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Corporate Risk Management: Integrating Liquidity, Hedging, and Operating Policies

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We analyze the value created by a dynamic integrated risk management strategy involving liquidity management, derivatives hedging, and operating flexibility, in the presence of several frictions. We show that liquidity serves a critical and distinct role in risk management, justifying high levels of cash. We find that the marginal value associated with derivatives hedging is likely to be low, though we explain why some empirical studies find a higher value. We explore the complex interactions between operating flexibility and financial risk management, finding that substitution effects are nonmonotonic and are affected by operating leverage, the nature of operating flexibility, and the effectiveness of the hedging instrument.

Key words: finance; corporate finance; risk management; hedging; operating flexibility; cash management

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1. Introduction

Risk management has become a critical dimension of corporate financial policy, particularly in light of recent global financial and economic crises. The corporate risk management literature focuses on the potential benefits of hedging with financial derivatives, addressing questions of why companies do (or should) use derivatives and under what circumstances value is created through such use. A separate strand of the corporate finance literature analyzes the rationale and benefit of cash holdings, including understanding the precautionary motive for liquidity in the presence of uncertainty. Yet another branch of corporate finance explores the value of operating flexibility, such as real options to shut down facilities or switch modes of production.

In practice, all three of these mechanisms are commonly used to manage risk; thus, it is important to understand how they can be coordinated in an integrated fashion, and what the relative contribution of each is in the presence of the others. We provide some new insights on corporate risk management from a normative perspective through a dynamic model that incorporates liquidity, hedging, and operating policies. The key contributions of the paper are briefly outlined below.

First, we examine the simultaneous impact of several common motivations for risk management, and we separate out the relative impact of each in the presence of the others. We specifically focus on the reduction of expected tax payments (Graham and

Rogers 2002), the avoidance of external financing costs (Froot et al. 1993), and the mitigation of financial distress and default costs (Smith and Stulz 1985). Our results indicate that avoiding distress costs is likely the strongest motivation to create value through risk management. This is consistent with recent survey evidence from Lins et al. (2010) regarding the role of cash. Although Aretz and Bartram (2010) find mixed evidence regarding the use of derivatives to avoid financial distress, as Guay and Kothari (2003) conclude, financial hedging may be used only to fine-tune a risk management strategy that is otherwise implemented using operational and other strategies, and this is particularly the case for distress cost avoidance, as we argue below.

Second, we examine the impact of personal taxes in the presence of uncertainty. Personal taxes create an indirect cost to tapping equity markets since shareholders receive payouts net of personal tax, while they provide capital at gross value. Although this friction is typically not highlighted, it can significantly drive up the effective cost of external financing and thus further motivate the need for corporate risk management.

Third, our structural model provides insights on the marginal benefits of each risk management mechanism when others are present, and when there are costs associated with each type of activity (an endogenously determined tax penalty to holding cash, transactions costs associated with a dynamic hedging program, and adjustment costs associated with managing

operating flexibility). We show that although there is some substitutability between risk management mechanisms, the three approaches are by no means redundant and must be coordinated to maximize value creation. The presence of alternative forms of risk management in our model also helps to explain the conflicting evidence surrounding whether (and how much) value is created through the use of derivatives by corporations. Based on a set of calibrated simulations, we estimate that the marginal value of hedging with derivatives, taking into account the presence of alternative risk management mechanisms, is likely to be no more than 2% on average. This is consistent with the lack of evidence of any value creation attributable to hedging in several recent studies. However, we find that for firms facing a key exposure that can be more effectively hedged, the value creation from hedging with derivatives could be significantly higher, as found by Haushalter (2000) for oil and gas firms, Allayannis and Weston (2001) for exporters, and Carter et al. (2006) for airlines.

Fourth, our results demonstrate why liquidity is an important, and in many circumstances the most effective, risk management mechanism, particularly when the ability of hedging tools to mitigate risk exposure is limited, and when there are large extraordinary costs involved in restructuring operations. Our findings thus provide theoretical support for the recent empirical findings of Bates et al. (2009) and furthermore suggest specific firm characteristics that may lead to higher cash balances.

Fifth, we show that even our relatively complex integrated risk management strategy falls significantly short of restoring the value loss due to frictions in our model. This result underscores that firms that limit their scope of risk management activities to managing a cash balance and using derivatives may be undervalued relative to their potential. This explains why companies are increasingly designing comprehensive enterprise risk management programs that go beyond standard financial risk management strategies.

Sixth, we examine the effect of varying levels of operating flexibility on the optimal financial risk management strategies, and the value derived thereof. We show that although operating flexibility and financial risk management are substitutes by and large, the relationship is more subtle. For instance, the average cash balance has a nonmonotonic relationship with the level of flexibility. Furthermore, we find that the correlation between firm risk and underlying risks of available derivatives influences not only the strength of the substitution effect but also the operating decisions of the firm through indirect effects.

The notion of integrated risk management is certainly not new. Meulbroek (2001, 2002) discusses the

importance of integrating various risks in an organization and coordinating alternative ways of managing the resulting net exposure. However, there has been limited work to date to develop a robust theoretical framework to analyze this issue. With few exceptions that we briefly discuss below, studies that have considered multiple mechanisms to manage risk have typically focused on just two of the three we examine, and have generally done so in an empirical context, often by simply including an extra regression variable.

The interaction between operating flexibility and hedging has been highlighted in several empirical studies, including Allayannis et al. (2001), Bartram (2008), Hankins (2011), and Pantzalis et al. (2001), all of whom document a negative relation between these forms of risk management. Mello et al. (1995) construct a model to illustrate how operating flexibility and hedging interact as substitute risk management mechanisms, but also point out that there can be an element of complementarity between them.

The interaction between operating flexibility and liquidity has received more limited attention. Although empirical analyses of liquidity typically include some characteristics of a firm's assets, such as tangibility, which may be related to flexibility, the interaction of operating flexibility with a firm's cash management policy has not been carefully explored. The primary emphasis in this literature has been on understanding the role of liquidity in alleviating investment distortions.

The interaction between hedging and liquidity has been addressed by including liquidity as a regression variable in empirical studies on hedging. The evidence suggests that users of derivatives have lower short-term liquidity than companies not using derivatives (e.g., Geczy et al. 1997). More recently, Allayannis and Schill (2010) examine the relationship between liquidity and hedging, as well as payout and leverage policies, and find a positive association between "conservative" policies and firm value. Because the use of derivatives is typically treated as a binary variable (or even indirectly proxied when disclosure data on derivatives is not available), there has been no direct effort to carefully analyze the interaction between liquidity and hedging as we do in our model. Although Mello and Parsons (2000) provide a dynamic model that combines liquidity, and hedging, cash is not a control variable as it is in our model. Rather, it accumulates or decreases based on firm profitability over time. Their key contributions are to emphasize that risk management policies that decrease the volatility of firm value or cash flow will likely not maximize firm value, and that the marking-

to-market feature of futures can result in an amplification of risk through hedging.¹

A recent paper by Bolton et al. (2011) provides a dynamic model that integrates liquidity and hedging, while also allowing partially reversible investment. The main focus of their paper is on the relationship between investment and marginal q in the presence of financing frictions that can be moderated by cash holdings, financial derivatives, or lines of credit. In contrast, we focus on the interplay between hedging, liquidity, and operating flexibility, and we develop new insights regarding integrated risk management, as detailed above.

Another key difference between our paper and Bolton et al. (2011) is the role of flexible capital. In our model, a firm has the flexibility to change its operating mode to control its exposure to underlying uncertainty.² In Bolton et al. (2011), the flexibility to reduce capital in times of negative profitability shocks allows the firm to generate liquidity to avoid distress costs. Thus, capital in their model is a latent, if costly, store of liquidity. This partially confounds the role of flexible capital and liquidity in their paper, and the need for liquidity is primarily driven by financial constraints rather than risk management in general. As a result, liquidity does not emerge in their model as being as critical as in our model. Their framework is less appropriate for companies whose key assets are human capital and other intangible assets that do not have significant liquidation value, and where restructuring (downsizing) involves significant costs, as we capture in our model. Our framework also allows us to readily explore the effects of varying degrees of operating flexibility. Finally, we examine the impact of a range of correlations between the hedging instrument and the firm's overall risk, whereas Bolton et al. (2011) assume a single, and very high, correlation value, leading to potentially biased results.³

¹ Rampini and Viswanathan (2010) also focus on the collateral implications of risk management. They examine the interaction of risk management and financing constraints and argue that allocating or reserving collateral to support financing needed for investment will limit a firm's ability to engage in risk management. They assume that debt and risk management contracts are secured, riskless, and single period, and the firm's only asset is its capital. In contrast, we allow for risky, unsecured, and long horizon debt and risk management contracts, and the ability to build up, and draw down, a cash balance.

² Bolton et al. (2011) have constant returns to scale, so their exposure to business risk (per unit of capital) is the same for all levels of capital stock.

