

$$(1 - p + ea^*)U(x_H) + (p - ea^*)U(x_L) \geq I, \tag{5}$$

where $a^* \in (0, 1)$ is the anticipated operational hedging effort. We focus on subgame perfect equilibrium: the entrepreneur's $t = 0$ choices anticipate her $t = 1$ incentives, and the investor's participation decision accounts for equilibrium effort.

3 Optimal Hedging and Financing Policies

This section characterizes the entrepreneur's optimal hedging and financing choices. We proceed by backward induction, first analyzing the entrepreneur's operational hedging incentives at $t = 1$ for a given financial hedge ratio (h) and debt contract, then characterizing the optimal $t = 0$ financing contract as debt for any financial hedge ratio, and finally determining the optimal financial hedge ratio that accounts for its effect on both financing costs and operational hedging incentives.

3.1 Operational Hedging Incentive Compatibility

We begin with the entrepreneur's operational hedging decision at $t = 1$, taking as given the financial hedge ratio h and a debt contract with face value D. After settling the off-taker contract, the firm's payoffs at $t = 2$ are

$$\pi_H(h) = (1-h)y_H + hP, \qquad \pi_L(h) = (1-h)y_L + hP, \tag{6}$$

in the high and low states, respectively. Let $a \in \{0,1\}$ denote operational hedging effort. If $a = 1$, the low-state probability falls from p to $p - e$, and the high-state probability rises from $1-p$ to $1-p+e$. The entrepreneur incurs a private cost c when exerting effort ($a = 1$).

Given debt face value D, the entrepreneur's payoff is $\pi_H(h) - D$ in the high state and $\max\{\pi_L(h) - D, 0\}$ in the low state. Hence, the entrepreneur chooses $a = 1$ if and only if

$$(1-p+e)\big(\pi_H - D\big) + (p-e)\max\{\pi_L - D, 0\} - c \geq (1-p)\big(\pi_H - D\big) + p\max\{\pi_L - D, 0\}. \tag{7}$$

Rearranging, the incentive-compatibility (IC) condition is

$$e\Big[\big(\pi_H - D\big) - \max\{\pi_L - D, 0\}\Big] \geq c. \tag{8}$$

There are two cases to consider: $D > \pi_L$ and $D \leq \pi_L$.

Case 1: Risky debt ($D > \pi_L$). When $D > \pi_L$, limited liability implies that the entrepreneur receives a zero payoff in the low state, and (8) reduces to

$$e\big(\pi_H(h) - D\big) \geq c. \tag{9}$$

Condition (20) captures a conventional debt-overhang problem: operational hedging increases the probability of repayment, transferring part of the benefit to creditors and weakening the entrepreneur's incentive to exert effort.

Case 2: Safe debt ($D \leq \pi_L$). When $D \leq \pi_L$, debt is risk-free and the entrepreneur's payoff is $\pi_H - D$ in the high state and $\pi_L - D$ in the low state. In this case, (8) becomes

$$e\big[(\pi_H - D) - (\pi_L - D)\big] = e\big(\pi_H(h) - \pi_L(h)\big) \geq c. \tag{10}$$

Using (6), condition can be written as

$$e(1-h)\Delta_y \geq c, \tag{11}$$

where $\Delta_y = y_H - y_L$.

Importantly, when debt is safe, the IC condition is independent of the face value D because the entrepreneur captures the entire increase in expected payoffs from operational hedging. In this case, only the entrepreneur's residual exposure to the adverse event matters. Because financial hedging reduces the entrepreneur's exposure by the factor $(1-h)$, it directly weakens the entrepreneur's incentive to undertake costly operational hedging—a channel we term *financial hedging overhang*.

Lemma 1. *If the project's payoffs are sufficiently hedged financially,*

$$h > 1 - \tfrac{c}{e\Delta_y} =: h_1, \tag{12}$$

then the entrepreneur's interim IC condition cannot be satisfied under any financing contract.

3.2 Optimal Financing Contracts

We now characterize the entrepreneur's optimal financing contract at $t = 0$ for a given financial hedge ratio (h), taking into account the anticipated operational hedging effort (a) at $t = 1$.

A feasible financing contract specifies that the investor provides I at $t = 0$ and receives state-contingent payments (x_H, x_L) at $t = 2$ in the high and low states, respectively. Feasibility satisfies limited liability ($x_H \leq \pi_H(h), x_L \leq \pi_L(h)$) and monotonicity ($x_H \geq x_L$). The investor has utility

$$U(x) = \begin{cases} x, & x \leq I, \\ I + \frac{1}{1+\gamma}(x - I), & x > I, \end{cases} \tag{13}$$

and the investor's participation constraint given anticipated effort $a \in \{0, 1\}$ is

$$(1 - p + ea)U(x_H) + (p - ea)U(x_L) \geq I. \tag{14}$$

Lemma 2. *The optimal financing arrangement binds the investor's participation constraint.*

Given that the project is risky and $I > y_L$, the relevant contract region has $x_L \leq I \leq x_H$. In this region, $U(x_L) = x_L$ and $U(x_H) = I + \frac{x_H - I}{1+\gamma}$. The binding participation constraint (14) implies

$$x_H = I + (1 + \gamma)\left(\frac{p - ea}{1 - p + ea}\right)(I - x_L). \tag{15}$$

Equation (15) reveals two key insights. First, increasing x_L reduces the required x_H, and this effect is stronger when the investor's risk-bearing capacity is more limited (higher γ) or when

the low state is more likely (higher p). Second, because the investor's marginal utility is higher below the kink, transferring the investor's payoffs from the high state to the low state strictly reduces financing costs. Therefore, the entrepreneur maximizes x_L subject to feasibility and monotonicity.

Lemma 3 (Debt is optimal)**.** *For any financial hedge ratio h, the optimal financing contract at $t = 0$ is debt. In particular,*

- *if $\pi_L(h) \geq I$, the optimal contract is safe debt: $x_H^* = x_L^* = I$;*
- *if $\pi_L(h) < I$, the optimal contract is risky debt: $x_L^* = \pi_L(h)$ and $x_H^* = D_a(h) > I$, where*

$$D_a(h) = I + (1+\gamma)\left(\frac{p - ea^*}{1 - p + ea^*}\right)(I - \pi_L(h)), \tag{16}$$

and $a^* \in \{0, 1\}$ is the operational effort level anticipated by the investor.

3.3 Optimal Hedging Strategies

To build intuition, we first characterize the optimal financial hedge ratio when operational hedging is unavailable. Define h_0 as the minimum ratio that makes debt risk-free:

$$\pi_L(h) \geq I \quad \Leftrightarrow \quad h \geq \frac{I - y_L}{P - y_L} := h_0. \tag{17}$$

Note that $\pi_L(h) \geq I$ if and only if $h \geq h_0$ and $h_0 \in (0, 1)$ because $P > I > y_L$.

To ensure that financial hedging is economically relevant when debt is risky, we impose that the marginal financing-cost saving from contracting with the off-taker outweighs the marginal cost:

$$\underbrace{(P - y_H)}_{\text{marginal hedging cost}} + \underbrace{(1+\gamma)\tfrac{p}{1-p}(P - y_L)}_{\text{marginal financing-cost savings}} > 0. \tag{18}$$

This condition is equivalent to a lower bound on financing frictions: $\gamma > \underline{\gamma}$, where

$$1 + \gamma > \frac{1-p}{p}\left(\frac{y_H - P}{P - y_L}\right) =: 1 + \underline{\gamma}. \tag{19}$$

Lemma 4. *When operational hedging is unavailable, the optimal financing and financial hedging policies consist of safe debt ($D^* = I$) and financial hedging up to the safe-debt threshold ($h^* = h_0$).*

When operational hedging is available at $t = 1$, the entrepreneur's financial hedging decision affects operational hedging incentives through two competing channels:

1. *Financial hedging overhang*: Higher h reduces the entrepreneur's residual exposure to the adverse event ($(1-h)\Delta_y$), directly weakening operational hedging incentives.

2. *Mitigation of debt overhang*: Higher h reduces the face value of risky debt by relaxing the investor's risk-bearing constraint, indirectly strengthening operational hedging incentives.

