Corporate resiliency and the choice between financial and operational hedging*

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Abstract

We study how firms manage two potential defaults: Financial default on their debt obligations, and operational default, i.e., failing to deliver on obligations to customers. Since operational hedging requires upfront costs, firms with limited ability to raise capital substitute between hoarding cash (financial hedging) to mitigate financial default risk and spending on inventories and supply-chain diversification (operational hedging) to mitigate operational default risk. Thus higher credit risk lowers marginal production costs and all else being equal, raises markup, a relationship that is stronger for financially constrained firms. Empirically, operational hedging measured by inventory and supply-chain diversification lowers markup and raises cost of goods sold. As predicted, markup increases and cost of goods sold decreases with the firm's credit risk, especially in episodes where capital markets impose financial constraints.

Keywords: financial default, operational default, resilience, liquidity, risk management, inventory, supply chains

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1. Introduction

We analyze how firms manage two types of obligations. Firms have financial debt contracts and operational contracts to deliver goods and services to customers. Economic shocks can make firms face financial default on their debt obligations, as well as operational default where they fail to deliver on their obligations to customers. Given limited cash flows and constraints on accessing the capital market, firms need to decide how to allocate their resources to mitigate the risk of these two types of default. We study a model of how firms substitute between these two default risks and present empirical evidence that supports the predictions of our model.

While financial default is a well-studied area in Financial Economics, there is significantly less work on operational default. The Covid-19 pandemic and its aftermath have raised the issue of corporate operational resilience to shocks that disrupt supply chains, lead to depletion of inventory and adversely affect firms' ability to deliver their products and services. To tackle such negative shocks, firms employ operational hedging methods that include holding excess inventory, increasing the pool of suppliers and shifting some of them to more secure locations, and maintaining backup capacity. These operational hedging methods are, however, financially costly. Firms are nevertheless willing to endure some higher costs of production in order to mitigate the risk of operational disruption and default on their ability to deliver on their obligations to customers. Such a failure not only impairs the firms' cash flow but they also impose a penalty on their reputation and franchise value.

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 they are likely to have inventory to support current

[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 16$^{\text{th}}$ 2020, and "From 'just in time' to 'just in case'", Financial Times, May 4, 2020.

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 would 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. Several corporate chief executive officers (CEOs) and investors contend that operational hedging is costly and occurs at the cost of financial efficiency.[3]

Our paper studies this tension between operational resiliency and financial efficiency, viz., the tradeoff that the firm faces between allocating cash to operational hedging or to the prevention of financial distress. The firm's need to optimally balance these two hedging demands —financial hedging and operational hedging — can help explain the lack of operational resilience in some firms, in particular, highly-leveraged, financially-constrained firms.

In our theoretical setting, a competitive (price-taking) levered firm faces two risks. First, a shock to cash flows from assets in place, which results in cash shortfall, may also result in financial default which wipes out the equity holders' value. Second, a shock that disrupts the firm's operation also reduces its output and its income. The shocks are potentially correlated, driven (say) by a common underlying macroeconomic driver. Both financial and operational defaults impose a loss on the value of the firm. The firm allocates its cash inflow to build up a buffer to mitigate the financial default risk, and to build up operational resiliency that helps delivering on its customers' contracts.

To put another way, our model captures a situation in which operational hedging increases future cash flows by minimizing the risk of operational disruption, but financial default can cause the firm to cease operations *before* the benefits of operational default materialize. That is, there is a potential maturity mismatch between operational and financial risk. Firms can mitigate this maturity mismatch by borrowing against long-term cash flows which are en-

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

[3] "Will coronavirus pandemic finally kill off global supply chains?" Financial Times, May 27, 2020. https://www.ft.com/content/4ee0817a-809f-11ea-b0fb-13524ae1056b

hanced by operational hedging. Doing that can potentially alleviate the need of substituting between financial hedging and operational hedging. However, this is feasible only if the firm can pledge future cash flow to outside investors. This intuition gives rise to our key prediction: if pledgeability is limited, financial and operating hedging become substitutes. In other words, a financially constrained and leveraged firm must decide between using cash to mitigate the risk of financial default or to mitigate the risk of operational default.

Our main prediction is thus that for a firm with significant credit risk and difficulty in raising capital, operational hedging decreases with the firm's credit spread which increases in financial default risk. Since operational hedging raises the firm's cost of production and lowers the profit margin, higher credit risk, which lowers operational hedging, raises the profit margin or the "operational spread". This results in a positive relationship between credit spread and operational spread.[4]

We empirically test our model's main prediction that the operational spread, measured by markup, or (Sales − cost of goods sold)/sales, widens in the firm's credit risk, the latter being measured by Altman's Z-score (Altman, 1968, 2013). The higher is the negative Z-score, the greater the credit risk. Z-score is a proxy for the risk of default in the near term, and thus captures the notion of credit risk in our model. We test the hypothesis controlling for firm characteristics including its market power, measured as an indicator of top-4 sellers in a firm's Fama-French 48 industry, and a firm's sales divided by the total sales of the Fama-French 48 industry that the firm belongs to. The results support our hypothesis. The estimated effect is statistically and economically significant: an increase of one standard deviation in the firm's negative Z-score raises the firm's markup by 5.0% relative to the sample median markup. We also find that higher credit risk strongly lowers the cost of goods sold after controlling for the firm's sales and characteristics, confirming the operational hedging mechanism via which credit risk affects the markup.

An important prediction of our model is that financial constraints increase the positive

[4]In our model, the effect of credit risk on operational hedging is due mostly to lack of funds to spend on operational hedging, which is an investment in operational resiliency, and not per se due to debt overhang, which reduces the incentives to invest due to leverage, as in Myers (1977).

relationship between the firm's markup and its credit risk. We thus test whether the positive markup-credit risk relationship becomes stronger during financing shocks. First, using the NBER-designated recessions, during which financing becomes generally constrained, we find a significantly more positive relationship between markup and credit risk during recessions. This relationship is not entirely driven by movement in product prices: there is a similarly significant negative relationship between the cost of goods sold and credit risk during recessions. Second, we employ shocks to firms' credit supply during the subprime crisis following Chodorow-Reich (2014)'s study of the negative impact on firms of the exogenous shocks to their relationship banks, following the collapse of Lehman Brothers in September 2008, which increased financial constraints on firms. We find that for firms that were exposed to the exogenous credit-supply shocks, credit risk had a significantly more positive effect on markup and a significantly more negative effect on cost of goods sold. This test helps alleviate concerns about the endogeneity of credit risk as we study the effect of the pre-crisis credit risk on the post-crisis markup and cost of goods sold for financially-constrained firms.[5]

We attend to an alternative explanation that ties the link between a firm's credit risk and its markup to market power. Chevalier and Scharfstein (1994) and (Gilchrist et al., 2017) suggest that liquidity-constrained firms with market power can raise prices (or keep prices higher in downturns) in order to boost their short-run profitability to support their immediate liquidity needs, even if it hurts their market share and long-term profitability. Notably, all our regressions include control variables that proxy for the firm's market power as well industry-year-quarter fixed effects which capture industry-wide changes in product prices and in concentration ratios.

We further test explicitly the market power explanation by adding to our main test of the markup-credit risk relationship an interaction term between the firm's credit risk and two measures of its market power, an indicator for top-4 sellers in the firm's industry or the firm's sales divided by its industry's total sales. By the market power hypothesis, the markup-credit risk relationship should be positive only for firms with higher market power

[5]Some other studies also examine the impact of the subprime mortgage crisis on firms' other real decisions (Giroud and Mueller, 2016).

who set their own prices. However, we find that market power has no significant effect on the markup-credit risk relationship, which should be positive by our model's prediction. This applies for the entire sample, for the recessions and for the 2008 shocks to lending banks. Even in recessions, the positive markup-credit risk relationship does not rise with market power.

Finally, we test an *ex-post* prediction of our model. If credit risk is high enough, then avoiding financial default becomes the dominant consideration affecting firm value, and variation in our empirical operational hedging measure does not protect the firm's value against shocks that can trigger operational default. We test this prediction using stock returns during the Covid era (2020 – 2021). Our model suggests that pre-Covid operational hedging choices should matter less for firms that enter Covid with high credit risk already. We find results that are consistent with the predictions of our theory. Operational hedging does help firms preserve their franchise values after a bad operational shock occurs, but only if their credit risk is relatively low.

In summary, our novelty is in proposing that firms need to hedge not only against a default on their financial contracts — their debt obligations —but also against a default on their operational contracts, their obligations to deliver products to their customers. Both hedging needs impose demands on their limited resources and induce a tradeoff between them for firms facing financial constraints.

1.1 Related literature

Our paper is related to studies of the real effects of financing frictions (see Stein (2003) for a review) which show that financing frictions can affect investment decisions and employment (Lemmon and Roberts, 2010; Duchin, Ozbas, and Sensoy, 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, Campello, and Weisbach, 2004; Sufi, 2009; Bolton, Chen, and Wang, 2011; Acharya, Davydenko, and Strebulaev, 2012).

In particular, our paper relates closely to Rampini and Viswanathan (2010). They show that more financially distressed firms may reduce risk management to save liquidity for current investment. However, our paper differs from Rampini and Viswanathan (2010) in three important ways. First, in Rampini and Viswanathan (2010), debt is fully collateralized in all states, which makes debt riskless. Thus, their model is silent regarding the relationship between a firm's credit risk and risk management. In contrast, in our model debt is risky because of uncertainty in cash flow and maturity mismatches between the firm's cash flow and debt obligations. Second, we introduce the notion of operational risk — default risk on supplier contract — that rationalizes a firm's incentive to engage in operational hedging. This notion allows us to study the relationship between credit risk and a firm's operational hedging policy. Third, one key model implication in Rampini and Viswanathan (2010) is that a firm with lower net worth does not conserve any liquidity, because its return on investment is so high that it exceeds the return on liquidity hoarding. In our paper, an incentive to conserve liquidity arises for firms with lower net worth due to the presence of risky debt. This latter pattern is documented in Acharya, Davydenko, and Strebulaev (2012); however, they do not analyze the interaction of credit and operational risk, which we study both theoretically and empirically.

Our paper also relates to Froot, Scharfstein, and Stein (1993), who propose a theory for the rationale for corporate hedging. In Froot, Scharfstein, and Stein (1993), hedging against cash shortfalls helps the firm mitigate the risk of not being able to finance valuable investment opportunities. In a more recent paper, Gamba and Triantis (2014) study firms' risk management policies through holding liquid assets (cash equivalent), purchasing financial derivatives, and maintaining operational flexibility. They demonstrate that the strongest motivation for hedging is to avoid financial distress. They show in the model that the three risk management tools are more of complements than substitutes, and cash holding is the most effective out of these three risk management mechanisms. We highlight instead that avoidance of financial default can make financial hedging and operational hedging substitutes. In our model, 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 for firms facing financial constraints or having low pledgeability of cash flows.[6] Recently, Hu, Varas, and Ying (2021) theoretically show that long-term debt has the benefit of risk management — long-term creditors share the loss of the firm value during the economic downturn. Consistently, we show that a firm's overall credit risk imposes a higher pressure for the firm to give up more operational hedging, in order to conserve more cash to withstand the imminent financial default risk.

Finally, our paper adds to the emerging literature of risk management in production networks. Kulchania and Thomas (2017) find that firms hold more cash to mitigate the consequences of supply chain disruption led by deregulation of trucking industry. Recently, Grigoris, Hu, and Segal (2022) empirically and theoretically study the relationship between trade credit extension to customers and risk premia. Specifically, firms that offer more trade credit earn lower risk premia. Finally, Ersahin, Giannetti, and Huang (2024) exploit the incidence of natural disasters to study how production networks adapt to idiosyncratic shocks, finding that trade credit extension keeps supply chains stable except when suppliers are financially constrained. By offering more trade credit to customer firms, a supplier firm hedges against its customer firms' default risk, and therefore lowers the cost of searching for new customers. Our novelty lies with the fact that we allow firms to default on *both* debt contracts and contracts with their customers. This extension gives rise to the competition between financial and operational hedging for the limited liquidity resources of the firm.

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

[6] 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.

costly operational default (default on the supplier contract). Our model introduces operational hedging in the setting of financial hedging of Acharya, Davydenko, and Strebulaev (2012), where we model financial hedging as saving cash in order to avoid default on its debt maturing before the settlement date of supplier contract.

The model features a single-levered firm with existing debt F in a three-period economy: $t = 0,\ 1,\ 2$. The debt is payable at $t = 1$. The firm has assets in place that generate a cash flow x_t at each period $t = 0,\ 1$. x_2 represents the "franchise value". Additionally, the firm has an outstanding supplier contract that stipulates a delivery of I units of goods at unit price p at $t = 2$. We assume that the firm is a price-taker in its supplier contracts.

There is a random shock u that affects both the firm's cash flow at $t = 1$ and its capacity to fulfill the supplier contract. The latter impact can be due to supply chain disruptions. In this sense, u is a systematic shock. The value of u is realized at $t = 1$. Specifically, the firm's cash flow 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 $h(u) = \frac{g(u)}{1-G(u)}$. To derive analytical solutions, 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.[7] Figure 1 illustrates the timeline of the model, which we further elaborate upon next.