³ There are several other fundamental differences that distinguish our model from that in Bolton et al. (2011). They focus on only one motivation for risk management, namely, avoiding financing costs, while we also incorporate several others, and compare their relative impact. Our model captures the joint impact of corporate and personal taxes on the indirect costs of carrying cash and issuing equity,

2. The Model

We model the operating, financing, and hedging decisions of a firm with a production process that can be suspended and reactivated over time in response to the fluctuations of a state variable affecting the cash flow. We use a discrete-time infinite-horizon framework.

2.1. Production Technology

The firm has operating flexibility in that it can decide to start production if it is idle, or it can temporarily cease operations. We denote m to be the status of the firm, where $m \in \{0, 1\}$, with 1 if operations are open/active, and 0 in the closed/idle status. While having two modes of operation simplifies our model structure, it also allows us to better represent situations where the firm's cash flow is either exposed, or not, to an underlying risk. This will allow us to draw clearer conclusions regarding the effects of state-contingent risk management strategies.

The firm's cash flow is determined by a stochastic factor, θ_1 , which is priced in the financial market. Under the risk-neutral probability measure, the stochastic process of the log of this price variable, $x_1 = \log \theta_1$, is described by

$$x_1(t) - x_1(t-1) = (1 - \kappa_1)(\bar{x}_1 - x_1(t-1)) + \sigma_1 \varepsilon_1(t), \quad (1)$$

where $0 \leq \kappa_1 \leq 1$ is the persistence parameter, $\sigma_1 > 0$ is the conditional standard deviation, $\bar{x}_1 = \log \bar{\theta}_1$ is the long-term mean, and ε_1 are independent and identically distributed standard normal variates.

The cash flow of the firm, $R(\theta_1, m)$, is equal to the fixed production rate, $q > 0$, times the difference between the price θ_1 and the average production cost per unit, A , if the firm is active (and zero if the firm is idle): $R(\theta_1, m) = q(\theta_1 - A)$ if $m = 1$, and $R(\theta_1, m) = 0$ if $m = 0$.⁴ Opening and closing decisions entail costs. A change in the operating policy is represented by a transition from m to m' . Hence, the cost of changing the operating status is the function $K(m, m') = K^c$ if $m = 1$ and $m' = 0$, $K(m, m') = K^o$ if $m = 0$ and $m' = 1$, and $K(m, m') = 0$ otherwise. For brevity, we denote the net cash flow from the firm's operations as $g(\theta_1, m, m') = R(\theta_1, m) - K(m, m')$.

whereas they impose an exogenous cost to carrying cash (which is constant) and issuing equity (proportional to asset size). In terms of the impact of hedging on cash holdings, we follow the convention for over-the-counter derivatives trading that contracts are marked to market when they are closed out, and are subject to default and costly to renegotiate, consistent with Fehle and Tsyplakov (2005). In contrast, Bolton et al. (2011) assume that market index futures are used, which are subject to cash margin requirements and are thus presumably riskless. Furthermore, the margin induces a positive relationship between hedging and liquidity, all else equal.

⁴ More general specifications could allow for a stochastic q subject to large downward jumps, or to other forms of operational risks that suddenly impact a firm in catastrophic ways. We do not attempt to specifically capture such operational risks in our model.

2.2. Hedging

The firm can take a long position in a perpetual and puttable swap contract issued by a bank. (We later, in §3.3, consider other derivative structures with nonlinear payoff structures and/or shorter lives.) The underlying asset of the swap is denoted θ_2 , and $x_2 = \log \theta_2$ follows the process

$$x_2(t) - x_2(t-1) = (1 - \kappa_2)(\bar{x}_2 - x_2(t-1)) + \sigma_2 \varepsilon_2(t), \quad (2)$$

where $0 \leq \kappa_2 \leq 1$, $\sigma_2 > 0$, $\bar{x}_2 = \log \bar{\theta}_2$, and ε_2 are independent and identically distributed standard normal variables. Without loss of generality, we restrict the analysis to the case where the two state variables θ_1 and θ_2 have positive correlation, $\mathbb{E}[\varepsilon_1(t)\varepsilon_2(t)] = \rho \geq 0$ and $\mathbb{E}[\varepsilon_1(t)\varepsilon_2(t')] = 0$ for any $t \neq t'$. When $0 < \rho < 1$, the swap offers an imperfect hedge of the risk of the firm.⁵ We also examine the case where $\rho = 1$, where the firm may seemingly be able to eliminate all the firm's risk. We denote $\theta = (\theta_1, \theta_2)$ as the vector of the exogenous state variables.

The swap price for a unit of product, s , is a given constant. Thus, if a firm enters into a swap agreement for a notional physical amount $h \geq 0$, at each subsequent date t it pays $\theta_2(t)$ and receives s for each unit of notional capital; that is, the net payoff from the swap to the firm is $h(s - \theta_2(t))$. The par value of the derivative contract for a unit notional amount, $h = 1$, excluding counterparty risk and the put provision at time t is

$$SP_t = SP(\theta_2(t)) = \sum_{i=1}^{\infty} \frac{s - F_i(\theta_2(t))}{(1+r)^i} < \infty, \quad (3)$$

where $F_i(\theta_2(t)) = \mathbb{E}_t[\theta_2(t+i)]$ is the forward price at time t for delivery of the asset at date $t+i$; $\mathbb{E}_t[\cdot]$ is the expectation under the risk-neutral probability measure, conditional on the information $\theta = \theta(t)$; and r is the risk-free rate. It can be shown that⁶

$$F_i(\theta_2(t)) = \theta_2(t)^{\kappa_2^i} \bar{\theta}_2^{1-\kappa_2^i} \exp\left(\frac{\sigma_2^2}{2} \frac{1 - \kappa_2^{2i}}{1 - \kappa_2^2}\right). \quad (4)$$

The firm can default on the swap, and may choose to change the notional amount from $h \geq 0$ to a higher

or lower level $h' \geq 0$. If it does wish to alter its position in the swap, it redeems the current contract at the *par value*, and enters into a new agreement at the current *fair value*, denoted SF_t . Hence, the net payoff from the transaction is $SP_t h - SF_t h'$. We assume that each transaction (closing the old contract and opening the new one) also entails a negotiation cost, nc , proportional to the value of the notional amount, so that the direct cost of adjusting the hedge is $(h' + h)nc$.

At the inception of the swap agreement, the fair value of the contract, SF_t , reflects both default risk and the option to close the swap position in the future, and thus it can be different from the par value, SP_t . This implies that there is an indirect cost associated with adjusting a swap position at a later date.⁷ We assume for simplicity that the bank selling the swap is not subject to default risk, and thus the only credit charge in the price of the contract is related to the default risk of the firm. Hence, the fair value of the swap contract at time t is

$$SF_t = \mathbb{E}_t \left[\sum_{i=1}^{\min\{T_d, T_p\}} \frac{s - \theta_2(t+i)}{(1+r)^i} \right] + \mathbb{E}_t \left[\chi_{\{T_d \geq T_p\}} \frac{SP(\theta_2(t+T_p))}{(1+r)^{T_p}} + \chi_{\{T_d < T_p\}} \frac{RS(\theta(t+T_d))}{(1+r)^{T_d}} \right], \quad (5)$$

where T_d is the default date and T_p is the date the swap position is closed, both stopping times with respect to the process $\{\theta(t)\}$. Through them, the fair value of the swap contract depends on the corporate policy decided by equity holders. This policy will be determined endogenously. The bank's recovery value on the swap upon defaults, $RS(\cdot)$, depends on the value of the firm, as will be shown below. In Equation (5), $\chi_{\{A\}}$ is the indicator function of the event A , $\{T_d \geq T_p\}$ is the set of paths such that default happens after the position in the swap is closed, and $\{T_d < T_p\}$ is the set where the opposite happens.

The first term in Equation (5) is the present value of the net payoff to the firm before the firm terminates the swap agreement due to rebalancing its hedge position, or defaults. The second term is the payoff to the bank if the firm terminates the swap or defaults. The bank is paid the par value in the former case, and a reduced recovery value in the latter.

Since the swap price, s , is fixed, SF_t and SP_t can be either positive or negative. Thus, as opposed to the typical swap contract where the swap price is set up so that $SF_t = 0$ at inception, here there may be an upfront payment: a cash inflow for the firm if $SF_t < 0$

⁵ In our model, we use a fairly general profit function and allow for a wide range of correlation between available hedging instruments and the profit. This is a more general mechanism than specifying a particular functional form for earnings before interest and taxes, as do many papers, where one variable (e.g., the revenue) can be perfectly hedged and another variable (e.g., production cost) cannot be hedged at all. The fundamental issue is that some risks in general can be readily hedged whereas others are not easy to hedge, if at all. This creates a situation for most firms where only a small fraction of the risk exposure can be hedged using derivatives.

