Efficiency or resiliency?
Corporate choice between financial and operational hedging*

Viral V. Acharya† Heitor Almeida‡ Yakov Amihud§ Ping Liu¶

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Abstract

We study the corporate choice between financial efficiency and operational resiliency. Firms substitute between saving cash for financial hedging, which mitigates the risk of financial default, and spending on operational hedging, which mitigates the risk of operational default such as a failure to deliver on obligations to customers. This tradeoff is particularly strong for financially constrained firms and results in a positive relationship between operational spread (markup) and financial leverage or credit risk. We present empirical evidence supporting this tradeoff, the effect being pronounced for constrained firms.

KEYWORDS: FINANCIAL DEFAULT, OPERATIONAL DEFAULT, RESILIENCE, LIQUIDITY, FINANCIAL CONSTRAINTS, RISK MANAGEMENT

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†New York University, Stern School of Business, NBER, and CEPR: vacharya@stern.nyu.edu.
‡University of Illinois at Urbana-Champaign, Gies College of Business, NBER: halmeida@illinois.edu.
§New York University, Stern School of Business: yamihud@stern.nyu.edu.
¶Purdue University, Krannert School of Management: liu2554@purdue.edu.

1. Introduction

The Covid-19 crisis has raised the issue of corporate resilience to shocks following disruptions in supply chains which adversely affect operations. Companies tackle such negative supply-chain shocks by operationally hedging against them. This includes diversifying the supply chains by allocating resources to increase the pool of suppliers and shifting some of them to nearby, more secure locations; maintaining backup capacity; and, holding excess inventory. In essence, companies endure a higher cost of production — through holding spare capacity and excess inventory, or rearranging their supply chains — in order to mitigate the risk of operational disruption.

A global survey by the Institute for Supply Management finds that by the end of May 2020, 97% of organizations reported that they would be or had already been impacted by coronavirus-induced supply-chain disruptions.[1] Consequently, U.S. manufacturing was operating at 74% of normal capacity, with Europe at 64%. The survey also finds that while firms in North America reported that operations have or are likely to have inventory to support current operations, confidence had declined to 64% in the U.S., 49% in Mexico and 55% in Canada. In Japan and Korea too, many firms were not confident that they will have sufficient inventory for Q4; and, almost one-half of the firms are holding inventory more than usual. In response, 29% of organizations were planning or have begun to re-shore or near-shore some or most operations.[2] However, such operational resiliency is not being favored by all firms as several corporate chief executive officers (CEOs) and investors contend that

[1] `https://www.prnewswire.com/news-releases/covid-19-survey-round-3-supply-chain-disruptions-continue-globally-301096403.html`. See also "Businesses are proving quite resilient to the pandemic", The Economist, May 16th 2020, and "From 'just in time' to 'just in case'", Financial Times, May 4th 2020.

[2] "Reshoring" and "nearshoring" is the process of bringing the manufacturing of goods to the firm's country or a country nearby, respectively.

operational hedging is costly and occurs at the cost of financial efficiency.[3]

Our paper studies one aspect of the tension between operation resiliency and financial efficiency, v.s., the tradeoff between the firm's allocation of cash to operational hedging and to the prevention of financial distress. While operational hedging may be beneficial on its own, it may compete for resources with the firm's demand for financial hedging. The need to optimally balance these two hedging needs — operational hedging and financial hedging — can help explain the lack of operational resilience in some firms.

In our theoretical setting, a competitive (price-taking) levered company faces two important risks. First, it faces a risk of financial default, because cash flows from assets in place are risky. Second, the firm faces the risk of operational default, such as failing on an existing commitment to deliver goods to costumers. The two risks — financial default and operational default — are possibly correlated. For example, an aggregate shock may affect the firm's cash flows, possibly enough to induce financial default, as well as the firm's suppliers, who may be unable to deliver to the firm, in turn causing the firm to default on its contract to deliver goods to its customers. Both financial and operational defaults lead to some loss in the franchise value of the firm.

The firm can use its cash inflow to build up cash buffers and mitigate the risk of financial default. The firm can also use the cash inflow to increase the likelihood that it will deliver on its promise to customers by allocating resources to operational hedging that includes holding excess inventory, maintaining backup capacity, and incurring greater expenses on supply chains. Naturally, such operational hedging raises the firm's cost of production or reduces its operational spread, viz., the "markup" or the price-to-cost margin per unit. Even an unlevered firm will in general optimally choose an interior level of operational hedging in order to protect its profitability while recognizing that an operational default leads to a loss

[3] `https://www.ft.com/content/4ee0817a-809f-11ea-b0fb-13524ae1056b`

of its franchise value.

Interestingly, as operational hedging reduces the risk of delivering to the firm's customers, it can potentially also reduce the risk of financial default by raising the level of its future cash flows. However, this is feasible only if the firm can pledge the benefits of operational hedging to outside investors. For firms that are financially constrained, such pledgeability may be low; in turn, financial and operating hedging become substitutes: In other words, a financially constrained firm must decide between using cash to mitigate the risk of financial default, or maintaining spare capacity, holding excess inventory, or spending cash on contracting with higher-cost suppliers.

Our principal theoretical result is that for a financially constrained firm, the optimal amount of operational hedging decreases with the firm's credit spread which is increasing in financial default risk. Operational hedging also reduces the operational spread (markup) as it increases firm's cost of production. In other words, the firm optimally sacrifices operational resiliency for financial efficiency. This creates a negative relation between the credit spread and the operational spread. More financial hedging that reduces the credit spread also reduces operational hedging and this is reflected in a wider markup. Similarly, our model also predicts that higher existing leverage is associated with a wider markup. This positive relation between leverage and markup is muted, possibly even reversed, for financially unconstrained firms as they can engage in operational hedging and simultaneously pledge superior operating cash flows to avoid financial default.[4]

We provide empirical tests of our model's prediction on the tradeoff between operational hedging and credit risk, or specifically, between the operational spread (markup) and financial leverage or measures of credit risk, and relate that to firms' financial constraint.

[4]In our model, the effect of leverage on operational hedging is due mostly to financing constraints (lack of funds to invest), and not to debt overhang (lack of incentives to invest due to leverage, as in Myers (1977)).

We start by documenting that markup or operational spread, measured as sales minus cost of goods sold divided by sales, is correlated with proxies for operational hedging in the expected way: higher inventory and greater supply chain diversification reduce the markup. This evidence supports the use of markup as a summary measure of the extent of operational hedging that the firm engages in. We then examine whether leverage and credit risk are correlated with the markup in the way predicted by our model.

We find that higher leverage and higher credit risk, measured using Altman's z-score, which necessitate allocation of cash to financial hedging, are positively related to the markup, implying a reduction in operational hedging. To gauge the economic significance of the effect, one standard deviation increase in the firm's negative z-score raises the firm's markup by 13% of the sample median markup. To deal with the endogeneity of financial leverage, we examine the near-term portion of long-term debt, which can be considered to be exogenous to the current state of the firm, having been determined in the past when it was issued. We find that the positive relation between the markup and leverage is stronger for the short-term portion of the long-term debt which matures in the next two years. Higher short-term portion of the long-term debt raises the markup about twice as strongly as does long-term debt. This is consistent with our model by which the near-term need to avert financial default diverts funds from longer-term operational hedging, and this is reflected in a wider operational spread when there is more long-term debt due.

We use two complementary strategies to test the prediction that the trade-off between operational hedging and credit spread is stronger for constrained firms. First, we consider cross-sectional variation in the degree of financial constraints and find that the trade-off between credit risk and operational spread is particularly strong in the group of firms that is more likely to be constrained. Second, we consider time-series variation in financial constraints by studying the effect of an exogenous shock to the credit supply of firms. We follow Chodorow-Reich (2014) who studies the negative impact of the subprime mortgage crisis and Lehman Brothers' collapse on lenders' abilities to extend credit to borrowers. A firms's exposure to this shock, in terms of its relationship banks being affected by the shock, reflects a tightening of its financing constraint. We find that exposed firms that were more highly levered prior to the crisis reduced operational hedging, i.e., increased their markup, by more than less exposed firms. This test uses time-series variation in financing constraints to measure our predicted tension between operational hedging and financial hedging. This test also helps address concerns about the endogeneity of financial leverage in that existing literature on the impact of the financial crisis has shown that pre-crisis leverage is an important pre-condition that determined post-crisis real effects through a liquidity demand channel (e.g., Giroud and Mueller, 2016)

Broadly speaking, our contribution in this paper is to study both theoretically and empirically the determinants of operational hedging and its tradeoff with financial hedging, especially for financially-constrained firms. To our best knowledge, the positive relationship between operational spread (markup) and financial leverage or credit risk has not been documented in the literature.

Our paper is related to studies of the real effects of financing constraints (see Stein (2003) for a review) which show that financing frictions can affect investment decisions and employment (Lemmon and Roberts, 2010; Duchin et al., 2010; Almeida et al., 2012; Giroud and Mueller, 2016, among others). The literature also studies the effect of financial constraints and financial distress on financial policies such as cash, credit lines, and risk management (e.g., Almeida et al., 2004; Sufi, 2009; Bolton et al., 2011; Acharya et al., 2012). Our paper also relates closely to those of Rampini and Viswanathan (2010) and Rampini et al. (2014), who show that more constrained or distressed firms may reduce risk management in order to preserve debt capacity for investment and other current expenditures. These studies focus on financial hedging through derivatives while our focus is on operational hedging. Our paper also relates to Froot et al. (1993), who propose a theory for the rationale for corporate hedging. In Froot et al. (1993), hedging against cash shortfalls helps the firm mitigate the risk of not being able to finance valuable investment opportunities. In our model, however, operational hedging is not a means to avoid financing shortfall but it is rather the other way around: Hedging against a shortfall of cash that presents a financial default risk reduces the resources allocated to operational hedging.[5]

Studies of the relationship between a firm's credit risk and its markup (e.g., Gilchrist et al., 2017; Dou and Ji, 2020) propose that financially constrained firms that need to increase short-term profits may raise their product price and thus their markup. Such an ability to extract higher profit by raising prices implicitly assumes market power. Our analysis controls for market power which is known to be positively associated with the firm's markup. We find that the effect of market power on the markup is indeed larger for constrained firms. Yet we find that our model's predicted positive association between the markup and leverage or credit risk persists after controlling for market power.

2. The model

2.1 Model setup

This section develops a model of a competitive (price-taking) levered firm's optimal operational hedging policy in the presence of costly financial default (default on debt service) and operational default (default on the supplier contract with customers). Our main goal is to show that a financially constrained firm faces a tension between operational hedging and

[5]See Bianco and Gamba (2019) for a recent theoretical contribution focusing on the risk management role of inventory. They focus on an all-equity firm so do not analyze the effect of credit risk on operational hedging as we do.

financial hedging, where we model financial hedging as saving cash in order to avoid default on its debt maturing before the settlement date of supply contracts with its customers.

Our model introduces operational hedging in the setting of Acharya et al. (2012) who study the impact of credit risk on the firm' s cash holding. The model features a single-levered firm with existing debt F in a three-period economy: $t = 0, 1, 2$. The firm has assets in place that generate a cash flow x_t at each period $t = 0, 1$. x_2 represents the franchise or the continuation value. Additionally, the firm has an outstanding supplier contract that stipulates a delivery of I units of goods at unit price p at $t = 2$. Our goal is to analyze the tension between the firm's cash holding and operational hedging decisions to avoid financial and operational defaults, respectively.

For our purpose, it is important to introduce a random shock u that affects both the firm's cash flow at $t = 1$ and its capacity to fulfill the supplier contract. Specifically, the firm's cash flow from assets in place at $t = 1$ is given by $x_1 = \bar{x}_1 + u$, and its production capacity is reduced from I to $(1 - \delta(u))I$, where $\delta(u)$ is decreasing and convex in u with continuous and finite first and second order derivatives. The probability distribution of u is given by the density function $g(u)$ with support $[0, \infty)$, the associated cumulative distribution function being $G(u)$ and the hazard function $h(u)$ being defined as

$$h(u) = \frac{g(u)}{1 - G(u)} \ . \tag{2.1}$$

To derive analytical results, we assume that u is exponentially distributed on $[0, \infty)$ with density function $g(u) = \alpha e^{-\alpha u}$. Then the cumulative distribution function $G(u) = 1 - e^{-\alpha u}$. Notably, the hazard function $h(u)$ is a constant α, which greatly simplifies our analyses.[6] Figure 1 illustrates the timeline of the model.

[6] Exponential distribution is a special case of Gamma distribution, which has been widely used to model the jump size distribution of uncretainty shocks in finance (e.g., Johnson, 2021).

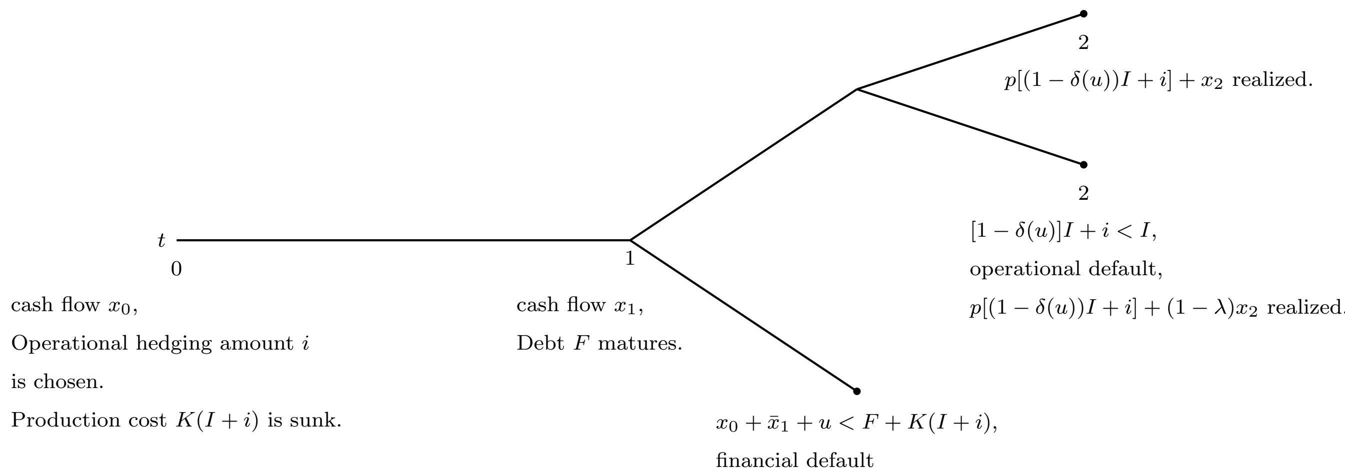

Figure 1: The timeline of the model

At date $t=0$, the assets in place generate a positive cash flow $x_0>0$. At this time, the firm starts producing I units of goods scheduled for delivery at $t=2$. Moreover, the firm can choose to hedge the operational risk by investing in excess inventory i, resulting in the total units of delivered goods being $(1-\delta(u))I+i$. Note that i can also be interpreted as spare production capacity. The cost of the production and operational hedging is summarized by an increasing and convex cost function $K(I+i)$ with continuous and finite first and second order derivatives. We assume that the firm is a price-taker in its supplier contracts. We also make the following assumption regarding the unit product price p and the marginal cost of production commitment I:

Assumption 2.1.

$$p>K'(I)\ . \tag{2.2}$$

Assumption 2.1 says that the firm enjoys some positive markup over the marginal cost of the production commitment. Since the production cost function K is convex, this assumption says that the firm can potentially choose a positive hedging policy i and still enjoy a positive marginal profit from the supplier contract. Market frictions preclude the firm from accessing outside financing, so that the firm's disposable cash at date-0 comes entirely from its internal cash flow. Thus, the cash reserve is $c = x_0 - K(I + i)$.

At date $t = 1$, the firm must make a debt payment of F, which is assumed to be predetermined (a legacy of the past). We assume that debt cannot be renegotiated due to high bargaining costs; for example, it might be held by dispersed bondholders prone to coordination problems. Failure to repay the debt in full at $t = 1$ results in financial default and liquidation, in which case future cash flow from the contractual delivery investment, $p[(1 - \delta(u)) + i]$, and franchise value, x_2, are lost. Since the period-1 cash flow, x_1, is random, there is no assurance that the firm has enough liquidity to repay the debt in full. Moreover, failure to deliver I units of goods results in operational default, also leading to a loss of the franchise value, x_2, by a portion $\lambda \in [0, 1)$. This can be interpreted as, for example, a loss of reputation with some of its customers who can switch to alternate suppliers.

Due to market frictions, external financing is unavailable also at $t = 1$, and hence the debt payment must be made out of the firm's internal funds. The financing friction gives rise to a tension between financial hedging versus operational hedging decisions at $t = 0$: On the one hand, the firm has incentive to spend on excess inventory i, to hedge against the operational shock and reduce the probability of operational default; on the other hand, such operational hedging heightens its credit risk between periods 0 and 1, thereby increasing the probability of a future cash shortfall and financial default.

2.2 Discussion

Before proceeding further, we want to stress that the exact specification of the model can vary widely without affecting the results qualitatively, as long as two assumptions are satisfied. First, default involves deadweight costs. Although we assume that all future cash flows are lost in default, an extension to a partial loss is straightforward. Second, external financing cannot be raised against the full income from the supplier contract settlement at date-2. If the firm can pledge a large enough fraction of its income from fulfilling the supplier contract as collateral, then current and future cash holdings can be viewed as time substitutes, and there is no role for precautionary savings of cash. As a result, the tension between financial hedging and operational hedging breaks down. In reality, the condition of partial pledgeability is likely to be universally met. While the base case model assumes that external financing is prohibited, Section 3.1 extends the model by allowing the firm to borrow up to a certain fraction τ of its cash flow from contract settlement at $t = 2$, and shows that our main results hold as long as financing constraints are sufficiently binding, i.e., τ is sufficiently small.