The relative strength of these channels depends on the severity of the financing friction.

When debt is risky ($h < h_0$), the IC condition for operational hedging is

$$IC(h) := e\big(\pi_H(h) - D_1(h)\big) - c \geq 0. \tag{20}$$

Proposition 1. *When financing frictions due to the investor's limited risk-bearing capacity are sufficiently severe, financial and operational hedging are complements in the risky-debt region:*

$$\exists\, \bar{\gamma} > 0 \text{ such that } \gamma \geq \bar{\gamma} \Rightarrow \big(\pi_H(h) - D_1(h)\big) \text{ is increasing in } h \text{ for } h \in [0, h_0). \tag{21}$$

The threshold is given by

$$\bar{\gamma} = \left(\frac{1-p+e}{p-e}\right)\left(\frac{y_H - P}{P - y_L}\right) - 1. \tag{22}$$

When debt is risky ($h < h_0$) and financing frictions are severe ($\gamma \geq \bar{\gamma}$), the debt overhang mitigation effect dominates the financial hedging overhang effect. Raising h reduces the face value of debt (D) sufficiently that the entrepreneur's residual claim in the high state increases, thereby making operational hedging more attractive. When debt becomes safe ($h \geq h_0$), the debt overhang channel vanishes, and only the financial hedging overhang channel remains—making higher h strictly detrimental to operational hedging incentives.

Proposition 2. *When financing frictions are sufficiently severe ($\gamma \geq \bar{\gamma}$), the entrepreneur's optimal hedging policies consist of financial hedging up to the safe-debt threshold ($h^* = h_0$) and operational hedging ($a^* = 1$) if $h_0 \leq h_1$, and no operational hedging ($a^* = 0$) if $h_0 > h_1$.*

The condition $h_0 \leq h_1$ has a transparent economic interpretation. Using $1 - h_0 = \frac{P-I}{P-y_L}$, we can rewrite

$$h_0 \leq h_1 \quad \Longleftrightarrow \quad e\Delta_y \left(\frac{P-I}{P-y_L} \right) \geq c \quad \Longleftrightarrow \quad \frac{e\Delta_y}{c} \geq \frac{P-y_L}{P-I}. \tag{23}$$

Corollary 1. *Financial and operational hedging are more likely to occur jointly when hedging is more efficient. Specifically, higher operational hedging effectiveness (e), larger exposure (Δ_y), lower effort cost (c), or more favorable hedge pricing (P) increase the likelihood that $h_0 \leq h_1$.*

When financing frictions are not sufficiently severe ($\gamma < \bar{\gamma}$), financial hedging and operational hedging become substitutes.

Proposition 3. *When financing frictions are not sufficiently severe ($\gamma < \bar{\gamma}$), financial and operational hedging are substitutes in the risky-debt region: $IC(h)$ is decreasing in h for $h \in [0, h_0)$. In equilibrium, the entrepreneur's optimal policies consist of either*

$$(h^*, a^*) = (0, 1) \quad \textit{if } IC(0) \geq 0, \tag{24}$$

or

$$(h^*, a^*) = (h_0, 0) \quad \textit{if } IC(0) < 0. \tag{25}$$

The model generates a rich interaction between financial and operational hedging that depends on the severity of financing frictions. When frictions are severe ($\gamma \geq \bar{\gamma}$), the two hedging instruments are complements: financial hedging relaxes the financing constraint, reduces debt overhang, and facilitates operational hedging. When frictions are moderate ($\gamma < \bar{\gamma}$), they are substitutes: firms choose either operational hedging with minimal financial hedging, or financial hedging to eliminate risk entirely while forgoing costly operational effort.

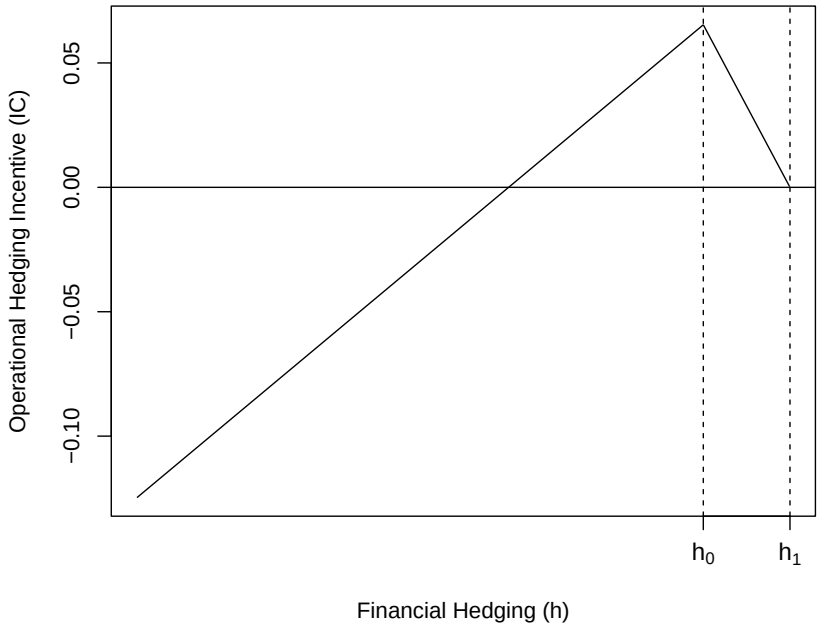


Figure 1. Incentive to pursue operational hedging vs. financial hedging ($h_0 \leq h_1$). The figure plots an example of the entrepreneur's incentive to pursue operational hedging at $t = 1$ versus the amount of financial hedging at $t = 0$, showing that the two types are complements for $h < h_0$ and substitutes when $h \geq h_0$.

4 Data and Sampling

We obtain financial and operational information for U.S. power generation firms from S&P's SNL Energy database. S&P collects power plant data from a variety of federal regulatory agencies and corporate SEC filings. We primarily rely on their collections of Federal Energy Regu-

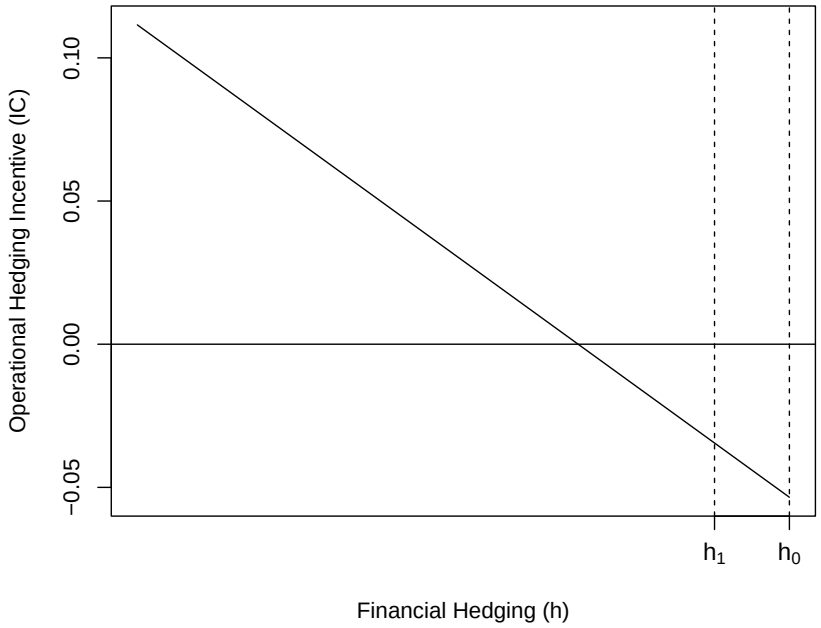


Figure 2. Incentive to pursue operational hedging vs. financial hedging ($h_0 > h_1$). The figure plots an example of the entrepreneur's incentive to pursue operational hedging at $t = 1$ versus the amount of financial hedging at $t = 0$ when the two types of hedges are substitutes for $h < h_0$.

latory Commission (FERC) Form 1, which is filed by all major regulated electric utilities since 1988, for items related to financials, generation, capacity, and fuel category (i.e., coal, natural gas, hydro, solar, wind, etc.).