⁶ This follows from a property of normal distributions, $F_i(\theta_2(t)) = \exp(\mathbb{E}_t[x_2(t+i)] + \frac{1}{2} \text{Var}_t[x_2(t+i)])$, and the observation that $\mathbb{E}_t[x_2(t+i)] = \kappa_2^i x_2(t) + \bar{x}_2(1 - \kappa_2^i)$ and $\text{Var}_t[x_2(t+i)] = \sigma_2^2(1 - \kappa_2^{2i})/(1 - \kappa_2^2)$.

⁷ This indirect cost is $(SF_t - SP_t)h'$, and thus the payoff from adjusting the hedge, net of both indirect and direct costs, can be rewritten as $(h - h')SP_t - (SF_t - SP_t)h' - (h' + h)nc$.

or an outflow if $SF_i > 0$.⁸ Because of the credit charge and the possibility of renegotiating the hedging contract, we can anticipate that in general $SF_i \neq SP_i$.

2.3. Financial Policy

The firm may retain a liquidity balance, b , in the form of cash (or cash-equivalent assets) earning a rate of return of r per period. This cash balance can increase by retaining after-tax operating earnings, by issuing equity, or by entering into a swap contract with negative value, or conversely by closing out a swap with positive value. If external equity is raised, we assume that a proportional flotation cost, λ , is incurred. The cash balance will decrease if the firm uses its cash to cover operating losses, pays opening and closing costs, enters into a positive value swap or closes out a negative value swap, or provides a payout to equity holders.

We assume that the firm has issued a nonredeemable defaultable consol bond with face value d .⁹ The firm pays a coupon rate r on the debt at the end of every period. The debt level is assumed to be constant over time for simplicity. As Gamba and Triantis (2008) show, when there are costs associated with debt rebalancing, firms will choose to actively manage their financial flexibility by adjusting the cash balance rather than the debt level, which is the structure we model here.

2.4. Personal and Corporate Taxes

Corporate pretax earnings depend on the state at a particular time and the set of decisions made at that time. We use w as shorthand for the earnings $w(\theta, m, b, h, m', b', h')$:

$$w = g(\theta_1, m, m') - r(d - b) + h(s - \theta_2) + (hSP(\theta_2) - h'SF(\theta, m', b', h') - nc(h' + h))\chi_{\{h' \neq h\}},$$

where $\chi_{\{h' \neq h\}}$ is the indicator function of event $h' \neq h$. We assume a convex corporate tax function $\tau_c(w) = \tau_c^+ \max\{w, 0\} + \tau_c^- \min\{w, 0\}$, where $\tau_c^+ \geq \tau_c^-$ and $\tau_c^- > 0$ to model a limited loss offset provision. Personal taxes are levied at rates $\tau_e \geq 0$ on payments to equity holders and $\tau_d \geq 0$ on payments to bondholders. With respect to taxes on payouts to equity, we do not distinguish between dividends and equity repurchases (nor do we separately consider capital gains).

⁸ To simplify our model, we fix the swap price at a constant level, rather than setting the price to yield a zero swap value. For robustness, we have also used different swap price levels, and this does not affect our results.

⁹ One could also interpret d as the debt net of the value of assets in place that provide a fixed stream of risk-free payments over time.

2.5. Financial Distress

If the after-corporate-tax operating cash flow, net of the payoff from the swap contract and from a change in the hedging policy, plus the cash balance, is lower than the interest on net debt, or $w - \tau_c(w) + b < 0$, the firm is in a liquidity crisis. Financial distress costs are a proportion, dc , of the cash shortfall from the coupon payment. In addition to raising cash from equity holders to cover the shortfall (with an effective cost of $(1 + dc)(1 + \lambda)$ per dollar of external equity in this case of distress), the firm may raise further capital to create a positive cash balance going forward. Any additional amount raised from equity holders is subject only to the standard proportional cost of λ .

2.6. Valuation of Securities

We base our valuation and the determination of the associated optimal policy on the objective of firm value maximization. We do so to focus on the normative question of how to minimize the impact of frictions on firm value. In practice, the risk management decisions of managers will clearly reflect a number of factors including the structure of managerial incentives as well as contractual terms and regulatory controls designed to prevent managerial and financial agency problems, particularly with respect to the use of derivatives. We do not attempt to capture these additional intricacies here.¹⁰

The value of equity at time t , with $\theta = \theta(t)$ is

$$E(\theta, m, b, h) = e(\theta, m, b, h, m', b', h') + \beta \mathbb{E}_\theta[E(\theta', m', b', h')], \quad (6)$$

where $e_t = e(\theta, m, b, h, m', b', h')$ is the cash flow to equity given the firm's decisions regarding the next period's operating state (m'), the cash balance level (b'), and the swap position (h'), which are made at the beginning of the period after the current state (θ) is observed; and θ' is the unknown end-of-period state. The discount factor for valuing equity flows is $\beta = (1 + r_z(1 - \tau_e))^{-1}$, where $r_z = r(1 - \tau_d)/(1 - \tau_e)$ is the certainty equivalent rate of return on equity; $\mathbb{E}_\theta[\cdot]$ is the expectation conditional on the current state (θ). The cash flow to equity $e(\theta, m, b, h, m', b', h') = \max\{cfe, 0\}(1 - \tau_e) + \min\{cfe, 0\}(1 + \lambda)$, where $cfe = \max\{w - \tau_c(w) + b, 0\} + \min\{w - \tau_c(w) + b, 0\}(1 + dc) - b'$ can be positive, in which case the payout to equity is taxed at the personal rate τ_e , or negative, in which case equity is raised, subject to the flotation cost λ .

¹⁰ The strategies employed to mitigate risk may themselves be subject to agency problems. For instance, cash may be hoarded and then inefficiently spent by managers, the flexibility inherent in some real assets may be inappropriately exploited, and derivatives may be used for speculation rather than hedging (Geczy et al. 2007).

To define the value of debt, we first denote the firm's policy as $\varphi(\theta, m, b, h)$ and the default indicator as $\delta(\theta, m, b, h)$. Upon default, the cash balance is paid out, a new cash balance is set at $b = d$ (the firm becomes unlevered), the swap contract is liquidated and settled ($h = 0$), and the operating policy is unchanged (i.e., in default, the optimal policy is $(m, d, 0)$). The value of corporate debt is¹¹

$$D(\theta, m', b', h') = \beta \mathbb{E}_\theta [cfd(\theta', m', b', h', \varphi)], \quad (7)$$

where the after-personal-tax cash flow to debt is

$$\begin{aligned} cfd(\theta', m', b', h', \varphi) &= (1 - \delta(\theta', m', b', h'))(rd(1 - \tau_d) + D(\theta', m'', b'', h'')) \\ &\quad + \delta(\theta', m', b', h') \min \{ rd(1 - \tau_d) + d, \\ &\quad \max \{ 0, b' + (1 - \gamma)E(\theta', m', d, 0) + h((s - \theta'_2) + SP(\theta'_2)) \} \}. \end{aligned}$$

The first term on the right-hand side is the payoff to bondholders when the firm is solvent. As above, the value of debt, D , is defined in relation to the policy $\varphi(\theta', m', b', h') = (m'', b'', h'')$. For this reason, φ is an argument of cfd . The second term is the residual payoff to bond holders in the event of default. We assume that the swap contract has priority over the debt contract.¹² This means that the bankruptcy proceeds, net of proportional verification costs, γ , are first used to pay the bank (swap counterparty) if the swap value is negative, and debt holders receive the remainder, if positive. If default occurs and the swap value is positive, the bank must pay to settle the swap contract, and this liquidation value becomes part of the firm value that is accessible to debt holders. If θ'_2 is low enough such that $(s - \theta'_2) + SP(\theta'_2) > 0$, then the bond holders would receive more than the unlevered going concern value of the firm net of bankruptcy costs, but their value is capped at par value.

Given our objective of firm value maximization, we solve the following equation:

$$\begin{aligned} V(\theta, m, b, h) &= \max_{(m', b', h')} \{ e(\theta, m, b, h, m', b', h') + \beta \mathbb{E}_\theta [E(\theta', m', b', h')] \\ &\quad + rd(1 - \tau_d) + D(\theta, m', b', h') \}, \end{aligned} \quad (8)$$

where the equity value, $E(\theta, m, b, h)$, that results from the policy (m', b', h') , as in (6), is positive. If at

the optimal solution the firm is solvent ($E(\theta, m, b, h) > 0$), then the optimal policy is (m^*, b^*, h^*) . Otherwise, the firm is in default; that is, $E(\theta, m, b, h) = 0$ and $(m, d, 0)$ is the optimal solution.