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

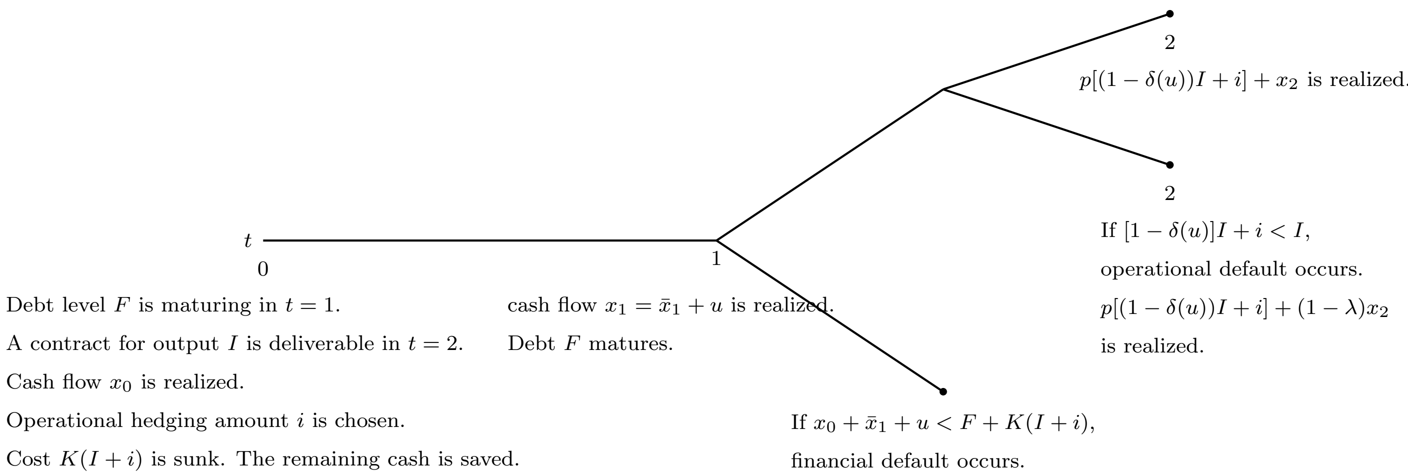

Figure 1: The timeline of the model

At date $t = 0$, the assets in place generate a positive cash flow $x_0 > 0$. In the meantime, 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 making a marginal investment i, resulting in the total units of delivered goods being $(1 - \delta(u))I + i$. i can also be interpreted as inventory, and/or spare production capacity.[8] 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.

To start with, we assume that market frictions preclude the firm from accessing outside financing at $t = 0, 1$. Thus, the firm's disposable cash at date-0 comes entirely from its internal cash flow. Thus, the cash reserve is $c = x_0 - K(I + i)$. We assume that legacy debt F payable at $t = 1$ cannot be renegotiated due to high bargaining costs; for example, it might be held by dispersed bondholders prone to coordination problems. Notice that the debt payment must be made out of the firm's internal funds, $c + x_1$. 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, $p[(1-\delta(u))I + i]$, and the franchise value, x_2, are lost. Since the period-1 cash flow, x_1, is random, there is no assurance that the firm has

[8]In our model the firm is operationally inflexible in the sense that its production amount is confined by the size of the customer contract. We do so to focus on the firm's operational hedging decisions, rather than its investment/disinvestment decisions.

enough liquidity to repay the debt in full. Even if there is no financial default, failure to deliver I units of goods can result in operational default, 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 reputation loss with its customers who can switch to alternate suppliers.

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 four assumptions are satisfied. First, default involves deadweight costs to shareholders. Although we assume that all future cash flows are lost in default, an extension to a partial loss is straightforward. Second, the outstanding debt matures before the supplier contract settlement date, giving rise to a maturity mismatch between the debt contract and the supplier contract. Third, external financing cannot be raised against the income from the supplier contract settlement at date-2. If the firm can pledge a large enough fraction of the income from the supplier contract settlement as collateral, then current and future cash holdings can be viewed as 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 τ is sufficiently small, i.e., the pledgeability level is sufficiently low. Fourth, the shock at $t = 1$ must affect both the date-1 cash flow and the firm's ability to honor the supplier contract. Although we assume a single random shock that affects both the cash flows from assets in place and its production capacity, extending our model to multiple shocks is possible.

2.3 Optimal hedging policies

The firm's optimal hedging policy depends on the relative likelihood of financial default to operational default, which, in turn, depends on the relative magnitudes of shock thresholds that triggers financial and operational defaults. We determine these thresholds next.

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 shock level that allows the firm to repay F in full and avoid default: $u_F = F + K(I+i) - x_0 - \bar{x}_1 = \bar{F} + K(I+i)$, 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 level (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 commitment I, the firm defaults on the supplier contract. Correspondingly, the "operational default boundary", u_O, is the minimum shock level that allows the firm to deliver its contractual amount of goods in full and avoid operational default: $(1-\delta(u_O))I+i = I$, or $u_O = \delta^{-1}\left(\frac{i}{I}\right)$. 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 level 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:

$$D(i, \bar{F}) \equiv u_F - u_O = \bar{F} + K(I+i) - \delta^{-1}\left(\frac{i}{I}\right) \quad . \tag{2.1}$$

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 the remaining of this subsection, we solve for the firm's optimal operational hedging policy. The detailed proofs are in Appendix I.B.[9]

2.4 Benchmark: Optimal hedging policy $\bar{i}$ when $F = 0$

When $\bar{F}$ is close to zero, the financial default boundary is always smaller than the operational default boundary given the first-best hedging choice $\bar{i}$ that ignores credit risk.[10]

2.5 Optimal hedging policy i^* 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 for $i \in [0, \bar{i}]$, 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. In Appendix IB.2, we show that in this case, a unique optimal operational hedging policy exists and the optimal hedging policy decreases with the firm's inherited debt level.

2.6 Optimal hedging policy $\hat{i}^*$ when $u_F < u_O$

We now turn to the more interesting 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 for $i \in [0, \bar{i}]$. In this case, the operational default boundary enters the equity value function. The equity value is E given in (IB.5), minus the expected cost proportional to the date-2 franchise value, λx_2. Therefore, the equity value is:

$$\hat{E} = E - \int_{u_F}^{u_O} \lambda x_2 g(u) du \ , \tag{2.2}$$

[9]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)).

[10]We formally show this in Appendix IB.1.

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

$$p - K'(I+i) = [V(u_F, i) - \lambda x_2] h(u_F) K'(I+i) + \frac{\lambda x_2 g(u_O)}{[1 - G(u_F)] I \delta'(u_O)} \,. \tag{2.3}$$

Define $\hat{i}^*$ as the firm's hedging policy that satisfies (2.3). A marginal increase in operational hedging will yield a marginal profit equal to its markup $p - K'(I+i)$. 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 increases the expected cost of financial default by increasing the financial default boundary u_F.[11] 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 (2.3). Therefore, the first-order condition (2.3) says that the firm chooses the 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 IB.3 that the first-order condition (2.3) admits a unique and positive interior solution $\hat{i}^*$ that maximizes E subject to $D(i, \bar{F}) > 0$ for $i \in [0, \bar{i}]$, under some mild technical conditions. Comparing the first-order conditions (IB.2), (IB.6) and (2.3), it is straightforward that $\bar{i} > \hat{i}^* > i^*$. Intuitively, when the firm's inherited net debt $\bar{F}$ is sufficiently low such that the operational default boundary u_O dominates the financial default boundary u_F, and in turn, operational default risk is the main concern of equity holders, the firm will invest more on operational hedging. The following lemma, proved in Appendix IB.3, formalizes the above statement.

Lemma 2.1. *If the production commitment I is sufficiently high and $\frac{K'(I+\bar{i})}{I}$ is sufficiently low, then $\bar{i} > \hat{i}^* > i^*$.*

We also prove in Appendix IB.3 that when $u_F < u_O$ for $i \in [0, \bar{i}]$, the firm's optimal

[11]Notice that the loss conditional on a financial default is reduced by λx_2. This is because the firm has already lost λx_2 due to operational default when it declares financial default.

operational hedging policy $\hat{i}^*$ decreases in its inherited net debt level:

Lemma 2.2. *When $\bar{F}$ is such that $0 < u_F < u_O$ for $i \in [0, \bar{i}]$, the optimal operational hedging policy $\hat{i}^*$, if exists, decreases in the firm's net debt level $\bar{F}$.*

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

The next proposition states the main results of our paper: The firm faces a tradeoff between saving cash (financial hedging) and investing in operational hedging. 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 and the firm cuts investment in operational hedging to conserve more cash in order to better hedge against the financial default risk. As a result, the optimal operational hedging, denoted generically by i^{**} to span various cases, is (weakly) lower.

Proposition 2.1. *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. The model can be extended to consider the effect of partial pledgeability ("PP") of cash flows from supplier contract settlement. We use subscript PP to denote respective quantities for this extension. The results from such extension are qualitatively identical to the base case in which the firm cannot pledge any date-2 cash flow to the creditors.

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 $0 \leq \tau \leq 1$. 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, given by $\tau p[(1 - \delta(u_{F,PP}))I + i$.[12] Thus, cash available for debt service at date 1 is $x_0 - K(I + i) + x_1 + \tau p[(1 - \delta(u_{F,PP}))I + i]$, 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 $\tau p[(1 - \delta(u_{F,PP}))I + i]$. While the operational default boundary u_O is the same as the base case, the financial default boundary is now given as:

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

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

Proposition 3.1. *If $\tau < \bar{\tau}$, 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 in Section 2. Since all the quantities are continuous in τ, Proposition IB.2 and Proposition 3.1 hold for small enough τ, i.e., $\tau \in [0, \bar{\tau}]$. Furthermore, the F-region in which debt level does not affect the optimal hedging policy increases with τ.

[12] Raising this amount is always feasible for $u \in [u_{F,PP}, \infty]$. Recall that δu decreases in u by assumption, thus the pledgeable income $\tau p[(1 - \delta(u))I + i]$ increases in u.

3.2 Operational spread and credit spread

The credit spread is defined by the ratio between the face value of debt F and the market value of debt L minus 1, where the market value of debt is given as:

$$L = F - \int_0^{u_F} \left[u_F - u - \tau p \left(\delta(u_F) - \delta(u)\right) I\right] g(u) du \ . \tag{3.2}$$

The second term on right-hand side is the expected bankruptcy cost. The operational spread is the markup, $p - K'(I + i)$. Intuitively, holding x_0 and $\bar{x}_1$ constant, the optimal operational hedging policy i^{**} decreases in debt level F by Proposition 2.1. Thus, credit spread and operational spread are positively correlated, as long as the market price of debt, $\frac{L}{F}$, decreases in F. In the next section, we numerically show that the operational spread and credit spread are positively correlated.

3.3 Debt maturity

So far, we assume that the firm's existing debt matures at date-1, before the supplier 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 its supplier contract settlement 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 degree of maturity mismatch between the firm's debt and the duration of its operational cash flows.

3.4 Hedging along the supply chain

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.[13] We assume that it is more costly if the firm chooses 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 arguments still go through. In particular, operational hedging measured as supply chain hedging (n) is decreasing in the firm's financial leverage and credit risk.

4. Numerical analysis

This section presents comparative statics from the model above. We illustrate the correlations between the optimal hedging policy i^{**} and debt F maturing at date-1, as well as between the credit spread and operational spread, as implied by the model solutions in Section 2.[14]

Throughout this section, we focus on the generalized version of the model in Section 3.1 with pledgeability level $\tau \in [0, 1]$. For numerical illustration, the cash flow shock u follows an exponential distribution with rate parameter $\alpha = 0.05$, i.e., the probability density function

[13] 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.

[14] Our model treats the debt level (F) as a model primitive. We can introduce the tax benefit of debt and solve for the optimal capital structure, but this is not the focus of our paper.

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, Chen, and Wang, 2011), we assume that a quadratic production cost function $K(I+i) = \kappa(I+i)^2$, in which $\kappa = 0.1$.[15]

Figure 1 presents the firm's optimal operational hedging policies i^{**} given different 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: 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 regardless of the date-1 production shock levels. As F increases, 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 decreases in the amount of debt maturing in the interim, especially if the firm faces difficulty in raising external funds, i.e., has a low pledgeability τ.

[INSERT Figure 1.]

Next, we plot the firm's credit spread against its operational spread, i.e., the markup $p - K'(I+i)$. Along the equilibrium path of the optimal hedging policies given different debt levels F, the credit spread and operational spread are positively correlated. This positive relationship is stronger when the firm's pledgeability τ is lower. This is consistent with the novel implication of our model: when the firm's credit risk is higher, the firm cuts the operational hedging activity by a larger extent to save more cash at date-0 and better hedge against the financial default risk, leading to a higher markup.

[INSERT Figure 2.]

[15] The other parameter values for numerical analysis are as follows: I (Contractual delivery amount) = 3, 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, and x_2 (Franchise value at date-2) = 10.

5. Empirical analysis

Our model produces two hypotheses on the link between operational hedging and credit risk. First, greater credit risk or probability of default lowers operational hedging, indicated by an increase in the price-to-unit cost difference, or the firm's markup. Second, the positive relationship between markup and credit risk is stronger for firms that are financially constrained, as indicated in our model by a lower pledgeability of future cash flows.

In our empirical analysis, we measure operational hedging by $Markup = (Sales - CGS)/Sales$, where CGS is the cost of goods sold. Increased spending on operational hedging lowers Markup. Operational hedging is measured by a higher level of inventory, whose hoarding indicates the propensity of the firm to engage in operational hedging, and by greater breadth of supply chains, which includes expanding and diversifying the number of suppliers that the firm works with.[16]

We begin our empirical analysis by presenting an example that illustrates the interaction between the firm's credit risk and its operational hedging policies. Vail Resorts, Inc., a mountain resort company that is included in our sample, was heavily indebted before the subprime mortgage crisis and the Great Recession. In its 2008 and 2009 annual reports, management expressed concerns regarding the company's highly levered capital structure. Item 1A, Risk Factors, says: "*Our indebtedness could adversely affect our financial health and prevent us from fulfilling our obligations.*"To make things worse, its lenders (e.g., U.S. Bank and Wells Fargo) experienced a 2.7% drop in loan provision during the financial crisis. Correspondingly, Vail held 5.6% less inventory (on average, scaled by its sales) during the recession period compared to the periods before that, and it also terminated the strategic alliance program with Ricoh Co., Ltd. a Japanese company that was Vail's office equipment supplier and stopped being a significant customer with General Mills, a consumer food company (Source: FactSet Revere database). In the meantime, its markup increased by 10.7%. Thus, a high credit risk in a period of tight financing appears to have lowered Vale's

[16]Operational hedging may encompass other measures; inventory and supply chain diversification may be the most salient and easy to measure.

inventory and forced the company to reduce its contracting with its suppliers, which lowered its per-unit costs.

Our formal empirical analysis is structured as follows. First, we validate that our proposed measures of operational hedging are consistent with our model mechanics. In the model, operational hedging mitigates the effects of shocks to firms' output, which is equivalent to its sales if a firm is a price-taker. We start by testing whether higher levels of inventory and supply chain breadth mitigate the negative effect on sales of economic shocks measured by the NBER-designated recessions. We then test whether Markup, our measure of the operational spread, declines with inventory and supply chain breadth.