FERC reports financial statements at both the subsidiary and parent levels following the USofA accounting standard.[3]. To take advantage of the granularity of the data, we use financial information at the bottom subsidiary level. Thus, compared to Compustat, our sample of electric utilities extends to private firms and private subsidiaries of public firms. It also covers derivative positions, which prior studies obtain from annual or quarterly filings, and operating metrics (such as capacity information at the subsidiary level, further disaggregated by fuel category and regulatory status), which are not available in Compustat.

[3]USofA stands for Uniform System of Accounts, which is FERC's own system for filing annual FERC reports. USofA is derived from the GAAP standard.

4.1 Operational Hedging

We measure firms' operational hedging mainly by their inventory holdings. Inventory is widely regarded as a buffer for firms to reduce their exposure to future adverse shocks. For example, firms can produce more than sales to accumulate inventory when production costs are low, and while storing inventory is costly, they can sell from inventory in adverse states when costs are unfavorable or production is disrupted. Consistent with this production cost-smoothing behavior, West (1990) shows that cost shocks play a predominant role in driving inventory fluctuations. Dasgupta et al. (2019) further show that the incentive to use inventory as a buffer against future adverse shocks is stronger when external financing is constrained, as selling from inventory could help firms generate internal cash flows to cover their operating losses and avoid bankruptcy in adverse states. So far, these studies mainly rely on inventory provided by Compustat for U.S. public firms.

To our advantage, FERC Form 1 requires firms to report their current-asset portion of natural gas stored underground (FERC Account 164), as well as liquefied gas (LNG) stored. These two variables offer ideal measures for power plants' operational hedging activities, as they capture the *on-site* gas inventory which can be withdrawn more easily when gas supply from pipelines is limited due to severe weather events or other production disruptions.[4] Freeman et al. (2021) show that on-site fuel storage can mitigate fuel shortage failures and economically reduce the dependence of power plants and gas grids on pipelines. For our main empirical analysis, we scale both current natural gas stored underground and LNG stored by the firm's beginning-of-period total assets and winsorize the ratios at the 1% level at both tails of the distribution to alleviate the impact of outliers. The resulting variables, *Gas Stored* and *LNG Stored*, are our main measures for operational hedging.

As shown in Table 1, the median power producer in the U.S. does not have any underground gas storage. This is expected, as power plants mostly rely on gas pipelines to supply

[4]Firms often manage their gas inventory by owning or leasing storage capacity from interstate pipelines. They purchase the natural gas, inject it into the leased space, and withdraw when necessary.

fuel. However, they can (and some firms in our sample indeed do) hold gas fuel inventory in underground facilities as a buffer to shocks. These underground facilities are depleted reservoirs in natural gas fields, aquifers, and salt cavern formations. LNG is commonly stored in above-ground tanks.

[TABLE 1 ABOUT HERE]

Besides the current-asset portion of gas storage, FERC Form 1 also reports firms' gas stored for long-term uses (FERC Account 117). Unlike the former, which are expected to be withdrawn within 12 months, these long-term gas storage facilities largely represent unexplored gas reservoirs. Intuitively, such storage cannot be depleted immediately in the face of fuel shortages and therefore does not serve the purpose of operational hedging. For this reason, we use long-term stored gas in a placebo test to capture gas storage incentives other than operational hedging. Similarly for LNG. FERC report the portion that is held for processing, which is not considered fuel inventory. As such, we also use it for the placebo test.

In addition, we measure operational hedging by excess capacity. Acharya et al. (2023) hypothesize that firms can maintain backup capacity to mitigate the risk of operational disruption. Our data allows us to directly measure excess capacity. Since 2009, FERC has reported power generation and operating capacity for power plants, as well as their capacity factor. The capacity factor is calculated as the net generation divided by operating capacity, multiplied by the number of hours in a year. For each electric utility firm since 2009, we compute *Excess Capacity* as one minus the capacity factor of the firm's natural gas power plants and use it as an additional measure for operational hedging.

4.2 Financial Hedging

Following the empirical literature on financial hedging (e.g., Haushalter 2002, Campello et al. 2011, Acharya et al. 2013, Pérez-González and Yun 2013, Gilje and Taillard 2017), we first focus on traded derivatives usage as a proxy for financial hedging. FERC requires firms to classify

their derivative instruments as assets or liabilities in the financial statements, which may include futures, options, swaps, and weather products. Moreover, it requires firms to distinguish each category according to their intended uses, i.e., derivative (assets or liabilities) used for hedging purposes vs. derivative (assets or liabilities) used for trading activities, which allows us to exclude derivative positions that potentially amplify the cash flow volatility rather than reducing it. So, we focus on the use of derivative instruments for *hedging* activities based on firms' own classification.

A potential issue with using the hedging position as a direct measure, however, is fair value accounting. The implosion of Enron highlighted problems with reporting financial derivatives. Since 2002, FERC has required firms to recognize their derivative positions based on the fair value rather than historical costs, which means that firms shall recognize changes in the fair value of the derivative assets (liabilities) as derivative assets-hedges (liabilities-hedges). This puts challenges in our measurement of financial hedging, as neither the derivative assets nor liabilities can reveal the fraction of firms' input or output that yields a fixed payoff from the financial hedging contract (i.e., the parameter h in our model).

Reflecting on the change in the reporting requirement as well as fair value accounting, we construct a financial hedging dummy, *Fin Hedge*, to capture firms' financial hedging activities. We assign a value of one to the dummy if either derivative assets-hedges or derivative liabilities-hedges is non-missing and non-zero, and assign a value of zero otherwise. The rationale is that unless the hedging contract does not yield any changes in fair value—an unlikely scenario given market volatility and uncertainty—the accounting items reflecting derivative assets or liabilities would at least show some positive or negative value if the firm had entered into a hedging contract for its input or output. So, our hedging dummy mainly captures variation in the extensive margin in the use of hedging derivatives.[5]

[5]This approach is largely consistent with prior empirical studies on hedging, with a few exceptions that use continuous measures. For example, Haushalter (2002) obtained the fraction of oil production and gas production hedged for 1992, 1993, and 1994 by sending surveys to 100 public firms in the US. Campello et al. (2011) capture the notional value of interest rate and foreign exchange derivatives using a web crawler program searching for keywords in firm filings. However, this is not feasible for our context, as the notional value of weather derivatives

4.3 Sample

We drop utility firms that are labeled as Electric Cooperative, Gas Pipeline, or Wholesale Transmission, as these firms either provide service solely to their members or do not own power plants. Also, we exclude any firm-year observation that has missing values on the book value of assets. In addition, utilities occurring wholly within ERCOT is not subject to the regulation of FERC and thereby not included in our sample.[6] We further require the observation to have non-missing values in the financial hedging dummy, total asset, net income, and leverage (defined as long-term debt divided by total assets).

Our final sample consists of 306 electric utility firms (4,424 observations) with available financial hedging data. The sample period for our main analysis is from 1995 to 2021.

We plot the distribution of the average use of financial and operational hedging by our sample firms in 2021 across different states. As shown in Panel A of Figure 3, states in the north, where winter freezes are more likely and distance to natural gas production is longer, on average report a higher level of gas inventory (as a fraction of the total assets) than states in the south, indicating a higher precautionary need against supply disruptions by firms with higher risk exposure. Moreover, they do not coincide with states that display a more intensive use of derivative contracts (Panel B of Figure 3).

[FIGURE 3 ABOUT HERE]

Notably, the U.S. power market is characterized by significant heterogeneity in the industrial organization (Figure B.1 in the Appendix). What we show in Figure 3 also suggests that the prevalence of hedging activities does not cluster by the electric power market, consistent with the non-existence of regulation on firms' hedging policies at the specific market-level. So, the hedging choices are largely determined by the firm.

and input and output derivatives are not reported in these filings.

[6]The transmission grid that the ERCOT administers is located solely within the state of Texas and is not synchronously interconnected to the rest of the U.S.

5 Empirical Results

In this section, we test our model's predictions using regulatory data from FERC on U.S. electric utilities and provide evidence of the interplay between financial hedging and firms' incentive to undertake operational hedging in the presence of financial frictions.