The fair value of the swap (from the firm's viewpoint) incorporates the credit charge and reflects the optimal hedging policy of the firm, as well as the optimal liquidity and operating policies, which in turn depend on the current state (θ, m, b, h) . Hence, given a decision (m', b', h') at the beginning of the period (assuming the firm is solvent) and given the default policy, the end-of-period cash flow to the firm from the swap once θ' is observed, per unit of notional amount, is

$$\begin{aligned} cfs(\theta', m', b', h', \varphi) &= (1 - \delta(\theta', m', b', h'))[(s - \theta'_2) + SP(\theta'_2)\chi_{\{h'' \neq h'\}}] \\ &\quad + SF(\theta', m'', b'', h')(1 - \chi_{\{h'' \neq h'\}})] \\ &\quad + \delta(\theta', m', b', h') \max \{ (s - \theta'_2) + SP(\theta'_2), \\ &\quad - (b' + (1 - \gamma)E(\theta', m', d, 0))/h' \}. \end{aligned}$$

The first part of the right-hand side represents the case where the firm is solvent. The first term in square brackets is the cash flow from the swap; the second term is the par value of the swap that is paid or received if the swap position is altered ($h'' \neq h'$); the third term is the new swap value if the notional amount is unchanged, based on the firm's operating (m'') and cash (b'') policies; $SF(\theta', m'', b'', h')$ is technically a continuation value rather than a cash flow, but this will allow us to properly capture the beginning of period value of the swap, as shown below. The second part of the right-hand side is the payoff when the firm defaults. If θ'_2 is such that $(s - \theta'_2) + SP(\theta'_2) > 0$ (typically when $\theta'_2 < s$), then it is a cash inflow for the firm. Otherwise, the firm pays the minimum between $-(s - \theta'_2) - SP(\theta'_2)$ and the after-bankruptcy-costs value of the unlevered asset, $(b' + (1 - \gamma)E(\theta', m', d, 0))/h'$, per unit of notional amount. As a consequence of default, the swap contract ceases and $h'' = 0$. As in the case of debt, the end-of-period value in the cash flow to the swap depends on the future decisions $(m'', b'', h'') = \varphi(\theta', m', b', h')$.

Thus, the fair value of the swap (per unit of notional capital) at the current state (θ, m, b, h) , based on the current decision (m', b', h') if the firm is solvent, is

$$SF(\theta, m', b', h') = \beta_0 \mathbb{E}_\theta [cfs(\theta', m', b', h', \varphi)], \quad (9)$$

where $\beta_0 = (1 + r)^{-1}$ is the appropriate discount factor for the swap.

Summarizing, the solution to the valuation problem is found by solving the system of simultaneous Equations (6)–(9). The numerical technique we use

¹¹ The discount factor $\beta = (1 + r(1 - \tau_d))^{-1}$ reflects the after-personal-tax rate of return on debt and is equal to $(1 + r_z(1 - \tau_e))^{-1}$ since $r_z = r(1 - \tau_d)/(1 - \tau_e)$.

¹² The U.S. Bankruptcy Code generally allows swap counterparties to exercise contractual rights in connection with their agreement without violating the automatic stay that arises in connection with a Chapter 11 bankruptcy petition (Sections 560 and 362(b)(17)). Financial swaps can thus be settled and paid ahead of debt obligations.

is value function iteration on a discretized version of the continuous state problem, following Terry and Knotek (2011).

3. Results

We now explore the impact of the drivers of risk management, the marginal and joint contributions of liquidity and hedging as financial risk management tools, and the interaction between operating flexibility and financial risk management.

3.1. Parameter Values

A structural estimation of our model is limited by the lack of detailed empirical data on the magnitude of hedging and the characterization of operating flexibility, and would lead to unreliable parameter estimates. Instead, we present a calibrated model to obtain results that help to explain existing empirical evidence, and to provide further empirical implications. Numerous robustness checks throughout our analysis serve to build confidence in these results.

Our base case parameters are shown in Table 1. The rationale for each of the parameter choices is described below. In many cases, the parameter selection corresponds directly to typical values found in the literature. In other cases, we set parameters such that moments of key variables from our simulations are consistent with those in recent empirical studies.¹³

The volatility and persistence of the log of the product price (and revenue, since the production rate (q) is set equal to 1) are set to $\sigma_1 = 15\%$ and $\kappa_1 = 0.80$ (on an annual basis), which are consistent with the range of values used in recent papers with similar processes (e.g., Hennessy and Whited 2005). The volatility of operating profitability is also affected by the long-term mean of θ_1 , which is set to 1 for simplicity (i.e., $\bar{x}_1 = 0$), the fixed production cost $A = 0.97$, and the closing and opening costs ($K^c = 0.3$ and $K^o = 0.1$). These values lead to a simulated volatility of the rate of return on equity of 0.24 (where the return is calculated inclusive of both change in equity value and the payout to equity holders). This simulated volatility is close to the average stock volatility of 0.29 reported in Wei and Zhang (2006) during 1976–1995, particularly considering that the empirical volatility reflects a stochastic discount rate, which we do not capture in our model. Our simulated volatility for the return on the firm's assets is about 18%, which is close to an

Table 1 Base Case Parameter Values

| | | |
|---------------|---|------|
| \bar{x}_1 | Long-term mean of product price variable | 0 |
| \bar{x}_2 | Long-term mean of underlying asset for swap | 0 |
| σ_1 | Annual volatility of x_1 | 15% |
| σ_2 | Annual volatility of x_2 | 15% |
| κ_1 | Persistence of x_1 | 0.8 |
| κ_2 | Persistence of x_2 | 0.8 |
| ρ | Correlation between product price and swap | 0.1 |
| s | Swap price | 1 |
| A | Fixed production cost | 0.97 |
| q | Production rate | 1 |
| K^o | Opening cost | 0.1 |
| K^c | Closing cost | 0.3 |
| r | Annual risk-free borrowing rate | 5% |
| d | Debt level | 0.4 |
| τ_θ | Personal tax rate on equity cash flows | 12% |
| τ_d | Personal tax rate on bond coupons | 25% |
| τ_c^+ | Corporate tax rate for positive earnings | 35% |
| τ_c^- | Corporate tax rate for negative earnings | 30% |
| dc | Proportional distress cost | 15% |
| nc | Swap negotiation cost | 1% |
| λ | Variable flotation cost for equity | 5% |
| γ | Proportional bankruptcy costs | 10% |

asset volatility of around 21% for firms with investment grade bonds, as calculated by Acharya et al. (2012) using the weighted average returns on the debt and equity of these firms.¹⁴

The underlying asset for the swap is assumed to have the same mean, volatility, and persistence as the product price in order to lead to simpler interpretation of our results (particularly under perfect correlation). The swap price is fixed at $s = 1$ for simplicity. However, we ran two robustness checks regarding this swap price specification. First, we used alternative fixed swap prices in the range of (0.92, 1.18), which corresponds to the range of feasible swap prices given the mean reverting process for θ_2 . Second, we ran several cases where the swap price is reset every time the position is renegotiated, such that the fair market value of a newly initiated swap is equal to zero. These tests confirmed that our firm valuation results are not sensitive to the specification of the swap price.

In our model, θ_1 represents the entire risk exposure of our firm, and the correlation ρ measures the ability of the firm to hedge this risk exposure using the derivatives contract. We believe that for most nonfinancial corporations, this correlation is likely to be quite low based on the following empirical evidence. Tufano (1996) finds that few gold mining companies hedge more than half of their three-year forward production, and the mean “delta-percentage” for three-year production is closer to 25%, indicating that even

¹³ We employ a Monte Carlo simulation procedure based on 10,000 paths and 150 steps (years), dropping the first 50 steps to limit the dependence on initial conditions. The simulated dynamics of the state variable θ were determined under the actual (not risk-neutral) probability. The risk premia used were $RP_1 = 6\%$ and $RP_2 = 0.6\%$ (consistent with $\rho = 0.1$). Additional details are available upon request.

¹⁴ As previously mentioned, we do not attempt to capture operational risks that may have sudden disastrous consequences. Such catastrophic events could quickly lead to negative asset values or zero equity values, yielding highly skewed return distributions.

firms with key exposures for which there are corresponding derivatives markets cannot or do not fully hedge these risks. Carter et al. (2006) find that airline companies hedge on average 15% of the next year's jet fuel exposure (though some hedge almost half), but they also report that jet fuel represents on average only about 14% of total operating expenses (though it may represent a higher percent of the total risk exposure). Bartram et al. (2010) find that financial hedging reduces foreign exchange exposure by about 45% for a global sample of manufacturing firms, but these firms would also face many other risks that are not as readily hedgeable. In fact, Campello et al. (2011) find that the total notional value of interest rate and foreign currency derivatives contracts are on average 14% of the total assets of the firm, conditional on the firms hedging (of which only half of them do in their sample), which is similar to the Graham and Rogers (2002) estimate of 13.2%. More conservatively, Guay and Kothari (2003) estimate that even under very generous assumptions, the median firm in their sample holds derivatives that can only hedge between 3% to 6% of their aggregate foreign exchange and interest rate risk.