A related feature in our model is that the outstanding debt matures before the supplier contract settlement date, giving rise to a maturity mismatch between debt contract and supplier contract. Effectively, the cash flow from the supplier contract can neither be fully pledged nor used as cash to cover debt obligations. In practice, supplier contracts often stipulate a considerable elapsed time from initiation to settlement, especially in the case of durable goods industry. Meanwhile, firms often have to borrow short-term debt or draw down their credit lines to finance their working capital needs during the production process. What is crucial here is that the shock at $t = 1$ can be severe enough to make the cash flow at date-1 fall short of the debt contract obligation and make the production capacity fall short of the supplier contract obligation. This creates the needs for both financial and operational hedging. The two needs compete with each other in our model. Although we assume a single uncertainty state affects both the cash flows from assets in place and the ability to fulfill the supplier contract, extending our model to different sources of uncertainties is possible.

Finally, shareholders may find it optimal to raise debt maturing at $t = 1$ that is more senior than the existing debt and invest in operational hedging. This occurs when sensitivity of function $\delta(u)$ with respect to u and the cost of operational default (captured by λ) are both sufficiently high.[7] In our base case model, we assume that financing constraints at $t = 0$ preclude the firm from accessing any additional financing. Explicitly modeling endogenous capital structure polices at date-0 is an interesting extension of our model.

2.3 Optimal hedging policies

In general, the firm has a positive amount of existing debt ($F > 0$). At date 0, the firm faces the following trade-off between investing its cash in the operational hedging and retaining it until the next period. The firm's optimal hedging policies depend on the relative likelihood of financial default and operational default, as will be shown below.

The amount of cash available for debt service at date 1 is $x_0 - K(I + i) + x_1$, where $x_0 - K(I + i)$ is the cash reserve and $x_1 = \bar{x}_1 + u$ is the interim-period cash flow from assets. The "financial default boundary", u_F, is the minimum cash flow shock that allows the firm to repay F in full and avoid default:

$$\begin{aligned} u_F &= F + K(I + i) - x_0 - \bar{x}_1 \\ &= \bar{F} + K(I + i) \ , \end{aligned} \tag{2.3}$$

where $\bar{F} = F - x_0 - \bar{x}_1$ is the net debt, i.e., debt minus date 0 and 1 predictable cash flows. The financial default boundary u_F increases with the level of net debt ($\bar{F}$) and operational hedging amount (i). For all realizations of u between 0 and u_F, the firm defaults on its debt contract and equity holders are left with nothing.

We also allow the firm to default on the supplier contract. The amount of goods that the firm can deliver at date-2 is $(1 - \delta(u))I + i$. If this amount is less than the production

[7] By contrast, as in Acharya et al. (2012), raising debt maturing at $t = 1$ solely to increase the cash reserve is value-neutral in this setting, as the increase in cash is exactly offset by the increase in the required debt repayment (i.e., cash is negative debt in this setting of "short-term" debt).

commitment I, the firm defaults on the supplier contract. Correspondingly, the "operational default boundary", u_O, is the minimum shock that allows the firm to deliver its contractual amount of goods in full and avoid operational default:

$$(1-\delta(u_O))I + i = I, \text{ or}$$
$$u_O = \delta^{-1}\left(\frac{i}{I}\right) . \tag{2.4}$$

Since the loss function δ is decreasing in u, its inverse function δ^{-1} is decreasing in i. This means that the operational default boundary u_O is decreasing with i, the amount of operational hedging the firm chose at date-0. In this sense, operational hedging reduces the operational default risk. For all realizations of u between 0 and u_O, the firm defaults on its supplier contract and equity holders lose a portion λ of the franchise value x_2.

Define $D(i, \bar{F})$ as the difference between financial and operational default thresholds for given net debt level $\bar{F}$ and operational hedging policy i:

$$D(i, \bar{F}) \equiv u_F - u_O = \bar{F} + K(I+i) - \delta^{-1}\left(\frac{i}{I}\right) . \tag{2.5}$$

2.3.1 Benchmark: Optimal hedging policy when $F = 0$

Consider first a benchmark case when the debt level $F = 0$. In this case, financial default is irrelevant: $u_F = 0$. In this case, the firm will choose the hedging policy $\bar{i}$ that maximizes the unlevered date-0 equity value:

$$\bar{E} = \int_0^{\infty} \Big[x_0 - K(I+i) + \bar{x}_1 + u + p\left[(1-\delta(u))I + i\right] + x_2\Big] g(u)du - \int_0^{u_O} \lambda x_2 g(u)du . \tag{2.6}$$

The last term of Equation (2.6) reflects the proportional loss of franchise value in case of operational default. The first-order condition is

$$\frac{\partial \bar{E}}{\partial i} = p - K'(I+i) - \lambda x_2 \frac{g(u_O)}{I\delta'(u_O)} = 0 \ , \tag{2.7}$$

where $u_O = \delta^{-1}\left(\frac{i}{I}\right)$. Define $\bar{i}$ being the solution for the first-order condition (2.7). In Appendix A.1, we show that $\bar{i}$ is also the unique optimal hedging level that maximizes the equity value (2.6), under mild technical conditions.

The following assumption ensures that the firm has enough cash flow at date-0 to choose the highest possible optimal operational hedging, which occurs when the firm is debt-free. It also ensures that u_F is continuous in $\bar{F}$ and $u_F = 0$ for sufficiently small $\bar{F}$:

Assumption 2.2.

$$K(I+\bar{i}) < x_0 + x_1 \ . \tag{2.8}$$

Since $D(i, \bar{F})$ is continuous in $\bar{F}$, u_F is always smaller than u_0 regardless of the value of i for sufficiently small $\bar{F}$.

As will be clear later, operational default boundary u_O only enters into equity value function if it is larger than the financial default boundary u_F. Thus, the main challenge in solving the model is that both u_F and u_O are endogenously determined by the firm's hedging policy. In what follows, we first solve for the firm's optimal hedging policy that maximizes the equity value; then we characterize the relationship between the hedging policy and the net debt level.[8] We do this in steps by considering the relative position of thresholds for financial and operational defaults, u_F and u_O, respectively, and then addressing its endogeneity to hedging policy and model primitives (such as leverage).

[8]It is straightforward to consider hedging being undertaken by a manager who maximizes equity value net of personal costs arising from firm"s bankruptcy (see, for example, Gilson (1989)). This extension is available upon request.

2.4 Optimal hedging policy when $u_F \geq u_O$

If the firm's inherited debt level is so high that the financial default boundary is greater than the operational default boundary, then the firm would have already declared financial default at date-1 for the shock values that would trigger the operational default. Thus, operational default boundary does not enter the equity value function in this case. The total payoff to equity holders is the sum of cash flows from assets in place and the payoff from the contractual fulfillment to customers, less the production cost, the operational hedging cost and the debt repayment, provided that the firm does not default on its debt in the interim. The market value of equity is therefore given as:

$$E = \int_{u_F}^{\infty} \Big[u - u_F + p\left[(1-\delta(u))I + i\right] + x_2 \Big] g(u)du \ , \tag{2.9}$$

where the last equality is from the definition of financial default boundary u_F in (2.3). Here,$(u - u_F)$ is the amount of cash left in the firm after debt F is repaid, and $p\left[(1-\delta(u))I+i\right] + x_2$ is period-2 cash flow, conditional on the firm not defaulting in the interim.

Equity holders choose the level of operational hedging i to maximize equity value E in (2.9) which yields the following first-order condition:

$$\frac{\partial E}{\partial i} = \Big[1 - G(u_F)\Big]\Big[p - K'(I+i) - V(u_F, i)h(u_F)K'(I+i)\Big] = 0 \ . \tag{2.10}$$

Define $V(u_F, i) \equiv p\left[(1-\delta(u_F))I + i\right] + x_2$, which is the firm's date-2 franchise value at the financial default boundary. Substituting that $\frac{\partial u_F}{\partial i}$ equals $K'(I+i)$, we can rewrite this first-order condition in terms of the "markup", $p - K'(I+i)$, as:

$$p - K'(I+i) = V(u_F, i)h(u_F)K'(I+i) \ . \tag{2.11}$$

The first-order condition (2.11) is intuitive. On the one hand, a marginal increase in operational hedging will yield the firm a marginal profit $p - K'(I+i)$. On the other hand, a marginal increases in operational hedging also increases the expected cost of financial default, which is the product of three terms on the right-hand side of Equation (2.11): the first term is the loss of date-2 franchise value had a financial default occurred; the second term is the hazard rate of a financial default; and, the last term is the marginal effect of additional operational hedging on the financial default boundary u_F. The first-order condition says that in equilibrium the firm chooses the optimal hedging policy i^* such that the marginal profit is equal to the marginal increase of the expected financial default cost.

Since u is exponentially distributed on $[0, \infty)$ with $g(u) = \alpha e^{-\alpha u}$ and $h(u) = \alpha$, the first-order condition (2.11) simplifies to

$$p - K'(I+i) = V(u_F, i)\alpha K'(I+i) \ . \tag{2.12}$$

Define i^* is the firm'optimal hedging policy that satisfies (2.12). The following assumption guarantees that a positive interior solution i^* exists and $D(i^*, \bar{F}) > 0$ for sufficiently large $\bar{F}$:[9]

Assumption 2.3. $p - K'(I) > (pI + x_2)\alpha K'(I)$.

Appendix A.2 proves that

Lemma 2.1. *If Assumption 2.3 holds and $\bar{F}$ is sufficiently large, then the first-order condition* (2.12) *admits a positive interior solution i^* is a uniquely solution that maximizes E subject to $D(i, \bar{F}) > 0$.*

[9] We assume that initial cash holdings are high enough to avoid the corner solution, i.e., the production cost of I units of goods and the chosen operational hedging level i, is less than $x_0 + x_1$.

Next, we study the correlation between the firm's optimal operational hedging policy and its inherited net debt level when u_F is always greater than u_O. Lemma 2.2, also proved in Appendix A.2, states that the optimal optimal operational hedging policy decreases in the firm's net debt level maturing in the interim:

Lemma 2.2. *When $\bar{F}$ is sufficiently high such that $D(i^*, \bar{F}) > 0$, the equilibrium operational hedging policy i^* decreases in the firm's net debt level $\bar{F}$.*

2.5 Optimal hedging policy when $u_F < u_O$

We now focus on the case in which the firm's inherited debt level is sufficiently low such that the financial default boundary is always below the operational default boundary. In this case, the operational default boundary enters the equity value function. The total expected payoff to the equity holders is as in Section 2.4, less an expected cost proportional to unlevered firm value at date-2, λx_2, if the firm defaults on its supplier contract, provided that the firm does not default on its debt in the interim. The market value of equity is therefore,

$$\hat{E} = E - \int_{u_F}^{u_O} \lambda x_2 g(u) du \ , \tag{2.13}$$

where the E is the equity value when $u_F > u_O$, as specified in (2.9).

Equity holders choose the optimal level of operational hedging i to maximize $\hat{E}$, which yields the following first-order condition:

$$p - K'(I+i) = [V(u_F, i) - \lambda x_2] h(u_F) K'(I+i) + \frac{\lambda x_2 g(u_O)}{[1 - G(u_F)] I \delta'(u_O)} \ . \tag{2.14}$$

Define $\hat{i}^*$ as the firm's optimal hedging policy that satisfies (2.14). Similar to the case in which $u_F > u_O$, a marginal increase in investment on spare production will yield the firm a marginal profit $p - K'(I+i)$. However, the effect of a marginal increase in i on the firm's expected loss from operational default and financial default is opposite. On the one hand, a marginal increases in operational hedging increase the expected cost of financial default by increasing the financial default boundary u_F.[10] On the other hand, a marginal increase in operational hedging decreases the expected cost of operational default since it reduces the operational default boundary u_O, which is captured by the last term of the first-order condition (2.14). Therefore, the first-order condition (2.14) says that in equilibrium the firm chooses the optimal hedging policy $\hat{i}^*$ such that the marginal profit ("markup") is equal to the marginal increase of the expected financial default cost net of the marginal decrease of the expected operational default cost. We show in Appendix A.3 that

Lemma 2.3. *If the production commitment I is sufficiently high and $\frac{K'(I+\bar{i})}{I}$ is sufficiently low, then $\hat{i}^*$ that satisfies* (2.14) *uniquely maximizes $\hat{E}$.*[11]

Intuitively, the condition that I is sufficiently high means that the supply contract value is important economically. The condition that $\frac{K'(I+\bar{i})}{I}$ is sufficiently low means that the firm's marginal production cost does not increase too fast as the production quantity increases. This condition makes sure that the firm has enough operational flexibility to do the operational hedging even if the production quantity is high and it has zero debt.

In summary, when the firm's inherited net debt $\bar{F}$ is sufficiently low such that the operational default boundary u_O always dominates the financial default boundary u_F, operational default risk is main concern of equity holders. Thus, the firm will invest more on operational hedging, i.e., $\hat{i}^* > i^*$. The following lemma, proved in Appendix A.3 confirms this intuition:

[10]Notice that the loss conditional on a financial default is reduced by λx_2. This is because the firm would declare operational default if $u_F < u < u_O$.

[11]Appendix A.3 also provide the conditions that I and $\frac{K'(I+\bar{i})}{I}$ need to satisfy. We continue to assume that initial cash holdings are high enough for the first-order condition to avoid corner solution.

Lemma 2.4. *If Lemma 2.3 holds, the operational hedging policy $\hat{i}^*$ that satisfies Equation* (2.14) *is higher than the operational hedging policy i^* that satisfies Equation* (2.11)*, i.e., $\hat{i}^* > i^*$.*

Similar to the $u_F > u_O$ case, Appendix A.3 derives that when u_F is always less than u_F, the firm's optimal operational hedging policy $\hat{i}^*$ decreases in its inherited net debt level:

Lemma 2.5. *If Lemma 2.3 holds, the equilibrium operational hedging policy $\hat{i}^*$ decreases in the firm's net debt level $\bar{F}$.*

2.6 Optimal hedging policy and net debt $\bar{F}$

We can now formally characterize the correlation between the firm's optimal operational hedging policy and its inherited net debt level $\bar{F}$. We will show that the firm's optimal operational hedging policy is $\hat{i}^*$ when the net debt level $\bar{F}$ is sufficiently low and is i^* when the net debt level is sufficiently high. The operational hedging policy is at a level $\tilde{i}$ in the "sliding region" such that $D = 0$, when the net debt level is intermediate. Recall that $D = u_F - u_O$ is defined in Equation (2.5).

Let $\bar{F}_{fb}$ is such that $\bar{F}_{fb} + K(I + \bar{i}) = 0$, i.e., $\bar{F}_{fb}$ is the maximal net debt level such that the firm is able to pay back the debt at date-1 when it chooses the maximal optimal hedging policy $\bar{i}$ that maximizes the unlevered firm value, as derived in Section 2.3.1. When $\bar{F} \leq \bar{F}_{fb}$, short-term debt is riskless and the firm chooses the optimal hedging policy as if the short-term debt level is zero. Moreover, we introduce $D^*(\bar{F}) \equiv D(i^*(\bar{F}), \bar{F})$ and $\hat{D}^*(\bar{F}) \equiv D(\hat{i}^*(\bar{F}), \bar{F})$, i.e., D^* and $\hat{D}^*$ are the differences between financial default boundary u_F and operational default boundary u_O when the firm chooses the operational hedging policy i^* and $\hat{i}^*$ respectively. Define $\bar{F}_0$ to be such that $\hat{D}^*(\bar{F}_0) = 0$ and $\bar{F}_1$ such that $D^*(\bar{F}_1) = 0$. Appendix A.4 shows that $\bar{F}_0$ and $\bar{F}_1$ exist and are unique with $\bar{F}_0 < \bar{F}_1$; $D^* < 0$ if $\bar{F} < \bar{F}_1$;

and, $D^* > 0$ if $\bar{F} > \bar{F}_1$. Similarly, $\hat{D}^* < 0$ if $\bar{F} < \bar{F}_0$ and $\hat{D}^* > 0$ if $\bar{F} > \bar{F}_0$. The following proposition formalizes this relationship between the firm's optimal operational hedging policy and its net debt level maturing at date-1:

Proposition 2.1. *If Lemma 2.3 holds, then*

I. If $0 \leq \bar{F} \leq \bar{F}_{fb}$, the firm's optimal operational hedging policy is $\bar{i}$.

II. If $\bar{F}_{fb} < \bar{F} \leq \bar{F}_0$, the firm's optimal operational hedging policy is $\hat{i}^*$.

III. If $\bar{F}_0 < \bar{F} < \bar{F}_1$, the firm's optimal operational hedging policy is $\tilde{i}$.

IV. If $\bar{F} \geq \bar{F}_1$, the firm's optimal operational hedging policy is i^*.

The next proposition states the main results of in our paper: saving cash to hedge against the financial default risk and invest it in spare production capacity/inventory to hedge the operational default risk compete with each other. When the firm is more financially leveraged in the interim, i.e., having higher net debt levels $\bar{F}$ maturing at date-1, financial hedging motive dominates the operational hedging motive; such a firm cuts investment in operational hedging to conserve more cash, in order to better weather the financial default. As a result, the intensity of equilibrium operational hedging, denoted by i^{**}, is lower.

Proposition 2.2. *When $\bar{F} > \bar{F}_{fb}$, the firm's optimal operational hedging policy i^{**} decreases in net debt $\bar{F}$.*

3. Model extensions

3.1 The effect of partial pledgeability

In our base-case model of Section 2, the firm has no access to external financing. In this subsection, we extend the model to consider the effect of partial pledgeability of cash flows from supplier contract settlement. We use subscript FC to denote respective quantities for this extension.

Suppose that at $t = 1$ the firm can use a fraction τ of its proceeds from date-2 supplier contract settlement (which is $\tau p[(1 - \delta(u))I + i]$) as collateral for new financing, where $0 \le \tau \le 1$. Here, $\tau = 0$ corresponds to our base case of extreme financing frictions, when the firm cannot raise any external financing against its future cash flow, whereas $\tau = 1$ implies frictionless access to external capital with payment backed by future cash flow. In practice, τ can also represent the ease of access to cash flow financing.