We then test the two central predictions of the model. First, we estimate the effect on Markup and on CGS of the firm's credit risk, measured by the negative value of Altman's (1968) Z-score, which indicates the likelihood of default and positively affects the credit spread. We control for firm characteristics and fixed effects as well as for market power in these tests.

Second, and most importantly, we use financing shocks to test whether lower pledgeability or tighter financial constraints strengthen the positive relationship between Markup and credit risk. In the first test, we examine the relationship between $Markup$ and $-(Z-score)$ during NBER-designated recession periods, when capital markets are depressed and financing is scarce. In the second test, we employ the impact of the subprime mortgage crisis of 2008 on lenders' ability to provide credit to borrowers, following Chodorow-Reich (2014). We test whether exposed firms — those whose lenders were more strongly hit by the crises — exhibited after the crisis a stronger relationship between their Markup (and CGS) and their $-(Z-score)$ measured before the crisis. In these tests, we directly consider the possibility that the effect of financing shocks operates through market power (firms' ability to raise prices) rather than through a cost channel as predicted by our model.

5.1 Data and empirical definition

We now describe these empirical results in detail. We employ quarterly data from 1971 to April 2020, a span of 197 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, inflation adjusted to 2019. Our sample includes $18,338$ firms with an average asset value of \$2.7 billion dollars (inflation adjusted to the end of 2019). Altogether we have $573,041$ firm-quarters.

5.1.1 Variable definitions

Our first dependent variable is the operational spread or Markup, defined 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. Our second dependent variable is the cost of goods sold ($COGSQ$), scaled by assets (ATQ), which by our model increases with operational hedging.

Our key explanatory variable proxies for the firm's ability to pay off its debt liabilities, viz., the negative of Altman's (1968) Z-score[17]. The model includes variables that 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 (e.g., Covas and Den Haan, 2011). 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. In models with CGS/Assets as the dependent variable we add to the control variables contemporaneous sales-

[17] In our calculation of the Z-score we use $OIBDP$ instead of $EBIT$ because the latter is not available in Compustat quarterly data.

to-assets ratio since cost of goods sold is partly and mechanically related to sales. The models include two variables that 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 is a dummy variable that equals one if the firm ranks among the top four sellers in the industry in a given quarter and zero otherwise, using Fama and French's 48 industries. The second variable is the firm's sales/industry sales.

The variables that indicate operational hedging are inventory and supply chain breadth. Inventory ($INVTQ$) scaled by sales indicates operational hedging, proxying for the excess production indicated by i in the theoretical model.[18] The 2020 Covid-19 pandemic highlighted the importance of inventory — which in many cases was impossible to replenish at reasonable cost or in a timely manner — and of supply chain diversification to circumvent shutdowns of some manufacturing facilities. We create a supply chain hedging variable using information from the Factset Revere relationship database on firms' suppliers.[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, the start and end date of the relationship, the type of the relationship (e.g., competitor, supplier, customer, partner, etc.), and the firms' geographic origins. We aggregate the relationship-level data to firm-quarter level and calculate three measures of supply chain hedging 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 with our main sample, yielding a total of $151,985$ firm-quarter observations covering $6,204$ 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 3 suppliers are not from the firm's region.

[18]A non-negligible number of firms report zero inventory in COMPUSTAT. Our model is irrelevant to firms that routinely do not hold any inventories. Therefore, the empirical analyses involved with inventory only include observations with strictly positive inventories. Our results are qualitatively the same when we include firms with zero inventories.

[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 supply chain hedging index, SCH, is the first principal component from the three individual measures. This first principal component explains 97% of the sample variance. The three measures (i)-(iii) have very similar weights being, respectively, 0.575, 0.580 and 0.578. A higher value of SCH indicates greater supply chain breadth and a more intensive hedging along the supply chain.

Table 1 presents summary statistics of the variables in our study. All continuous variables in our analysis are winsorized at the 1% and 99% tails.

[INSERT Table 1.]

5.2 Hedging operational risk through supply chain and inventory

Operational hedging in our model — indicated by i — can be interpreted as either building up extra inventory (Section 2) or a more stable supply chain (Section 3.4). Greater i increases production expenditures, but enabling firms to deliver on their contracts and to have higher sales in times of a severe economic shock, depressing output. We thus examine the effect of our measures of operational hedging — inventory holding and supply chain hedging — on firms' sales during periods of recessions, using the NBER designation.

For each recession period, we estimate a separate cross-sectional regression with the dependent variable being $\Delta sales/assets$, the change in the average level of firm sales (scaled by total assets) between the recession periods and the eight-quarter period before the recession. Because a recession may have warning signs which affect the firms' operational hedging before its onset we use the inventory and supply chain hedging data that ends four quarters before the onset of each recession. The control variables include Tobin's Q, the natural logarithm of total assets, cash holdings, cash flow, and asset tangibility. All the control variables are fixed as of the latest quarter before the onset of the recession. The model includes Fama-French's 48 industry fixed effects and we cluster the standard errors at industry level.

[INSERT Table 2.]

Table 2 presents the results. In Panel A, a higher level of inventory and supply chain hedging before the recession mitigates the decline in sales during the recession compared with the average sales during the eight pre-recession quarters. Naturally, sales declined during the recessions,[20] but less so for higher level of operational hedging: We find that the coefficients of the pre-recessions Inventory/sales and SCH are positive and mostly significant. Five of the six coefficients of Inventory/sales are significant at the 0.05 or lower levels, one coefficient is significant at the 0.10 level and one (for the 1981Q2-1982Q2 recession) it is positive and insignificant. For SCH we have data only for the recession of 2007Q4 to 2009Q2. In Panel B we find that a higher level of pre-recession supply chain hedging significantly mitigates the decline in sales during the recession. Overall, our results show that firms with more intensive operational hedging suffer less severe disruptions in output deliveries, measured by sales, when recession shocks hit.

We clarify the economic significance of our results by standardizing the coefficients of Inventory/sales and of SCH so that they represent the units of standard deviation change in $\Delta sales/assets$ as a result of one standard deviation change in the operational hedging variable.[21] We find that the six coefficients of Inventory/sales are, in the order of the six recessions, 0.037, 0.016, 0.013, 0.016, 0.021 and 0.011. This means that an inventory-sales ratio that is 0.1 higher mitigates the reductions in sales scaled by assets during recessions by 0.002. And, a one unit higher SCH mitigates sale reductions during recessions by 0.002.

Our finding that the shock to sales due to a recession is mitigated for firms with operational hedging — firms with higher inventory and a greater extent of supply chain hedging — is consistent with the implications of our model.

[20]The average sales-assets ratio is 0.011 lower during the recessions, compared with the previous eight-quarter periods. The average decline in sales-assets ratio ranges from -0.019 to 0.007, across the six recessions in our sample. Apart from the first recession (1973Q4 — 1975Q1), all recessions witness an average decline in sales-assets ratio.

[21]Specifically, to obtain the standardized β we multiply the estimated β coefficient by the ratio of the Standard deviation of the explanatory variable to that of $\Delta sales/assets$, the dependent variable.

5.3 Markup, CGS and operational hedging

To confirm that higher operational hedging raises production cost and lowers markup, we estimate the following model:

$$Y_{j,t} = \sum_k \beta_k OpHedging_{j,t-1} + \sum_m \beta_m Control\ variables_{j,t-1}$$
$$+ firm\ FE + industry \times year - quarter\ FE \tag{5.1}$$

The dependent variable $Y_{j,t}$ is either $Markup_{j,t}$ or $CGS/assets_{j,t}$ for firm j in quarter t, and $OpHedging_{j,t-1}$ are the operational hedging variables that we focus on, Inventory/sales and SCH, the supply chain hedging variable. The control variables are Tobin's Q, log assets, cash holdings, cash flow, asset tangibility, and two variables that measure market power, which is known to affect markup. The model includes firm and Fama-French 48 Industry $\times$ year-quarter fixed effects; standard errors are clustered by firm and by year-quarter.

[INSERT Table 3.]

We find in Table 3 that Markup and CGS are both affected by the two variables that indicate operational hedging. Higher values of inventory and supply chain hedging, which raise the firm's unit cost, significantly lower Markup and raise CGS. To illustrate the economic significance of the estimated effect, by the estimation in column (1), one standard deviation increase in SCH lowers markup by 0.01, and one standard deviation increase in Inventory/sales lowers markup by 0.04. After controlling for firms' market power variables and industry-quarter fixed effects (Column (2)), the estimated effects of SCH is 0.007 while that of Inventory/Sales remains the same. Columns (3) and (4) show that both measures of operational hedging raise the production costs scaled by assets after controlling for the contemporaneous Sales/assets ratio, which is added to the explanatory variables. Specifically, one standard deviation increase in SCH raises the CGS/assets ratio by 0.001 whether or not we control for the firms' market power and for the industry-quarter fixed effects, and one standard deviation increase in Inventory/sales raises the CGS/assets ratio by 0.003, and such effect increases to 0.004 once we control for the firms' market power and for the industry-quarter fixed effects. Overall, the results suggest that Markup and CGS are significantly affected by operational hedging activities.

5.4 Baseline results

We now test the main hypothesis of our model that firms closer to financial distress spend less on operational hedging, resulting in a lower production cost, reflected in a higher operation spread which we capture by Markup or a lower level of CGS/sales. We estimate Model (5.1) where $Y_{j,t}$ is either $Markup_{j,t}$ or $CGS/assets_{j,t}$ and the main explanatory variable is lagged -(Z-score) which measures credit risk. By our hypothesis, -(Z-score) should have a positive effect on Markup and a negative effect on CGS/assets. The model includes the control variables used earlier as well as the firm and industry-quarter fixed effects, also clustering standard errors by firm and by year-quarter.

[INSERT Table 4.]

Table 4 presents our baseline results. As predicted in Proposition 3.1, the operational spread measured by Markup is positively affected by the firm's -(Z-score). Faced with a higher likelihood of financial default and a greater need for liquidity to hedge financial risk, firms reduce expenses on operational hedging. Then unit cost declines and Markup increases. The economic meaning of the estimated effects is seen in that by column (1), an increase of one standard deviation in -(Z-score) raises the median firm's markup by 6.4% or by 5.0% after controlling for market power and industry-quarter fixed effects. In columns (3) and (4) we find that an increase of one standard deviation in -(Z-score) lowers the median CGS/assets by 2%, with almost a similar effect after controlling for market power variables and industry-quarter fixed effects. Together, the empirical results are consistent with our key model prediction that the need to avoid financial default induces firms to shift funds from operation hedging to financial hedging.

5.5 The effect of market power

In our model, the firm is a price taker, and the industry $\times$ Year-quarter fixed effects control for the effect of price changes on markup in the industry to which the firm belongs. Chevalier and Scharfstein (1994) and Gilchrist et al. (2017) propose that firms with market power that are subject to liquidity constraint may raise their price in order to increase short-term cash flow while forgoing the benefit of increasing market share and long run profit. The benefit is greater for firms with market power whose customer base is sticky. Thus the positive effect of credit risk on markup can potentially be explained by market power.

We test the role of market power on the markup-credit risk relationship by augmenting the model estimated in Table 4 with interaction terms between -(Z-score) and the two market power variables. If firms with greater market power raise prices in response to greater credit risk and liquidity needs as predicted by the aforementioned theories, the impact of -(Z-score) on markup should be stronger for firms with higher market power, reflected in positive coefficients for the interaction terms.

The results in the first two columns of Table IC.1 do not support this hypothesis. They shows the opposite: Higher market power *lowers* the reaction of markup to -(Z-score), as indicated by the negative and statistically significant coefficients on the interaction terms between market power variables and -(Z-score). The coefficients of -(Z-score) continue to be significantly positive, and the economic magnitudes are similar to those in the first two columns of Table 4. Overall, the results do not support the explanation that the positive effect of -(Z-score) on markup is due to market power. The effect of firms' credit risk on their markup strategies are at least partially through unit cost, as suggested by our model.

5.6 Effect of financial constraint

In this section we test our prediction that when there is a lower pledgeability of the firm's future cash flows, corresponding to a lower τ in our model, there is a stronger positive relationship between markup and credit risk. Because financial constraints and the firm's performance are naturally related, we employ in our tests two plausibly exogenously imposed shocks to financial constraints. By our model's prediction, there should be a greater positive relationship between markup and credit risk during these shocks because firms needed to cut spending on operational hedging and shift liquidity to hedge against financial default.

5.6.1 Recession periods

During economic recessions market liquidity is scarce, making it harder for forms to raise capital upon demand if they need to service their short-term financial obligations (e.g., Fernández-Villaverde and Guerrón-Quintana, 2020). We test the effect of recessions on the markup-credit risk relationship by augmenting the baseline estimation in Table 4 with interaction terms -(Z-score) $\times$ Recession where the dummy variable Recession equals one during the NBER-designated recession quarters, zero otherwise. As before, because the explanatory firm-specific variables are affected themselves by the business cycle we fix their level during recession periods at their respective values as of the most recent quarter before the starts of the recession.[22]

The results presented in Table 5 suggest that the firms with higher credit risk reduce their operational hedging when market conditions make them more financially constrained. We find that firms entering the recessions with higher -(Z-score) have a greater increase in their markup (Panel A) and a greater cut in their CGS/assets ratio (Panel B). This is reflected in the interaction terms -(Z-score) $\times$ Recession having positive and significant coefficients in columns (1)-(2), and negative and significant coefficients in columns (3)-(4). Panel C shows that during recessions firms with higher credit risk exhibit a greater reduction in their spending on operational hedging, indicated by their Inventory/sales ratio. In Panel D we find a greater reduction in supply chain hedging during the 2007-2009 recession, but this analysis has a lower power since data are available only for one recession (the coefficient is insignificant).

[22] See the recommendation, for instance, in Roberts and Whited (2013) on the issue of studying the effects of shocks on the dependent variables.

[INSERT Table 5.]