The lack of derivatives instruments that closely track most of the risks that firms face is at least one key reason why the ability of derivatives to reduce firm's risk exposures appears to be muted in practice. Rather than trying to arbitrarily break out different types of risk that can or cannot be hedged, or to attempt to calibrate correlation based on inadequate data, we use our general formulation and assume $\rho = 0.1$ as our base case correlation. As will be shown in the next section, this yields reasonable values for both the magnitude of derivatives positions and the value attributable to hedging, consistent with empirical evidence. Recognizing that correlation could be a critical parameter in our model, we also conduct sensitivity analysis across a wide spectrum of correlation values. We even analyze the unrealistic extreme case of perfect correlation, which will allow us to clearly identify some limitations of hedging with derivatives even in a best case scenario.

The personal tax on equity income (τ_e) is assumed to be 12%, equal to the estimate provided by Graham (2000). The personal tax on bond income (τ_d) is set at 25%, consistent with Hennessy and Whited (2005). The corporate tax rate on income (τ_c^+) is set to the current marginal tax rate of 35%, and, because of limited carrybacks and carryforwards, the effective tax on losses (τ_c^-) is assumed to be somewhat lower at 30%. This convexity is consistent with the corporate tax function applied in Hennessy and Whited (2005). Overall, the effective tax benefit/penalty from interest payments on debt/cash is between 18% and 13% (depending on whether there are profits or losses).

The issuance cost (λ) is assumed to be 5% of the level of equity raised, a number that is consistent with empirical studies that directly estimate these costs (e.g., Altinkilic and Hansen 2000) as well as those that indirectly estimate them using structural models (Hennessy and Whited 2005).

When the firm is in a situation of distress, it typically must pay a significant premium to raise capital to cover its deficit. This additional distress cost (dc), which is proportional to the deficit amount, is assumed to be 15%. This may reflect the need to sell assets in a fire-sale situation, or to assume costly terms in agreements for capital infusions. Our assumption of 15% is close to the 14% fire-sale discount estimated in Pulvino (1998), and at the midpoint of the 5%–25% distress cost range assumed by Strebulaev (2007).

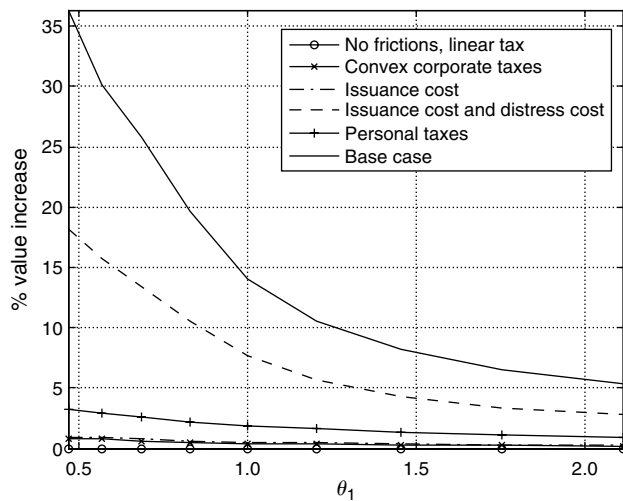
The cost associated with a bankruptcy restructuring (γ) is assumed to be 10% of the value of the newly unlevered firm. Although there is significant variation in estimates of bankruptcy costs provided in the literature, our results are not particularly sensitive to the level of bankruptcy costs. Overall, however, a firm typically experiences distress before entering bankruptcy, and thus the total costs associated with poor performance can be quite significant.

We assume that the cost of setting up and/or renegotiating the swap (nc) is 1% of the sum of the par values of the new and old swap (i.e., 1% to initiate a new position and 1% to close out an existing position). This typically results in a lower cost than in Fehle and Tsyplakov (2005), who use a fixed cost, but may still be higher than in practice if highly liquid and standardized swaps are used. We will show later, in §3.3, that our results do not appear to be highly sensitive to this cost.

Finally, we set the debt level (d) equal to 0.4. Based on the resulting simulated leverage values, we find an average market leverage ratio of 24%. The average simulated cash balance as a percent of firm value is 19%, and the average net leverage ratio is approximately 5%. These values are consistent with recent evidence presented in Bates et al. (2009), particularly for the late 1990s. In fact, our simulated values for mean leverage and cash balance are precisely the empirical values shown for two of their sample years (1997 and 1999). We assume that the risk-free rate (r) is 5%, which is also the coupon rate on debt and the yield on the cash balance.

3.2. Relative Impact of Frictions Motivating Risk Management

As described previously, there are several different motivations in our model for managing risk, including issuance, distress, and bankruptcy costs, and convex personal and corporate taxes. We begin by

Figure 1 Relative Impact of Various Motivations for Financial Risk Management

Notes. This figure shows the value of risk management when different underlying frictions are turned on and off, thus allowing the relative impact of each motivation for risk management to be analyzed. The plots are based on initial values of $h = 0$, $b = 0$, and $\theta_2 = 1$.

studying the relative impact of these frictions in Figure 1. The base case curve in Figure 1 shows the value of risk management when all these frictions are present. The value of risk management is calculated as the percentage increase in firm value from dynamically managing both cash balance and swap positions (with $\rho = 0.1$ between the swap's underlying asset and the product price), relative to the firm value when neither of these risk management controls are present. In §3.4, we explore the role of operating flexibility in contributing to risk management; for now, we assume that the firm has the base level of operating flexibility (i.e., $K^o = 0.1$ and $K^c = 0.3$).

The first observation to draw from Figure 1 is that risk management becomes less valuable when firm profitability increases, as expected. Overall, the potential value from carefully managing both liquidity and the swap position can be quite significant. At the long-run mean value of $\theta_1 = 1$, the value of risk management when all frictions are present is approximately equal to 14%. For high θ_1 values, the value increase is only about 5%. On the other extreme, the value increase becomes very large (over 35%), but this is because there are very small firm values for low θ_1 values; thus avoiding distress, bankruptcy and issuance costs can have a large effect on the percentage increase in firm value. This underscores that financial risk management, taking into account not only the use of derivatives but also the contribution of managing an internal cash balance, can greatly enhance corporate value. We will soon examine the relative roles of liquidity and hedging in creating value. But first, it is useful to understand the relative

roles of the various frictions in driving the need for risk management, which are represented by the other curves in Figure 1.

As a conceptual check, the “no frictions, linear tax” curve is included to show that there is no value attained from risk management when there are no issuance, distress and bankruptcy costs, and when personal and corporate taxes are perfectly linear (i.e., $\tau_c^+ = \tau_c^- = 0.40$ and $\lambda = -\tau_e = -0.12$). The other curves in Figure 1 are intermediate cases where only the one cost indicated in the case name is equal to its base case value, while the others are as in the “no frictions” case (the case of “issuance cost and distress costs” is the one case where two frictions are simultaneously present, as specified in the model).¹⁵ The intermediate curves exhibit the same general shape for the value increase due to risk management as the base case, but each of these curves is significantly below the base case curve, as expected given that the base case reflects all of the frictions at once. Convex corporate taxes and equity issuance cost, two key rationales for risk management frequently discussed in the literature, are the source for limited value enhancement from risk management in our context (both curves are close to the x-axis).

The most significant value driver appears to be distress costs. We show distress costs together with equity issuance costs in Figure 1, since both are incurred in the event of distress. However, because issuance costs on their own have limited impact, it is the distress costs that are driving the overall value impact. Of course, the precise magnitude of the value effect we find depends on the level of distress costs assumed, but these are consistent with the prior literature, as discussed earlier. Recent events have shown that when financial distress affects an entire industry and/or a credit freeze impacts the ability of companies across the entire economy to raise financing, then there is significant value to maintaining liquidity, despite the costs associated with doing so (Campello et al. 2011). The mean and median annual distress probability from our base case simulations are 1.6% and 1.0%, respectively. While there does not appear to be an easy way to benchmark these figures against data, these do not seem to be particularly high distress frequencies. Thus, our finding on the importance of distress costs as a driver of risk management does not seem to be driven by unreasonable estimates of distress costs or frequencies.¹⁶

¹⁵ The values are from the numerical solution of the model using 9 points for each θ , 19 points for h , and 18 points for b , based on the parameter values in Table 1, except as indicated otherwise above. The plots are based on initial values of $h = 0$, $b = 0$, and $\theta_2 = 1$.