Conditional on survival, raising new financing at $t = 1$ in this setting is value-neutral. Therefore, we can assume without loss of generality that the firm always raises the amount equal to the cash shortfall when the cash flow shock hits the financial default boundary $u_{F,FC}$. Thus, cash available for debt service at date 1 is $x_0 - K(I + i) + x_1 + \tau p[(1 - \delta(u_{F,FC}))I + i]$, which is the sum of the cash reserve $x_0 - K(I + i)$, the random cash flow $x_1 = \bar{x}_1 + u$, and the newly borrowed amount $\tau p[(1 - \delta(u_{F,FC}))I + i]$. The financial default boundary is now given as:[12]

$$u_{F,FC} = \bar{F} + K(I + i) - \tau p[(1 - \delta(u_{F,FC}))I + i] \ . \tag{3.1}$$

In turn, the value of equity when $u_{F,FC} > u_O$ can be written as

$$E_{FC} = \int_{u_{F,FC}}^{\infty} \Big[(u - u_{F,FC}) - \tau p[(1-\delta(u_{F,FC}))I + i] + p[(1-\delta(u_{F,FC}))I + i] + x_2\Big] g(u)du \ . \tag{3.2}$$

The partial pledgeability case can be solved in an analogues manner as the zero pledgeability case. We define $\hat{i}^*_{FC}$ as the optimal hedging policy that maximizes the equity value when $u_{F,FC} < u_O$; $\tilde{i}_{FC}$ as the optimal hedging policy that equalizes the operational and financial default boundaries $u_O(\tilde{i}_{FC}) = u_{F,FC}(\tilde{i}_{FC}, \bar{F})$; and, i^*_{FC} as the optimal hedging pol-

[12] The operational default boundary u_O is the same as the base case.

icy that maximizes the equity value when $u_{F,FC} > u_O$. Specifically, i^*_{FC} and $\hat{i}^*_{FC}$ are given respectively by the following first-order conditions:

$$p - K'(I + i^*_{FC}) = V(u_{F,FC}, i^*_{FC})\, h(u_{F,FC})\, \frac{[K'(I + i^*_{FC}) - \tau p]}{[1 - \tau p \delta'(u_{F,FC}) I]} \;, \tag{3.3}$$

$$\begin{aligned} p - K'(I + \hat{i}^*_{FC}) = {} & \Big[V(u_{F,FC}, \hat{i}^*_{FC}) - \lambda x_2\Big]\; h(u_{F,FC})\, \frac{[K'(I + \hat{i}^*_{FC}) - \tau p]}{[1 - \tau p \delta'(u_{F,FC}) I]} \\ & + \frac{\lambda x_2 g(u_O)}{[1 - G(u_{F,FC})] I \delta'(u_O)} \;. \end{aligned} \tag{3.4}$$

As long as the the firm is sufficiently financially constrained, i.e., τ is sufficiently low, the optimal hedging policy is of the same form as that in the baseline case. Consequently, the intensity of equilibrium operational hedging, denoted by i^{**}, is lower when the inherited net debt level $\bar{F}$ is higher.

Define $\bar{F}_{fb,FC}$ to be such that

$$\bar{F}_{fb,FC} + K(I + \bar{i}_{FC}) = \tau * p * \bar{i}_{FC} \;. \tag{3.5}$$

In other words, $\bar{F}_{fb,FC}$ is the maximal net debt level such that the firm is able to pay back the debt at date-1 even if the production shock u is severe enough to obliterate the entire production capacity I. $\bar{F}_{0,FC}$ and $\bar{F}_{1,FC}$ are defined analogously to the respective thresholds in Proposition 2.1: $\bar{F}_{0,FC}$ is such that $u_{F,FC}(\hat{i}^*_{FC}, \bar{F}_{0,FC}) = u_O(\hat{i}^*_{FC})$; $\bar{F}_{1,FC}$ is such that $u_{F,FC}(i^*_{FC}, \bar{F}_{1,FC}) = u_O(i^*_{FC})$. The following proposition characterizes the firm's optimal hedging policy as a function of $\bar{F}$ when the pledgeability is imperfect, i.e., $\tau < \bar{\tau} < 1$:[13]

Proposition 3.1. *There exists $\bar{\tau} < 1$ such that if $\tau < \bar{\tau}$, then*

[13]The proofs of Proposition 3.1 and Proposition 3.2 are very similar to the base case although the algebra is much more involved. The proofs are available upon request.

I. If $0 \leq \bar{F} \leq \bar{F}_{fb,FC}$, the firm's optimal operational hedging policy is $\bar{i}$.

II. If $\bar{F}_{fb,FC} < \bar{F} \leq \bar{F}_{0,FC}$, the firm's optimal operational hedging policy is $\hat{i}^*_{FC}$.

III. If $\bar{F}_{0,FC} < \bar{F} < \bar{F}_{1.FC}$, the firm's optimal operational hedging policy is $\tilde{i}_{FC}$.

IV. If $\bar{F} \geq \bar{F}_{1,FC}$, the firm's optimal operational hedging policy is i^*_{FC}.

Proposition 3.2. *If $\tau < \bar{\tau}$ and $\bar{F} > \bar{F}_{fb,FC}$, the firm's optimal operational hedging policy i^{**} decreases in $\bar{F}$.*

When $\tau = 0$, the general case is reduced to the zero-pledgeability case we just presented in Section 2. Since all the quantities are continuous in τ, Proposition 3.1 and Proposition 3.2 hold for small enough τ, i.e., $\tau \in [0, \bar{\tau}]$.

3.2 Operational spread and credit spread

Consistent with Acharya et al. (2012), the credit spread is defined by the ratio between the face value F and the market value of debt D minus 1. The market value of debt is given as:

$$D = F - \int_0^{u_F} \left[u_F - u - \tau p \left(\delta(u_F) - \delta(u)\right) I\right] g(u) du \ . \tag{3.6}$$

The second term of Equation (3.6) is the expected bankruptcy cost. Then, the credit spread s is

$$s = \frac{F}{D} - 1 \ . \tag{3.7}$$

The operational spread is the markup, $p - K'(I+i)$. Our model predicts that the operational spread and credit spread are positively correlated. The operational spread is the markup, $p - K'(I+i)$. To see this, note that $\frac{di^{**}}{dcs} = \frac{\partial i^{**}}{\partial F}\frac{dF}{ds} = \frac{\partial i^{**}}{\partial F} D$. By Proposition 2.2, the above quantity is smaller than zero, meaning that in equilibrium, the operational hedging level i^{**}

decreases in the credit spread s. The operational spread also decreases in the operational hedging level i. Thus, we have the following proposition:

Proposition 3.3. *In equilibrium, operational spread and credit spread are positively correlated.*

3.3 Debt maturity

So far, we focused on the case in which the firm's existing debt matures at date-1, before the supply contract delivery. What happens if the debt matures at date-2, at the same date as the contract delivery? If the debt maturity date is aligned with the delivery date of the supplier contract, then the firm can use its entire cash flow from the supply contract payment to pay off its debt. Thus, the optimal operational hedging policy in the "long-term" debt case is the same as the case of perfect pledgeability ($\tau = 1$). In fact, although we interpret τ as the pledgeability of the cash flow from the supplier contract, we can also treat $(1 - \tau)$ as the proportion of the firm's debt that matures before the contract delivery, i.e., the mismatch between the firm's debt maturity structure and the duration of its operational cash flows.

3.4 Supply chain diversification

We can modify our model slightly to accommodate the case in which the firm hedges against the operational default risk by choosing multiple suppliers instead of choosing spare production capacity or excess inventory. Suppose that the production function becomes $K = K(I, n)$, in which $n \geq \underline{n}$ denotes the measure of suppliers that the firm chooses to enlist in the production process, and $\underline{n}$ denotes the minimal measure of suppliers that the firm needs to keep the production running.[14] We assume that it is more costly if the firm chooses

[14]We assume that n represents the measure, instead of number of suppliers, in order to use the first-order conditions, consistent with our baseline model.

a more diversified supply chain, i.e., n being large. Mathematically, it means that the first- and second-order partial derivatives of K with respect to n are both positive: $K_n(I, n) > 0$ and $K_{nn}(I, n) > 0$. We assume that the production loss function $\delta(u, n)$ depends on both the production shock u and the measure of suppliers n. Consistent with the baseline model, $\delta(u, n)$ is decreasing and convex in both u and n with continuous and finite first- and second-order derivatives, $\delta_u(u, n) < 0$, $\delta_n(u, n) < 0$, $\delta_{uu}(u, n) > 0$ and $\delta_{nn}(u, n) > 0$. In addition, we assume that the cross-partial derivative of $\delta(u, n)$. $\delta_{un}(u, n) < 0$.

In this setting, the operational default threshold u_O is such that $\delta(u_O, n) = 0$. Then $\frac{\partial u_O}{\partial n} = -\frac{\delta_n(u_O,n)}{\delta_u(u_O,n)} < 0$. It can be verified that the second-order derivative of u_O with respect to n is greater than zero, which is the same as the baseline case. In this setting, our previous lemmas and propositions still go through.[15] In particular, operational hedging measured as supply chain diversification (n) is decreasing in firm's financial leverage and credit risk.

4. Numerical analysis

We show comparative statics from the model using numerical analysis. First, we treat the debt level (F) as predetermined and try to show the evolution of the optimal hedging policy i^{**} for different levels of debt F maturing at date-1. Then we numerically solve for the optimal debt, taking into consideration that the firm may have tax-shield benefits of debt that have to be traded off against the cost of lower operational hedging at higher leverage.

Throughout this section, we focus on the generalized version of the model in Section 3.1, which features a pledgeability $\tau \in [0, 1]$. As mentioned in Section 2.1, the cash flow shock u follows an exponential distribution with rate parameter $\alpha = 0.05$, i.e., the probability density

[15] There are some technical modifications. The term p ceases to enter the left hand-sides of first-order conditions (2.11) and (2.14). Consequently, the firm will not add additional suppliers when $u_F > u_O$, i.e., $u^* = \underline{u}$. The second-order conditions and the optimal hedging policies across different levels of debt F are qualitatively identical.

function of u, $g(u) = 0.05e^{-0.05u}$. The production loss function is assumed to be $\delta(u) = e^{-u}$. Consistent with neoclassic investment literature (Bolton et al., 2011), we assume that a quadratic production cost function $K(I + i) = \kappa(I + i)^2$, in which $\kappa = 0.1$. All parameter values are in Table 1. Given the stylized nature of our model, we do not attempt to match any model-implied quantities with respective empirical moments. Therefore, the choice of the parameter values is just for illustrative purpose. That being said, the numerical results in exogenous debt case are based on analytical results in Proposition 3.1 and Proposition 3.2; thus, they are robust to specific parameter choices.

[INSERT Table 1.]

Figure 1 presents the firm's optimal operational hedging policies i^{**} given different short-term debt levels F. The blue, red and yellow lines represent the cases of low ($\tau = 0$), intermediate ($\tau = 0.4$) and high pledgeability ($\tau = 0.8$) cases, respectively. In all three cases, the optimal hedging policy i^{**} is flat when the debt level F is low. This corresponds to the scenario I of Proposition 3.1: debt does not affect the firm's optimal hedging policy when the debt level is sufficiently low, i.e., the debt is guaranteed to be paid off at date-1 even if the worst production shock occurs at date-1 that "wipes out" the firm's entire production capacity. As the debt level F increases, the optimal hedging policy i^{**} exhibits a negative correlation with the debt level maturing at date-1. Moreover, the negative slope is steeper and holds for a wider range of debt levels F the lower is the pledgeability τ. Overall, the optimal operational hedging policy intensity decreases in the amount of debt maturing in the interim, especially if the firm is financially constrained, i.e., has a low pledgeability τ.[16]

When τ is high, the tension between choosing operational hedging and financial hedging should be relaxed. Nevertheless, as the yellow line of Figure 1 shows, the negative relationship

[16]From Equation (3.5), $\bar{F}_{fb}$ increases in the pledgeability τ. Thus the F-region in which debt level does not affect the optimal hedging policy increases with τ.

between operational hedging policy and inherited debt level F is still present in our numerical examples. This demonstrates a "debt overhang" effect when firm chooses how much to hedge against the operational default risk. Intuitively, the benefit of operational hedging is "truncated" at the cash flow threshold F below which the firm declares bankruptcy, in which case the equity holders lose the franchise value anyways. Thus as the debt level increases, this cash flow threshold increases and equity holders' benefit of operational hedging diminishes. In response, equity holders lower the operational hedging activity.

[INSERT Figure 1.]

In what follows, we plot the firm's credit spread against its operational spread, i.e., the markup $p - K'(I + i)$. Proposition 3.3 is confirmed in Figure 2: When the firm chooses optimal hedging policy given the debt level F, the credit spread and operational spread are positively correlated. This positive relationship is stronger when the firm is more financially constrained, i.e., its pledgeability τ is lower. This is consistent with the novel implication of our model: when the firm's credit spread is higher, the financially constrained firm cuts the operational hedging activity by a larger extent to save more cash at date-0, hoping to avoid financial default given the more likely cash shortfall at date-1. Later, in Panel B of Table 4, we empirically confirm the pattern in Figure 2 that the positive relationship between credit risk and markup is more pronounced for financially constrained firms.

[INSERT Figure 2.]

5. Empirical analysis

5.1 Empirical predictions

Our model shows that operational hedging declines with the amount of the firm's credit risk, captured by its credit spread. A higher credit risk induces the firm to allocate more resources to avert financial default and spend less on operational hedging, which result in lower costs and higher price-unit cost margin or operational spread. Our model also predicts that higher existing leverage, especially shorter-term leverage that imposes a liquidity requirement, induces the firm to allocate resources to avoid financial default while spending less on operational hedging, which again raises the operational. We further show that the positive relation between operational spread and both leverage and credit risk should be stronger when the firm is financially constrained.

We test this implication as follows. First, we document that the markup, our measure of operational spread, is negatively correlated with indicators associated with operational hedging, as we predict. Specifically, we find that markup declines in the level of inventory whose hoarding indicates the propensity of the firm to engage in operational hedging, and it also declines in measures of supply chain diversification. The estimation controls for firm characteristics and for market power that affect markup. This initial test suggests that the markup can be taken as a summary measure of the extent of operational hedging that the firm engages in. We then examine whether measures of leverage and credit risk affect the operational spread in the way predicted by our model. In particular, we test whether markup is an increasing function of credit risk and leverage, especially the portion of debt that matures within two years. This breakdown is particularly important because our model focuses on the consequences for operational hedging of the immediate needs to avoid financial default, which is especially intense when debt is due for redemption. Notably, the maturity time of the short-term portion of the long-term debt has been determined in the past when the long-term debt was issued and thus it is exogenous to the current state of the firm and its current production plans. We propose that the need to avoid financial default induces the form to reduce operational hedging, leading to a wider markup. At the same time, there should be a muted effect of the long-term debt on operational hedging and on markup.

Next, we test the prediction that the trade-off between operational hedging and credit spread is stronger for constrained firms. We use both cross-sectional and time-series variation in financing constraints. We use cash holdings to sort firms into constrained and unconstrained groups. The level of cash held by firms reflects managerial private information about cash needs and about potential financial constraint. After controlling for other determinants of cash holdings, high cash firms are more likely to be constrained than low cash firms. To implement this proxy, we construct the residual level of cash after controlling for basic determinants of cash holdings such as cash flow uncertainty (Riddick and Whited, 2009). We sort firms into high-cash and low-cash groups. As two robustness checks, we also eliminate data on the largest firms, which are likely to hold cash for tax reasons prior to the change in the US tax code in 2018, and firms with positive pre-tax foreign income. The results are qualitatively the same.

We also use time-series variation in financing constraints by analyzing the negative impact of credit risk on markup. Specifically, we exploit an exogenous shock to credit supply to firms to test our prediction that the positive effects of credit risk and leverage on markup are greater when firms are financially constrained. We analyze the negative impact of the subprime mortgage crisis of 2008 on lenders' abilities to extend credit to borrowers, following Chodorow-Reich (2014). Specifically, we test whether exposed firms whose credit risk and leverage were higher prior to the crisis reduced operational hedging by more than less exposed firms, leading to a higher markup. This test uses time series variation in financing constraints to measure the key tension between operational hedging and liquidity hoarding emphasized in our paper, and it helps address concerns about the endogeneity of leverage; studies of the impact of the financial crisis show that pre-crisis leverage is an important determinant of the post-crisis real effects through a liquidity channel (e.g., Giroud and Mueller, 2016).

5.2 Data and empirical definition

We employ quarterly data from 1973 to April 2020, a span of 189 quarters, from Compustat. We exclude firms in the financial industries (SIC codes 6000-6999) and utility industries (SIC codes 4900-4949), and firms involved in major mergers (Compustat footnote code AB). We include firm-quarter observations with market capitalization greater than \$10 million and quarterly sales more than \$1 million at the beginning of the quarter. Our sample includes $17,697$ firms with an average asset value of \$2.3 billion dollars (inflation adjusted to 2004). Altogether we have $560,910$ firm-quarters.

5.2.1 Variable definitions

Our dependent variable is the operational spreads or *Markup*, which we define empirically as sales ($SALEQ$) minus cost of goods sold ($COGSQ$) divided by sales. This measure of the price-unit cost spread proxies for our model's marginal cost of production of the contracted output quantity, which we use the measure the effect of operational hedging cost. Our independent variables of interest are proxies for the firm's ability to pay off its debt liabilities. Our independent variables of interest are proxies for the firm's ability to pay off its debt liabilities. We use two measures: z-score (e.g. Altman, 2013)[17] and financial leverage, the

[17]z-score is computed using the following formula: z-score = 1.2×(current assets ($ACTQ$)−current liabilities ($LCTQ$))/assets+1.4× retained earnings (REQ)/assets+3.3×EBIT ($OIBDPQ$)/assets+0.6×market value of equity ($PRCCQ \times CSHOQ + PSTKQ + DVPQ$)/total liabilities ($LTQ$)+1.0×sales/assets. We use $OIBDP$ instead of $EBIT$ because the latter is not available in Compustat quarterly data.

financial debt ($DLTTQ + DLCQ$) divided by total assets (ATQ). We use the negative value of z-score so that a higher value means that the firm has greater financial risk. We include variables to control for the firm's investment needs and its debt capacity. We control for firm size by including total assets in logarithms. To control for the firm's investment opportunities we include Tobin's Q, the sum of common shares outstanding ($CHOQ$) multiplied by the stock price at the close of the fiscal quarter ($PRCCQ$), preferred stock value ($PSTKQ$) plus dividends on preferred stock ($DVPQ$), and liabilities (LTQ), scaled by total assets, to control for the firm's potential investment.[18] To control for the firm's debt capacity, we include cash holdings ($CHEQ$), cash flow ($IBQ + DPQ$) and tangible assets ($PPENTQ$), all scaled by total assets. We use three variables to control for market power, given that markup is associated with monopoly power (Lerner, 1934) and with inventory behavior (e.g. Amihud and Medenelson, 1989). One variable is "top 3 industry seller", which equal one if the firm's sales ranks among the top three sellers in the industry in a given quarter, using Fama and French's 38 industries, and zero otherwise. The second variable is the firm's sales/industry sales, and the third is Herfindahl's index for the industry.