Our setting offers several advantages in empirically testing the model's prediction. First, the electric utility industry is heavily exposed to weather risks. Weather affects both the demand for electricity and the supply of their input (e.g., natural gas) and drives the fluctuation of firms' cash flows (Lin et al. 2021, Lin et al. 2025). Moreover, more severe weather conditions could increase the probability of disruption, which is associated with high economic and social stakes. Second, there is limited variation in the production technology across different power producers in the same category, which ensures that the investment and hedging policies we analyze are comparable across our sample firms and match closely with our model's setup. Finally, the availability of detailed regulatory data makes it possible for us to measure the form of operational and financial hedges that are most relevant to this industry.

5.1 Refinancing Needs and Firms' Hedging Choices

We first empirically establish the relation between firms' financial hedging and their financing needs. In our model, firms' incentive to hedge using a financial contract stems from the need to raise external financing from investors with limited risk-bearing capacity. Our model predicts that, by locking a fraction of the project's output or input at a fixed price in advance, financial hedging transfers a fraction of the project's risk from the entrepreneur to the off-taker (or the counterparty of the derivative position) and reduces the firm's cost of borrowing.

We show that firms indeed engage in financial hedging prior to refinancing their outstanding debt. Here, we focus on the refinancing of firms' existing debt rather than their total external financing need (I in the model) because the former is based on the maturity shaped by firms' past debt issuance decisions and contractual debt schedules. This predetermined

structure is less affected by simultaneous changes in unobserved risk exposure or managerial decisions, allowing us to isolate variations in financial hedging driven by refinancing pressure. Following Xu (2018), we argue that firms normally have a need to issue new debt when retiring old ones. We proxy for firms' refinancing needs in year t by the cash flow payment for the retirement of long-term debt in year $t+1$ and estimate the following regression:

$$Hedge_{i,t} = \alpha + \beta \times Re\text{-}financing_Need_{i,t} + \gamma \times Controls_{i,t-1} + \kappa_i + \delta_t + \varepsilon_{i,t} \tag{26}$$

where the dependent variable here is the financial hedging dummy, $Fin_Hedge_{i,t}$, developed in Section 4.2, which equals 1 if firm i's derivative assets held for hedging purposes in year t or derivative liabilities held for hedging purposes have a non-missing and non-zero value in the FERC Form 1 filing, and 0 otherwise. $Re\text{-}financing_Need_{i,t}$ for firm i in year t is proxied by its cash outflows incurred in year $t+1$ for retiring long-term debt, scaled by firm i's beginning-of-period total assets. In addition, our estimation controls for firm-fixed effects, year-fixed effects, and firm characteristics that may also affect financial hedging. The control variables include firm size, profitability, and leverage, and are all lagged by one period. The regression results are presented in Table 2.

[TABLE 2 ABOUT HERE]

As shown in Column 1 of Table 2, the use of financial hedging increases with firms' refinancing needs. The economic magnitude is also considerable: A one standard deviation increase in the firm's refinancing need is associated with a 2.1% increase in the use of derivatives for hedging purposes ($\beta \times SD(Re\text{-}financing_Need) = 0.621 \times 0.034 = 2.1\%$), which is about 8% of the sample mean. The evidence is consistent with our model's prediction.

An important distinction between financial and operational hedging in our model is that we assume firms' financial hedging contracts to be publicly observable before the investor considers the entrepreneur's financing offer, while the effort exerted by the entrepreneur to undertake operational hedging is unobservable. As such, firms could commit to a lower cash

flow volatility through financial contracts prior to refinancing their debt to reduce the borrowing costs, while committing to so through operational hedging would be challenging. This assumption is consistent with the common practice that banks require power plants to engage in a certain level of financial hedging to demonstrate resilience in their cash flow when deciding the amount and cost of their borrowing. It is also consistent with recent findings by Babenko et al. (2024) that the large majority of loan agreements in oil-and-gas industry include covenants that specify aspects of firms' financial hedging policies and require periodic reports of derivative positions to lenders. To verify that lenders do not extend the same requirement to operational hedging, we estimate Regression (26), replacing the dependent variable with the measures we developed in Section 4.1 for operational hedging, *Gas Stored* and *LNG Stored*. As shown in Columns 2 and 3 of Table 2, firms' natural gas stored underground and LNG stored do not respond to their refinancing needs, consistent with our model's setup.

Next, we test our model's prediction that financial hedges reduce firms' *ex ante* cost of borrowing as they reduce the project's payoff uncertainty. We estimate the following regression:

$$Borrowing_Cost_{i,t} = \alpha + \beta \times Hedge_{i,t-1} + \gamma \times Controls_{i,t-1} + \kappa_i + \delta_t + \varepsilon_{i,t} \tag{27}$$

where the dependent variable, $Borrowing_Cost_{i,t}$, is firm i's interest payment on long-term debt in year t, divided by the amount of long-term debt at the beginning-of-period. The independent variable of interest here is the financial hedging dummy, $Fin_Hedge_{i,t-1}$, denoting whether firm i has a hedging derivative position in year $t-1$. Our estimation controls for firm-fixed effects, year-fixed effects, and firm characteristics that may also affect financing costs. The control variables include firm size, profitability, leverage, and z-score, all lagged by one period. We also control for the firm's financing needs at the same period. The regression results are presented in Table 3.

[TABLE 3 ABOUT HERE]

Consistent with our prediction, we show in Column 1 of Table 3 that financial hedging

lowers firms' subsequent cost of borrowing. For our sample firm, annual interest rates for those that have a derivative position are 20 basis points lower than those without. The effect we find is also in line with insights and evidence in earlier work such as Froot et al. (1993), Haushalter (2002), Campello et al. (2011), Gilje and Taillard (2017) that financial derivatives can improve firm value by reducing their external financing costs.

In contrast, Columns 2 and 3 of Table 3 show that operational hedging does not reduce firms' borrowing costs. As discussed earlier, this is mainly due to the lack of contractability of operational hedging relative to financial hedging. When financial frictions due to the investors' limited risk-bearing capacity are present, entering into a financial contract (or a combination of financial contracts) to guarantee more stable cash flows provides a stronger commitment than reserving higher inventory buffers or excess capacity, although the latter could reduce the probability of the bad state and the riskiness of the debt as we show in our model. However, if regulation improves the extent to which operational hedges can be observed or committed, operational hedging could potentially serve a more effective role in reducing firms' borrowing costs.[7]

5.2 Evidence of Financial Hedging Overhang

We move on to test our model's novel prediction on the tension between financial and operation hedging. Our hypothesis is that as financial hedging reduces the entrepreneur's exposure to adverse shocks, it decreases the entrepreneur's incentive to pursue costly operational hedging, inducing a financial hedging overhang. We test this hypothesis by estimating the following regression:

$$Op_Hedge_{i,t} = \alpha + \beta \times Fin_Hedge_{i,t-1} + \gamma \times Controls_{i,t-1} + \kappa_i + \delta_t + \varepsilon_{i,t} \qquad (28)$$

[7] For example, FERC Order 898 mandates regulated utilities to provide more accounts related to storage since 2025, which could potentially be used to finance firms' external borrowing in the future.

where the dependent variable, $Op_Hedge_{i,t}$, is one of our measures of firm i's operational hedging in year t developed in Section 4.1, namely, gas stored underground ($Gas_Stored_{i,t}$), liquefied gas stored ($LNG_Stored_{i,t}$), and excess capacity ($Excess_Capacity_{i,t}$). The independent variable of interest here is the financial hedging dummy, $Fin_Hedge_{i,t-1}$, denoting whether firm i has a hedging derivative position in year $t-1$. Again, our estimation controls for firm-fixed effects, year-fixed effects, and firm characteristics in year $t-1$ that may also affect the optional hedging decisions, such as firm size, profitability, and leverage.

[TABLE 4 ABOUT HERE]

Our regression results, as presented in Table 4, show evidence that financial hedges substitute operational hedges for our sample firms. Across all three measures, we find that firms that hedge via financial derivatives subsequently engage in less operational hedging. The economic magnitude is also considerable: when entering into a financial contract, firms, on average, reduce their subsequent on-site gas inventory (scaled by the beginning-of-period assets) by 0.3 percentage points, which represents 25% of the average gas inventory-to-asset ratio. Similarly, they reduce their LNG storage by 0.02 percentage points (33% of the sample mean) and excess capacity by 2.7 percentage points (3.5% of the sample mean). Our results suggest that the financial hedging overhang is present for the average firm in our sample.