¹⁶ We have also examined the impact of including both fixed and variable components of distress costs. Allowing for a fixed cost

Another potentially significant driver of risk management appears to be the avoidance of the impact of what we call convex personal taxes. To see this effect clearly, imagine that a firm pays out a dollar to shareholders in a particular period and then goes back to the shareholders in the subsequent period to raise a dollar of equity. Even in the absence of an equity issuance cost, investors lose from this round trip payout issuance because they are taxed on income, but yet they do not receive a tax subsidy when providing new equity capital to the firm. The greater the uncertainty, the more likely that this payout-issuance cycle would repeat, and thus the larger the value loss due to this personal tax convexity. Although derivatives can help to decrease this value loss to the extent that it can reduce the variability in profitability, the cash balance serves a vital role in preserving value by smoothing out the outflow-inflow fluctuations. This is consistent with empirical findings that firms hold considerable cash and equity issuance is infrequent. We are able to attribute a specific value to the ability to smooth out the payout-issuance fluctuations in the presence of convex personal taxes (and corporate taxes that induce a tax penalty to maintaining cash within the firm).¹⁷

The relative impact of the various motivations for risk management depend on parameter assumptions. For instance, while the convex personal tax effect is analogous to the issuance cost effect, in that they are both triggered by equity issuance, the personal tax effect figures more prominently in our results because the personal tax rate on equity is assumed to be 12% and the proportional issuance cost is 5%.¹⁸ Some of the parameters, such as distress and issuance costs, vary across firms, leading to potentially different rankings of the impact of these frictions in the cross section. Nevertheless, our results provide some useful insight into the relative importance of various motivations for risk management under a set of reasonable input assumptions. Note also that summing

of 0.05 and a proportional cost of 0.184 yields an equivalent expected total distress cost in our simulation as our base case (proportional cost of 0.15), providing for a controlled comparison of the effect of the distress cost structure. The value difference of this specification is negligible. Since we report, in §3.4, results on optimal risk management policies, we also examine the effect of having both a fixed and variable distress cost, and we find that the introduction of the fixed cost leads to a higher optimal liquidity balance. This suggests that not only the magnitude, but also the composition of the distress costs, can affect the liquidity levels observed in practice.

¹⁷ Recent work by Larkin et al. (2013) also shows that companies are valued at a premium when they smooth their dividends.

¹⁸ We have verified that reducing the personal tax rate on equity to 5%, which is the level of the proportional issuance cost, leads to the identical value effect for the personal tax convexity as for the issuance cost friction.

up the value creation from mitigating the impact of each of the different frictions (i.e., the various single-friction value curves in Figure 1) falls short of the total value created when all frictions are considered at once (the base case curve). This points to an interesting compounding effect when multiple frictions are considered simultaneously.

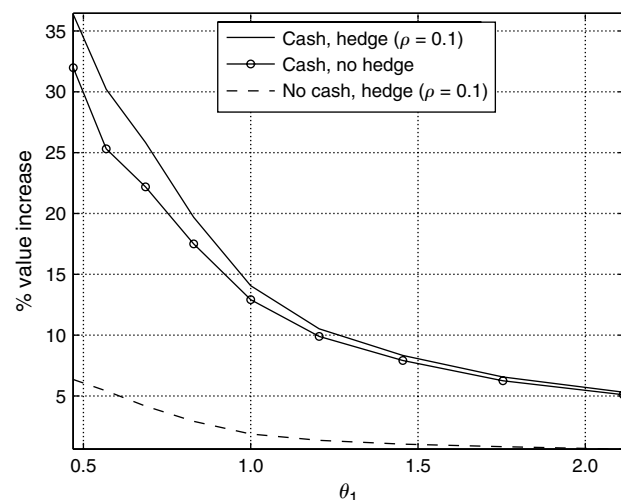
These observations lead us to explore more carefully the relative value contributions of hedging and liquidity, and whether the combination of these two risk management mechanisms is relatively effective in mitigating the effects of frictions and tax convexities in the presence of uncertainty. We will then examine the contribution of operating flexibility to risk management and how this interacts with the firm's liquidity and hedging policies.

3.3. Relative Value Contributions of Liquidity and Hedging

Figure 2 shows the percentage increase in firm value due to risk management plotted against θ_1 , under three risk management scenarios: (1) the firm can dynamically manage a liquidity balance, but cannot hedge with a swap; (2) the firm can dynamically manage a swap position, but cannot keep a liquidity balance; and (3) the firm can dynamically manage both its liquidity balance and a swap position. We continue to assume for now that $\rho = 0.1$; thus, the case with both liquidity balance and swap is simply the base case curve shown in Figure 1.

The top two curves in Figure 2 demonstrate that maintaining a cash balance, and optimally rebalancing it over time, adds significant value to the firm, due

Figure 2 Relative Contribution of Liquidity and Hedging to the Value of Risk Management



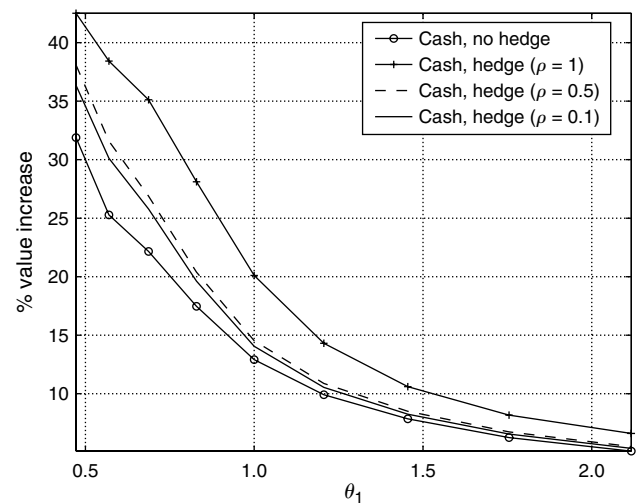
Notes. This figure shows the value increase attributable to risk management under three different risk management scenarios: (1) dynamically managed cash balance and no swap; (2) dynamically managed hedge and no cash balance; and (3) both cash balance and swap positions are dynamically managed. The plots are based on initial values of $h = 0$, $b = 0$, and $\theta_2 = 1$.

to avoiding distress and equity issuance costs. Keep in mind that there is a significant tax penalty in our model associated with holding cash, and yet liquidity still proves to be quite valuable to the firm. This finding lines up with recent empirical evidence in Bates et al. (2009) showing that cash has become an increasingly important cushion against rising risk levels in the economy. They attribute this increase in cash holdings, at least in part, to the increase in idiosyncratic risk over their sample period. As we illustrate shortly, as it becomes increasingly more difficult to hedge the risk of the firm using derivatives contracts, cash holdings play a more important role in managing risk. We also will show that the ability to employ operating flexibility, while valuable to the firm, increases the need for cash to prevent additional frictions associated with large discretionary costs incurred while exercising the operating flexibility, which cannot be easily hedged.

The incremental value associated with the derivatives hedge (with $\rho = 0.1$) ranges from 0 to 4% of firm value when the firm also has a cash balance (and is somewhat larger if there is no cash balance), and is approximately 1.5% at the long-term mean level of $\theta_1 = 1$. This result sheds some light on the recent debate in the empirical literature regarding the value created by hedging with derivatives. Our result suggests that the value increase from hedging, averaging over a cross section of (surviving) firms, may well not be much more than 2%, and may only be significantly perceptible for firms facing low profitability. Some empirical papers, particularly Guay and Kothari (2003) and Jin and Jorion (2006), provide evidence that is consistent with this result, finding that value increases from hedging are not statistically or economically significant. In contrast, Allayannis and Weston (2001) estimate that hedging with foreign exchange derivatives increases value by approximately 5% on average for their sample of nonfinancial multinationals, and Carter et al. (2006) estimate value increases between 5% and 10% for airlines hedging their oil exposure with derivatives.

There are some additional factors, however, to consider in addressing the apparent lack of consistency in the empirical findings. First, our results so far are based on $\rho = 0.1$, representing a situation where the extent to which derivatives are correlated with the overall risk of the firm is rather limited because of the large number of unhedgeable risks the firm faces. Some firms may be able to hedge a more significant portion of their exposure using derivatives, particularly in industries with key risk factors, such as highly volatile input or output commodity prices. In Figure 3, we plot the percentage value increase attributable to risk management as in Figure 2, but we explore the effect of higher correlations between θ_1

Figure 3 Effect of Swap Correlation on Contribution of Hedging to the Value of Risk Management



Notes. This figure shows the increase in firm value due to risk management assuming the firm holds an optimally rebalanced cash position, and either has no swap (lowest curve), or can dynamically manage a swap position, where the price of underlying asset of the swap (θ_2) has correlation of 0.1, 0.5, or 1.0 with the firm's underlying uncertainty (θ_1), represented by the successively higher curves on the graph. The plots are based on initial values of $h = 0$, $b = 0$, and $\theta_2 = 1$.

and θ_2 of either 0.5 or 1. Going from the case of $\rho = 0.1$ to that of $\rho = 0.5$, the value increase attributable to risk management does become larger as expected, but rather incrementally (less than an additional 0.5% at $\theta_1 = 1$). However, when the swap is perfectly correlated with the firm's risk, the value increase is much more substantial, indicating that the effect of correlation on the value increase due to hedging can be quite nonlinear.¹⁹

This nonlinearity can also be seen by examining the mean (and standard deviation) of the cash and hedging positions shown in Table 2, which are based on our simulations.²⁰ Note that neither the cash nor hedge amounts change significantly going from $\rho = 0.1$ to $\rho = 0.5$, yet there are large changes when ρ increases further to 1.²¹ The average hedge ratio is

¹⁹ We have also examined the case where $\rho = 0.05$, and we find results that are very similar to those with $\rho = 0.1$ and thus do not report them here.