We use variables that are associated with operational hedging. The disruptions of supply chains during the 2020 Covid-19 pandemic highlighted the importance of a new form of operational hedging, supply chain diversification. Indeed our model accommodates supply chain diversification as a measure of operational hedging (see Section 3.4). We thus create operational hedging measures using information on firms' supply chains using information from the Factset Revere relationship database.[19] It contains a comprehensive relationship-level data between firms, starting from April 2003. An observation in this database is the relationship between two firms with information about the identities of the related parties,

[18]The definition follows, Covas and Den Haan (e.g. 2011).

[19]Factset Revere has much better coverage of supply chain information than the COMPUSTAT segment data and used by some studies about supply chain (e.g. Ding et al., 2020).

the start and end date of the relationship, the type of the relationship (e.g., competitor, supplier, customer, partner, etc.), and importantly, the firms' geographic origins.

We aggregate the relationship-level data to firm-quarter level and calculate three measures of supply chain diversification for each firm in each quarter: (i.) ln(1+number of suppliers); (ii.) ln(1+number of supplier regions), where supplier regions are country and state/province combination; (iii.) ln(1+number of out-of-region suppliers), that is, suppliers that are not from the firm's region. We merge the supply-chain data to our main sample, yielding a total of $149,617$ firm-quarter observations covering $6,165$ firms, from mid-2003 to the first quarter of 2020. The median firm has 4 suppliers from 3 regions in a given quarter, out of which 2 suppliers are not from the same region as the firm. We create three composite measures of supply chain diversification using the three aforementioned individual measures.

(1) Supply chain diversification index, the first principal component score from a principal component analysis using three individual measures: supply chain diversification index = $0.5809 \times \ln(1+\text{number of suppliers}) + 0.6077 \times \ln(1+\text{number of supplier regions}) + 0.5414 \times \ln(1+\text{number of out-of-region suppliers})$.[20] A higher supply chain diversification index indicates a more diversified supply chain network.

(2) Supply chain diversification ranking, the average across the three supply chain variables of the ranking of the firm-quarter ranking for each of the individual measure. The ranking for each of the three series is scaled by the number of non-missing variables. A smaller value of supply chain diversification ranking indicates a more diversified supply chain network.

(3) Standardized supply chain diversification, the average of the value of the three supply chain variables where each is subtracted by the respective sample mean then scaled by

[20] The first principal component explains 86% of the sample variance.

the standard deviation of the variable. A higher standardized supply chain diversification indicates a more diversified supply chain network.

Finally, our analysis includes inventory ($INVTQ$) divided by sales as an indicator of operational hedging.

Table 2 presents summary statistics of the variables in our study. All continuous variables in our analysis are winsorized at the 1% and 99% tails. We find that *Markup* has a mean of 0.328 and its median is 0.341, which is close. The median firm has a z-score of 2.116 which, by Altman's analysis, indicates a state which is close to financial distress, and the mean is 3.567. The median leverage is 0.207 and the mean is 0.238. Measures of market power indicate that most firms operate in a competitive environment: For 75% of the sample, the Herfindahl index is below 0.068 and the firm's sales is 0.003 of the industry sales. Thus, normally it can be expected that markup reflects a magnitude that is close to the average competitive magnitude and deviations around it arise, among other things, by the considerations that are analyzed by our model.

[INSERT Table 2.]

5.3 The relationship between markup and operational hedging

Our model implies that higher operational hedging activities translates into lower markup through increased marginal production cost. We test whether this implication is supported by the evidence. We estimate the following model using data for firm j in quarter t,

$$Y_{j,t} = \sum_{k} \beta_k X_{k,j,t-1} + \sum_{m} Control\ variables_{m,j,t-1} + firm\ FE + year\ FE \tag{5.1}$$

The dependent variable $Y_{j,t}$ is $\ln(Markup_{j,t})$ and $X_{k,j,t-1}$ are the explanatory variables that we focus on which include either of the three supply chain diversification measures and ln(*inventory*/*sales*). Inventory serves here as an indicator of the firm's propensity to expend resources for the purpose of operational hedging, consistent with our model in which the firm produces a higher output than contracted for as a means to avert the cost of a shortfall on its contract with customers in case of a negative shock to output. The control variables are Tobin's Q, log assets, cash holdings, cash flow, asset tangibility, and the three variables that measure market power, which is known to affect markup. The model includes firm and year fixed effects with standard errors clustered by firm and by year.

[INSERT Table 3.]

By the results in Table 3, markup is negatively affected by indicators of operational hedging. It is significantly lower when the firm spends more on supply chain diversification and when it engages in increasing inventory. All three measures of supply chain diversification indicate that. markup is declining in the PCA index of the three supply chain diversification variables; it is declining in the index of standardized average of these variables; and it is increasing in the ordinal index of average ranking by which a lower number means a higher ranking. To illustrate the economic significance of the estimated effect, by the estimation in Column (2), a rise of one place in the ranking of supply chain diversification, which means a decline by one unit, increases log(*Markup*) by 0.053 which is 5% of its mean. By the estimation in column (1), one standard deviation increase in Supply chain diversification index will lower markup by 1%, and 10% increase in inventory-sales ratio lowers markup by 0.5%. Overall, the results suggest that markup is a reasonable summary of firms' operational hedging activities, as our model implies.[21] Thus, in the following sections, we examine the relationship between markup and firms' credit risk.

[21] Using individual supply chain diversification measures instead of composite measures yields qualitatively similar results.

5.4 Baseline results

We estimate the main prediction of our model of the tradeoff between allocating funds to avert financial default and spending on operational hedging. We propose that firms in financial distress and with high leverage will reduce spending on operational hedging, resulting in a higher operation spread which we proxy by markup. We estimate Model (5.1) where $Y_{j,t} = Markup_{j,t}$ and the explanatory variables $X_{k,j,t-1}$ include the variables that indicate he firm's credit risks: -(z-score), since the credit spread increases in this variable, and leverage. As before, the control variables are Tobin's Q, cash holdings, log assets, cash flow, asset tangibility, and the three measures of market power, as well as firm and year fixed effects.

[INSERT Table 4.]

Table 4, Panel A, presents our baseline results. As predicted in Proposition 3.2 of our model, the operational spread, measured by markup, is positively affected by the firm's credit risks measured by either the credit spread or the leverage ratio. To gauge the economic significance of the effect, one standard deviation increase in the firm's negative z-score raises the firm's markup by 0.04 standard deviation, or 5% of the sample median markup. And, one standard deviation increase in leverage results in 0.02 standard deviation increase in markup. In column (3) we include both -(z-score) and leverage and find that the coefficient of -(z-score) remains unchanged in both magnitude and statistical significance while the coefficient of leverage declines in magnitude and it is no longer significant.

In our theoretical model, it is the liquidity need to avoid financial default that presses the firm to divert resources from operation hedging. This is because the firm's existing debt matures before the contracted delivery date of its output. This maturity mismatch between debt obligations and operational cash flow contributes to the tension between financial hedging and operational hedging. It follows that short-term leverage should have a larger impact on operational hedging or markup than the impact of long-term leverage.

We test this hypothesis by studying the effect of the portion of debt which matures in the coming two years. Importantly, the short-term part of the long-term debt had its maturity determined in the past when the debt was issued. Thus it is not determined simultaneously with operational hedging policies in response to the current state of the firm and its environment.

The results in column (4) of Table 4, Panel A, show that the effect on markup of the short-term debt — the part of long-term that matures in the next two years — is more than twice as large as that of the remaining long-term debt maturing in more than two years, with the difference between the coefficients being statistically significant at the 0.05 level.[22] The result supports our theoretical prediction that it is the pressing liquidity need that induces firms to shift funds from operational hedging to the accommodation of the need to avoid financial default. In column (5), we include -(z-score) together with the two leverage variables, the short term and long-term part of leverage. We find that the coefficients of both -(z-score) and the short-term part of the long-term debt are positive and significant, as predicted by our model, while the coefficient of the remaining long-term debt is positive but smaller in magnitude and statistically insignificant.

Figure 3 presents binned scatter plots of the relationship between operational spread and either -(z-score) or leverage. Following the methodology of Rampini et al. (2014),[23] we first residualize *Markup*, -(z-score) and leverage with respect to the baseline control variables (including the firm and year fixed effects), as in Table 4. We then add back the unconditional

[22] In untabulated result, we also test for the significance of the difference between coefficients on long-term debt maturing in the next two years and remaining long-term leverage, the difference is 0.035 with t-statistics equal to 2.37.

[23] We thank Raj Chetty for making the relevant STATA program available.

mean of the respective variables in the estimation sample to facilitate interpretation of the scale. Finally we divide the x-axis variable into twenty equal-sized groups (vingtiles) and plot the means of the y-variable within each bin against the mean value of x-variable within each bin. Figure 3a and Figure 3b correspond to the estimations in columns (1) and (2) of Table 4, Panel A, respectively. We see that the markup monotonically increases with one-period lagged values of both -(z-score) and leverage. Notably, the monotonic relationships between the firm's credit risk and markup across all the bins shows that that our results are driven by extreme observations. These results support our prediction on the negative relationship between a firm's credit risk and the intensity of its operational hedging, reflected in a positive relation between the credit spread and leverage and its operational spread or markup.

We now turn to test our prediction that the tradeoff between operational hedging and financial hedging is particularly strong when pledgeability is low, that is, low τ. In terms of our empirical model, we expect that that for financially constrained firms that find it harder to raise funds there are stronger effects on markup of -(z-score) and of Leverage, particularly the portion of it that is due within two years. Our classification of firms into those which are financially constrained and those that are unconstrained is based on the level of cash holding.

Firms commonly ensure their liquidity by holding cash. This mechanism is particularly important for firms that face higher cost of raising capital. Evidence by Almeida et al. (2004) shows that financially constrained firms have greater propensity to hoard cash out of their cash flow, and Farre-Mensa and Ljungqvist (2016) find that corporate cash holdings are twice as high for firms that are classified as constrained than for unconstrained firms. We expect that the level of cash held by firms reflects managerial private information about the firm's cash needs and about potential financial constraint. This information is superior to the information provided by common measures, which Farre-Mensa and Ljungqvist (2016) consider inadequate to gauge the extent of financial constraint. Given managerial superior information, outsiders can infer from cash holdings what is the managers' private information about the firm's credit risk. Indeed, observed corporate cash holdings include information that affects firm value. Faulkender and Wang (2006) find a higher market valuation of cash holdings for constrained firms than for unconstrained firms[24] and conclude that "firms that can easily raise funds when they need cash should not carry a lot of cash" (p. 1978). It follows that the level of corporate cash informs about the managers' views on their firms' financial constraints.[25]

We use the observed level of cash as an indicator of the managerial information about future cash needs and the firm's potential difficulty in raising funds, that is, about the firm's financial constraint. Riddick and Whited (2009, p. 1730) propose that precautionary holding of cash is motivated by income uncertainty and by the cost of external financing or financial constraint. To focus on the role of financial constraint we control for the uncertainty motive for cash hoarding by following Opler et al. (1999) who find a positive effect on cash holdings of the firm cash flow volatility[26] measured by Sigma, the standard deviation of annual cash flow divided by net assets, where cash flow is net income minus dividend plus depreciation and net assets are total assets minus cash. In our analysis, Sigma is the standard deviation of quarterly cash flow divided by net assets over the recent 12 quarters.[27] Opler et al. (1999) find that the firm's Sigma and the average industry Sigma have a strong positive effect on cash holdings. We control for the firm's Sigma and include industry dummy variables (using the 2-digit SIC code) that control for industry volatility and for other industry-related

[24]Similar results are found by Denis and Sibilkov (2010).
[25]In terms of our model, high cash can be seen as a proxy for low pledgeability (the parameter τ).
[26]Kim et al. (1998) find both theoretically and empirically that volatility induces higher cash holdings.
[27]We require at least 6 quarters with non-missing cash flow data.

determinants of cash holdings.

We apply the following procedure. In each quarter we do a cross section regression of cash holding on Sigma and on the industry dummy variables, where cash holding is cash plus marketable securities divided by net assets. The residuals from this regression are construed as cash holding after controlling for the uncertainty motive for holding cash and for industry characteristics. We then divide the sample into two halves by whether the firm's lagged cash holding is above or below the median. Finally, we estimate our base model of Table 4, Panel A, separately for the high-cash and low-cash subsamples. We posit that high level of corporate cash indicates managerial information about greater financial constraint, which proxies for our model's limited extent of pledgeability τ which constrains financing. We conduct the following two robustness checks. First, we repeat the above procedure after eliminating data on the top 10% largest firms in terms of total asset value in the previous quarter. Moreover, we repeat the above procedure after eliminating data on firms with positive pre-tax foreign income.

We expect that for firms with high residual cash holding there is a stronger positive relation between operational spread, proxied by *Markup* which is the dependent variable, and the credit spread, proxied by -(z-score). Moreover, for constrained firms, there is a greater effect on markup of the cash need measured by leverage, especially the part of the long-term debt which matures in the next two years. For the unconstrained firms, we expect these relationships to be muted or non-existent.

The results are presented in Table 4, Panel B. Consistent with our expectation, the effects of -(z-score) and leverage are positive and significant for constrained firms — those with high lagged level of residual cash — but they are insignificant for half of the sample with low lagged level of residual cash, which we consider to include unconstrained firms. When we split leverage into its short-term and long-term components, the coefficient of long-term leverage maturing in the next two years is positive and statistically significant, while the coefficient of the remaining long-term leverage is marginally or not statistically significant, for both high and low residual cash holding subsamples (columns (3) and (7)). The coefficient of long-term leverage maturing in the next two years for the constrained subsample is about four times larger for the constrained firms than it is for unconstrained firms. In the final regression for unconstrained firms in column (8) we find that the effects of all variables are insignificant, both economically and statistically, which strongly contrasts with the significant effects of -(z-score) and of short-term debt for constrained firms in column (4).

One concern is that large, multinational firms have abnormally high cash holdings, and they are not financially constrained. To address this issue, in Panel C of Table 4, we repeated the above exercises excluding top 10% largest firms in each quarter in terms of lagged total assets. In Panel D of Table 4, we repeated the above exercises excluding firms with positive pre-tax foreign income as of the most recent fiscal year end. As shown in Panel C and Panel D of Table 4, excluding large or multinational firms yields qualitatively the same results as those presented in Panel B of Table 4.

We conclude that our estimation results are consistent with our model's predictions and the numerical results in Section 4 that for operational hedging is more strongly affected by credit risk and by cash needs for low-pledgeability firms, indicated by low τ, which indicates constrained financing. Empirically, the operational spread is positively affected by credit spread and leverage only for constrained firms but not for unconstrained firms.

5.5 Effect of financial constraint: the consequences of a shock to credit supply

We exploit the financial shocks during the crisis of 2008 to test our prediction that when a firm becomes financially constrained, there is a stronger effect of its credit risk and leverage on operational hedging. In our model, greater financial constraint is captured by a lower pledgeability parameter τ. During the financial crisis of 2008, a number of banks could no longer extend credit to firms with which they had lending relationship beforehand. We test whether for firms that were adversely affected by this shock to credit, the effect of -(z-score) and leverage on markup became stronger.

We first find the relationship between our sample firms and bank lenders using data from the LPC-Dealscan database. We then follow Chodorow-Reich (2014) who use three variables to measure the negative impact of the subprime mortgage crisis on lenders' abilities to extend credit to the borrowers.[28] The first variable (% # Loans) is a direct measure of changes in loan supply for a firm's lenders. For each lender, it calculates the Proportional changes in the (weighted) number of loans that the lender extended to all the firms other than the firm in question, between the 9-month period from October 2008 to June 2009, and the average of 18-month period containing October 2005 to June 2006 and October 2006 to June 2007. The weight is the lender's share of each loan package commitment. The second measure (Lehman exposure) is Lehman exposure, the exposure to Lehman Brothers through the fraction of a bank's syndication portfolio where Lehman Brothers had a lead role. The third measure (ABX exposure) captures banks' exposure to toxic mortgage-backed securities, which is calculated using the correlation between banks' daily stock return and the return on the ABX AAA 2006-H1 index. Then, for each firm and each of the three variables, it

[28]We thank Chodorow-Reich for sharing his data with us.

calculates a weighted average of the measure over all members of the last pre-crisis loan syndicate of the firm, in which the weight is each lender's share in the firm's last pre-crisis loan syndicate.[29] We construct the three variables in a way so that a larger value implies a larger exposure to the financial crisis on the lenders' side. For this analysis, we restrict our sample firms to the 2,429 firms in Chodorow-Reich (2014).

We use the following regression specification.

$$\begin{aligned} Markup_{j,t} = {} & \alpha + \beta_1 \times X_{j,2007} \times Lender\ exposure_{j,t} + \beta_2 \times Lender\ exposure_{j,t} \\ & + \sum_k \beta_{3,k} \times Control\ variable_{j,t-1} \\ & + \sum_k \beta_{4,k} \times Controls\ variables_{j,t-1} \times Lender\ exposure_{j,t} + \theta_j + \eta_t + \epsilon_{j,t} \end{aligned} \tag{5.2}$$

We estimate the differential effect on $Markup_{i,t}$ for firms that entered the post-crisis period with different levels $X_{i,2007}$ being either -(z-score) or leverage, given different levels of the firm's exposure to the crisis. Notably, $X_{i,2007}$ is fixed before the crisis as of the end of 2007. The comparison is between the two-year period before the crisis (July 2006 to June 2008) and the two-year period after the crisis (January 2009 to December 2010). The lenders' exposure to the financial crisis equals zero for the two-year period before the crisis, and equals its actual respective values for the two-year period after the crisis. The control variables are the same as in the baseline regression (Table 4) and they are fixed at the end of year 2007 for the post-crisis years, to be consistent with $X_{i,2007}$. Our test focuses on β_1, the coefficient of the interaction between the crisis exposure and the credit risk variables. The model includes firm and year fixed effects and standard errors are at firm levels.[30] Naturally, in these regressions which are confined to a short time period, the number of observations is

[29] Please refer to Chodorow-Reich (2014) for detailed constructions of the three variables.