We perform a falsification test to show that the substitution by financial hedging is most relevant to firms' operational hedging activities, such *on-site* gas inventory as we explore in our baseline test, rather than any gas reserved by the firm. We utilize two additional variables provided by FERC FORM 1, namely firms' gas stored for long-term uses ($Gas_Long_Term_{i,t}$) and LNG held for processing ($LNG_Process_{i,t}$) as placebos. We replace the operational hedging variables, $Gas_Stored_{i,t}$ and $LNG_Stored_{i,t}$, with our placebos and re-estimate regression (28). As shown in Table 5, firms' gas stored for long-term and LNG held for processing are not affected by their financial hedging, consistent with our view that long-term gas storage and LNG held for processing reflect other decisions than operational hedging and thus are

not substituted by financial hedges.

[TABLE 5 ABOUT HERE]

5.3 Heterogeneity Tests

Our model also generates novel predictions regarding the indirect effect of financial hedging in encouraging operational hedging. As financial hedging reduces the project's payoff uncertainty and the face value of risky debt, it indirectly incentivizes operational hedging by mitigating the conventional debt overhang problem. Our model, therefore, predicts that operational hedging is less sensitive to financial hedging when financing friction is more severe (Propositions 2 and 3) or when financial hedging is more efficient (Corollary 1). In this section, we test these predictions.

5.3.1 The Role of Financing Frictions

We first explore the variation in the severity of financing frictions. In our model, financial frictions originated from investors' limited risk-bearing capacity (e.g., γ in the model). Therefore, we use credit spreads from the FRED database to proxy for the aggregate financing friction. As firms in the utility sector on average have a BBB rating, we use the BBB credit spreads to categorize each firm's observations into terciles. The ones in the top (bottom) tercile are considered to have high (low) financing friction. We estimate regression (28) for the two groups separately, controlling for firm-fixed effects, year-fixed effects, and lagged firm characteristics, such as firm size, profitability, and leverage. The results are reported in Table 6. Consistent with our model, the substitution effect of operational hedging by financial hedging is less pronounced when financing frictions are more severe, because the complementarity effect starts to kick in.

[TABLE 6 ABOUT HERE]

5.3.2 The Role of Financial Hedging Efficiency

We further examine the role of financial hedging efficiency to generate heterogeneity of the interplay between financial and operational hedging. Our model predicts that, when financial hedging is more efficient (or less costly) in mitigating debt overhang, the incentive compatibility condition is more likely to be satisfied, and financial and operational hedges are more likely to occur together. In our setting, this corresponds to a higher payoff from the firm's financial hedging contract (P) or a lower external financing need (I), as in both cases, the firm does not have to hedge a large fraction of the project's payoff to make the debt safe.

Following Acharya et al. (2013), we use speculators' ease of access to capital, defined as the ratio of the growth in broker-dealers' total financial assets to the growth in households' total financial assets, to proxy for the payoff from the firm' financial hedging contract (P). If broker-dealers have ample capital, they are willing to take the opposite side of producers' hedge-motivated futures positions at relatively low costs, which increases the firm's payoff from their financial hedging contracts, all else equal.

We obtain the data from the U.S. Flow of Funds, which provides quarterly balance sheet information on assets and liabilities across all sectors. The growth in broker-dealers' total financial assets is computed using security brokers and dealers balance sheet data, while the corresponding series for households is based on the balance sheets of households and nonprofit organizations. We then classify each firm's observations into terciles. The ones in the top (bottom) tercile are considered to have high (low) financial hedging efficiency. Consequently, we expect the substitution between financial and operational hedging to be weaker (or even reverse) when broker-dealers' capital constraints are less binding (i.e., when the ratio is higher).

We estimate regression (28) for the high and low efficiency groups separately. As shown in Panel A of Table 7, we find evidence consistent with our prediction: while operational hedging decreases with financial hedging in the low efficiency group, it is not sensitive to financial

hedging in the high effiency group.

[TABLE 7 ABOUT HERE]

In Panel B of Table 7, we explore firms' refinancing need to generate heterogeneity in the efficiency of financial hedges to reduce debt overhang. Our idea is that when the firm's refinancing needs are low (e.g., I in the model is low), it does not have to hedge a large fraction of the project's payoff to make the debt safe. This makes the incentive compatibility condition more likely to be satisfied and that financial and operational hedges are more likely to occur together.

To implement, we classify firms into terciles based on their refinancing needs each year. The ones in the top (bottom) tercile are considered to have high (low) refinancing needs. We expect the substitution of operational hedging by financial hedging to be weaker (or even reverse) when refinancing needs are lower. By estimating regression (28) for the high and low refinancing groups separately, we find evidence consistent with our prediction: while operational hedging decreases with financial hedging in the high refinancing group, it is not sensitive to financial hedging in the low refinancing group.

Taken together, the results we find in this section provide strong supporting evidence for our model's mechanism.

6 Concluding Remarks

In this paper, we study firms' hedging policies, focusing on the interplay between financial and operational hedging. Our parsimonious model of risk management highlights a tension between financial and operational hedging. The former *reallocates* risk to specialized investors, which decreases the firm's subsequent incentives to *reduce* risk by undertaking the latter, inducing a *financial hedging overhang problem*. Furthermore, we show that as financial hedges lower the firm's cost of financing, it indirectly incentivizes operational hedging by mitigating

the conventional debt overhang problem.

Using U.S. electric utilities as a laboratory, we provide evidence consistent with the model's predictions. In particular, we show that firms that hedge via financial contracts subsequently engage in less operational hedging, including on-site underground natural gas storage, LNG stored, and excess capacity. Moreover, we provide direct evidence that financial hedges respond to firms' refinancing need and reduce borrowing cost. However, due to limited contractability, operational hedges do not have the same effect, although they physically reduce risk.

In all, our paper provides important insights into potential avenues for incentivizing operational hedging and enhancing the power grid's resilience.

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Appendix A Proofs

Proof of Lemma 1. The entrepreneur's private benefit from operational hedging is maximized when debt is safe, because in that case she captures the entire increase in expected payoff. Under safe debt, the benefit equals $e(\pi_H - \pi_L) = e(1-h)\Delta_y$. If $e(1-h)\Delta_y < c$, then even under safe debt, the entrepreneur will not exert effort, and therefore the IC condition cannot hold under any (weakly) riskier financing contract. Rearranging gives $h > 1 - \frac{c}{e\Delta_y} =: h_1$. □

Proof of Lemma 2. If (14) held strictly, the entrepreneur could reduce (x_H, x_L) slightly while preserving feasibility and monotonicity, increasing her expected payoff. Hence, the constraint must bind at the optimum. □

Proof of Lemma 3. Fix h and anticipated effort a. Because the entrepreneur has full bargaining power, the participation constraint binds (Lemma 2). In the relevant region $x_L \le I \le x_H$, x_H is pinned down by x_L via (15). The entrepreneur's expected payoff is decreasing in x_H and increasing in x_L, and (15) implies that increasing x_L decreases x_H. Hence, the entrepreneur chooses the maximum feasible x_L.

If monotonicity binds before limited liability, then $x_L = x_H$ and binding the participation constraint yields $x_L = x_H = I$ (i.e., safe debt). If limited liability binds first, then $x_L = \pi_L(h)$ and x_H is determined by (15), giving (16) (i.e., risky debt). In either case, the optimal financing contract is debt. □

Proof of Lemma 4. Fix $h < h_0$, so that $\pi_L(h) < I$ and debt is risky. With $a = 0$, the face value is $D_0(h) = D_{a=0}(h)$ from (**??**):

$$D_0(h) = I + (1+\gamma)\frac{p}{1-p}\big[I - \pi_L(h)\big]. \tag{Appendix A.1}$$

The entrepreneur receives a payoff only in the high state, so her expected payoff is $(1-p)\big(\pi_H(h) - D_0(h)\big)$. Because $\pi_H(h)$ and $\pi_L(h)$ are linear in h, $\pi_H(h) - D_0(h)$ is linear in h with slope

$$\tfrac{d}{dh}\big(\pi_H(h) - D_0(h)\big) = (P - y_H) + (1+\gamma)\tfrac{p}{1-p}(P - y_L), \tag{Appendix A.2}$$

which is strictly positive by (19). Hence, the entrepreneur's expected payoff is strictly increasing on $[0, h_0)$.