We attend again to the theory on the effect of market power on the markup-credit risk relationship following Gilchrist et al. (2017) proposition that increased credit risk during economic downturns induces firms with market power to raise prices and markups. We augment our analysis of the model in table 5 with a triple interaction terms, market power × -(Z-score) × recession. If it is market power that drives the positive effect of -(Z-score) on markup during recessions then we expect the coefficient of market power × -(Z-score) × recession to be positive and significant. The results in the Appendix Table IC.1, Columns (3) and (4), do not support this prediction. We find that the coefficients of market power × -(Z-score) × Recession are statistically insignificant for both measures of market power, while the coefficients of -(Z-score) × Recession continue to be significantly positive, and the economic magnitudes are similar to those in the first two columns of Table 5. We conclude that there is no support for the proposition that the positive markup-credit risk relationship in recession periods is driven by market power; our proposition instead is that this relationship results from the adjustment of production costs through operational hedging policies.

5.6.2 Shock to credit supply in 2008

Our second test of the effects of financing constraints on the markup-credit risk relationship employs the shock due to the financial crisis of 2008. During this crisis, especially starting in Fall 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 whose lenders were adversely affected by the 2008 crisis — we call them "exposed firms"— there was stronger positive effect -(Z-score) on markup and on CGS/assets. Following our model we propose that exposed firms with higher credit risk allocated more resources to avoid financial default at the expense of reduced spending on operational hedging. Consequently, a firm whose lender is negatively shocked more aggressively reduces its operational hedging cost and consequently its Markup increases by more for any given level of -(Z-score).

We use Chodorow-Reich (2014) measures of the adverse impact of the 2008 crisis on lenders' abilities to extend credit.[23] (i) %# Loans reduction, the proportional change in the (weighted) number of loans that the lender extended to all firms (except the firm in question), the difference between the loans in the nine-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. (ii) Lehman exposure, the exposure to Lehman Brothers through the fraction of a bank's syndication portfolio where Lehman Brothers had a lead role. (iii) ABX exposure, the extent of banks' exposure to toxic mortgage-backed securities, calculated using the correlation between banks' daily stock return and the return on the ABX AAA 2006-H1 index.

We find the relationship between our sample firms and bank lenders using data from the LPC-Dealscan database. Then, for each firm and each of the three measures, we calculate a weighted average of the measure over all members of the last pre-crisis loan syndicate of the firm, where the weight the lender's share in the firm's last pre-crisis loan syndicate. The detailed constructions of the three variables at the firm level are in Chodorow-Reich (2014). We construct the three variables in a way so that a larger value implies greater exposure to the financial crisis through the firm's lenders. For this analysis, we restrict our sample firms to the $2,429$ firms in Chodorow-Reich (2014).

We use the following regression specification:

$$\begin{aligned} Y_{j,k,t} = \alpha + \beta_1 \times -(Z - score)_{j,2007} \times Lender\ exposure_{j,t} + \beta_2 \times Lender\ exposure_{j,t} \\ + \sum_m \beta_{3,m} \times Control\ variable_{m,j,t-1} \\ + \sum_k \beta_{4,m} \times Controls\ variables_{m,j,t-1} \times Lender\ exposure_{j,t} + \theta_j + \eta_{k,t} + \epsilon_{j,t}\ , \end{aligned} \tag{5.2}$$

where Y denotes either Markup or CGS/assets, and j, k, t stands for a firm j in industry k in quarter t. The values of Y before and after the crisis are for the two-year periods July 2006 to June 2008 and January 2009 to December 2010, respectively. Notably, $-(Z - score)_{j,2007}$ is fixed before the crisis as of the end of 2007. The lenders' exposure to the financial crisis

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

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), being fixed at the end of year 2007 for the post-crisis years. The model includes firm fixed effects and Industry-quarter fixed effects and standard errors are at firm levels. In these regressions which are confined to a short time period, the number of observations is naturally small.

[INSERT Table 6.]

Table 6 presents the results. Consistent with our proposition, the coefficient β_1 is positive and significant for the Markup model (even-numbered columns) and negative and significant for the CGS/assets model (odd-numbered columns). In other words, markup expanded for firms with higher credit risk whose lenders were more adversely affected by the financial crisis. These firms preferred to reduce spending on operational hedging, as seen in the lowering of CGS/assets, and employ their resources to avoid financial default. To gauge the economic significance of the joint impacts of the firm's credit risk and its exposure to financial crisis using Column (1) as an example, a one unit higher value of the firm's -(Z-score) and a reduction of the number of loans by its lender to other borrowers by 10% during the financial crisis led to a wider Markup by 0.009. By Column (3), a one unit higher value of the firm's -(Z-score) and a 10% exposure of its lender to Lehman led to a wider Markup by 0.016.

Again, we test whether our result of a positive markup-credit risk relationship during the financial crisis are explained by firms' market power that enables them to raise prices. We add to the variables in Table 6 a triple interaction term market power $\times$ -(Z-score) $\times$ (lender) exposure. If it is market power that drives the positive effect of -(Z-score) on markup during the financial crisis, then we expect coefficient of the triple interaction term to be positive and significant. The results in the Appendix Table IC.2 do not support this prediction. We find that for both measures of market power, the coefficients of market power $\times$ -(Z-score) $\times$ (lender) exposure are statistically insignificant, while the coefficients of -(Z-score) $\times$ lender exposure continue to be significantly positive, and their economic magnitudes are similar to those in Table 6. We conclude that there is no support for the proposition that it is market power that drives the markup-credit risk relationship for firms more exposed to financial crisis; our proposition is that this relationship results from the adjustment of production costs through operational hedging policies which is stronger for firms that are more exposed to the financial crisis.

Next, we study the dynamic effects of the interaction term $\beta_1 \times -(Z - score)_{j,2007} \times$ $Lender\ exposure_{j,t}$ before and after the crisis. We replace the Lender Exposure variable in equation (5.2) with an interaction terms $\beta_n \times -(Z - score)_{j,2007} \times (Lenderexposure, D_n)$ where the dummy variable D_n equals one for the indicated quarter n and zero otherwise. The indicated n equals $-4, \ldots, -1, 1, \ldots, 4, 5+$. This numbering applies to the last four quarters in the pre-crisis period, Q3-Q4 of 2007 and Q1-Q2 of 2008, then for the four post-crisis periods, Q1-Q4 of 2009, lastly, $D_{5+} = 1$ for the quarters Q1-Q4 of 2010.

We expect the coefficients β_n to be insignificant for $n = -4, \ldots, -1$, the pre-crisis period, and to be significant for $n = 1, \ldots, 4$, the post-crisis period.

Table 7 presents the results. In all columns, the coefficients β_n are mostly significant after the crisis starting from $n = 2$ while being insignificant before the crisis. At the bottom of each column we present F-tests of the joint significance of all the coefficients β_n, 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 β_n for the post-crisis four quarters while it shows insignificance of the coefficients for the pre-crisis four quarters. Figure 3 illustrates the point estimates, as well as the 95% confidence intervals of the coefficients on the product of -(Z-score) and alternative measures of lender exposure for the periods of four quarters before and after the financial crisis.

[INSERT Table 7.]

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, causing its markup to rise.

5.7 Operational hedging and stock returns during Covid

Our model suggests that operational hedging does not affect the firm's franchise value when credit risk is high (Section 2.5). If credit risk is high enough, then avoiding financial default becomes the priority for the firm because any shock that would cause operational default triggers financial default first. In that case, variation in operational hedging does not affect the firm's value as shocks that can trigger operational default are dominated by shocks affecting financial default.

We test this prediction using stock returns during the Covid era. We can think of the Covid shock as a highly negative realization of the shock (u) in our theory, which creates both financial and operational default risks. Then, the logic above suggests that pre-Covid operational hedging choices should matter less for the value of firms that enter Covid with pre-existing high credit risk. Specifically, we regress each firm's stock return during 2020 and 2021 against our two measures of operational hedging, SCH and inventory-sales ratio, as of the end of 2019. We control for the book-to-market and size factors. We also control for the percentage changes in sales during 2019, to cater for the mechanical changes of inventory-sales ratio due to sale changes. We split our sample to two halves according to sample median -(Z-score) and run the regression separately.

Table 8 presents the results. Both SCH and inventory-sales ratio at the end of 2019 are significantly and positively associated with stock performance during 2020 and 2021, only for firms with -(Z-score) below the sample median -(Z-score). For firms relatively distant from financial default, operational hedging practices such as hedging along supply chains and stacking up inventories allow firms to better weather disruptions in their operations due to Covid, thus preserving their equity values. The findings suggest that operational hedging helps firms preserve their franchise values after a bad operational shock occurs, but only if their credit risk is relatively low. These results are consistent with the intermediate predictions of our theory (Section 2.5).

[INSERT Table 8.]

6. Conclusion

In this paper, we study the corporate choice between financial efficiency and operational resiliency. We build 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 firms that face difficulty raising external finance and results in a positive relationship between operational spread (markup) and credit risk.

We present empirical evidence supporting our model predictions. First, we document that markup is a reasonable summary of firms' operational hedging activities, measured as inventory holdings and supply chain hedging. Then we document a positive relationship between the markup and a firm's credit risk. This positive relationship is stronger when firms have a greater motivation to hoard liquidity in order to avert financial default, and it increases during recessions and in the aftermath of the subprime financial crisis for firms whose lenders were more exposed to the financial crisis. Overall, our empirical findings confirm that the tension between financial and operational hedging is more pronounced when firms face greater difficulty raising external funds.

We conclude by pointing out fruitful areas for future research. On the theoretical end, one can build a general equilibrium model that extends the current partial equilibrium framework to a production network model in which product pricing, credit risk and operational hedging decisions are determined as equilibrium outcomes of the entire system, with 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 credit risk 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.

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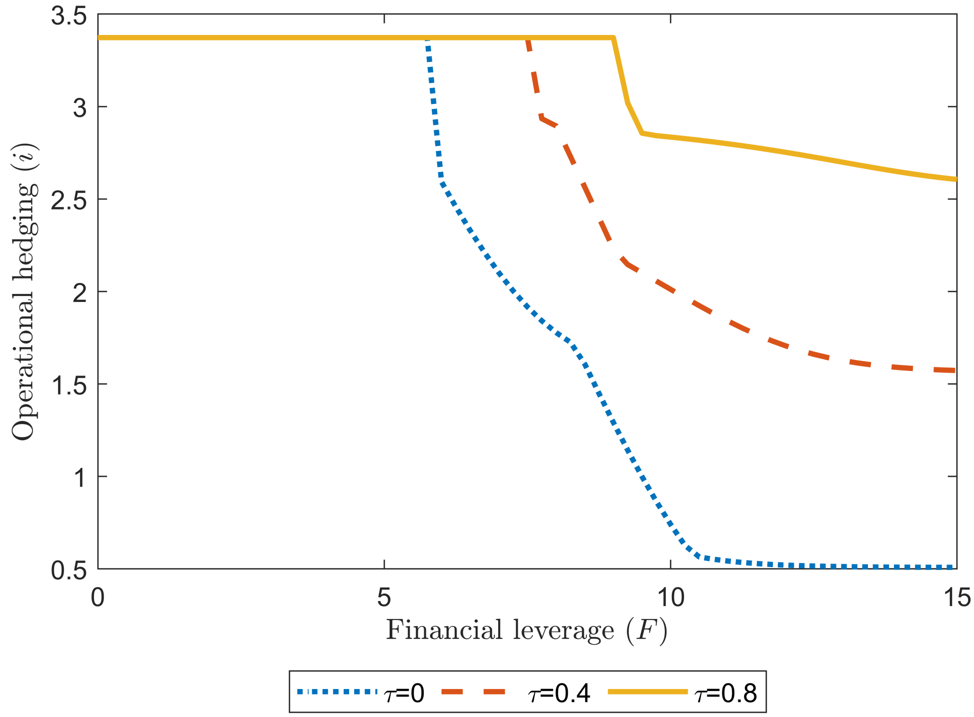

Figure 1: **Firm's optimal hedging policy i^{**} and debt level F**

Optimal hedging policy i^{**} given debt level F for $\tau = 0$, $\tau = 0.4$ and $\tau = 0.8$, where τ is a measure of the extent of the need for pledgeability, which proxies financial constraint.

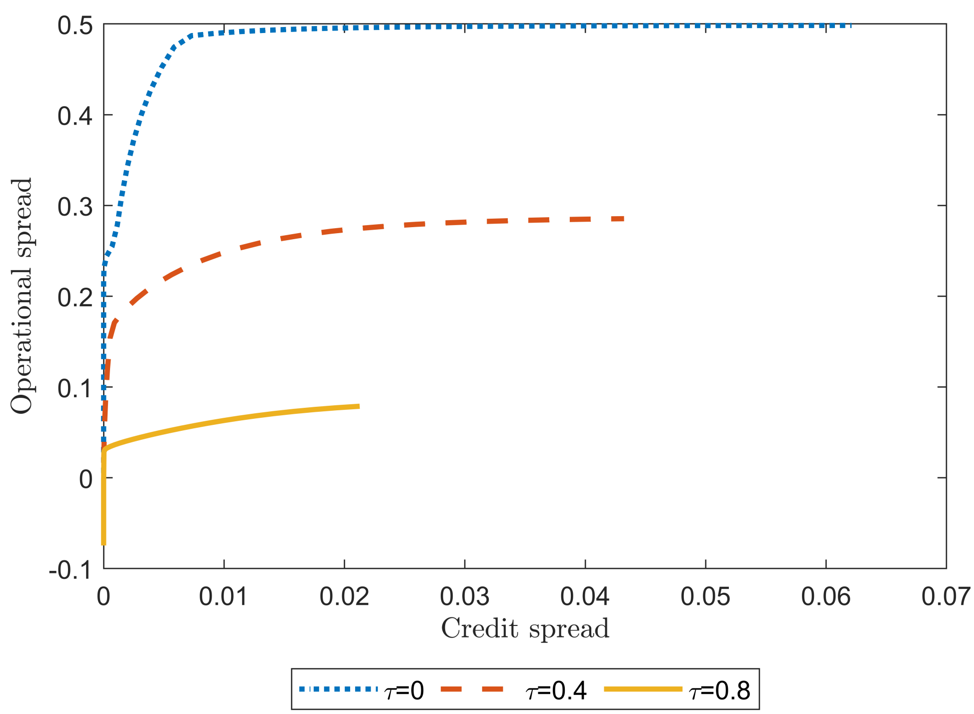

Figure 2: **Credit spread and operational spread**

The credit spread and operational spread under the optimal hedging policy i^{**} given debt level F for $\tau = 0$, $\tau = 0.4$ and $\tau = 0.8$.