[30] Our results are qualitatively similar if we cluster the standard errors at both firm and year levels.

much smaller.

[INSERT Table 5.]

Table 5 presents the results. We find that the coefficient β_1 is positive and significant for all interactive terms except for the $-$(z-score) $\times$ Lehman exposure. Our results mean that the effect of credit risk, proxied by -(z-score), or leverage, was greater for firms whose lenders were adversely affected by the financial crisis. These firms because financially constrained and thus their needs to avoid financial default forced them to reduce spending on operational hedging which we capture by the widening of markup. To gauge the economic significance of the joint impacts of the firm's credit risk and its exposure to financial crisis on the borrower's operational spread, taking column (1) as an example, one unit increase in the firm's negative z-score yields additional 0.01 markup when the firm's lenders reduce number of loans to other borrowers by 10% more during the financial crisis. Column (2) shows that a firms that enters the crisis period with 0.1 higher leverage ratio will increase its markup by an additional 0.008 when the firm's lenders reduce number of loans to other borrowers by 10% more during the financial crisis. According to column (3), a firm that enters the crisis period with 0.01 higher short-term leverage ratio witnesses an additional 0.003 markup when the firm's lenders reduce number of loans to other borrowers by 10% more during the financial crisis, while a firm that enters the crisis period with 0.01 higher long-term leverage ratio witnesses no change in markup when its lenders has the same exposure to the crisis. This is consistent with our results in Table 4, column (3), which represents a near-term liquidity need, proxied by the amount of leverage maturing in the near future, has a stronger effect on Markup than the long-term leverage. Using two alternative exposures to financial crisis yields qualitatively similar results.

One concern about the above results is that the interaction between the size of exposure of the firm' s lender and the firm' s measures its financial vulnerability — leverage and -z score — indicates firm characteristics which in turn affect the firm' s markup. We address this concern by studying the dynamic effects of this interaction term before and after the crisis. If markup is affected by the interaction term before the crisis, then this relationship is not a result of the financial constraint imposed on the firm as a result of the crisis. We use dummy variables denoted D_n. The dummy variable for all quarters between Q3/2006 and Q2/2007, denoted D_0, equals zero. Thereafter, the first four dummy variables relate to the before-crisis period, Q3/2007 to Q2/2008 and the other four quarters relate to the after-crisis period, Q1/2009 to Q4/2009. The first pre-crisis dummy variable, denoted D_{-4}, equals 1 in Q3/2007 and zero otherwise and the fourth, denoted D_{-1}, equals 1 in Q2/2008 and zero otherwise. Then the fifth variable, denoted D_{+1}, equals 1 in Q1/2009 and zero otherwise and the eighth variable, denoted D_{+4}, equals 1 in Q4/2009 and zero otherwise. We also define a dummy variable $D_{+5\,—\,+8}$ that equals 1 in quarters 5 to 8 after the crisis, Q1/2010 to Q4/2010, and zero otherwise. The interaction terms for each quarter during the period between Q3/2007 and Q4/2009 are $Y \times LE \times D_n$, $n = -4, -3, -2, -1, +1, +2, +3.+4$, and $Y \times LE \times D_{+5\,—\,+8}$ for the four quarters Q1/2010 to Q4/2010. Consistent with the regression model of (5.2), Y is -(Z-score) or Leverage as of the end of 2007. LE is one of the three measures of the size of lender exposure to the financial crisis used in this section: % # Loans, Lehman exposure and ABX exposure. We do a regression of the markup of firm j in quarter t, $Markup_{j,t}$, on $Y_j \times LE_j \times D_n$, the control variables, firm fixed effect and year fixed effect. Consistent with the regression model of (5.2), all the other control variable are fixed at their Q4/2007 level for post-crisis quarters (from Q1/2009 to Q4/2010), and equal to their respective one-quarter lag-values for pre-crisis quarters (from Q3/2006 to Q2/2008). As in the regression model of (5.2), as an additional control, the model includes the products of each control variable by lender exposure to the financial crisis, which equals zero for the two-year period before the crisis, and equals its actual respective sizes for the two-year period after the crisis.

Table 6 presents the results. In all columns, the joint effects of lender's exposure and the firms' credit risk is mostly significant after the crisis while being insignificant before the crisis. This indicates that for financially vulnerable firms — those with higher -(Z-score) and Leverage — the financial constraint imposed on firms whose lenders were more strongly exposed to the financial crisis made them reduce their operational hedging, which is reflected by the widening of their Markup. This relationship occurred only after the crisis but not before it. At the bottom of each column we present F-tests of the joint significance of all the coefficients of the interaction terms, conducted separately for the four quarters before the crisis and the four quarters after it. In all tests, the F-value shows strong statistical significance of the coefficients of the interaction terms for the post-crisis four quarters while it shows insignificance of the coefficients for the pre-crisis four quarters. This supports our proposition that greater financial constraint increases the need of firms to shift resources from operational hedging to financial hedging if their financial position is more vulnerable, as indicated by higher values of -(Z-score) and Leverage.[31]

[INSERT Table 6.]

Overall, the results show that the tension between operational hedging spending and the needs to avoid financial default is stronger when the firm is hit by a negative shock to its ability to raise capital. Then, it foregoes spending on operational hedging activities and diverts cash to service its financial needs. As shown in Table 5 and consistent with our model's predictions, the positive relationship between markup and the credit risk is stronger when the firm becomes more financially constrained.

[31]In untabulated results, the results are qualitatively similar when replacing Leverage by ST Leverage.

6. Conclusion

In this paper, we studied the corporate choice between financial efficiency and operational resiliency. We built a model in which a competitive (pricing-taking) firm substitutes between saving cash for financial hedging, which mitigates the risk of financial default, and spending on operational hedging, which mitigates the risk of operational default such as a failure to deliver on obligations to customers. This tradeoff is particularly strong for financially constrained firms and results in a positive relationship between operational spread (markup) and financial leverage or credit risk.

We presented empirical evidence supporting our model predictions. First, we documented that markup is a reasonable summary of firms' operational hedging activities, measured as inventory holdings and supply chain diversification, as our model implies. Then we documented a positive relationship between a firm's credit risk, measured as -(Z-score), total financial leverage, as well as the near-term portion of long-term leverage. Using a novel measure of financial constraints based on firms' cash holdings, we showed that the tradeoff between financial and operational hedging is more pronounced for financially constrained firms, i.e., those with higher liquidity-motivated cash holdings. Moreover, we showed that firms that entered the subprime financial crisis with high credit risks increased their markup by a larger extent if their lenders were more exposed to the financial crisis. Overall, our empirical findings confirm our model prediction that the tension between financial and operational hedging is more pronounced for financially constrained firms.

While our paper takes a first step towards understanding the tension between financial efficiency and operational resiliency, which manifested during the recent Covid-19 pandemic, more theoretical and empirical analyses along this line of research are needed. On the theoretical end, one can build a general equilibrium model that extends the current partial equilibrium framework to a production network model in with product pricing, financial (leverage) and operational hedging decisions are determined as equilibrium outcomes of the entire system, with one firm's operational hedging determining the operational hazard for its upstream and downstream firms in the network. Such a model can be used to analyze production network externalities in operational hedging such as underinvestment in operational resiliency arising from leverage spillovers across firms. On the empirical end, a more detailed research on forms of operational hedging, understanding their relative tradeoffs, and identifying their linkage to product prices with a microscope, are needed; all of this requires gathering of richer data on operational hedging. We leave these exciting extensions for future research.

REFERENCES

Acharya, Viral V., Sergei A. Davydenko, and Ilya A Strebulaev, 2012, Cash holdings and credit risk, *The Review of Financial Studies* 25, 3572–3609.

Almeida, Heitor, Murillo Campello, Bruno Laranjeira, and Scott Weisbenner, 2012, Corporate debt maturity and the real effects of the 2007 credit crisis, *Critical Finance Review* 1, 3–58.

Almeida, Heitor, Murillo Campello, and Michael S. Weisbach, 2004, The cash flow sensitivity of cash, *The Journal of Finance* 59, 1777–1804.

Altman, Edward I, 2013, Predicting financial distress of companies: revisiting the z-score and zeta® models, in *Handbook of research methods and applications in empirical finance* (Edward Elgar Publishing).

Amihud, Yakov, and Haim Medenelson, 1989, Inventory behaviour and market power: An empirical investigation, *International Journal of Industrial Organization* 7, 269–280.

Bianco, Marco, and Andrea Gamba, 2019, Inventory and corporate risk management, *Review of Corporate Finance Studies* 8, 97–145.

Bolton, Patrick, Hui Chen, and Neng Wang, 2011, A unified theory of tobin's q, corporate investment, financing, and risk management, *The Journal of Finance* 66, 1545–1578.

Chodorow-Reich, Gabriel, 2014, The employment effects of credit market disruptions: Firm-level evidence from the 2008–9 financial crisis, *The Quarterly Journal of Economics* 129, 1–59.

Covas, Francisco, and Wouter J. Den Haan, 2011, The cyclical behavior of debt and equity finance, *American Economic Review* 101, 877–99.

Denis, David J, and Valeriy Sibilkov, 2010, Financial constraints, investment, and the value of cash holdings, *The Review of Financial Studies* 23, 247–269.

Ding, Wenzhi, Ross Levine, Chen Lin, and Wensi Xie, 2020, Corporate immunity to the covid-19 pandemic, *Journal of Financial Economics,* forthcoming.

Dou, Winston Wei, and Yan Ji, 2020, External financing and customer capital: A financial theory of markups, *Management Science* forthcoming.

Duchin, Ran, Oguzhan Ozbas, and Berk A. Sensoy, 2010, Costly external finance, corporate investment, and the subprime mortgage credit crisis, *Journal of Financial Economics* 97, 418–435.

Farre-Mensa, Joan, and Alexander Ljungqvist, 2016, Do measures of financial constraints measure financial constraints?, *The Review of Financial Studies* 29, 271–308.

Faulkender, Michael, and Rong Wang, 2006, Corporate financial policy and the value of cash, *The journal of finance* 61, 1957–1990.

Froot, Kenneth A., David S. Scharfstein, and Jeremy C. Stein, 1993, Risk management: Coordinating corporate investment and financing policies, *the Journal of Finance* 48, 1629–1658.

Gilchrist, Simon, Raphael Schoenle, Jae Sim, and Egon Zakrajšek, 2017, Inflation dynamics during the financial crisis, *American Economic Review* 107, 785–823.

Gilson, Stuart C., 1989, Management turnover and financial distress, *Journal of Financial Economics* 25, 241–262.

Giroud, Xavier, and Holger Mueller, 2016, Redistribution of local labor market shocks through firms' internal networks, Technical report, National Bureau of Economic Research.

Johnson, Timothy C., 2021, Economic uncertainty, aggregate debt, and the real effects of corporate finance, *Critical Finance Review* 10, forthcoming.

Kim, Chang-Soo, David C Mauer, and Ann E Sherman, 1998, The determinants of corporate liquidity: Theory and evidence, *Journal of Financial and Quantitative Analysis* 335–359.

Lemmon, Michael, and Michael R. Roberts, 2010, The response of corporate financing and investment to changes in the supply of credit, *Journal of Financial and Quantitative Analysis* 555–587.

Lerner, Aba P., 1934, The concept of monopoly and the measurement of monopoly power, *Review of Economic Studies* 157–175.

Myers, Stewart C, 1977, Determinants of corporate borrowing, *Journal of Financial Economics* 5, 147–175.

Opler, Tim, Lee Pinkowitz, René Stulz, and Rohan Williamson, 1999, The determinants and implications of corporate cash holdings, *Journal of financial economics* 52, 3–46.

Rampini, Adriano A., Amir Sufi, and S. Viswanathan, 2014, Dynamic risk management, *Journal of Financial Economics* 111, 271–296.

Rampini, Adriano A., and S. Viswanathan, 2010, Collateral, risk management, and the distribution of debt capacity, *The Journal of Finance* 65, 2293–2322.

Riddick, Leigh A, and Toni M Whited, 2009, The corporate propensity to save, *The Journal of Finance* 64, 1729–1766.

Stein, Jeremy C, 2003, Agency, information and corporate investment, in *Handbook of the Economics of Finance*, volume 1, 111–165 (Elsevier).

Sufi, Amir, 2009, Bank lines of credit in corporate finance: An empirical analysis, *The Review of Financial Studies* 22, 1057–1088.

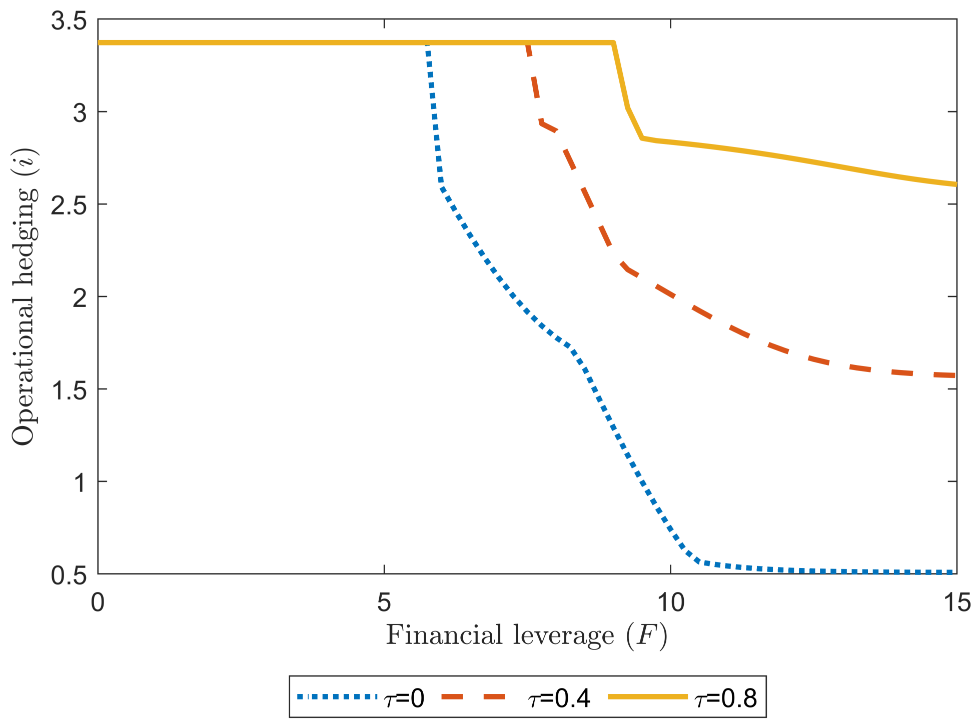

Figure 1: **Firm's optimal hedging policy i^{**} and debt level F**

Optimal hedging policy i^{**} given debt level F for $\tau = 0$, $\tau = 0.4$ and $\tau = 0.8$. All other parameters are presented in Table 1.

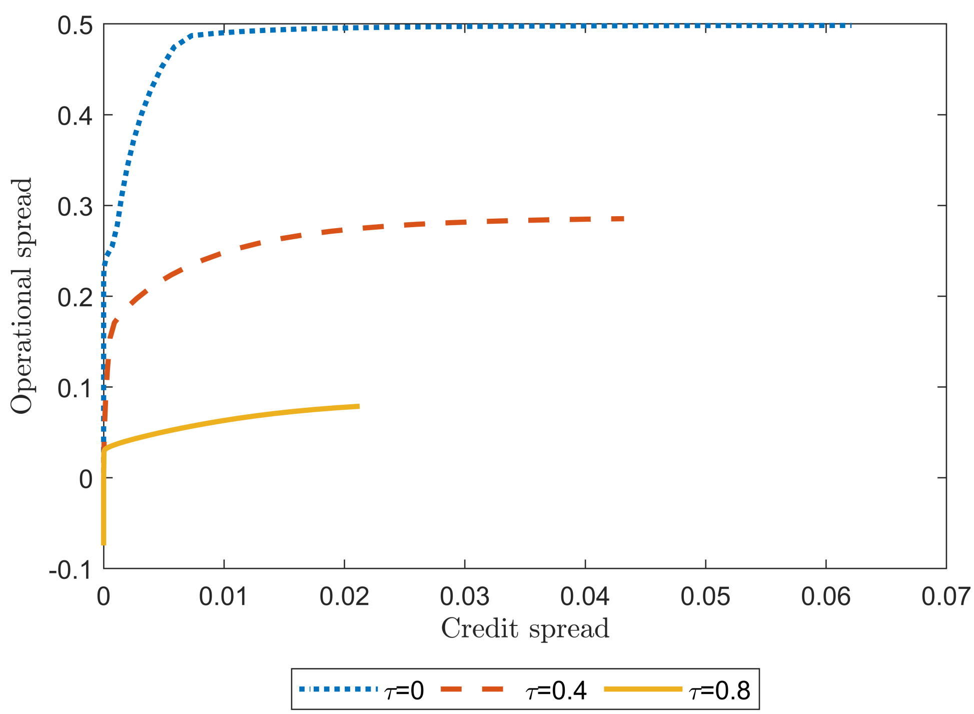

Figure 2: **Credit spread and operational spread**

The credit spread and operational spread under the optimal hedging policy i^{**} given debt level F for $\tau = 0$, $\tau = 0.4$ and $\tau = 0.8$. All other parameters are presented in Table 1.