For $h \ge h_0$, debt is safe with face value I, so the entrepreneur's expected payoff is $(1-h)\mathbb{E}[y] + hP - I$, which is strictly decreasing in h because $P < \mathbb{E}[y] = y_H - p\Delta_y$ by assumption. Therefore, the optimum is attained at the smallest h that makes debt safe (i.e., $h^* = h_0$). □

Proof of Proposition 1. For $h < h_0$, debt is risky and $D_1(h)$ is given above. Differentiating yields

$$\tfrac{d}{dh}\big(\pi_H(h) - D_1(h)\big) = (P - y_H) + (1+\gamma)\tfrac{p-e}{1-p+e}(P - y_L). \tag{Appendix A.3}$$

This derivative is nonnegative if and only if

$$1+\gamma \geq \frac{1-p+e}{p-e} \cdot \frac{y_H - P}{P - y_L}, \tag{Appendix A.4}$$

which defines the threshold $\bar{\gamma}$. Because $IC(h)$ in (**??**) is an affine transformation of $\pi_H(h) - D_1(h)$, the same condition implies that $IC(h)$ increases in h on $[0, h_0)$. □

Proof of Proposition 2. First, consider $h < h_0$ (risky debt). When $\gamma \geq \bar{\gamma}$, Proposition 1 implies that $IC(h)$ and $\pi_H(h) - D_1(h)$ are increasing in h. Hence, increasing h weakly relaxes the interim IC and (by the same logic as Lemma 4) weakly improves financing terms while debt remains risky. Therefore, the entrepreneur (weakly) prefers a higher h up to the point where debt becomes safe.

Second, for $h \geq h_0$ debt is safe with face value I, and the entrepreneur's expected payoff (conditional on $a = 1$) is

$$(1-h)\big(y_H - (p-e)\Delta_y\big) + hP - I - c, \tag{Appendix A.5}$$

which is strictly decreasing in h because $P < y_H - p\Delta_y < y_H - (p-e)\Delta_y$. Thus, among safe-debt hedges, the entrepreneur prefers the smallest h that achieves safety, namely h_0. Combining both steps yields $h^* = h_0$.

Finally, whether $a^* = 1$ is implementable at $h = h_0$ is determined by the interim IC under safe debt:

$$e\big(\pi_H(h_0) - \pi_L(h_0)\big) = e(1-h_0)\Delta_y \geq c, \tag{Appendix A.6}$$

which is equivalent to $h_0 \leq h_1$ (with h_1 defined in Lemma 1). If $h_0 > h_1$, then even under safe debt, the IC fails, and therefore it cannot be satisfied under any financing arrangement. □

Proof of Corollary 1. The results follow from the equivalent condition $\frac{e\Delta_y}{c} \geq \frac{P-y_L}{P-I}$. Note that the LHS increases in e, Δ_y, and decreases in c, while the RHS decreases in P (because $y_L < I$). □

Proof of Proposition 3. If $\gamma < \bar{\gamma}$, then Proposition 1 implies $\frac{d}{dh}(\pi_H(h) - D_1(h)) < 0$ for $h \in [0, h_0)$, and therefore $IC(h)$ in (**??**) is strictly decreasing on $[0, h_0)$.

If $IC(0) \geq 0$, then operational hedging can be induced with $h = 0$. Because $IC(h)$ is decreasing for $h < h_0$ and because operational hedging incentives under safe debt are also decreasing in h (since $e(1-h)\Delta_y - c$ decreases in h), the entrepreneur strictly prefers the smallest hedge ratio among contracts that implement $a = 1$, i.e., $h^* = 0$.

If $IC(0) < 0$, then $IC(h) < 0$ for all $h \in [0, h_0)$ by monotonicity. Moreover, if $IC(h_0) < 0$ under safe debt, then no $h \geq h_0$ can satisfy IC because the safe-debt IC equals $e(1-h)\Delta_y - c$ and is decreasing in h. Hence $a^* = 0$ for all feasible hedging choices, and Lemma 4 implies that the optimal policy is to choose $h^* = h_0$ and issue safe debt. □

Appendix B The U.S. Power Market

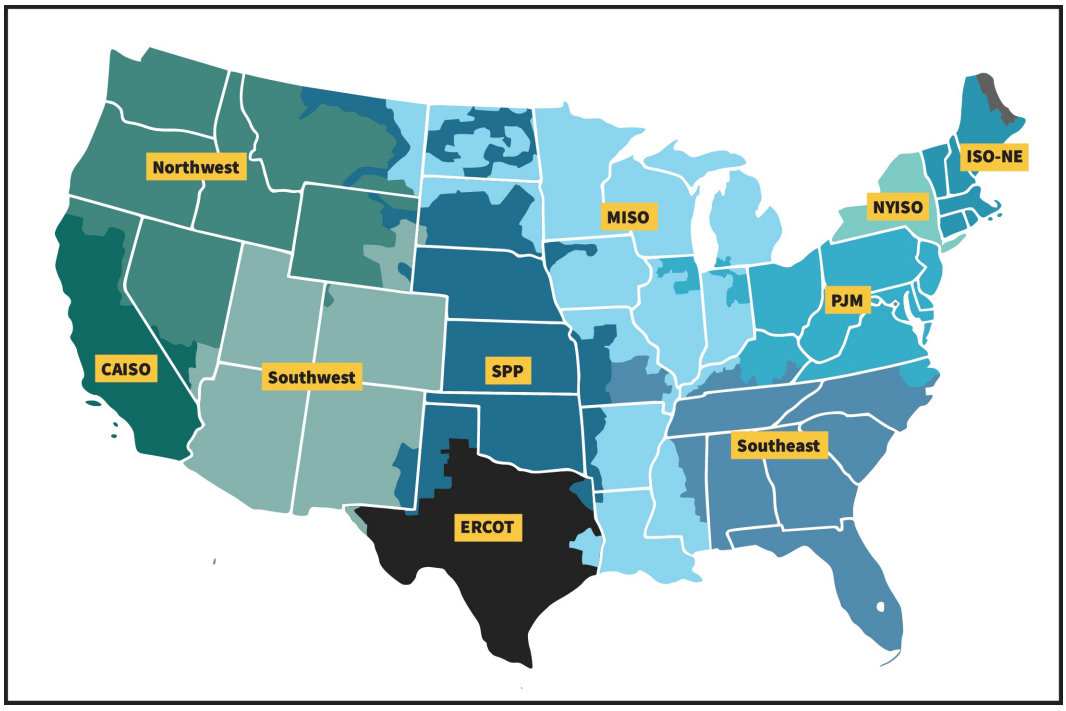


Figure B.1. The U.S. Power Market This figure presents an overview of the U.S. electric power market structure obtained from FERC (https://www.ferc.gov/electric-power-markets). Utilities in traditional wholesale markets, such as Southeast, Southwest, and Northwest, are frequently vertically integrated – they own the generation, transmission, and distribution systems used to serve electricity consumers. By contrast, in a deregulated wholesale market such as ERCOT, utilities that serve retail customers are only responsible for delivering electricity to their customers; the electricity is generated by other entities.