Figure 3A: Markup – Coefficient on -(Z-score) × LE: % # Loans reduction

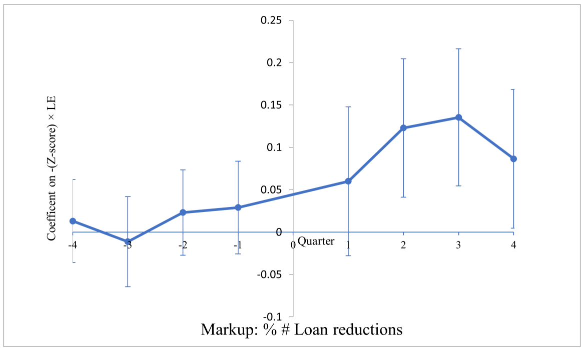

Figure 3B: Markup – Coefficient on -(Z-score) × LE: Lehman exposure

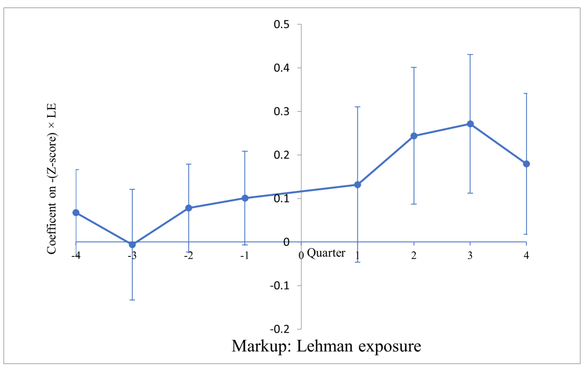

Figure 3C: Markup – Coefficient on -(Z-score) × LE: ABX exposure

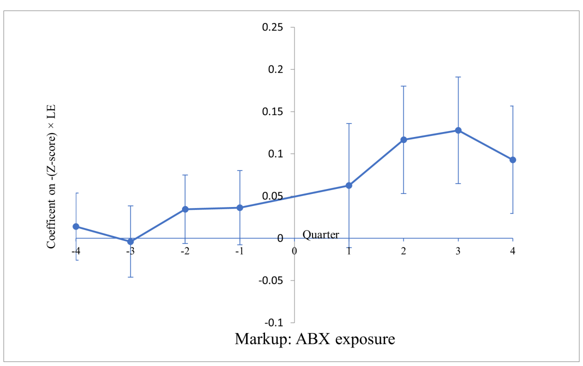

Figure 3D: CGS – Coefficient on -(Z-score) × LE: % # Loans reduction

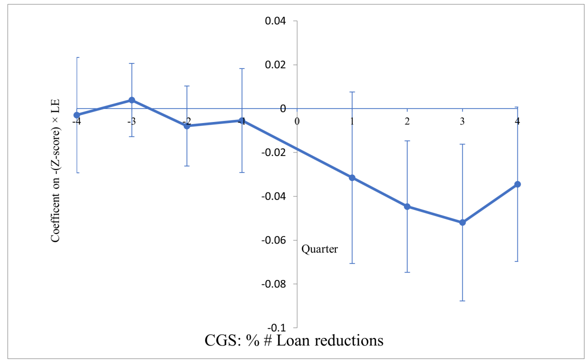

Figure 3E: CGS – Coefficient on -(Z-score) × LE: Lehman exposure

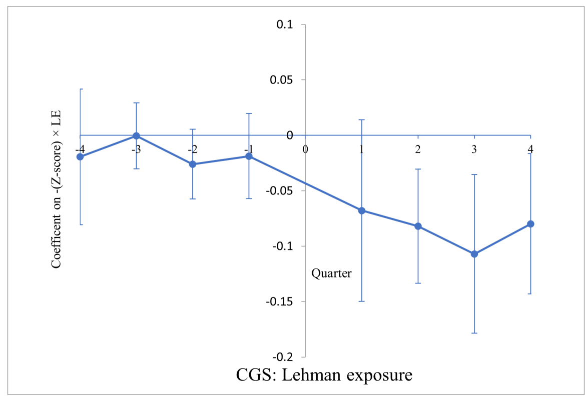

Figure 3F: CGS – Coefficient on -(Z-score) × LE: ABX exposure

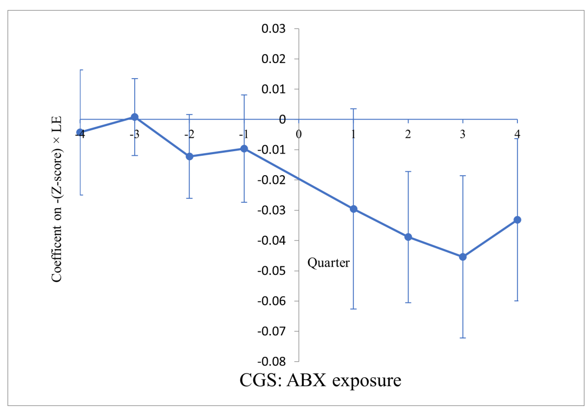

Figure 3: **Markup, CGS and credit risk: Dynamic effects of exposure to the financial crisis**

This figure plots the the point estimates of the coefficients on -(Z-score) × LE in the markup and CGS regressions, as of Table 7, and their 95% confidence intervals.

Table 1: **Summary statistics** — Compustat 1973-2020

Summary statistics of the variables in our sample from 1971 to April 2020. The data are quarterly from Compustat; The variable names are in parentheses. Markup = (sales($SALEQ$) − cost of goods sold($COGSQ$))/$Sales$. CGS/assets = CGS($COGSQ$)/total assets(ATQ). Z-score is Altman (2013)'s measure calculated from quarterly data. Tobin's Q = (common shares outstanding($CHOQ$) × 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 two variables, all employing Fama and French's 48 industries: a dummy variable for the top 4 industry seller = 1 if the firm's sales are among the top four sellers in the industry (0 otherwise); and firm's Sales/Industry sales. The operational hedging variables include Inventory ($INVQ$)/Sales, which is restricted to be strictly positive, and Supply chain hedging index. The supply chain variables are composed from three raw measures: (i) ln(1+number of suppliers), (ii) ln(1+number of supplier regions), (iii) ln(1+number of suppliers not from the firm's region). Data are quarterly (source: Factset), covering $6,204$ firms from mid-2003 to the first quarter of 2020. Supply chain hedging is the first principal component score from a principal component analysis (PCA) that equals 0.5745 × (i) + 0.5796 × (ii) + 0.5779 × (iii) where (i)-(iii) indicate the above three measures.

The sample requires that the lagged firm capitalization is at least \$10 million and quarterly sales are at least \$1 million (inflation adjusted to the end of 2019). All continuous variables are winsorized at both the 1st and 99th percentiles.

VARIABLES	N	Mean	S.D.	P25	P50	P75
Markup: (sales-cogs)/sales	572,345	0.317	0.428	0.208	0.338	0.508
CGS/assets	569,049	0.209	0.188	0.079	0.162	0.277
-(Z-score)	573,041	-3.542	5.872	-3.995	-2.082	-1.081
Tobin's Q	573,041	1.981	1.597	1.073	1.446	2.211
Cash holdings	573,041	0.164	0.197	0.024	0.082	0.232
Cash flow	573,041	0.010	0.056	0.005	0.021	0.035
Asset tangibility	573,041	0.303	0.243	0.104	0.235	0.448
Top 4 industry seller	573,041	0.039	0.193	0.000	0.000	0.000
Sales/industry sales	573,041	0.009	0.026	0.000	0.001	0.005
Total assets	573,041	2,738.859	8,390.609	79.178	299.321	1,338.695
Inventory/sales	485,267	0.595	0.533	0.222	0.487	0.794
Supply chain hedging (SCH)	116,430	-0.010	1.697	-1.334	-0.381	0.956

Table 2: **The effect of operational hedging on changes in sales during NBER recessions**

Cross-sectional regressions of changes in the sales/assets ratio during recessions on the pre-recession level of firms' operational hedging. The dependent variable is Δ sales/assets, the difference between its average level of the recession quarters and its average over eight quarters before the recession. The recession quarters are so designated by the NBER. The main independent variables are the inventory/sales ratio or supply chain hedging measured by the supply chain hedging PCA index, fixed at four quarters before the onset of recession (or earlier). The control variables include Tobin's Q, natural logarithm of total assets, cash holdings, cash flow, and asset tangibility. All the control variables are fixed as of the latest quarter before the onset of each recession. We include Fama-French 48 industry fixed effects and cluster the standard errors at industry level. $*$, $**$, $***$ denote significance below 10%, 5%, and 1% levels, respectively.

VARIABLES	Δ *sales/assets*					
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Inventory-sales ratio						
Recession period	1973Q4 — 1975Q1	1979Q2 — 1980Q2	1981Q2 — 1982Q2	1989Q4 — 1991Q1	2001Q1 — 2001Q3	2007Q4 — 2009Q2
Inventory/sales	0.037**	0.016**	0.013*	0.016***	0.021***	0.011**
Standard error	0.015	0.008	0.007	0.004	0.004	0.005

Panel B: Supply chain hedging PCA, for the recession of 2007Q4 to 2009Q2

	Supply chain hedging (SCH)
SCH	0.002**
Standard error	0.001
Control variables	Yes
FF-48 industry fixed effects	Yes

Table 3: **Markup, CGS and operational hedging**

Estimation of the relationship between Markup (columns (1) and (2)), CGS (columns (3) and (4)) and measures of operational hedging. The variables are defined in Table 1. The control variables include Tobin's Q, ln(Total assets), Cash holdings, Cash flow, and Tangible assets. Additionally, we control for contemporaneous sales/assets in CGS regressions (columns (3) and (4)). In even-numbered columns, we also control for market power variables: a dummy variable for the top 4 industry seller and Sales/total sales. All explanatory variables are lagged by one quarter. The regressions include firm and Fama-French 48 Industry × year-quarter fixed effects. Standard errors are clustered at firm and year-quarter levels. $*$, $**$, $***$ denote significance below 10%, 5%, and 1% levels, respectively.

VARIABLES	*Markup*		*CGS/assets*	
	(1)	(2)	(3)	(4)
SCH PCA	-0.0076***	-0.0042**	0.00088***	0.00063**
	(0.0021)	(0.0018)	(0.00030)	(0.00029)
Inventory/sales	-0.076***	-0.076***	0.0061***	0.0067***
	(0.014)	(0.014)	(0.0013)	(0.0013)
Market power variables	No	Yes	No	Yes
Other Control variables	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes
Industry × Year-quarter fixed effects	No	Yes	No	Yes
Observations	93,853	92,762	93,772	92,681
R-squared	0.698	0.718	0.975	0.977

Table 4: **Markup, CGS and credit risk**

Estimation of the relationship between Markup, CGS and -(Z-score). The dependent variable in the panel regression is the quarterly Markup (columns (1) and (2)) and CGS (columns (3) and (4)). The control variables include Tobin's Q, Ln(total assets), Cash holdings, Cash flow, and Tangible assets. Additionally, we control for contemporaneous sales/assets in CGS regressions (columns (3) and (4)). In even-numbered columns, we also control for market power variables: a dummy variable for the top 4 industry seller, and Sales/industry sales. All explanatory variables are lagged by one quarter. The regressions include firm and Fama-French 48 Industry $\times$ year-quarter fixed effects. Standard errors are clustered at firm and year-quarter levels. $*$, $**$, $***$ denote significance below 10%, 5%, and 1% levels, respectively.

VARIABLES	*Markup*		*CGS/assets*	
	(1)	(2)	(3)	(4)
-(Z-score)	0.0037***	0.0029***	-0.00058***	-0.00054***
	(0.00057)	(0.00053)	(0.000080)	(0.000079)
Market power variables	No	Yes	No	Yes
Other Control variables	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes
Industry $\times$ Year-quarter fixed effects	No	Yes	No	Yes
Observations	571,388	564,418	568,015	561,177
R-squared	0.614	0.634	0.949	0.951

Table 5: **Markup, CGS, operational hedging and credit risk: NBER recessions**

Regressions of Markup, CGS, inventory and supply chain hedging on firms' -(Z-score) that interacts with Dummy variable for NBER recession periods. We exclude the Covid-related recession during the first two quarters of 2020. *Recession* = 1 if the quarter is classified as NBER recession, and = 0 otherwise. For each recession, the values of -(Z-score) and control variables during recession periods are fixed as of the most recent quarter before the onset of the recession. The firm-level control variables (including market power variables) are as in Table 4. Additionally, we control for contemporaneous sales/assets in CGS regressions (columns (3) and (4)). Panel A examines markup. Panel B examines CGS. Panel C examines inventory-sales ratio. Panels D examine Supply chain hedging. The variable definitions are in Table 1. The regressions include firm and Fama-French 48 Industry $\times$ year-quarter fixed effects. Standard errors are clustered by firm and year-quarter levels. $*$, $**$, $***$ denote significance below 10%, 5%, and 1% levels, respectively.