Figure 5A: -(Z-score) and markup

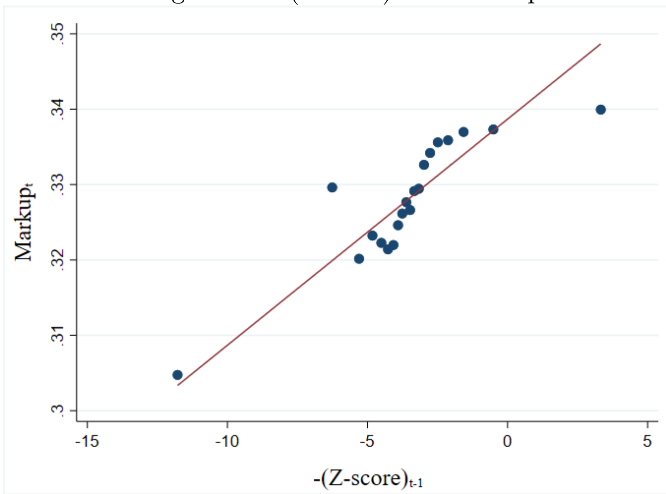

Figure 5B: Financial leverage and markup

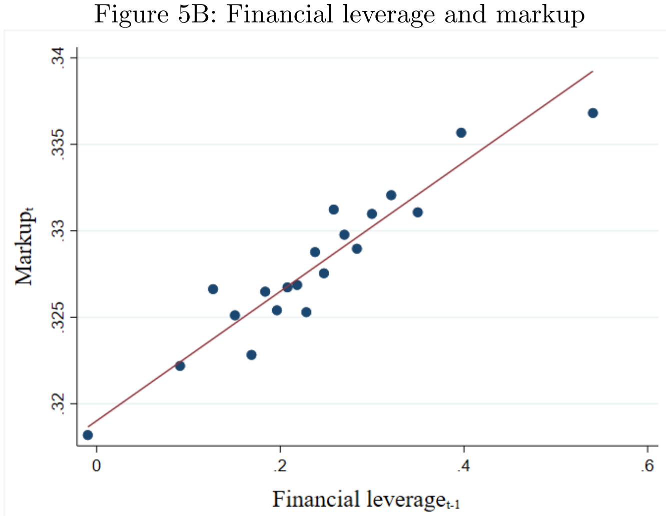

Figure 3: **Markup and Credit risk**

We first residualize the y-axis variable and x-axis variable with respect to the baseline control vector (including the fixed effects) in Table 4. We then add back the unconditional mean of the y and x variables in the estimation sample to facilitate interpretation of the scale. Finally we divide the (residualized) x-axis variable into twenty equal-sized groups (vingtiles) and plot the means of the y-variable within each bin against the mean value of x-variable within each bin.

Table 1: **Parameter values for numerical analysis**

The table presents the parameter values used for the numerical analyses in Section 4.

Parameter	Interpretation	Value
α	Rate of the exponential distribution of u	0.05
I	Contractual delivery amount	3
κ	Production cost parameter	0.1
λ	Proportional cost of operational default	0.5
p	Unit price	1.2
t	Tax rate	0.3
x_0	Cash flow at date-0	5
$\bar{x}_1$	Certain cash flow at date-1	5
x_2	Franchise value at date-2	10

Table 2: **Summary statistics** — COMPUSTAT 1973-2020

This table presents the summary statistics of the variables in our sample from 1973 to April 2020. The data are quarterly from COMPUSTAT; The variable names are in parentheses. Markup = (sales(SALEQ) $-$ cost of goods sold(COGSQ))/$Sales$. z-score is Altman (2013)'s measure calculated from quarterly data. Leverage = (long-term debt(DLTTQ) + short-term debt(DLCQ))/total assets(ATQ). Tobin's Q = (common shares outstanding(CHOQ)$\times$stock price at the close of the fiscal quarter(PRCCQ)+ preferred stock value(PSTKQ) + dividends on preferred stock(DVPQ) + liabilities(LTQ))/total assets. Cash holdings ($CHEQ$), Cash flow (= $IBQ + DPQ$) and Tangible assets ($PPENTQ$) are divided by Total assets. Market power is measured by the following three variables, all employing Fama and French's 38 industries: Top 3 industry seller = 1 if the firm's sales are among the top three sellers in the industry (0 otherwise); Sales/Industry sales; and Herfindahl index. The operational hedging variables include Inventory ($INVQ$)/Sales and Supply chain diversification index, Supply chain diversification ranking and Standardizes supply chain diversification. They are composed from three raw measures: (i) log(1+number of suppliers), (ii) log(1+number of supplier regions), (iii) log(1+number of suppliers not from the firm's region). Data are quarterly (source: Factset), covering $6,066$ firms from mid-2003 to the first quarter of 2020. Supply chain diversification index is the first principal component score from a principal component analysis that equals $0.5809 \times$ (i) + $0.6077 \times$ (ii) + $0.5414 \times$ (iii) where (i)-(iii) indicate the above three measures. Supply chain diversification ranking is the average ranking of the firm-quarter ranking in terms of each of the individual measures. A smaller value of supply chain diversification ranking indicates a more diversified supply chain network. Standardized supply chain diversification is the average of the individual measures in each quarter standardized by their cross-section standard deviation for the quarter. A higher standardized supply chain diversification indicates a more diversified supply chain network.

The sample requires that the lagged firm capitalization is at least $10 million and quarterly sales are at least $1 million. All continuous variables are winsorized at both the 1st and 99th percentiles.

VARIABLES	N	mean	sd	p25	p50	p75
Markup: (sales-cogs)/sales	560,910	0.328	0.394	0.210	0.341	0.513
-(Z-score)	534,448	-3.569	5.684	-4.048	-2.116	-1.116
Financial leverage	546,248	0.238	0.212	0.048	0.207	0.363
Tobin's Q	560,910	1.961	1.527	1.085	1.451	2.196
Cash holdings	560,910	0.161	0.194	0.023	0.080	0.226
Cash flow	560,910	0.012	0.051	0.007	0.021	0.035
Asset tangibility	560,910	0.309	0.247	0.105	0.241	0.462
Top 3 industry seller	560,910	0.021	0.145	0.000	0.000	0.000
Sales/industry sales	560,910	0.006	0.018	0.000	0.001	0.003
Herfindahl index	560,910	0.058	0.054	0.027	0.043	0.068
Total assets	560,910	2,313.182	6,836.232	76.900	278.227	1,199.486
Inventory/sales	550,016	0.478	0.512	0.060	0.373	0.699
Supply chain diversification index	107,719	0.098	1.650	-1.165	-0.268	1.042
Supply chain diversification ranking	107,719	0.436	0.230	0.249	0.448	0.624
Standardized supply chain diversification	107,719	0.082	0.952	-0.641	-0.125	0.628

Table 3: **Markup and operational hedging**

Estimation of the relationship between Markup and measures of operational hedging. The variables are defined in Table 2. The control variables include Tobin's Q, ln(Total assets), Cash holdings, Cash flow, Tangible assets, Top 3 industry seller, Sales/total sales, and Herfindahl index. All explanatory variables are lagged. The regressions include firm and year fixed effects. Standard errors are clustered at firm and year levels. $*$, $**$, $***$ denote significance below 10%, 5%, and 1% levels, respectively.

VARIABLES	Log(*Markup*)		
	(1)	(2)	(3)
Log(inventory/sales)	-0.045***	-0.045***	-0.045***
	(0.0086)	(0.0086)	(0.0086)
Supply chain diversification index	-0.0072**		
	(0.0029)		
Supply chain diversification ranking		0.053***	
		(0.017)	
Standardized supply chain diversification			-0.012**
			(0.0050)
Control variables		Yes	
Firm fixed effects		Yes	
Year fixed effects		Yes	
Observations	104,797	104,797	104,797
R-squared	0.867	0.868	0.867

Table 4: **Markup and credit risk**

Estimation of the relationship between Markup, -(Z-score) and Leverage. Leverage is also divided into the short-term debt maturing in 2 years and the remainder, both scaled by total assets. Panel A presents the full-sample estimation. Panel B presents the estimations separately, for firms with high v.s. low financial constraint in the previous quarter. Financial constraint is measured by cash holdings after controlling for risk and industry characteristics. In each quarter, cash holding (cash plus marketable assets divided by net assets) is regressed across firms on cash flow volatility (the standard deviation over 12 quarters of cash flow divided by net assets) and industry dummy variables (using 2-digit SIC code). Then, the sample of firms is divided into two halves by whether the firm's residual cash holding is above or below the median. High residual cash holding indicates the firm being financially constrained. Panel C and Panel D repeat the analyses in Panel B, excluding top 10% largest firms in terms of total asset value in the previous quarter, and firms with positive pre-tax foreign incomes as of the most recent fiscal year-end, respectively. The dependent variable in the panel regression is *Markup* in the following quarter. The control variables include Tobin's Q, ln(Total assets), Cash holdings, Cash flow, Tangible assets, Top 3 industry seller, Sales/total sales, and Herfindahl index. All explanatory variables are lagged. The regressions include year and firm fixed effects. Standard errors are clustered at firm and year levels. $*$, $**$, $***$ denote significance below 10%, 5%, and 1% levels, respectively. The complete table is presented in Table A.1.

Panel A: Full sample

VARIABLES	*Markup*			
	(1)	(2)	(3)	(4)
-(Z-score)	0.0030***			0.0031***
	(0.00057)			(0.00060)
Financial leverage		0.037***		
		(0.011)		
Long-term debt maturing in the next 2 years/total assets			0.071***	0.046***
			(0.017)	(0.016)
Remaining long-term leverage			0.036***	0.013
			(0.012)	(0.012)
Control variables	Yes			
Firm fixed effects	Yes			
Year fixed effects	Yes			
Observations	533,520	545,284	472,465	446,642
R-squared	0.630	0.622	0.640	0.646

Panel B: High v.s. low financial constraint

VARIABLES	*Markup*							
	High financial constraint				Low financial constraint			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
-(Z-score)	0.0029***			0.0030***	0.00038			0.00096
	(0.00074)			(0.00081)	(0.00100)			(0.0011)
Financial leverage		0.060**				0.0019		
		(0.023)				(0.013)		
Long-term debt maturing in the next 2 years/total assets			0.151***	0.124***			0.039**	0.027*
			(0.046)	(0.045)			(0.016)	(0.014)
Remaining long-term leverage			0.042*	0.0079			0.018	0.013
			(0.023)	(0.024)			(0.013)	(0.013)
Control variables	Yes							
Firm fixed effects	Yes							
Year fixed effects	Yes							
Observations	209,640	210,343	187,629	180,114	203,489	212,438	180,259	168,484
R-squared	0.725	0.722	0.732	0.736	0.495	0.493	0.511	0.509

Panel C: High v.s. low financial constraint (Excluding large firms)

VARIABLES	*Markup*							
	High financial constraint				Low financial constraint			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
-(Z-score)	0.0028***			0.0031***	0.000083			0.00065
	(0.00075)			(0.00081)	(0.00090)			(0.00097)
Financial leverage		0.056**				-0.0017		
		(0.025)				(0.013)		
Long-term debt maturing in the next 2 years/total assets			0.149***	0.121**			0.035**	0.027*
			(0.050)	(0.049)			(0.015)	(0.015)
Remaining long-term leverage			0.033	-0.0027			0.019	0.015
			(0.026)	(0.027)			(0.013)	(0.013)
Control variables	Yes							
Firm fixed effects	Yes							
Year fixed effects	Yes							
Observations	188,643	188,032	168,135	162,344	182,967	189,754	160,196	150,571
R-squared	0.722	0.720	0.730	0.734	0.492	0.490	0.510	0.507

Panel D: High v.s. low financial constraint (Excluding firms with positive foreign income)

VARIABLES	*Markup*							
	High financial constraint				Low financial constraint			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
-(Z-score)	0.0032***			0.0035***	0.00080			0.0014
	(0.00089)			(0.00098)	(0.0011)			(0.0013)
Financial leverage		0.079**				0.0010		
		(0.030)				(0.015)		
long-term debt maturing in the next 2 years/total assets			0.158**	0.133**			0.041**	0.026
			(0.059)	(0.059)			(0.019)	(0.019)
Remaining long-term leverage			0.056*	0.016			0.020	0.014
			(0.032)	(0.035)			(0.015)	(0.015)
Control variables	Yes							
Firm fixed effects	Yes							
Year fixed effects	Yes							
Observations	147,218	148,622	131,106	125,353	142,715	149,926	125,225	116,102
R-squared	0.710	0.707	0.719	0.722	0.479	0.478	0.494	0.490

Table 5: **Markup and credit risk: Exposure to the financial crisis**

Regressions of Markup on firms' -(Z-score), Leverage, as well as ST leverage (Long-term debt maturing in the next 2 years/total assets) and Remaining LT leverage (Remaining long-term leverage) that interact with the extent of exposures to the 2008 financial crisis. We restrict our sample firms to the 2,429 firms in Chodorow-Reich (2014). The two-year periods before and after the crisis are July 2006 to June 2008, and January 2009 to December 2010, respectively. The three measures for crisis exposure are % # Loans reduction, Lehman exposure and ABX exposure, using Chodorow-Reich (2014)'s definitions and data. The values of -(z-score), short-term leverage and long-term leverage are as of the end of 2007. The firm-level control variables, as in Table 4, are fixed at the end of year 2007, for the post-crisis years. The variable definitions are in Table 2. The regressions include year and firm fixed effects. Standard errors are clustered by firm. $*$, $**$, $***$ denote significance below 10%, 5%, and 1% levels, respectively.

	Panel A: % # Loans reduction			Panel B: Lehman exposure			Panel C: ABX exposure		
VARIABLES					*Markup*				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
-(Z-score) × lender exposure	0.096***			0.183***			0.090***		
	(0.032)			(0.067)			(0.026)		
Leverage × lender exposure		0.786***			1.280**			0.630**	
		(0.285)			(0.531)			(0.255)	
ST leverage × lender exposure			2.541**			4.080**			1.917**
			(1.150)			(2.042)			(0.964)
Remaining LT leverage			0.579*			0.943*			0.415
× lender exposure			(0.319)			(0.563)			(0.284)
Lender exposure	-0.165	-0.421	-0.451	-0.128	-0.471	-0.243	-0.376	-0.526	-0.537
	(0.385)	(0.392)	(0.431)	(0.692)	(0.731)	(0.794)	(0.323)	(0.323)	(0.355)
Control variables					Yes				
Control variables × exposure					Yes				
Firm fixed effects					Yes				
Year fixed effects					Yes				
Observations	20,963	21,871	19,622	20,963	21,871	19,622	20,963	21,871	19,622
R-squared	0.897	0.892	0.894	0.897	0.892	0.894	0.897	0.893	0.895

Table 6: **Markup and credit risk: :**
Dynamic effects of exposure to the financial crisis

Regressions of Markup on firms' -(Z-score) and leverage that interact with the extent of lender exposures to the 2008 financial crisis in each quarter D_n, $n = -1, -2, -3, -4, 1, 2, 3, 4, +5 — +8$ relative to the financial crisis, from 4 quarters before it to 8 quarters after it. We restrict our sample firms to the $2,429$ firms in Chodorow-Reich (2014). The two-year periods before and after the crisis are July 2006 to June 2008, and January 2009 to December 2010, respectively. The three measures for crisis exposure are % # Loans reduction, Lehman exposure and ABX exposure, using Chodorow-Reich (2014)'s definitions and data. The values of -(Z-score) and Leverage are as of the end of 2007. The firm-level control variables, as in Table 4, are fixed at the end of year 2007, for the post-crisis quarters. The variable definitions are in Table 2. The last two rows show the results from F-test for joint significance of the coefficients of the interaction terms between Y and the size of lender exposure to the financial crisis (LE) for quarters D_n, where $n = +1, +2, +3, +4$ and for quarters $n = -1, -2, -3, -4$ relative to the financial crisis. The regressions include year and firm fixed effects. Standard errors are clustered by firm. $*$, $**$, $***$ denote significance below 10%, 5%, and 1% levels, respectively.

	Panel A: $Y = -(Z - score)$			Panel B: $Y = Leverage$		
	% # Loans reduction	Lehman exposure	ABX exposure	% # Loans reduction	Lehman exposure	ABX exposure
VARIABLES	*Markup*					
	(1)	(2)	(3)	(4)	(5)	(6)
$Y \times$ Lender exposure (LE), D_{+1}	0.062	0.177**	0.054	1.574***	3.247***	1.298***
	(0.042)	(0.080)	(0.035)	(0.477)	(0.866)	(0.423)
$Y \times LE$, D_{+2}	0.135***	0.255***	0.124***	0.959**	1.545**	0.818**
	(0.039)	(0.075)	(0.031)	(0.397)	(0.709)	(0.354)
$Y \times LE$, D_{+3}	0.146***	0.271***	0.135***	1.044***	1.549**	0.868***
	(0.042)	(0.078)	(0.033)	(0.390)	(0.720)	(0.335)
$Y \times LE$, D_{+4}	0.080**	0.165**	0.082***	0.297	0.395	0.228
	(0.040)	(0.077)	(0.031)	(0.405)	(0.748)	(0.358)
$Y \times LE$, $D_{+5\,—\,+8}$	0.080**	0.160*	0.083***	0.496	0.487	0.429
	(0.039)	(0.082)	(0.031)	(0.376)	(0.684)	(0.335)
$Y \times LE$, D_{-1}	0.015	0.058	0.023	0.205	0.226	0.293
	(0.026)	(0.046)	(0.021)	(0.351)	(0.553)	(0.308)
$Y \times LE$, D_{-2}	-0.010	0.017	0.008	-0.173	-0.444	-0.033
	(0.024)	(0.044)	(0.019)	(0.352)	(0.611)	(0.309)
$Y \times LE$, D_{-3}	-0.013	0.001	-0.006	-0.309	-0.522	-0.280
	(0.021)	(0.044)	(0.018)	(0.278)	(0.507)	(0.242)
$Y \times LE$, D_{-4}	0.014	0.069*	0.015	0.251	0.617	0.181
	(0.021)	(0.042)	(0.017)	(0.287)	(0.475)	(0.249)
Lender exposure, D_n	Yes					
Control variables	Yes					
Control variables×lender exposure	Yes					
Firm fixed effects	Yes					
Year fixed effects	Yes					
Observations	20,245	20,245	20,245	21,113	21,113	21,113
R-squared	0.896	0.896	0.896	0.891	0.891	0.891
F-statistic for $n = +1$ to $+4$	4.28***	4.17***	5.34***	5.79***	5.60***	5.09***
F-statistic for $n = -1$ to -4	0.61	0.92	0.69	1.01	1.01	1.10

A. Appendix

Table A.1: **Markup and credit risk — Complete table**

This table reports the complete table of Panel A, Table 4.