²⁰ To test the statistical significance of the differences of the averages across cases, one would divide the standard deviations we report by 100 (the square root of the 10,000 simulation runs). Given the resulting magnitudes, this would result in highly statistically significant differences for all the results we report.

²¹ The range of hedge ratios shown in Table 2 appears generally consistent with the limited empirical information available. Since the production quantity is equal to 1 in our model, the hedge rate h can be interpreted as the notional value of the hedging contracts. The median value of the firm in our base model is 1.64, and is generally between 1 and 3 in the various cases we examine. Thus, the notional value of the hedge as a proportion of firm value is

Table 2 Cash, Hedging, and Operating Policies

| | Cash/value | Hedge | Operate | Change |
|------------------------|------------------|------------------|------------------|------------------|
| CB nH | 0.208 (0.114) | 0.000 (0.000) | 0.597 (0.218) | 0.073 (0.038) |
| CB H ($\rho = 0.1$) | 0.192 (0.113) | 0.030 (0.046) | 0.607 (0.214) | 0.071 (0.037) |
| CB H ($\rho = 0.5$) | 0.192 (0.110) | 0.051 (0.071) | 0.606 (0.216) | 0.070 (0.036) |
| CB H ($\rho = 1$) | 0.115 (0.074) | 0.188 (0.179) | 0.688 (0.209) | 0.055 (0.031) |
| nCB H ($\rho = 0.1$) | 0.000 (0.000) | 0.041 (0.066) | 0.687 (0.214) | 0.054 (0.032) |

Notes. This table shows the mean (and standard deviation) of four metrics: the level of cash balance normalized by the value of the firm (b/V); the hedge ratio (h); the operating mode (1 if operating, 0 if closed); and the frequency of change from one operating state to another. There are five different cases shown: for the first four rows, there is a cash balance (“CB”) and either no hedge (first row, “nH”), or a hedge (“H”) with correlation (ρ) of either 0.1, 0.5, or 1, in the second, third, and fourth rows, respectively; the fifth row allows for a hedge with $\rho = 0.1$, but no cash balance (“nCB”).

almost four times larger when $\rho = 1$ as opposed to when $\rho = 0.5$. It may seem surprising that the hedge ratio is not equal to 1 when $\rho = 1$. There are multiple reasons for this, including the nonlinearity of cash flows due to operating flexibility and particularly the payment of switching costs, the existence of a cash balance, and a potential region of indifference where value remains flat with an increasing hedge ratio. A simplified example provided in the appendix makes this finding much easier to understand.

When $\rho = 1$, the hedge takes on more of a role in managing the risk exposure, and thus the firm optimally chooses to hold a much smaller cash balance. Note that the firm has a greater likelihood of being in operation (“operate”) under the perfect correlation scenario. Although this may appear to be due to the fact that the exposure to a declining θ_1 can be much better hedged, this is not the appropriate explanation. A firm that should close operations because it is losing money should still do so regardless of the hedge it has in place. The hedge can still generate positive cash flow when θ_1 is low, but the firm can also avoid losses from its operations by closing. The explanation is instead more subtle. While the firm chooses to keep a lower cash balance when $\rho = 1$ since the hedge can effectively offset operating losses, this puts it in a position where it has less cash to use to optimally close operations when θ_1 is low. It thus finds itself not closing in many cases where it should rather than issuing costly equity to finance the closing costs. We find that the likelihood of changing the operating state (“change”) is indeed lower when

$\rho = 1$, and the firm continues to operate in many states rather than closing. This same explanation holds in the last row of Table 2 where the firm holds no cash balance. We will further explore the relationships between operating policy and financial risk management in the next section.

As discussed earlier, we believe it is unlikely that a firm’s total exposure will be highly correlated with available derivatives. Thus, it may well be, as Jin and Jorion (2006) and others have argued, that the high levels of value increase attributed to hedging instead reflect other endogenous factors, including governance practices that, while leading to the use of derivatives for hedging, increase value for other independent reasons. At a minimum, our results make clear that the extent to which a firm’s risk exposure can be hedged by derivatives contracts is a critical explanatory variable that needs to be considered in empirical studies on the value contribution of hedging programs.

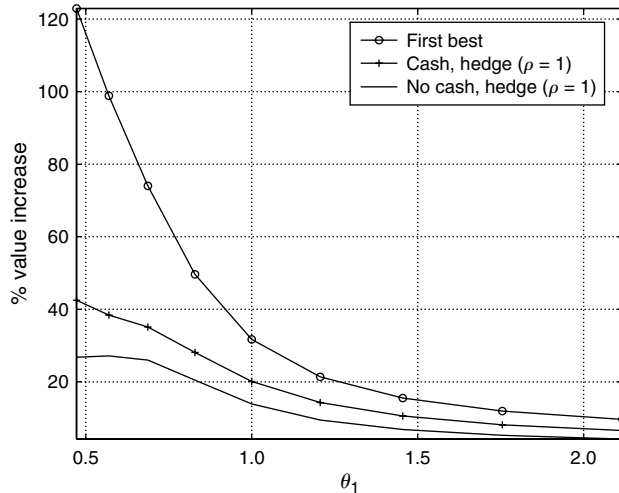
The second key factor to consider in evaluating the contribution of hedging with derivatives is that we have so far only considered one type of derivative, namely, a swap contract. Option contracts may be more effective hedging instruments for some companies than linear derivative contracts such as forwards and swaps. Note, however, that the swap position in our model can be dynamically adjusted at relatively low cost, so the hedging profile is effectively nonlinear and quite flexible. In fact, the effective maturity of the swap contract in our simulations, taking rebalancing into account, is 2.24 years on average. However, to ensure that the nature of our swap is not skewing our results, we have explored a version of our model where one-period put options are used rather than infinite maturity (or one-period) swap contracts, and find essentially equivalent results.²²

A perfectly correlated hedge, together with a dynamically managed cash balance, appear to significantly increase firm value, but are these financial risk management tools able to fully eliminate the value loss due to frictions? To address this question, we calculate the value of the firm under a first-best case where all frictions are eliminated, i.e., zero issuance, distress, and bankruptcy costs, and using linear functions for both personal equity tax ($\lambda = -\tau_e$) and corporate tax ($\tau_c^+ = \tau_c^-$). Figure 4 shows that there is a significant value gap between the best financial risk management case and the first-best case.

To fully appreciate this result, first note from comparing the bottom two curves in Figure 4 that having

roughly in the 1%–10% range. Allayannis and Weston (2001) provide statistics for notional (nominal) amounts of derivatives as well as debt and equity values for their sample of firms, and these lead to a very similar range.

²² When $\theta_1 = 1$, the value of risk management using one-year put options instead of the swap is 13.0%. When a one-year swap is used, the value is 13.3%. Both of these values are close to our base case value of 14.1%.

Figure 4 Risk Management with a Perfectly Correlated Swap vs. First-Best Value

Notes. This figure shows the percentage increase in firm value due to risk management under three different risk management scenarios: (1) no cash balance, but a swap with perfect correlation ($\rho = 1$); (2) cash balance, and a swap with $\rho = 1$; and (3) the “first best value” (equivalent to the “no frictions” case, as explained in the text). The plots are based on initial values of $h = 0$, $b = 0$, and $\theta_2 = 1$.

cash is quite valuable even if the firm has access to a perfectly correlated swap contract, which can completely eliminate the variability in operating profitability. When the firm’s profitability is low, a perfectly correlated swap with swap price equal to 1 (and $h = 1$) will ensure that a profit will be locked in, but the profit is small enough that it will not cover the closing cost if it is optimal to close production.²³ Similarly, in states where the production is closed, the firm does not have cash flow to pay for opening costs if profitability returns and it is optimal to reopen production. Maintaining a cash balance adds value by avoiding issuance costs (and the convexity in personal equity taxes) in these two instances. The opening and closing costs in our model can be viewed more broadly as representative of restructuring costs, capital expenditures, and other extraordinary expenses faced by firms in practice that would not be offset by gains in conventional hedging positions. Liquidity thus plays an important role in an integrated risk management system by providing a mechanism to absorb some of the effects of uncertainty that are otherwise difficult to mitigate through hedging.