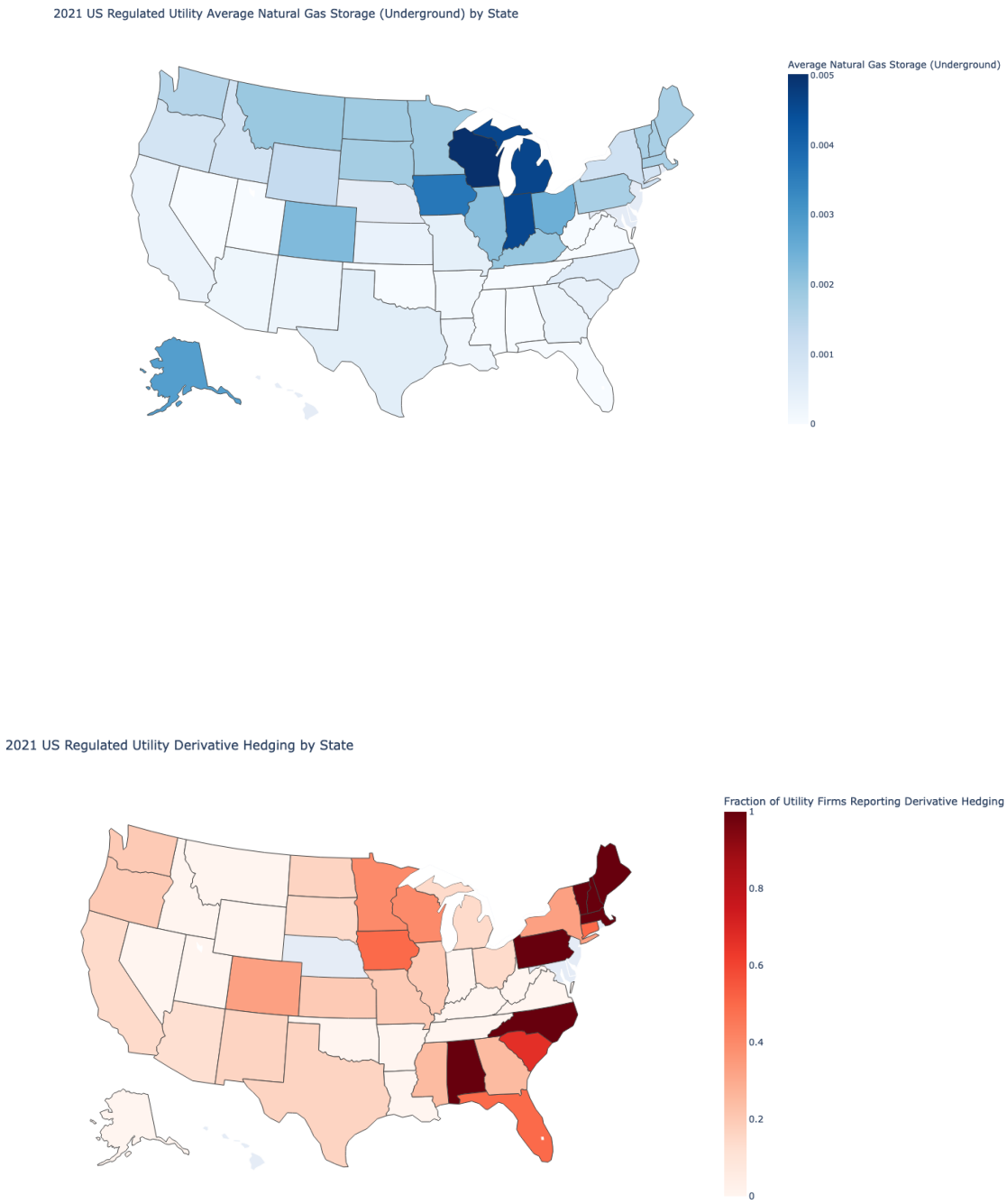


Figure 3. The Use of Financial and Operational Hedging This figure presents electric utilities' use of financial and operational hedging in year 2021. The upper panel shows the average natural gas stored underground by state. The lower panel displays the fraction of utility firms reporting derivatives hedging activities in each state.

Table 1. Summary Statistics

The sample consists of U.S. electric utilities that own power generators and are subject to the regulation of FERC. Observations are at the bottom subsidiary and year level. *Gas Stored*, *LNG Stored*, and *Excess Capacity* are the measures for operational hedging. *Gas Stored* is the current-asset portion of natural gas stored underground, divided by the firm's lagged assets. *LNG Stored* is liquefied gas stored, divided by lagged assets. *Excess Capacity* is calculated as one minus the capacity factor of the firm's natural gas power plants, where capacity factor is calculated as the net generation divided by operating capacity, multiplied by the number of hours in a year. *Fin Hedging* is a dummy variable we construct to measure firms' financial hedging. We focus on the use of derivative instruments for *hedging* activities based on firms' own classification. The dummy takes a value of one if either derivative assets-hedges or derivative liabilities-hedges is non-missing and non-zero, and assign a value of zero otherwise. *Gas Long Term* and *LNG Process* represent firms' gas stored for long-term uses and LNG held for processing, respectively. Both of them are divided by lagged assets. They capture firms' incentive to hold gas for other purposes than operational hedging. All ratios are winsorized at the 1% level at both tails of the distribution to alleviate the impact of outliers. Detailed sample screening and main variable constructions are discussed in Section 4.

	Obs.	Mean	Median	Std. dev.
Gas Stored	4,424	0.013	0.000	0.027
LNG Stored	4,420	0.0006	0.0000	0.0027
Excess Capacity	1,025	0.763	0.771	0.181
Fin Hedge	4,424	0.235	0.0000	0.424
Gas Long Term	4,424	0.0008	0.0000	0.0032
LNG Process	4,420	0.00002	0.0000	0.0001

Table 2. Refinancing Needs and Firms' Hedging Choices

This table presents evidence that firms engage in financial hedging prior to Refinancing their long-term debt. The sample consists of U.S. electric utilities that own power generators and are subject to the regulation of FERC. Sample screening and main variable constructions are discussed in Section 4. We perform regression (26):

$$Hedge_{i,t} = \alpha + \beta \times Re\text{-}financing_Need_{i,t} + \gamma \times Controls_{i,t-1} + \kappa_i + \delta_t + \varepsilon_{i,t}$$

where the dependent variable in Column 1 is $Fin_Hedge_{i,t}$, which is a financial hedging dummy that equals 1 if firm i's derivative assets or liabilities held for hedging purposes in year t have a non-missing and non-zero value, and 0 otherwise. The dependent variable in Column 2 (3) is $GasStored_{i,t}$ ($LNG_Stored_{i,t}$), which is firm i's natural gas stored underground (liquefied gas stored) in year t scaled by its beginning-of-period total assets. $Re\text{-}financing_Need_{i,t}$ for firm i in year t is proxied by its cash outflows incurred in year $t+1$ for retiring long-term debt, scaled by firm i's beginning-of-period total assets. We control for firm-fixed effects, year-fixed effects, and firm characteristics lagged by one period, such as firm size, profitability, and leverage. Standard errors in parentheses are clustered at the firm level. One star (*) indicates significance at the 10% level, two stars 5%, and three stars 1% level.

Dependent variable:	**Fin Hedge**	**Gas Stored**	**LNG Stored**
Dep. Var. Mean:	0.268	0.012	0.0006
	(1)	(2)	(3)
Refinancing Need	**0.621*** **	**–0.009**	**–0.000**
	(0.170)	(0.006)	(0.001)
Other Firm Characteristics	Yes	Yes	Yes
Firm F.E.	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes
Clusters	Firm	Firm	Firm
R-squared	0.546	0.803	0.873
Observations	3,648	3,648	3,648

Table 3. The Impact of Hedging on Financing Costs

This table shows the effect of hedging on firms' financing costs. The sample consists of U.S. electric utilities that own power generators and are subject to the regulation of FERC. Sample screening and main variable constructions are discussed in Section 4. We perform regression (27):

$$Borrowing_Cost_{i,t} = \alpha + \beta \times Hedge_{i,t-1} + \gamma \times Controls_{i,t-1} + \kappa_i + \delta_t + \varepsilon_{i,t}$$

where the dependent variable is $Borrowing_Cost_{i,t}$, which is firm i interest payment on long-term debt in year t, divided by the amount of long-term debt at the beginning-of-period. $Fin_Hedge_{i,t-1}$ is a financial hedging dummy denoting whether firm i has a hedging derivative position in year $t-1$. It equals 1 if firm i's derivative assets or liabilities held for hedging purposes in year $t-1$ have a non-missing and non-zero value, and 0 otherwise. $GasStored_{i,t-1}$ ($LNG_Stored_{i,t-1}$) represent firm i's operational hedging in year $t-1$, which is firm i's natural gas stored underground (liquefied gas stored) in year $t-1$ scaled by its beginning-of-period total assets. We control for firm-fixed effects, year-fixed effects, and firm characteristics lagged by one period, such as firm size, profitability, leverage, and z-score. We also control for the firm's financing needs at the same period. Standard errors in parentheses are clustered at the firm level. One star (*) indicates significance at the 10% level, two stars 5%, and three stars 1% level.