VARIABLES	Markup			
	(1)	(2)	(3)	(4)
-(Z-score)	0.0030***			0.0031***
	(0.00057)			(0.00060)
Financial leverage		0.037***		
		(0.011)		
Long-term debt maturing in the next 2 years/total assets			0.071***	0.046***
			(0.017)	(0.016)
Remaining long-term leverage			0.036***	0.013
			(0.012)	(0.012)
Tobin's Q	0.020***	0.014***	0.014***	0.020***
	(0.0020)	(0.0021)	(0.0020)	(0.0023)
Log assets	0.0090***	0.0045	0.0036	0.0080**
	(0.0032)	(0.0034)	(0.0034)	(0.0032)
Cash holdings	-0.057***	-0.076***	-0.070***	-0.045***
	(0.016)	(0.016)	(0.016)	(0.016)
Cash flow	0.88***	0.86***	0.83***	0.85***
	(0.053)	(0.052)	(0.054)	(0.054)
Asset tangibility	-0.032**	-0.028*	-0.022	-0.033**
	(0.016)	(0.015)	(0.015)	(0.015)
Top 3 industry seller	0.010*	0.010*	0.0084	0.0078
	(0.0055)	(0.0054)	(0.0055)	(0.0058)
Sales/industry sales	-0.87***	-0.78***	-0.68***	-0.75***
	(0.14)	(0.14)	(0.13)	(0.13)
Herfindahl index	0.12***	0.11***	0.11***	0.11***
	(0.035)	(0.034)	(0.031)	(0.032)
Firm fixed effects	Yes			
Year fixed effects	Yes			
Observations	533,520	545,284	472,465	446,642
R-squared	0.630	0.622	0.640	0.646

A.1 Second-order condition in benchmark case ($F = 0$)

The second-order derivative of $\bar{E}$ with respect to i is:

$$\frac{\partial^2 \bar{E}}{\partial i^2} = -K''(I+i) - \frac{\lambda x_2}{I^2} \frac{g'(u_O) - g(u_O)\frac{\delta''(u_O)}{\delta'(u_O)}}{[\delta'(u_O)]^2} < 0 \tag{A.1}$$

Since $\delta(u)$ is decreasing and convex in u, $\frac{\partial^2 \bar{E}}{\partial i^2}$ is always negative if the production commitment I is sufficiently high. In other words, the objective function $\bar{E}$ is concave in i. Thus, $\bar{i}$ is the unique optimal solution that maximizes the equity value (2.6).

A.2 Optimal hedging policy when $u_F \geq u_O$

We begin this subsection by proving Lemma 2.1. First, we show that i^* that satisfies the first-order condition (2.11) is the unique optimal solution for the maximization problem when $u_F > u_O$. Define $S = p - K'(I+i) - V(u_F, i)h(u_F)K'(I+i)$.[32] Taking the derivative of S with respect to i:

$$\frac{\partial S}{\partial i} = -\begin{bmatrix} K''(I+i) + \frac{\partial V(u_F,i)}{\partial i} h(u_F)K'(I+i) \\ +V(u_F,i)\frac{\partial h(u_F)}{\partial u_F}\frac{\partial u_F}{\partial i}K'(I+i) + V(u_F,i)h(u_F)\frac{\partial^2 u_F}{\partial i^2} \end{bmatrix} \tag{A.2}$$

$$\frac{\partial V(u_F, i)}{\partial i} = p[1 - \delta'(u_F)IK'(I+i)] > 0 \tag{A.3}$$

and

$$\frac{\partial^2 u_F}{\partial i^2} = K''(I+i) > 0 \tag{A.4}$$

Using these quantities,

$$\frac{\partial S}{\partial i} = -\begin{bmatrix} K''(I+i) + p[1 - \delta'(u_F)IK'(I+i)]h(u_F)K'(I+i) \\ +V(u_F,i)\frac{\partial h(u_F)}{\partial u_F}[K'(I+i)]^2 + V(u_F,i)h(u_F)K''(I+i) \end{bmatrix} \tag{A.5}$$

[32] S the term inside the bracket after $[1 - G(u_F)]$ of the left hand-side of the first-order condition (2.10).

$\frac{\partial S}{\partial i}$ is smaller than zero. Thus, the second-order condition for maximization $[1-G(u_F)]\frac{\partial S}{\partial i}$ at $i=i^*$ is smaller than zero. By the first-order condition (2.10), $S=0$ if $i=i^*$. Since $\frac{\partial S}{\partial i}<0$, we have $S>0$ if $i<i^*$ and $S<0$ if $i>i^*$. Since $\frac{\partial}{\partial i}E=[1-G(u_F)]S$, E increases in i for $i<i^*$ and decreases in i for $i>i^*$. Therefore i^* is the unique optimal solution to the maximization problem.

Now we prove that Assumption 2.3 is sufficient condition that guarantees a positive interior solution i^* and $D(i^*,\bar{F})>0$ when $\bar{F}$ is sufficiently large. Denote $\underline{i}$ such that $p-K'(I+\underline{i})=(p(I+\underline{i})+x_2)\alpha K'(I+\underline{i})$. Notice that $\underline{i}$ must be strictly greater than zero. This is because the left hand-side of the above equation decreases with i, the right hand-side increases with i, and left hand-side is strictly greater than the right hand-side when $i=0$ by Assumption 2.3.[33] For any $\bar{F}>0$, the right hand-side of the first-order condition (2.12) when $i=\underline{i}$ is $V(u_F,\underline{i})\alpha K'(I+\underline{i})$, which is smaller than $(p(I+\underline{i})+x_2)\alpha K'(I+\underline{i})=p-K'(I+\underline{i})$. The left hand-side of the first-order condition (2.12) decreases with i. The right hand-side of the first-order condition (2.12) increases with i.[34] So the optimal i^* that satisfies the first-order condition (2.12) must be strict greater than $\underline{i}$. Denote $\bar{F}_M$ such that $D(\underline{i},\bar{F}_M)=0$. Then for any $\bar{F}\geq\bar{F}_M$, we must have $D(i^*(\bar{F}),\bar{F})>D(\underline{i},\bar{F})>0$. This is because $D(\bar{F},i)$ increases in $\bar{F}$ and i, and $i^*(\bar{F})>\underline{i}$. Thus, we have proved that for $\bar{F}>\bar{F}_M$, the first-order condition (2.12) admits a positive interior solution i^* and the financial default boundary u_F is greater than the operational default boundary u_O when the firm chooses the optimal hedging policy i^*. Since we have proved that the first-order condition (2.12) is also the sufficient condition for the solution of the constrained maximization problem subject to $D(i,\bar{F})>0$, we have proved Lemma 2.1.

In what follows, we proof Lemma 2.2: The firm's optimal operational hedging policy i^* decreases in $\bar{F}$. Define $M(i^*(\bar{F}),\bar{F})\equiv E(i^*(\bar{F}),\bar{F})$ the value function under optimal hedging policy i^*.[35] By the first-order condition, $\frac{\partial M}{\partial i^*}=0$. Differentiating both sides with respect to $\bar{F}$:

$$\frac{\partial^2 M}{\partial i^{*2}}\frac{\partial i^*}{\partial \bar{F}}+\frac{\partial M}{\partial i\partial \bar{F}}=0 \tag{A.6}$$

From equation (A.6) we get $\frac{\partial i^*}{\partial \bar{F}}=-\frac{\partial^2 M}{\partial i^*\partial \bar{F}}/\frac{\partial^2 M}{\partial i^{*2}}$. Since $\frac{\partial^2 M}{\partial i^{*2}}<0$ by the second-order condition,

[33] The monotonicities of the left and right hand-side are due to the fact that $K(I+i)$ is convex in i.

[34] This is because u_F increases with i and $\delta(u)$ decreases with u. Consequently, $(1-\delta(u_F))$ increases with i. $K'(I+i)$ increases with i because the convexity of K in i.

[35] The optimal hedging policy i^* and the associated financial default boundary u_F are all functions of $\bar{F}$.

so the sign of $\frac{\partial i^*}{\partial \bar{F}}$ is the same as the sign of $\frac{\partial M}{\partial i^* \partial \bar{F}}$. Taking the partial derivative of the first-order condition (2.10) with respect to $\bar{F}$

$$\begin{aligned}\frac{\partial^2 M}{\partial i^* \partial \bar{F}} &= [1-G(u_F)]\left[pI\delta'(u_F)\frac{\partial u_F}{\partial \bar{F}}h(u_F)K'(I+i^*) - V(u_F,i^*)\frac{\partial h(u_F)}{\partial u_F}\frac{\partial u_F}{\partial \bar{F}}K'(I+i)\right]\\ &= [1-G(u_F)]\left[pI\delta'(u_F)h(u_F)K'(I+i^*) - V(u_F,i^*)\frac{\partial h(u_F)}{\partial u_F}K'(I+i)\right]\end{aligned} \tag{A.7}$$

Since u follows a exponential distribution, $\frac{\partial h(u_F)}{\partial u_F} = 0$. Thus, Equation (A.7) is smaller than zero. Therefore, $\frac{\partial i^*}{\partial \bar{F}} < 0$.

A.3 Optimal hedging policy when $u_F < u_O$

We begin this subsection by proving Lemma 2.3. First, we show that $\hat{i}^*$ that satisfies the first-order condition (2.14) is the unique optimal solution for the maximization problem. Define $\hat{S} = p - K'(I+i) - [V(u_F,i) - \lambda x_2]h(u_F)K'(I+i) - \frac{\lambda x_2 g(u_O)}{1-G(u_F)}\frac{\partial u_O}{\partial i}$.[36] Taking the derivative of $\hat{S}$ with respect to i:

$$\frac{\partial \hat{S}}{\partial i} = -\left[\begin{array}{c} K''(I+i) + \frac{\partial V(u_F,i)}{\partial i}h(u_F)K'(I+i) + [V(u_F,i)-\lambda x_2]\frac{\partial h(u_F)}{\partial u_F}\frac{\partial u_F}{\partial i}K'(I+i) \\ +[V(u_F,i)-\lambda x_2]h(u_F)\frac{\partial^2 u_F}{\partial i^2} + \lambda x_2 \frac{\partial}{\partial i}\left[\frac{g(u_O)}{[1-G(u_F)]I\delta'(u_O)}\right] \end{array}\right] \tag{A.8}$$

$$\frac{\partial}{\partial i}\left[\frac{g(u_O)}{[1-G(u_F)]I\delta'(u_O)}\right] = \left[\frac{g'(u_O)\delta'(u_O) - g(u_O)\delta''(u_O)}{[1-G(u_F)][\delta'(u_O)]^2 I} + \frac{g(u_F)K'(I+i)g(u_O)}{[1-G(u_F)]^2}\right]\frac{1}{I\delta'(u_O)} \tag{A.9}$$

The absolute value of (A.9) is small if the production commitment I is sufficiently high and $\frac{K'(I+\bar{i})}{I}$ is sufficiently low. In the numerical analysis, we assume that $K(I+i)$ is of quadratic form, $K(I+i) = \kappa(I+i)^2$, where $\kappa > 0$, which is standard in the investment literature. Then $\frac{K'(I+\bar{i})}{I}$ is sufficiently low if κ is sufficiently small. Using quantities (A.3), (A.4) and

[36] $\hat{S}$ the term inside the bracket after $[1-G(u_F)]$ of the left hand-side of the first-order condition (2.14).

(A.9), $\frac{\partial \hat{S}}{\partial i}$ is

$$\frac{\partial \hat{S}}{\partial i} = - \left[\begin{array}{c} K''(I+i) + p[1-\delta'(u_F)IK'(I+i)]h(u_F)K'(I+i) \\ +[V(u_F,i)-\lambda x_2]\frac{\partial h(u_F)}{\partial u_F}[K'(I+i)]^2 + [V(u_F,i)-\lambda x_2]h(u_F)K''(I+i) \\ +\lambda x_2 \left[\frac{g'(u_O)\delta'(u_O)-g(u_O)\delta''(u_O)}{[1-G(u_F)][\delta'(u_O)]^2 I} + \frac{g(u_F)K'(I+i)g(u_O)}{[1-G(u_F)]^2} \right] \frac{1}{I\delta'(u_O)} \end{array} \right] \tag{A.10}$$

$\frac{\partial S}{\partial i}$ is always smaller than zero, thus, the second-order condition for maximization $[1 - G(u_F)]\frac{\partial \hat{S}}{\partial i}$ at $i = \hat{i}^*$ is smaller than zero. By the first-order condition (2.14), $S = 0$ if $i = \hat{i}^*$. Since $\frac{\partial \hat{S}}{\partial i} < 0$, we have $\hat{S} > 0$ if $i < \hat{i}^*$ and $\hat{S} < 0$ if $i > \hat{i}^*$. Since $\frac{\partial}{\partial i}\hat{E} = [1 - G(u_F)]\hat{S}$, $\hat{E}$ increases in i for $i < \hat{i}^*$ and decreases in i for $i > \hat{i}^*$. Therefore $\hat{i}^*$ is the unique optimal solution to the maximization problem.

Now we prove Lemma 2.4: $\hat{i}^* > i^*$. i^* satisfies the first-order condition (2.11):

$$\begin{aligned} p - K'(I+i^*) &= V(u_F,i^*)h(u_F)K'(I+i^*) \\ &> V(u_F,i^*)h(u_F)K'(I+i^*) - \lambda x_2 h(u_F)K'(I+i^*) + \frac{\lambda x_2 g(u_O)}{[1-G(u_F)]I\delta'(u_O)} \end{aligned} \tag{A.11}$$

The inequality holds because $\lambda x_2 h(u_F)K'(I+i^*) > 0$ and $\frac{\lambda x_2 g(u_O)}{[1-G(u_F)]I\delta'(u_O)} < 0$. Now taking derivative of both sides of the first-order condition in $u_O > u_F$ case, (2.14), with respect to i. The derivative of the left-hand side is $-K''(I+i) < 0$. The derivative of the right-hand side is

$$\begin{aligned} & p[1-\delta'(u_F)IK'(I+i)]h(u_F)K'(I+i) + [V(u_F,i)-\lambda x_2]\frac{\partial h(u_F)}{\partial u_F}[K'(I+i)]^2 \\ & + [V(u_F,i)-\lambda x_2]h(u_F)K''(I+i) \\ & + \lambda x_2 \left[\frac{g'(u_O)\delta'(u_O)-g(u_O)\delta''(u_O)}{[1-G(u_F)][\delta'(u_O)]^2 I} + \frac{g(u_F)K'(I+i)g(u_O)}{[1-G(u_F)]^2} \right] \frac{1}{I\delta'(u_O)} \end{aligned} \tag{A.12}$$

The quantity (A.12) is always greater than zero if the production commitment I is sufficiently high and $\frac{K'(I+\bar{i})}{I}$ is sufficiently low. Thus the left-hand side of Equation (2.14) decreases in i and the right-hand side of Equation (2.14) increases in i. Since $\hat{i}^*$ satisfies the first-order condition in $u_O > u_F$ case, (2.14). We must have $\hat{i}^* > i^*$.

In what follows, we prove Lemma 2.5: the firm's optimal operational hedging policy $\hat{i}^*$ decreases in $\bar{F}$. Define $\hat{M}(\hat{i}^*(\bar{F}), \bar{F}) \equiv E(\hat{i}^*(\bar{F}), \bar{F})$ the value function under optimal hedging policy $\hat{i}^*$.[37] Similar to the $u_F > u_O$ case, $\frac{\partial \hat{i}^*}{\partial \bar{F}} = -\frac{\partial^2 \hat{M}}{\partial \hat{i}^* \partial \bar{F}} / \frac{\partial^2 \hat{M}}{\partial \hat{i}^{*2}}$. Since $\frac{\partial^2 \hat{M}}{\partial \hat{i}^{*2}} < 0$ by the second-order condition, so the sign of $\frac{\partial \hat{i}^*}{\partial \bar{F}}$ is the same as the sign of $\frac{\partial \hat{M}}{\partial \hat{i}^* \partial \bar{F}}$. Taking the partial derivative of the first-order condition (2.10) with respect to $\bar{F}$

$$\begin{aligned}
\frac{\partial^2 \hat{M}}{\partial \hat{i}^* \partial \bar{F}} &= [1 - G(u_F)] \left[\begin{array}{c} pI\delta'(u_F)\frac{\partial u_F}{\partial \bar{F}} h(u_F) K'(I + \hat{i}^*) - [V(u_F, \hat{i}^*) - \lambda x_2] \frac{\partial h(u_F)}{\partial u_F} \frac{\partial u_F}{\partial \bar{F}} K'(I + i) \\ -\frac{\lambda x_2}{I} \frac{g(u_O) g(u_F)}{[1 - G(u_F)]^2 \delta'(u_O)} \frac{\partial u_F}{\partial \bar{F}} \end{array} \right] \\
&= [1 - G(u_F)] \left[\begin{array}{c} pI\delta'(u_F) h(u_F) K'(I + i^*) - [V(u_F, i^*) - \lambda x_2] \frac{\partial h(u_F)}{\partial u_F} K'(I + i) \\ -\frac{\lambda x_2}{I} \frac{g(u_O) g(u_F)}{[1 - G(u_F)]^2 \delta'(u_O)} \end{array} \right]
\end{aligned} \tag{A.13}$$

Since u follows an exponential distribution, $\frac{\partial h(u_F)}{\partial u_F} = 0$. Thus, Equation (A.13) is always smaller than zero if the production commitment I is sufficiently high. Therefore, $\frac{\partial i^*}{\partial \bar{F}} < 0$ if the production commitment I is sufficiently high.