VARIABLES	Panel A: *Markup*		Panel B: *CGS/assets*		Panel C: *Inventory/sales*	Panel D: *SCH*
	(1)	(2)	(3)	(4)	(5)	(6)
Recession periods:	1973Q4 – 1975Q1, 1979Q2 – 1980Q2, 1981Q2 – 1982Q2 1989Q4 – 1991Q1, 2001Q1 – 2001Q3, 2007Q4 – 2009Q2					2007Q4 – 2009Q2
-(Z-score) $\times$ Recession	0.0019**	0.0016***	-0.00023**	-0.00025**	-0.0016***	-0.00072
	(0.00075)	(0.00051)	(0.00011)	(0.00010)	(0.00050)	(0.0023)
-(Z-score)	0.0035***	0.0028***	-0.00057***	-0.00053***	-0.0027***	0.012***
	(0.00056)	(0.00052)	(0.000077)	(0.000077)	(0.00047)	(0.0020)
Market power variables	No	Yes	No	Yes	Yes	Yes
Other Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry $\times$ Year-quarter fixed effects	No	Yes	No	Yes	Yes	Yes
Observations	563,120	554,348	560,343	551,691	543,351	112,336
R-squared	0.616	0.636	0.948	0.950	0.730	0.862

Table 6: **Markup, CGS and credit risk: Exposure to the financial crisis**

Regressions of Markup and CGS on firms' -(Z-score) that interacts with the extent of exposures to the 2008 financial crisis. The sample firms includes 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 variables. 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 values of -(Z-score) are as of the end of 2007. The firm-level control variables (including market power variables), as in Table 4, are fixed at the end of 2007 for the entire post-crisis periods. Additionally, we control for contemporaneous sales/assets in CGS regressions (columns (2), (4) and (6)). The specification is as in the model

$$\begin{aligned} Y_{j,k,t} &= \alpha + \beta_1 \times X_{j,2007} \times Lender\ exposure_{j,t} + \beta_2 \times Lender\ exposure_{j,t} \\ &+ \sum_m \beta_{3,m} \times Control\ variable_{m,j,t-1} \\ &+ \sum_k \beta_{4,m} \times Controls\ variables_{m,j,t-1} \times Lender\ exposure_{j,t} + \theta_j + \eta_{k,t} + \epsilon_{j,t}\ . \end{aligned}$$

The variable definitions are in Table 1. The regressions include firm and Fama-French 48 Industry $\times$ year-quarter fixed effects. Standard errors are clustered by firm. $*$, $**$, $***$ denote significance below 10%, 5%, and 1% levels, respectively.

	% # Loans reduction		Lehman exposure		ABX exposure	
VARIABLES	*Markup*	*CGS/assets*	*Markup*	*CGS/assets*	*Markup*	*CGS/assets*
	(1)	(2)	(3)	(4)	(5)	(6)
-(Z-score) × lender exposure	0.086**	-0.030***	0.160**	-0.058***	0.084***	-0.027***
	(0.034)	(0.011)	(0.072)	(0.021)	(0.027)	(0.008)
Lender exposure	-0.699	0.017	-0.969	-0.149	-0.902**	0.019
	(0.455)	(0.157)	(0.689)	(0.221)	(0.410)	(0.129)
Market power variables				Yes		
Market power variables × lender exposure				Yes		
Other Control variables				Yes		
Other Control variables × lender exposure				Yes		
Firm fixed effects				Yes		
Industry × Year-quarter fixed effects				Yes		
Observations	20,621	20,613	20,621	20,613	20,621	20,613
R-squared	0.905	0.987	0.905	0.987	0.906	0.987

Table 7: **Markup, CGS and credit risk: Dynamic effects of exposure to the financial crisis**

Regressions of Markup and CGS on firms' -(Z-score) that interacts with the extent of lender exposures to the 2008 financial crisis in each quarter D_n, $n = -1, -2, -3, -4, +1, +2, +3, +4, +5 + (+5 — +8)$ relative to the financial crisis, from 8 quarters before it to 8 quarters after it. (The default category is from 5 to 8 quarters before the crisis.) The sample is 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 's variables in Chodorow-Reich (2014). The values of -(Z-score) are as of the end of 2007. The firm-level control variables (including market power variables), as in Table 4, are fixed at the end of 2007 for the post-crisis quarters. The variable definitions are in Table 1. The last two rows show the results from F-test for joint significance of the coefficients of the interaction terms between $-(Z - score)$ and the size of LE for quarters D_n. The regressions include firm and Fama-French 48 Industry × year-quarter fixed effects. Standard errors are clustered by firm. $*$, $**$, $***$ denote significance below 10%, 5%, and 1% levels, respectively.

	% # Loans reduction		Lehman exposure		ABX exposure	
VARIABLES	*Markup*	*CGS/assets*	*Markup*	*CGS/assets*	*Markup*	*CGS/assets*
$-(Z - score) \times LE$, D_{-4}	0.013	-0.003	0.068	-0.019	0.014	-0.004
	(0.025)	(0.013)	(0.050)	(0.031)	(0.020)	(0.011)
$-(Z - score) \times LE$, D_{-3}	-0.011	0.004	-0.006	-0.00041	-0.004	0.001
	(0.027)	(0.009)	(0.065)	(0.015)	(0.022)	(0.006)
$-(Z - score) \times LE$, D_{-2}	0.023	-0.008	0.078	-0.026	0.034*	-0.012*
	(0.026)	(0.009)	(0.051)	(0.016)	(0.021)	(0.007)
$-(Z - score) \times LE$, D_{-1}	0.029	-0.005	0.101*	-0.019	0.036	-0.010
	(0.028)	(0.012)	(0.055)	(0.020)	(0.022)	(0.009)
$-(Z - score) \times LE$, D_1	0.060	-0.032	0.132	-0.068	0.062*	-0.030*
	(0.045)	(0.020)	(0.091)	(0.042)	(0.037)	(0.017)
$-(Z - score) \times LE$, D_2	0.123***	-0.045***	0.244***	-0.082***	0.117***	-0.039***
	(0.042)	(0.015)	(0.080)	(0.026)	(0.032)	(0.011)
$-(Z - score) \times LE$, D_3	0.135***	-0.052***	0.272***	-0.107***	0.128***	-0.045***
	(0.041)	(0.018)	(0.081)	(0.036)	(0.032)	(0.014)
$-(Z - score) \times LE$, D_4	0.086**	-0.035*	0.180**	-0.080**	0.093***	-0.033**
	(0.042)	(0.018)	(0.082)	(0.032)	(0.032)	(0.014)
$-(Z - score) \times LE$, D_{+5+}	0.083*	-0.021	0.170*	-0.046*	0.087**	-0.022**
	(0.043)	(0.014)	(0.091)	(0.025)	(0.034)	(0.010)
Lender exposure, D_n				Yes		
Control variables				Yes		
Control variables × Lender exposure				Yes		
Firm fixed effects				Yes		
Industry × year-quarter fixed effects				Yes		
Observations	19,914	19,906	19,914	19,906	19,914	19,906
R-squared	0.903	0.987	0.903	0.987	0.904	0.987
F-statistic for $n = +1$ to $+4$	3.83***	2.88**	3.79***	3.08**	4.62***	3.57***
F-statistic for $n = -1$ to -4	0.63	0.74	1.29	1.00	1.21	1.57

Table 8: **Operational hedging and stock return during Covid period**

Regressions of 2020 — 2021 stock return and on firms' operational hedging measures at the end of 2019. The two operational operational hedging measures are supply chain diversification index and inventory-sales ratio, defined in Table 1. The control variables include natural logarithm of Book-to-market ratio (Ln(B/M)), defined as the book value of equity over market value of equity, natural logarithm of stock capitalization (Ln(size)), and % changes in sales in 2019. The regressions include Fama-French 48 Industry fixed effects. High and low -(Z-score) are defined as -(Z-score) at the end of 2019 above and below the sample median, respectively. Standard errors are clustered by firm. $*$, $**$, $***$ denote significance below 10%, 5%, and 1% levels, respectively.

	2020 — 2021 stock return		
	Full sample	High -(Z-score)	Low -(Z-score)
	(1)	(2)	(3)
Ln(inventory/sales)	0.015	-0.020	0.051*
	(0.030)	(0.054)	(0.029)
SCH PCA	0.064***	0.021	0.049**
	(0.023)	(0.035)	(0.022)
Ln(B/M)	-0.227***	-0.161	-0.296***
	(0.075)	(0.184)	(0.074)
Ln(size)	-0.135***	-0.171***	-0.052*
	(0.034)	(0.057)	(0.026)
% changes in sales, 2019	-0.190	-0.359	0.132
	(0.218)	(0.354)	(0.254)
Industry fixed effects		Yes	
Observations	1,664	795	737
R-squared	0.070	0.096	0.161

Internet Appendix

I.A. Complete table of Table 4

Table IA.1: **Markup, CGS and credit risk — Complete table**

This table reports the complete table of Table 4.

VARIABLES	*Markup*		*CGS/assets*	
	(1)	(2)	(3)	(4)
-(Z-score)	0.0037***	0.0029***	-0.00058***	-0.00054***
	(0.00057)	(0.00053)	(0.000080)	(0.000079)
Tobin's Q	0.021***	0.019***	-0.0048***	-0.0048***
	(0.0020)	(0.0019)	(0.00036)	(0.00035)
Ln assets	0.0073***	0.0058**	0.0035***	0.0036***
	(0.0028)	(0.0026)	(0.00049)	(0.00054)
Cash holdings	-0.070***	-0.065***	0.0010	0.0012
	(0.015)	(0.015)	(0.0022)	(0.0022)
Cash flow	0.91***	0.85***	-0.19***	-0.18***
	(0.044)	(0.038)	(0.0072)	(0.0069)
Asset tangibility	-0.035**	-0.0061	-0.015***	-0.015***
	(0.014)	(0.014)	(0.0029)	(0.0029)
Top 4 industry seller		-0.00019		0.00018
		(0.0047)		(0.0019)
Sales/industry sales		-0.28***		0.071***
		(0.078)		(0.021)
Sales/AT			0.75***	0.75***
			(0.0054)	(0.0054)
Market power variables	No	Yes	No	Yes
Other Control variables	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes
Industry × Year-quarter fixed effects	No	Yes	No	Yes
Observations	571,388	564,418	568,015	561,177
R-squared	0.614	0.634	0.949	0.951

I.B. Omitted proofs in Section 2.3

IB.1 Detailed solutions of the benchmark case in which $F = 0$

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

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

The last term of Equation (IB.1) reflects the proportional loss of franchise value in case of operational default. The first-order condition is

$$\frac{\partial \bar{E}}{\partial i} = p - K'(I+i) - \lambda x_2 \frac{g(u_O)}{I\delta'(u_O)} = 0$$
$$p - K'(I+i) = \lambda x_2 \frac{g(u_O)}{I\delta'(u_O)} \ , \tag{IB.2}$$

where $u_O = \delta^{-1}\left(\frac{i}{I}\right)$. Define $\bar{i}$ being the solution for the first-order condition (IB.2). In Appendix IB.1, we show that $\bar{i}$ is also the unique optimal hedging level that maximizes the equity value (IB.1), under some mild technical conditions.

The following assumption ensures that the firm has enough cash flow at date-0 to choose the highest optimal operational hedging level $\bar{i}$, when $\bar{F}$ is sufficiently small such that $u_F = 0$:

Assumption IB.1.

$$K(I+\bar{i}) < x_0 \ , \tag{IB.3}$$

where $\bar{i}$ is the solution of equation (IB.2).

Since $D(i, \bar{F})$ is continuous in $\bar{F}$, u_F is always smaller than u_O for $i \in [0, \bar{i}]$ when $\bar{F}$ is sufficiently small.

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

$$\frac{\partial^2 \bar{E}}{\partial i^2} = -K''(I+i) - \frac{\lambda x_2}{I^2} \frac{g'(u_O) - g(u_O)\frac{\delta''(u_O)}{\delta'(u_O)}}{[\delta'(u_O)]^2} < 0 \tag{IB.4}$$

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 (IB.1).

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

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:

$$E = \int_{u_F}^{\infty} \Big[u - u_F + p\left[(1-\delta(u))I + i\right] + x_2 \Big] g(u)du \ , \tag{IB.5}$$

where u_F is given in (2.3). $(u - u_F)$ is the amount of cash left in the firm after debt F is repaid, and $p\,[(1-\delta(u))I + i] + x_2$ is the firm's period-2 cash flow and franchise value, conditional on the firm not defaulting in the interim.

Equity holders choose the level of operational hedging i to maximize equity value E in (IB.5), which yields the following first-order condition:

$$p - K'(I+i) = V(u_F, i)h(u_F)K'(I+i) \ , \tag{IB.6}$$

where $V(u_F, i) \equiv p\,[(1-\delta(u_F))I + i] + x_2$ is the firm's date-2 cash flow and franchise value at the financial default boundary. Define i^* as the firm's hedging policy that satisfies (IB.6). On the one hand, a marginal increase in operational hedging yields a marginal profit equal to its markup $p - K'(I+i)$. 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 (IB.6): the first term is the loss of date-2 cash flow and franchise value if financial default occurs; 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 the firm chooses the hedging policy i^* such that the markup is equal to the marginal increase of the expected financial default cost.

Comparing the first-order conditions (IB.2) and (IB.6), it is straightforward that $\bar{i} > i^*$.[24] Next we show that the first-order condition (IB.6) admits a unique and positive interior solution i^* that maximizes E subject to $D(i, \bar{F}) > 0$ for $i \in [0, \bar{i}]$ under some technical condition.

The following assumption guarantees that a positive interior solution i^* exists and $D(i^*, \bar{F}) > 0$ for sufficiently large $\bar{F}$:

Assumption IB.2. $p - K'(I) > (pI + x_2)\alpha K'(I)$.

Lemma IB.1. *If Assumption IB.2 holds and $\bar{F}$ is sufficiently large, then the first-order condition* (IB.7) *guarantees a unique and positive interior solution i^* that maximizes E subject to $D(i, \bar{F}) > 0$.*

Proof. Since u is exponentially distributed on $[0, \infty)$ with $g(u) = \alpha e^{-\alpha u}$ and $h(u) = \alpha$, the first-order condition (IB.6) simplifies to

$$p - K'(I+i) = V(u_F, i)\alpha K'(I+i) \ . \tag{IB.7}$$

[24] We prove this claim formally in Appendix IB.3.

Define i^* is the firm's optimal hedging policy that satisfies (IB.7).