Dependent variable:	**Borrowing Cost**		
Dep. Var. Mean:	0.052	0.052	0.052
	(1)	(2)	(3)
Fin Hedge	**–0.002*** **		
	(0.000)		
Gas Stored		0.042	
		(0.116)	
LNG Stored			0.015
			(0.451)
Other Firm Characteristics	Yes	Yes	Yes
Firm F.E.	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes
Clusters	Firm	Firm	Firm
R-squared	0.628	0.803	0.7137
Observations	2,447	2,447	2,447

Table 4. Financial Hedging Overhang

This table shows the effect of financial hedging on firms' subsequent operational hedging. The sample consists of U.S. electric utilities that own power generators and are subject to the regulation of FERC. Sample screening and main variable constructions are discussed in Section 4. We perform regression (28):

$$Op_Hedge_{i,t} = \alpha + \beta \times Hedge_{i,t-1} + \gamma \times Controls_{i,t-1} + \kappa_i + \delta_t + \varepsilon_{i,t}$$

where the dependent variable, $Op_Hedge_{i,t}$, takes one of the measures of operational hedging, which in Column 1 is $Gas_Stored_{i,t}$, in Column 2 is $LNG_Stored_{i,t}$, and in Column 3 is $Excess_Capacity_{i,t}$. $Fin_Hedge_{i,t-1}$ is a financial hedging dummy denoting whether firm i has a hedging derivative position in year $t-1$. It equals 1 if firm i's derivative assets or liabilities held for hedging purposes in year $t-1$ have a non-missing and non-zero value, and 0 otherwise. We control for firm-fixed effects, year-fixed effects, and firm characteristics lagged by one period, such as firm size, profitability, and leverage. Standard errors in parentheses are clustered at the firm level. One star (*) indicates significance at the 10% level, two stars 5%, and three stars 1% level.

Dependent variable:	**Gas Stored**$_t$	**LNG Stored**$_t$	**Excess Capacity**$_t$
Dep. Var. Mean:	0.012	0.0006	0.763
	(1)	(2)	(3)
Fin Hedge$_{t-1}$	**–0.003***** (0.001)	**–0.0002***** (0.000)	**–0.027***** (0.013)
Other Firm Characteristics	Yes	Yes	Yes
Firm F.E.	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes
Clusters	Firm	Firm	Firm
R-squared	0.770	0.831	0.829
Observations	4,164	4,160	1,024

Table 5. Falsification Test

This table presents the falsification test on the effect of financial hedging on operational hedging. The sample consists of U.S. electric utilities that own power generators and are subject to the regulation of FERC. Sample screening and main variable constructions are discussed in Section 4. We perform the same regression as regression (28), replacing the dependent variable with two placebo variables. The new dependent variable in Column 1 is firms' gas stored for long-term uses ($Gas_Long_Term_{i,t}$), and in Column 2 is LNG held for processing ($LNG_Process_{i,t}$). These variables reflect firms' decisions on natural gas and LNG with considerations other than operational hedging. $Fin_Hedge_{i,t-1}$ is a financial hedging dummy denoting whether firm i has a hedging derivative position in year $t-1$. It equals 1 if firm i's derivative assets or liabilities held for hedging purposes in year $t-1$ have a non-missing and non-zero value, and 0 otherwise. We control for firm-fixed effects, year-fixed effects, and firm characteristics lagged by one period, such as firm size, profitability, and leverage. Standard errors in parentheses are clustered at the firm level. One star (*) indicates significance at the 10% level, two stars 5%, and three stars 1% level.

Dependent variable:	**Gas Long term**$_t$	**LNG Process**$_t$
Dep. Var. Mean:	0.0007	0.00003
	(1)	(2)
Fin Hedge$_{t-1}$	**–0.00004**	**0.00001**
	(0.00004)	(0.00001)
Other Firm Characteristics	Yes	Yes
Firm F.E.	Yes	Yes
Year F.E.	Yes	Yes
Clusters	Firm	Firm
R-squared	0.919	0.792
Observations	4,164	4,160

Table 6. The Role of Financing Frictions

This table presents evidence of the heterogeneity of the effect of financial hedging on operational hedging by examining the role of financing frictions (captured by the parameter γ in the model). We use BBB credit spreads from FRED as a proxy for aggregate financing frictions in the utility sector to classify each firm's observations into terciles. The ones in the top (bottom) tercile are considered to have high (low) financing friction. We estimate regression (28) for the two groups separately. For all these regressions, we control for firm-fixed effects, year-fixed effects, and firm characteristics lagged by one period, such as firm size, profitability, and leverage. Standard errors in parentheses are clustered at the firm level. One star (*) indicates significance at the 10% level, two stars 5%, and three stars 1% level.

Dependent variable:	**Gas Stored**$_t$		**LNG Stored**$_t$	
Sample:	BBB Credit Spreads		BBB Credit Spreads	
	Low	High	Low	High
	(1)	(2)	(3)	(4)
Fin Hedge$_{t-1}$	**–0.006****	**–0.001**	**–0.0002****	**–0.0005**
	(0.003)	(0.001)	(0.0001)	(0.0003)
Firm Characteristics	Yes	Yes	Yes	Yes
Firm F.E.	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes
R-squared	0.791	0.845	0.823	0.916
Observations	899	1,483	896	1,482

Table 7. The Role of Financial Hedging Efficiency

This table presents evidence of the heterogeneity of the effect of financial hedging on operational hedging by examining the role of financial hedging efficiency. In our model, financial hedging is more efficient when the firm's payoff from their financial hedging contracts (P) is higher or when their external financing need (I) is lower. In Panel A, we use speculators' ease of access to capital, defined as the ratio of the growth in broker-dealers' total financial assets to the growth in households' total financial assets, to proxy for P. Following Acharya et al. (2013), we obtain the data from the U.S. Flow of Funds, which provides quarterly balance sheet information on assets and liabilities across all sectors. The growth in broker-dealers' total financial assets is computed using security brokers and dealers balance sheet data, while the corresponding series for households is based on the balance sheets of households and nonprofit organizations. We then classify each firm's observations into terciles. The ones in the top (bottom) tercile are considered to have high (low) financial hedging efficiency. In Panel B, we use the firm's refinancing need to proxy for I, and the high (low) Refinancing group consists of firms in the top (bottom) tercile each year. We estimate regression (28) for the two groups separately. For all these regressions, we control for firm-fixed effects, year-fixed effects, and firm characteristics lagged by one period, such as firm size, profitability, and leverage. Standard errors in parentheses are clustered at the firm level. One star (*) indicates significance at the 10% level, two stars 5%, and three stars 1% level.

Panel A. Broker-dealer Financial Assets

Dependent variable:	**Gas Stored**$_t$		**LNG Stored**$_t$	
Sample:	Broker-dealer Financial Assets		Broker-dealer Financial Assets	
	Low	High	Low	High
	(1)	(2)	(3)	(4)
Fin Hedge$_{t-1}$	**–0.003*****	**0.001**	**–0.00008***	**–0.00007**
	(0.001)	(0.002)	(0.00004)	(0.00001)
Firm Characteristics	Yes	Yes	Yes	Yes
Firm F.E.	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes
R-squared	0.831	0.859	0.857	0.944
Observations	1,539	917	1,539	916

Panel B. Refinancing Need

Dependent variable:	**Gas Stored**$_t$		**LNG Stored**$_t$	
Sample:	Refinancing Need		Refinancing Need	
	High	Low	High	Low
	(1)	(2)	(3)	(4)
Fin Hedge$_{t-1}$	**–0.003*****	**0.009**	**–0.0002****	**0.0003**
	(0.001)	(0.007)	(0.0001)	(0.0002)
Firm Characteristics	Yes	Yes	Yes	Yes
Firm F.E.	Yes	Yes	Yes	Yes
Year F.E.	Yes	Yes	Yes	Yes
R-squared	0.730	0.868	0.816	0.928
Observations	1,669	168	1,665	168