A.4 Optimal operational hedging policy and net debt $\bar{F}$

First of all, $\bar{i}$ in Appendix A.1 is the optimal equity-maximizing hedging policy given the inherited net short-term debt level $\bar{F}$ is sufficiently low, i.e., $\bar{F} \leq \bar{F}_{fb}$. $\bar{F}_{fb}$ is such that $\bar{F}_{fb} + K(I + \bar{i}) = 0$, i.e., $\bar{F}_{fb}$ is the maximal net debt level such that the firm is able to pay back the debt at date-1 it chooses the maximal optimal hedging policy $\bar{i}$ that maximizes the unlevered firm value. When $\bar{F} > \bar{F}_{fb}$, the firm has to choose the optimal hedging policy i that balances the concerns over financial and operational default, which we elaborate on below.

Notice that $D(i, \bar{F})$ is continuously differentiable in both i and $\bar{F}$ with partial derivatives:

[37]The optimal hedging policy $\hat{i}^*$ and the associated financial default boundary u_F are all functions of $\bar{F}$.

$$\frac{\partial D}{\partial i} = K'(I+i) - \frac{1}{I\delta'(u_O)} \ , \tag{A.14a}$$

$$\frac{\partial D}{\partial \bar{F}} = 1 \ . \tag{A.14b}$$

Notice that $\frac{\partial D}{\partial i} > 0$ because $K'(I+i) > 0$ and $\delta'(u) < 0$ by assumption. The following lemma is for technical purpose. It facilitates our proof that both $D^*(\bar{F}) = 0$ and $\hat{D}^*(\bar{F}) = 0$ has unique solutions, which we denote as $\bar{F}_0$ and $\bar{F}_1$, respectively.

Lemma A.1.

$$\frac{dD^*}{d\bar{F}} > 0 \ \textit{if} \ u_F(i^*) \geq u_O(i^*) \tag{A.15a}$$

$$\frac{d\hat{D}^*}{d\bar{F}} > 0 \ \textit{if} \ u_F(\hat{i}^*) \geq u_O(\hat{i}^*) \tag{A.15b}$$

Proof. First we prove the following inequality:

$$\frac{dD^*}{d\bar{F}} = \frac{\partial D^*}{\partial \bar{F}} + \frac{\partial D^*}{\partial i^*}\frac{\partial i^*}{\partial \bar{F}} > 0 \tag{A.16}$$

Using Equations (A.14a) and (A.14b) Inequality (A.16) is equivalent to

$$\left[K'(I+i^*) - \frac{1}{I\delta'(u_O)}\right]\left(-\frac{\partial i^*}{\partial \bar{F}}\right) < 1 \tag{A.17}$$

From Appendix A.2, $\frac{\partial i^*}{\partial \bar{F}} = -\frac{\partial^2 M}{\partial i^* \partial \bar{F}} / \frac{\partial^2 M}{\partial i^{*2}}$. $\frac{\partial^2 M}{\partial i^* \partial \bar{F}}$ is given by Equation (A.7). $\frac{\partial^2 M}{\partial i^{*2}}$ is given by $[1 - G(u_F)]\frac{\partial S}{\partial i^*}$ where $\frac{\partial S}{\partial i^*}$ is given by Equation (A.5) at $i = i^*$. Thus, Inequality (A.17) is equivalent to

$$\frac{V(u_F,i^*)\frac{\partial h(u_F)}{\partial u_F}K'(I+i^*)-pI\delta'(u_F)h(u_F)K'(I+i^*)}{\left[\begin{array}{c}K''(I+i^*)+p[1-\delta'(u_F)IK'(I+i^*)]h(u_F)K'(I+i^*)\\ +V(u_F,i^*)\frac{\partial h(u_F)}{\partial u_F}[K'(I+i^*)]^2+V(u_F,i^*)h(u_F)K''(I+i^*)\end{array}\right]}\frac{1-I\delta'(u_O)K'(I+i^*)}{-I\delta'(u_O)}<1 \tag{A.18}$$

Algebraic simplification shows that the above inequality is equivalent to

$$\begin{aligned}&V(u_F,i^*)\frac{\partial h(u_F)}{\partial u_F}K'(I+i^*)+pI\left[\delta'(u_O)-\delta'(u_F)\right]h(u_F)K'(I+i^*)\\&<\left[1+V(u_F,i^*)h(u_F)\right]K''(I+i^*)\left[-I\delta'(u_O)\right]\end{aligned} \tag{A.19}$$

Since u follows a exponential distribution, $\frac{\partial h(u)}{\partial u}=0$ and the first term of the left-hand side of Inequality (A.19) is equal to zero. the second term on the left-hand side is (weakly) smaller than zero if $u_F \geq u_O$ because $\delta(u)$ is convex in u. Therefore the left-hand side of Inequality (A.19) is (weakly) smaller than zero. The right-hand side of Inequality (A.19) is strictly greater than zero. Therefore, Inequality (A.19) holds and $\frac{dD^*}{d\bar{F}}>0$.

Now we prove the following inequality:

$$\frac{d\hat{D}^*}{d\bar{F}}=\frac{\partial\hat{D}^*}{\partial\bar{F}}+\frac{\partial\hat{D}^*}{\partial\hat{i}^*}\frac{\partial\hat{i}^*}{\partial\bar{F}}>0 \tag{A.20}$$

Inequality (A.16) is equivalent to

$$\left[K'(I+\hat{i}^*)-\frac{1}{I\delta'(u_O)}\right]\left(-\frac{\partial\hat{i}^*}{\partial\bar{F}}\right)<1 \tag{A.21}$$

From Appendix A.3, $\frac{\partial\hat{i}^*}{\partial\bar{F}}=-\frac{\partial^2\hat{M}}{\partial\hat{i}^*\partial\bar{F}}/\frac{\partial^2\hat{M}}{\partial\hat{i}^{*2}}$. $\frac{\partial^2\hat{M}}{\partial i^*\partial\bar{F}}$ is given by Equation (A.13). $\frac{\partial^2\hat{M}}{\partial\hat{i}^{*2}}$ is given by $[1-G(u_F)]\frac{\partial\hat{S}}{\partial\hat{i}^*}$ where $\frac{\partial\hat{S}}{\partial\hat{i}^*}$ is given by Equation (A.10) at $i=\hat{i}^*$. Thus, Inequality (A.21) is equivalent to

$$\frac{\begin{bmatrix} [V(u_F,\hat{i}^*)-\lambda x_2]\frac{\partial h(u_F)}{\partial u_F}K'(I+\hat{i}^*) \\ -pI\delta'(u_F)h(u_F)K'(I+\hat{i}^*) \\ +\frac{\lambda x_2}{I}\frac{g(u_O)g(u_F)}{[1-G(u_F)]^2\delta'(u_O)} \end{bmatrix}}{\begin{bmatrix} K''(I+\hat{i}^*)+p[1-\delta'(u_F)IK'(I+\hat{i}^*)]h(u_F)K'(I+\hat{i}^*) \\ +[V(u_F,\hat{i}^*)-\lambda x_2]\frac{\partial h(u_F)}{\partial u_F}[K'(I+\hat{i}^*)]^2 \\ +[V(u_F,\hat{i}^*)-\lambda x_2]h(u_F)K''(I+\hat{i}^*) \\ +\lambda x_2\left[\frac{g'(u_O)\delta'(u_O)-g(u_O)\delta''(u_O)}{[1-G(u_F)][\delta'(u_O)]^2I}+\frac{g(u_F)K'(I+\hat{i}^*)g(u_O)}{[1-G(u_F)]^2}\right]\frac{1}{I\delta'(u_O)} \end{bmatrix}}\frac{1-I\delta'(u_O)K'(I+\hat{i}^*)}{-I\delta'(u_O)}<1 \tag{A.22}$$

Algebraic simplification shows that the above inequality is equivalent to

$$\begin{aligned}&[V(u_F,\hat{i}^*)-\lambda x_2]\frac{\partial h(u_F)}{\partial u_F}K'(I+\hat{i}^*)+pI\left[\delta'(u_O)-\delta'(u_F)\right]h(u_F)K'(I+\hat{i}^*)+\frac{\lambda x_2}{I}\frac{g(u_O)g(u_F)}{[1-G(u_F)]^2\delta'(u_O)}\\ &<\Big[1+[V(u_F,\hat{i}^*)-\lambda x_2]h(u_F)\Big]K''(I+\hat{i}^*)\left[-I\delta'(u_O)\right]-\lambda x_2\frac{g'(u_O)\delta'(u_O)-g(u_O)\delta''(u_O)}{[1-G(u_F)][\delta'(u_O)]^2I}\end{aligned} \tag{A.23}$$

Since u follows a exponential distribution, $\frac{\partial h(u)}{\partial u}=0$ and the first term of the left-hand side of Inequality (A.23) is equal to zero. the second term on the left-hand side is (weakly) smaller than zero if $u_F \geq u_O$ because $\delta(u)$ is convex in u. The first term of the right-hand side of Inequality (A.23) is strictly greater than zero. Therefore, to show that Inequality (A.23) holds, we need to show that:

$$\frac{\lambda x_2}{I}\frac{g(u_O)g(u_F)}{[1-G(u_F)]^2\delta'(u_O)}<-\lambda x_2\frac{g'(u_O)\delta'(u_O)-g(u_O)\delta''(u_O)}{[1-G(u_F)][\delta'(u_O)]^2I} \tag{A.24}$$

Or, equivalently,

$$
\begin{aligned}
&\frac{\lambda x_2}{I}\frac{g(u_O)g(u_F)}{[1-G(u_F)]^2\delta'(u_O)}+\lambda x_2\frac{g'(u_O)\delta'(u_O)-g(u_O)\delta''(u_O)}{[1-G(u_F)][\delta'(u_O)]^2 I}<0\\
\Leftrightarrow\ &\frac{\lambda x_2}{I[1-G(u_F)]\delta'(u_O)}\left[\frac{g(u_O)g(u_F)}{[1-G(u_F)]}+\frac{g'(u_O)\delta'(u_O)-g(u_O)\delta''(u_O)}{\delta'(u_O)}\right]<0\\
\Leftrightarrow\ &\frac{g(u_O)g(u_F)}{[1-G(u_F)]}+\frac{g'(u_O)\delta'(u_O)-g(u_O)\delta''(u_O)}{\delta'(u_O)}>0
\end{aligned}
\tag{A.25}
$$

Since $g(u)=\alpha\exp(-\alpha u)$, $\alpha g(u)=-g'(u)$, and $\frac{g(u_F)}{[1-G(u_F)]}=\alpha$, the inequality (A.25) is equivalent to

$$\frac{\delta''(u_O)}{\delta'(u_O)}<0 \tag{A.26}$$

which always holds since $\delta(u)$ decreases and convex in u by assumption. Therefore, $\frac{d\hat{D}^*}{d\bar{F}}>0$. Q.E.D.

Now we prove Proposition 2.1. First, i^* and $\hat{i}^*$ are continuously differentiable in $\bar{F}$ and $D(i,\bar{F})$ is continuously differentiable in both i and f. It follows that $D^*(\bar{F})$ and $\hat{D}^*(\bar{F})$ are continuously differentiable, thus continuous in $\bar{F}$.

Secondly, from Section 2.4 and Section 2.5, we know that u_F is greater than u_O, i.e., $D^*,\hat{D}^*>0$ when $\bar{F}$ is sufficiently high, i.e., $\bar{F}\geq\bar{F}_M$.[38] On the other hand, if $F=0$, $u_F=0$, which is always lower than u_O. Since $D^*(\bar{F})$ and $\hat{D}^*(\bar{F})$ are continuous in $\bar{F}$, $D^*,\hat{D}^*<0$ for all $\bar{F}$ that is sufficiently low. Again by the continuity of $D^*(\bar{F})$ and $\hat{D}^*(\bar{F})$ in $\bar{F}$, there must exist $\bar{F}_0$ and $\bar{F}_1$ such that $\hat{D}^*(\bar{F}_0)=0$ and $D^*(\bar{F}_1)=0$. By Lemma A.1, $\frac{d\hat{D}^*}{d\bar{F}}>0$ whenever $\hat{D}^*\geq 0$ and $\frac{dD^*}{d\bar{F}}>0$ whenever $D^*\geq 0$. It follows that $\bar{F}_0$ and $\bar{F}_1$ are unique. Moreover, $\hat{D}^*<0$ for all $\bar{F}<\bar{F}_0$ and $\hat{D}^*>0$ for all $\bar{F}>\bar{F}_0$. Similarly, $D^*<0$ for all $\bar{F}<\bar{F}_1$ and $D^*>0$ for all $\bar{F}>\bar{F}_1$.

From Lemma 2.4, $\hat{i}^*>i^*$ for any given $\bar{F}$. At $\bar{F}=\bar{F}_1$, $D^*(\bar{F}_1)=0$. Since $\frac{\partial D}{\partial i}>0$, we must have $\hat{D}^*(\bar{F}_1)=D(\hat{i}^*(\bar{F}_1),\bar{F}_1)>0$. Thus, $\bar{F}_1>\bar{F}_0$.

If $\bar{F}\leq\bar{F}_0$, then $D^*<0$ and $\hat{D}^*\leq 0$. Thus, maximizing the firm's equity value minus the manager's aversion to financial default subject to $u_F\leq u_O$ will yield the optimal operational

[38] From Lemma 2.1, $D^*>0$ if $\bar{F}\geq\bar{F}_M$. From Lemma 2.4, for a given $\bar{F}$, $\hat{i}^*>i^*$. Since $D(i,\bar{F})$ increases in i, $\hat{D}^*>0$ when $\bar{F}\geq\bar{F}_M$.

hedging policy $\hat{i}^*$. Meanwhile, maximizing the firm's equity value minus the manager's aversion to financial default subject to $u_F \geq u_O$ will yield a corner solution $\tilde{i} > i^*$ otherwise, in which $\tilde{i}$ is such that $D(\tilde{i}, \bar{F}) = 0$.[39] Since $\tilde{i}$ is also feasible for the maximization problem of the firm's equity value minus the manager's aversion to financial default subject to $u_F \leq u_O$ and $\hat{E} = E$ when $i = \tilde{i}$, $\tilde{i}$ must yield a lower expected payoff for the shareholders and the manager combined compared with $\hat{i}^*$. Thus, the firm's optimal operational hedging policy is $\hat{i}^*$.

If $\bar{F}_0 < \bar{F} < \bar{F}_1$, then $D^* < 0$ and $\hat{D}^* > 0$. Thus, maximizing the firm's equity value minus the manager's aversion to financial default subject to $u_F \leq u_O$ or subject to $u_F \geq u_O$ will yield the same corner solution $\tilde{i}$, in which $\tilde{i}$ is such that $D(\tilde{i}, \bar{F}) = 0$.[40] Thus, the firm's optimal operational hedging policy is $\tilde{i}$.

If $\bar{F} \geq \bar{F}_1$, then $D^* \geq 0$ and $\hat{D}^* > 0$. Thus, maximizing the firm's equity value minus the manager's aversion to financial default subject to $u_F \geq u_O$ will yield the optimal operational hedging policy i^*. Meanwhile, maximizing the firm's equity value minus the manager's aversion to financial default subject to $u_F < u_O$ will yield a corner solution $\tilde{i} < \hat{i}^*$.[41] Since $\tilde{i}$ is also feasible for the maximization problem of the firm's equity value minus the manager's aversion to financial default subject to $u_F \geq u_O$ and $\hat{E} = E$ when $i = \tilde{i}$, $\tilde{i}$ must yield a lower expected payoff for the shareholders and the manager combined compared with i^*. Thus, the firm's optimal operational hedging policy is i^*.

Now we prove Proposition 2.2. From Proposition 2.1 and Lemma 2.2, when $\bar{F} > \bar{F}_1$, $i^{**} = i^*$ and thus decreases in $\bar{F}$. Similarly, from Proposition 2.1 and Lemma 2.5, when $\bar{F} < \bar{F}_0$, $i^{**} = \hat{i}^*$ and thus decreases in $\bar{F}$. Moreover, $\frac{\partial \tilde{i}}{\partial \bar{F}} = -\frac{\partial D}{\partial \bar{F}} / \frac{\partial D}{\partial \tilde{i}}$. Since both partial derivatives on the right-hand side are positive from Inequalities (A.14a) and (A.14b), $\frac{\partial \tilde{i}}{\partial \bar{F}} < 0$. When $\bar{F}_0 < \bar{F} < \bar{F}_1$, $i^{**} = \tilde{i}$ and thus decreases in $\bar{F}$. Lastly, at $\bar{F} = \bar{F}_1$, since $D^* = 0$, $i^* = \tilde{i}$,

[39] Since $\frac{\partial D}{\partial i} > 0$, the feasible set of i for the maximization problem of the firm's equity value minus the manager's aversion to financial default subject to $u_F \geq u_O$, if not empty, contains i values all higher than i^*. From Appendix A.2, E decreases in i for $i > i^*$.

[40] This is because, the feasible set i for the maximization problem of the firm's equity value minus the manager's aversion to financial default subject to $u_F \geq u_O$ contains i values higher than i^* and from Appendix A.2, E decreases in i for $i > i^*$. Meanwhile, the feasible set i for the maximization problem of the firm's equity value minus the manager's aversion to financial default subject to $u_F \leq u_O$ contains i values lower than $\hat{i}^*$ and from Appendix A.3, $\hat{E}$ increases in i for $i < i^*$.

[41] Since $\frac{\partial D}{\partial i} > 0$, the feasible set of i for the maximization problem of the firm's equity value minus the manager's aversion to financial default subject to $u_F \leq u_O$, if not empty, contains i values lower than $\hat{i}^*$ and from Appendix A.3, $\hat{E}$ increases in i for $i < \hat{i}^*$.

so $i^{**} = i^* = \tilde{i}$ at $\bar{F} = \bar{F}_1$ and thus is continuous in $\bar{F}$ at $\bar{F} = \bar{F}_1$. Similarly, at $\bar{F} = \bar{F}_0$, since $\hat{D}^* = 0$, $\hat{i}^* = \tilde{i}$, so $i^{**} = \hat{i}^* = \tilde{i}$ at $\bar{F} = \bar{F}_0$ and thus is continuous in $\bar{F}$ at $\bar{F} = \bar{F}_0$. Therefore, i^{**} decreases in $\bar{F}$.