First, we show that i^* that satisfies the first-order condition (IB.6) is the unique optimal solution for the maximization problem when $u_F > u_O$. Define $S = p - K'(I+i) - V(u_F,i)h(u_F)K'(I+i)$. Taking the derivative of S with respect to i:

$$\frac{\partial S}{\partial i} = -\begin{bmatrix} K''(I+i) + \frac{\partial V(u_F,i)}{\partial i}h(u_F)K'(I+i) \\ +V(u_F,i)\frac{\partial h(u_F)}{\partial u_F}\frac{\partial u_F}{\partial i}K'(I+i) + V(u_F,i)h(u_F)\frac{\partial^2 u_F}{\partial i^2} \end{bmatrix} \tag{IB.8}$$

$$\frac{\partial V(u_F,i)}{\partial i} = p[1-\delta'(u_F)IK'(I+i)] > 0 \tag{IB.9}$$

and

$$\frac{\partial^2 u_F}{\partial i^2} = K''(I+i) > 0 \tag{IB.10}$$

Using these quantities,

$$\frac{\partial S}{\partial i} = -\begin{bmatrix} K''(I+i) + p[1-\delta'(u_F)IK'(I+i)]h(u_F)K'(I+i) \\ +V(u_F,i)\frac{\partial h(u_F)}{\partial u_F}[K'(I+i)]^2 + V(u_F,i)h(u_F)K''(I+i) \end{bmatrix} \tag{IB.11}$$

$\frac{\partial S}{\partial i}$ 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 (IB.6), $S = 0$ 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 IB.2 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 IB.2, since $K(I+i)$ is convex in i. For any $\bar{F} > 0$, the right hand-side of the first-order condition (IB.7) 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 (IB.7) decreases with i. The right hand-side of the first-order condition (IB.7) increases with i. 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. So the optimal i^* that satisfies the first-order condition (IB.7) 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 (IB.7) 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 (IB.7) is also the sufficient condition for the solution of the constrained maximization problem subject to $D(i, \bar{F}) > 0$, we have proved Lemma IB.1. Q.E.D.

Lemma IB.2 states that the optimal optimal operational hedging policy decreases in the firm's net debt level $\bar{F}$ in this case:

Lemma IB.2. *When $\bar{F}$ is sufficiently high such that $u_F > u_O$ for $i \in [0, \bar{i}]$, the optimal operational hedging policy i^*, if exists, decreases in the firm's net debt level $\bar{F}$.*

Proof. Notice that the optimal hedging policy i^* and the associated financial default boundary u_F are all functions of $\bar{F}$. 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^*. By the first-order condition, $\frac{\partial M}{\partial i^*} = 0$. Differentiating both sides with respect to $\bar{F}$:

$$\frac{\partial^2 M}{\partial i^{*2}} \frac{\partial i^*}{\partial \bar{F}} + \frac{\partial M}{\partial i \partial \bar{F}} = 0 \tag{IB.12}$$

From equation (IB.12) 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, so the sign of $\frac{\partial i^*}{\partial \bar{F}}$ is the same as the sign of $\frac{\partial M}{\partial i^* \partial \bar{F}}$.

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

Since u follows a exponential distribution, $\frac{\partial h(u_F)}{\partial u_F} = 0$. Thus, Equation (IB.13) is smaller than zero. Therefore, $\frac{\partial i^*}{\partial \bar{F}} < 0$. Q.E.D.

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

We begin this subsection by proving the following lemma:

Lemma IB.3. *If the production commitment I is sufficiently high and $\frac{K'(I+\bar{i})}{I}$ is sufficiently low, then $\hat{i}^*$ that satisfies* (2.3) *uniquely maximizes $\hat{E}$.*

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

$$\frac{\partial \hat{S}}{\partial i} = -\left[\begin{array}{c} K''(I+i) + \frac{\partial V(u_F,i)}{\partial i}h(u_F)K'(I+i) + [V(u_F,i) - \lambda x_2]\frac{\partial h(u_F)}{\partial u_F}\frac{\partial u_F}{\partial i}K'(I+i) \\ +[V(u_F,i) - \lambda x_2]h(u_F)\frac{\partial^2 u_F}{\partial i^2} + \lambda x_2 \frac{\partial}{\partial i}\left[\frac{g(u_O)}{[1-G(u_F)]I\delta'(u_O)}\right] \end{array}\right] \tag{IB.14}$$

$$\frac{\partial}{\partial i}\left[\frac{g(u_O)}{[1-G(u_F)]I\delta'(u_O)}\right] = \left[\frac{g'(u_O)\delta'(u_O) - g(u_O)\delta''(u_O)}{[1-G(u_F)][\delta'(u_O)]^2 I} + \frac{g(u_F)K'(I+i)g(u_O)}{[1-G(u_F)]^2}\right]\frac{1}{I\delta'(u_O)} \tag{IB.15}$$

The absolute value of (IB.15) 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 (IB.9), (IB.10) and (IB.15), $\frac{\partial \hat{S}}{\partial i}$ is

$$\frac{\partial \hat{S}}{\partial i} = -\left[\begin{array}{c} K''(I+i) + p[1 - \delta'(u_F)IK'(I+i)]h(u_F)K'(I+i) \\ +[V(u_F,i) - \lambda x_2]\frac{\partial h(u_F)}{\partial u_F}[K'(I+i)]^2 + [V(u_F,i) - \lambda x_2]h(u_F)K''(I+i) \\ +\lambda x_2\left[\frac{g'(u_O)\delta'(u_O) - g(u_O)\delta''(u_O)}{[1-G(u_F)][\delta'(u_O)]^2 I} + \frac{g(u_F)K'(I+i)g(u_O)}{[1-G(u_F)]^2}\right]\frac{1}{I\delta'(u_O)} \end{array}\right] \tag{IB.16}$$

$\frac{\partial \hat{S}}{\partial i}$ 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 (2.3), $\hat{S} = 0$ 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. Q.E.D.

Intuitively, the condition that I is sufficiently high means that the supply contract value is not trivial. 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 flexibility to do the operational hedging even if the production quantity is high.

Now we prove Lemma 2.1. i^* satisfies the first-order condition (IB.6):

$$\begin{aligned} p - K'(I+i^*) &= V(u_F, i^*)h(u_F)K'(I+i^*) \\ &> V(u_F, i^*)h(u_F)K'(I+i^*) - \lambda x_2 h(u_F)K'(I+i^*) + \frac{\lambda x_2 g(u_O)}{[1-G(u_F)]I\delta'(u_O)} \end{aligned} \tag{IB.17}$$

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, (2.3), with respect to i. The derivative of the left-hand side is $-K''(I+i) < 0$. The derivative of the right-hand side is

$$\begin{aligned} & p[1-\delta'(u_F)IK'(I+i)]h(u_F)K'(I+i) + [V(u_F,i) - \lambda x_2]\frac{\partial h(u_F)}{\partial u_F}[K'(I+i)]^2 \\ & + [V(u_F,i) - \lambda x_2]h(u_F)K''(I+i) \\ & + \lambda x_2 \left[\frac{g'(u_O)\delta'(u_O) - g(u_O)\delta''(u_O)}{[1-G(u_F)][\delta'(u_O)]^2 I} + \frac{g(u_F)K'(I+i)g(u_O)}{[1-G(u_F)]^2}\right]\frac{1}{I\delta'(u_O)} \end{aligned} \tag{IB.18}$$

The quantity (IB.18) 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 (2.3) decreases in i and the right-hand side of Equation (2.3) increases in i. Since $\hat{i}^*$ satisfies the first-order condition in $u_O > u_F$ case, (2.3). We must have $\hat{i}^* > i^*$. Meanwhile, $\bar{i}$ satisfies the first-order condition (IB.2):

$$\begin{aligned} p - K'(I+i^*) &= \lambda x_2 \frac{g(u_O)}{I\delta'(u_O)} \\ &< V(u_F, i^*)h(u_F)K'(I+i^*) - \lambda x_2 h(u_F)K'(I+i^*) + \frac{\lambda x_2 g(u_O)}{[1-G(u_F)]I\delta'(u_O)} \end{aligned} \tag{IB.19}$$

In a similar way, we can prove that $\bar{i} > \hat{i}^*$.

In what follows, we prove Lemma 2.2: 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 $\hat{i}^*$. 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 $\frac{\partial \hat{M}}{\partial \hat{i}^* \partial \bar{F}}$.

$$\begin{aligned}
\frac{\partial^2 \hat{M}}{\partial \hat{i}^* \partial \bar{F}} &= [1-G(u_F)] \left[\begin{array}{c} pI\delta'(u_F)\frac{\partial u_F}{\partial \bar{F}} h(u_F) K'(I+\hat{i}^*) - [V(u_F,\hat{i}^*) - \lambda x_2] \frac{\partial h(u_F)}{\partial u_F} \frac{\partial u_F}{\partial \bar{F}} K'(I+i) \\ -\frac{\lambda x_2}{I} \frac{g(u_O) g(u_F)}{[1-G(u_F)]^2 \delta'(u_O)} \frac{\partial u_F}{\partial \bar{F}} \end{array} \right] \\
&= [1-G(u_F)] \left[\begin{array}{c} pI\delta'(u_F) h(u_F) K'(I+i^*) - [V(u_F,i^*) - \lambda x_2] \frac{\partial h(u_F)}{\partial u_F} K'(I+i) \\ -\frac{\lambda x_2}{I} \frac{g(u_O) g(u_F)}{[1-G(u_F)]^2 \delta'(u_O)} \end{array} \right]
\end{aligned} \tag{IB.20}$$

Since u follows an exponential distribution, $\frac{\partial h(u_F)}{\partial u_F} = 0$. Thus, Equation (IB.20) 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.

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

We now formally characterize the correlation between the firm's optimal operational hedging policy and its inherited net debt level $\bar{F}$.

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 Appendix IB.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. Recall that $D = u_F - u_O$ is defined in Equation (2.1). 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 $D^*(\bar{F}_1) = 0$. This subsection shows that $\bar{F}_0$ and $\bar{F}_1$ exist and are unique with $\bar{F}_0 < \bar{F}_1$. $\hat{D}^* < 0$ if $\bar{F} < \bar{F}_0$ and $\hat{D}^* > 0$ if $\bar{F} > \bar{F}_0$. Similarly, $D^* < 0$ if $\bar{F} < \bar{F}_1$; and, $D^* > 0$ if $\bar{F} > \bar{F}_1$. The following proposition formalizes this relationship between the firm's optimal operational hedging policy and its net debt level maturing at date-1:

Proposition IB.1. *If Lemma IB.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 $\tilde{i}$ such that $u_F = u_O$.*

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

First of all, $\bar{i}$ in Appendix IB.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:

$$\frac{\partial D}{\partial i} = K'(I + i) - \frac{1}{I\delta'(u_O)} \ , \tag{IB.21a}$$

$$\frac{\partial D}{\partial \bar{F}} = 1 \ . \tag{IB.21b}$$

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 IB.4.

$$\frac{dD^*}{d\bar{F}} > 0 \textit{ if } u_F(i^*) \geq u_O(i^*) \tag{IB.22a}$$

$$\frac{d\hat{D}^*}{d\bar{F}} > 0 \textit{ if } u_F(\hat{i}^*) \geq u_O(\hat{i}^*) \tag{IB.22b}$$

Proof. First we prove the following inequality:

$$\frac{dD^*}{d\bar{F}} = \frac{\partial D^*}{\partial \bar{F}} + \frac{\partial D^*}{\partial i^*}\frac{\partial i^*}{\partial \bar{F}} > 0 \tag{IB.23}$$

Using Equations (IB.21a) and (IB.21b) Inequality (IB.23) is equivalent to

$$\left[K'(I + i^*) - \frac{1}{I\delta'(u_O)}\right]\left(-\frac{\partial i^*}{\partial \bar{F}}\right) < 1 \tag{IB.24}$$

From Appendix IB.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 (IB.13). $\frac{\partial^2 M}{\partial i^{*2}}$ is given by $[1 - G(u_F)]\frac{\partial S}{\partial i^*}$ where $\frac{\partial S}{\partial i^*}$ is given by Equation (IB.11) at $i = i^*$. Thus, Inequality

(IB.24) is equivalent to

$$\frac{V(u_F,i^*)\frac{\partial h(u_F)}{\partial u_F}K'(I+i^*)-pI\delta'(u_F)h(u_F)K'(I+i^*)}{\left[\begin{array}{c} K''(I+i^*)+p[1-\delta'(u_F)IK'(I+i^*)]h(u_F)K'(I+i^*) \\ +V(u_F,i^*)\frac{\partial h(u_F)}{\partial u_F}[K'(I+i^*)]^2+V(u_F,i^*)h(u_F)K''(I+i^*) \end{array}\right]}\frac{1-I\delta'(u_O)K'(I+i^*)}{-I\delta'(u_O)}<1 \tag{IB.25}$$

Algebraic simplification shows that the above inequality is equivalent to

$$\begin{aligned} & V(u_F,i^*)\frac{\partial h(u_F)}{\partial u_F}K'(I+i^*)+pI\left[\delta'(u_O)-\delta'(u_F)\right]h(u_F)K'(I+i^*) \\ & <\left[1+V(u_F,i^*)h(u_F)\right]K''(I+i^*)\left[-I\delta'(u_O)\right] \end{aligned} \tag{IB.26}$$

Since u follows a exponential distribution, $\frac{\partial h(u)}{\partial u}=0$ and the first term of the left-hand side of Inequality (IB.26) 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 (IB.26) is (weakly) smaller than zero. The right-hand side of Inequality (IB.26) is strictly greater than zero. Therefore, Inequality (IB.26) holds and $\frac{dD^*}{dF}>0$.

Now we prove the following inequality:

$$\frac{d\hat{D}^*}{d\bar{F}}=\frac{\partial\hat{D}^*}{\partial\bar{F}}+\frac{\partial\hat{D}^*}{\partial\hat{i}^*}\frac{\partial\hat{i}^*}{\partial\bar{F}}>0 \tag{IB.27}$$

Inequality (IB.23) is equivalent to

$$\left[K'(I+\hat{i}^*)-\frac{1}{I\delta'(u_O)}\right]\left(-\frac{\partial\hat{i}^*}{\partial\bar{F}}\right)<1 \tag{IB.28}$$

From Appendix IB.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 (IB.20). $\frac{\partial^2\hat{M}}{\partial\hat{i}^{*2}}$ 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 (IB.16) at $i=\hat{i}^*$. Thus, Inequality

(IB.28) is equivalent to

$$\frac{\begin{bmatrix} [V(u_F,\hat{i}^*)-\lambda x_2]\frac{\partial h(u_F)}{\partial u_F}K'(I+\hat{i}^*) \\ -pI\delta'(u_F)h(u_F)K'(I+\hat{i}^*) \\ +\frac{\lambda x_2}{I}\frac{g(u_O)g(u_F)}{[1-G(u_F)]^2\delta'(u_O)} \end{bmatrix}}{\begin{bmatrix} K''(I+\hat{i}^*)+p[1-\delta'(u_F)IK'(I+\hat{i}^*)]h(u_F)K'(I+\hat{i}^*) \\ +[V(u_F,\hat{i}^*)-\lambda x_2]\frac{\partial h(u_F)}{\partial u_F}[K'(I+\hat{i}^*)]^2 \\ +[V(u_F,\hat{i}^*)-\lambda x_2]h(u_F)K''(I+\hat{i}^*) \\ +\lambda x_2\left[\frac{g'(u_O)\delta'(u_O)-g(u_O)\delta''(u_O)}{[1-G(u_F)][\delta'(u_O)]^2I}+\frac{g(u_F)K'(I+\hat{i}^*)g(u_O)}{[1-G(u_F)]^2}\right]\frac{1}{I\delta'(u_O)} \end{bmatrix}}\frac{1-I\delta'(u_O)K'(I+\hat{i}^*)}{-I\delta'(u_O)}<1 \tag{IB.29}$$

Algebraic simplification shows that the above inequality is equivalent to

$$\begin{aligned}&[V(u_F,\hat{i}^*)-\lambda x_2]\frac{\partial h(u_F)}{\partial u_F}K'(I+\hat{i}^*)+pI\left[\delta'(u_O)-\delta'(u_F)\right]h(u_F)K'(I+\hat{i}^*)+\frac{\lambda x_2}{I}\frac{g(u_O)g(u_F)}{[1-G(u_F)]^2\delta'(u_O)}\\ &<\Big[1+[V(u_F,\hat{i}^*)-\lambda x_2]h(u_F)\Big]K''(I+\hat{i}^*)\left[-I\delta'(u_O)\right]-\lambda x_2\frac{g'(u_O)\delta'(u_O)-g(u_O)\delta''(u_O)}{[1-G(u_F)][\delta'(u_O)]^2I}\end{aligned} \tag{IB.30}$$

Since u follows a exponential distribution, $\frac{\partial h(u)}{\partial u}=0$ and the first term of the left-hand side of Inequality (IB.30) 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 (IB.30) is strictly greater than zero. Therefore, to show that Inequality (IB.30) holds, we need to show that:

$$\frac{\lambda x_2}{I}\frac{g(u_O)g(u_F)}{[1-G(u_F)]^2\delta'(u_O)}<-\lambda x_2\frac{g'(u_O)\delta'(u_O)-g(u_O)\delta''(u_O)}{[1-G(u_F)][\delta'(u_O)]^2I} \tag{IB.31}$$

Or, equivalently,

$$\begin{aligned}&\frac{\lambda x_2}{I}\frac{g(u_O)g(u_F)}{[1-G(u_F)]^2\delta'(u_O)}+\lambda x_2\frac{g'(u_O)\delta'(u_O)-g(u_O)\delta''(u_O)}{[1-G(u_F)][\delta'(u_O)]^2I}<0\\ \Leftrightarrow\ &\frac{\lambda x_2}{I[1-G(u_F)]\delta'(u_O)}\left[\frac{g(u_O)g(u_F)}{[1-G(u_F)]}+\frac{g'(u_O)\delta'(u_O)-g(u_O)\delta''(u_O)}{\delta'(u_O)}\right]<0\\ \Leftrightarrow\ &\frac{g(u_O)g(u_F)}{[1-G(u_F)]}+\frac{g'(u_O)\delta'(u_O)-g(u_O)\delta''(u_O)}{\delta'(u_O)}>0\end{aligned} \tag{IB.32}$$

Since $g(u)=\alpha\exp(-\alpha u)$, $\alpha g(u)=-g'(u)$, and $\frac{g(u_F)}{[1-G(u_F)]}=\alpha$, the inequality (IB.32) is equivalent to

$$\frac{\delta''(u_O)}{\delta'(u_O)} < 0 \tag{IB.33}$$

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

IB.4.1 Proof of Proposition IB.1

Now we prove Proposition IB.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 2.5 and Section 2.6, we know that u_F is greater than u_O, i.e., $D^*, \hat{D}^* > 0$ when $\bar{F}$ is sufficiently high, i.e., $\bar{F} \geq \bar{F}_M$. To see this, from Lemma IB.1,$D^* > 0$ if $\bar{F} \geq \bar{F}_M$. From Lemma 2.1, for a given $\bar{F}$, $\hat{i}^* > i^*$. Since $D(i, \bar{F})$ increases in i, $\hat{D}^* > 0$ when $\bar{F} \geq \bar{F}_M$. 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 IB.4, $\frac{d\hat{D}^*}{d\bar{F}} > 0$ 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 2.1, $\hat{i}^* > i^*$ 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, $\bar{F}_1 > \bar{F}_0$.

To conserve space, we omit the argument $\bar{F}$ in i^*, $\tilde{i}$ and $\hat{i}^*$. If $\bar{F} \leq \bar{F}_0$, then $D^* < 0$ and $\hat{D}^* \leq 0$. Thus, maximizing the equity value subject to $u_F \leq u_O$ will yield the optimal operational hedging policy $\hat{i}^*$. Meanwhile, maximizing the equity value subject to $u_F \geq u_O$ will yield a corner solution $\tilde{i} > i^*$, in which $\tilde{i}$ is such that $D(\tilde{i}, \bar{F}) = 0$. Indeed, for a given $\bar{F}$ in this region, the feasible set of i for the maximization problem of the equity value subject to $u_F \geq u_O$, if not empty, is $i \geq \tilde{i} > i^*$. From Appendix IB.2, the equity value E decreases in i for $i > i^*$. Since $\tilde{i}$ is also feasible for the maximization problem of the equity value 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, compared with $\hat{i}^*$. Thus, the 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 equity value 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 $D(\tilde{i}, \bar{F}) = 0$. This is because, for a given $\bar{F}$ in this region, the feasible set of i for the maximization problem of the equity value subject to $u_F \geq u_O$ is $i \geq \tilde{i} > i^*$, and from Appendix IB.2, equity value E decreases in i for $i > i^*$. Meanwhile, the feasible set of i for the maximization problem of the equity value subject to $u_F \leq u_O$ is $i \leq \tilde{i} < \hat{i}^*$ and from Appendix IB.3, $\hat{E}$ increases in i for $i < \hat{i}^*$. Thus, the 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 equity value subject to $u_F \geq u_O$ will yield the optimal operational hedging policy i^*. Meanwhile, maximizing the equity value subject to $u_F < u_O$ will yield a corner solution $\tilde{i} < \hat{i}^*$. Indeed, for a given $\bar{F}$ in this region, the feasible set of i for the maximization problem of the equity value subject to $u_F \leq u_O$, if not empty, is $i \leq \tilde{i} < \hat{i}^*$ and from Appendix IB.3, $\hat{E}$ increases in i for $i < \hat{i}^*$. Since $\tilde{i}$ is also feasible for the maximization problem of the equity value 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, compared with i^*. Thus, the optimal operational hedging policy is i^*.

Now we prove Proposition 2.1. From Proposition IB.1 and Lemma IB.2, when $\bar{F} > \bar{F}_1$, $i^{**} = i^*$ and thus decreases in $\bar{F}$. Similarly, from Proposition IB.1 and Lemma 2.2, 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 (IB.21a) and (IB.21b), $\frac{\partial \tilde{i}}{\partial \bar{F}} < 0$. 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 $D^* = 0$, $i^* = \tilde{i}$, 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 $\bar{F}$.

IB.5 Partial pledgeability

The value of equity when $u_{F,PP} > u_O$ can be written as

$$E_{PP} = \int_{u_{F,PP}}^{\infty} \Big[(u - u_{F,PP}) - \tau p[(1-\delta(u_{F,PP}))I + i] + p[(1-\delta(u))I + i] + x_2\Big] g(u) du \ . \quad \text{(IB.34)}$$

The value of equity when $u_{F,PP} < u_O$ is $E_{PP} - \int_{u_F}^{u_O} \lambda x_2 g(u) du$.

The partial pledgeability case can be solved in an analogues manner as the zero pledgeability case. We define $\hat{i}^*_{PP}$ as the optimal hedging policy that maximizes the equity value when $u_{F,PP} < u_O$; $\tilde{i}_{PP}$ as the optimal hedging policy that equalizes the operational and financial default boundaries $u_O(\tilde{i}_{PP}) = u_{F,PP}(\tilde{i}_{PP}, \bar{F})$; and, i^*_{PP} as the optimal hedging policy that maximizes the equity value when $u_{F,PP} > u_O$. Specifically, i^*_{PP} and $\hat{i}^*_{PP}$ are given respectively by the following first-order conditions:

$$p - K'(I + i^*_{PP}) = V(u_{F,PP}, i^*_{PP})\ h(u_{F,PP})\ \frac{[K'(I + i^*_{PP}) - \tau p]}{[1 - \tau p \delta'(u_{F,PP}) I]}\ , \quad \text{(IB.35)}$$

$$p - K'(I + \hat{i}^*_{PP}) = \Big[V(u_{F,PP}, \hat{i}^*_{PP}) - \lambda x_2\Big] \; h(u_{F,PP}) \, \frac{[K'(I + \hat{i}^*_{PP}) - \tau p]}{[1 - \tau p \delta'(u_{F,PP}) I]}$$
$$+ \frac{\lambda x_2 g(u_O)}{[1 - G(u_{F,PP})] I \delta'(u_O)} \; . \tag{IB.36}$$

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

$$\bar{F}_{fb,PP} + K(I + \bar{i}_{PP}) = \tau * p * \bar{i}_{PP} \; . \tag{IB.37}$$

In other words, $\bar{F}_{fb,PP}$ 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. $\bar{F}_{0,PP}$ and $\bar{F}_{1,PP}$ are defined analogously to the respective thresholds in Proposition IB.1: $\bar{F}_{0,PP}$ is such that $u_{F,PP}(\hat{i}^*_{PP}, \bar{F}_{0,PP}) = u_O(\hat{i}^*_{PP})$; $\bar{F}_{1,PP}$ is such that $u_{F,PP}(i^*_{PP}, \bar{F}_{1,PP}) = u_O(i^*_{PP})$. The following proposition characterizes the firm's optimal hedging policy as a function of $\bar{F}$ when the pledgeability is imperfect, i.e., $\tau < \bar{\tau} < 1$:[25]

Proposition IB.2. *There exists $\bar{\tau} < 1$ such that if $\tau < \bar{\tau}$, then*

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

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

III. If $\bar{F}_{0,PP} < \bar{F} < \bar{F}_{1.PP}$, the firm's optimal operational hedging policy is $\tilde{i}_{PP}$ such that $u_{F,PP} = u_O$.

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

[25] The proofs of Proposition IB.2 and Proposition 3.1 are similar to the base case although the algebra is much more involved. The proofs are available upon request.

I.C. Empirical results with interaction terms between credit risk and market power

In this appendix, we augment our baseline regressions , Table 4, Table 5 and Table 6 in the main text with the interaction terms between market power variables — Dummy variable for the top 4 industry seller, Sales/industry sales — and -(Z-score). All the variable definitions are the same as of respective definitions in Table 1.

Table IC.1: **Interactions between market power variables and -(Z-score): Baseline and NBER recessions**

Estimation of the relationship between Markup, -(Z-score), the market power — proxied by Dummy variable for the top 4 industry seller, Sales/industry sales — and the interaction terms between the market power and -(Z-score). In columns (3) and (4), we further include the interaction terms between market power, -(Z-score) and the dummy variable *Recession* that equals one during the NBER-designated recession quarters, zero otherwise. The regressions include firm and Fama-French 48 Industry × year-quarter fixed effects. Control variables are the same as Table 4. Standard errors are clustered at firm and year-quarter levels. *, **, *** denote significance below 10%, 5%, and 1% levels, respectively.

VARIABLES	*Markup*			
	(1)	(2)	(3)	(4)
Top 4 industry seller × -(Z-score) × Recession			-0.00034	
			(0.0017)	
Sales/industry sales × -(Z-score) × Recession				0.00048
				(0.021)
Top 4 industry seller × -(Z-score)	-0.0029**		-0.0027**	
	(0.0011)		(0.0012)	
Sales/industry sales × -(Z-score)		-0.076***		-0.075***
		(0.018)		(0.020)
-(Z-score) × Recession			0.0016***	0.0017***
			(0.00051)	(0.00053)
-(Z-score)	0.0029***	0.0030***	0.0028***	0.0028***
	(0.00053)	(0.00053)	(0.00052)	(0.00052)
Market power variables	Yes	Yes	Yes	Yes
Market power variables × Recession	No	No	Yes	Yes
Other control variables	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes
Industry × Year-quarter fixed effects	Yes	Yes	Yes	Yes
Observations	564,418	564,418	554,348	554,348
R-squared	0.634	0.634	0.636	0.636

Table IC.2: **Interactions between market power variables and -(Z-score): Financial crisis**

Regressions of Markup on -(Z-score), exposure to the 2008 financial crisis, market power and interaction terms among the three variables. We augmented the regression models in Table 6 with market power × -(Z-score) × Exposure. The variable definitions are in Table 1. The regressions include firm and Fama-French 48 Industry × year-quarter fixed effects. Standard errors are clustered by firm. *, **, *** denote significance below 10%, 5%, and 1% levels, respectively.

VARIABLES	*Markup*					
	% # Loans reduction		Lehman exposure		ABX exposure	
	(1)	(2)	(3)	(4)	(5)	(6)
Top 4 industry seller × -(Z-score) × Exposure	0.078		0.109		0.042	
	(0.094)		(0.161)		(0.084)	
Sales/industry sales × -(Z-score) × Exposure		0.511		0.578		0.193
		(0.688)		(1.118)		(0.616)
-(Z-score) × lender exposure	0.086**	0.083**	0.159**	0.156**	0.084***	0.083***
	(0.034)	(0.035)	(0.072)	(0.073)	(0.027)	(0.027)
Lender exposure	-0.700	-0.710	-0.971	-0.976	-0.905**	-0.904**
	(0.455)	(0.457)	(0.689)	(0.691)	(0.410)	(0.412)
Market power variables	Yes					
Market power variables × Exposure	Yes					
Market power variables × -(Z-score)	Yes					
Other control variables	Yes					
Other control variables × Exposure	Yes					
Firm fixed effects	Yes					
Industry × Year-quarter fixed effects	Yes					
Observations	20,621	20,621	20,621	20,621	20,621	20,621
R-squared	0.905	0.905	0.905	0.905	0.906	0.906