However, there are important limitations associated with liquidity as a risk management tool that should

²³ Note that despite locking in this profit by holding the swap, the firm may still benefit from closing down production if θ_1 is low enough and operating losses are significant, as discussed earlier. The firm can then earn the profits from the swap contract (assuming the swap position is maintained) without having these profits partially offset by the operating losses it would face with an open facility.

be kept in mind. First, there is a cost associated with holding cash. Second, even a substantial cash balance position will gradually be depleted if the firm continues to suffer losses over a long period of time. Thus, even the cash and perfect hedge position will still trigger issuance and/or distress costs with some probability. Although the expected value of these costs can be reduced by holding a high cash balance, such a cash policy is itself costly. Third, the firm may not have a sufficient string of positive outcomes to build a large cash balance without issuing equity, which is costly.²⁴

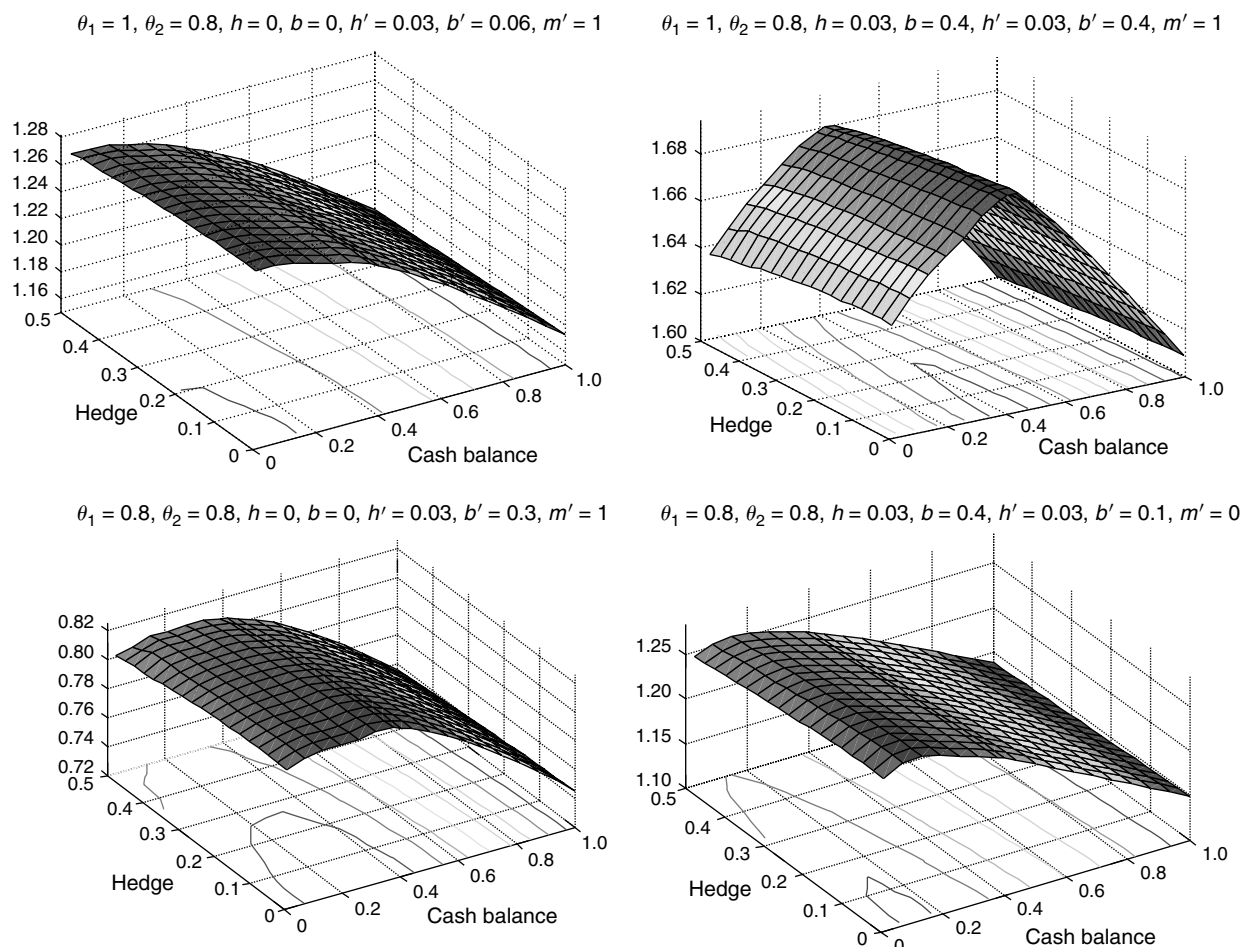
Thus, although a perfectly correlated swap and a cash balance certainly enhance firm value significantly, there is still a value loss relative to the first-best case where all frictions can be avoided. If it were possible to avoid these frictions through enterprise risk management mechanisms that are not as costly as holding cash, and are more intricately designed to not only offset operating cash flow exposure, but also minimize the impact of occasional extraordinary costs such as those due to restructuring, significant additional value could be recognized. It is thus not surprising that companies are increasingly designing sophisticated enterprise risk management programs in pursuit of this additional value gain.²⁵

Finally, we examine the marginal benefits of liquidity and hedging to gain a better appreciation of their relative contributions to value creation in different states. In the value surfaces shown in Figure 5, each graph shows firm value for a particular current state ($\theta_1, \theta_2, m, b, h$) against possible selections of new cash balance (b') and hedge (h') levels. In each graph, the optimal (b', h') pair that maximizes firm value (i.e., corresponds to the peak of the value surface) is indicated above each graph. The optimal production policy is also shown above each graph as m' , which is 1 if it is optimal to continue to keep production open in the next period, and 0 if the firm should close production (the facility is currently open in all graphs). The four panels in Figure 5 are organized to show the effects of both current profitability as well as existing cash balance and hedge levels, as

²⁴ There are also transaction costs associated with managing the dynamic swap position. If these costs are set to zero for the “cash, hedge ($\rho = 1$)” case, the value due to risk management is equal to 22.8% at $\theta_1 = 1$, in contrast to a value of 20% shown in Figure 4 with transaction costs. Thus, the costs decrease the value of risk management by about 3% (at $\theta_1 = 1$, and when $\rho = 1$), representing part of the differential between the best financial risk management case and the first best case.

²⁵ In a recent effort to quantify the value attributable to firm-wide enterprise risk management programs, Hoyt and Liebenberg (2011) estimate an average value premium of 16.5% for U.S. insurers that have implemented such programs. This figure is roughly in line with our results of potential gains moving toward a first-best valuation, particularly if transaction costs were considered.

Figure 5 Marginal Values of Liquidity and Hedging



Notes. These four graphs show firm values plotted against potential new hedge ratio (h') and cash level (b') selections, assuming four different current states (i.e., four different $(\theta_1, \theta_2, m, b, h)$ combinations). The top row assumes an average θ_1 value (1.0), and the bottom row assumes a lower than average θ_1 value (0.8). $\theta_2 = 0.8$ in all graphs. The left column assumes there is currently no hedge and a zero cash balance ($h = b = 0$). The right column assumes average levels of $h = 0.03$ and $b = 0.4$. The optimal choice of h' and b' levels are shown above each graph, and can be seen to generate the highest value level on the surface (also seen by looking at the iso-value curves projected on the bottom plane). The optimal production decision for the firm in each panel is also shown above each graph as m' , where a value of 1 signifies open production and 0 signifies closed.

follows. The top row assumes $\theta_1 = 1$, and the bottom row assumes a below-average profitability of $\theta_1 = 0.8$. The left column assumes the firm currently has no cash balance or swap ($b = h = 0$), and the right column assumes $b = 0.4$ and $h = 0.03$, which are roughly the steady-state average levels for the base case from our simulations.²⁶ In all cases, we choose the asset value underlying the swap, θ_2 , to be equal to 0.8, to have a zero fair value of the swap.²⁷

²⁶ Note that the values in the right column reflect the fact that the firm starts with $b = 0.4$, and thus are roughly 0.4 higher than the corresponding graphs in the left column.

²⁷ While the fixed swap price, s , received each period is equal to 1, and thus the periodic cash flow $s - \theta_2$ equals 0 when $\theta_2 = 1$, the nonlinearity of the swap valuation captured in Equation (5) (due to the distributional assumptions, the effect of credit risk, and the right to close the contract at any date) is such that $SF(0.8) \approx 0$.

Looking across the four graphs, the marginal values of liquidity and hedging appear to be quite state specific, reflecting a variety of factors. Comparing the top two graphs, note that when the firm starts with no cash, it accumulates what it makes in the current period, but it does not increase the cash balance further given the high cost of issuing equity. In the right graph, the firm's marginal values of cash are much higher at the lower cash balance levels since the firm already has a significant cash balance. Focusing on the two graphs in the left column, the firm in the lower row has a higher marginal value of cash given the risk of distress associated with a low θ_1 value. It is willing to issue equity to create a liquidity position that can provide protection against distress, and allow it to also potentially close production in the following period if profitability remains low. In the bottom right graph, the firm begins with a substantial cash balance

and uses a large part of this to close down production, leading to a distinct set of marginal values.

The graphs also illustrate that the marginal value of hedging is less state dependent than the marginal value of cash. Since there are relatively low costs associated with rebalancing a hedge, there is less of a hysteresis effect; that is, the existing swap position does not strongly affect the choice of future hedge position. In contrast, the choice of cash balance level is potentially affected by significant frictions such as issuance costs and convex personal taxes associated with issuing equity, as well as the tax penalty of holding cash in the firm.²⁸

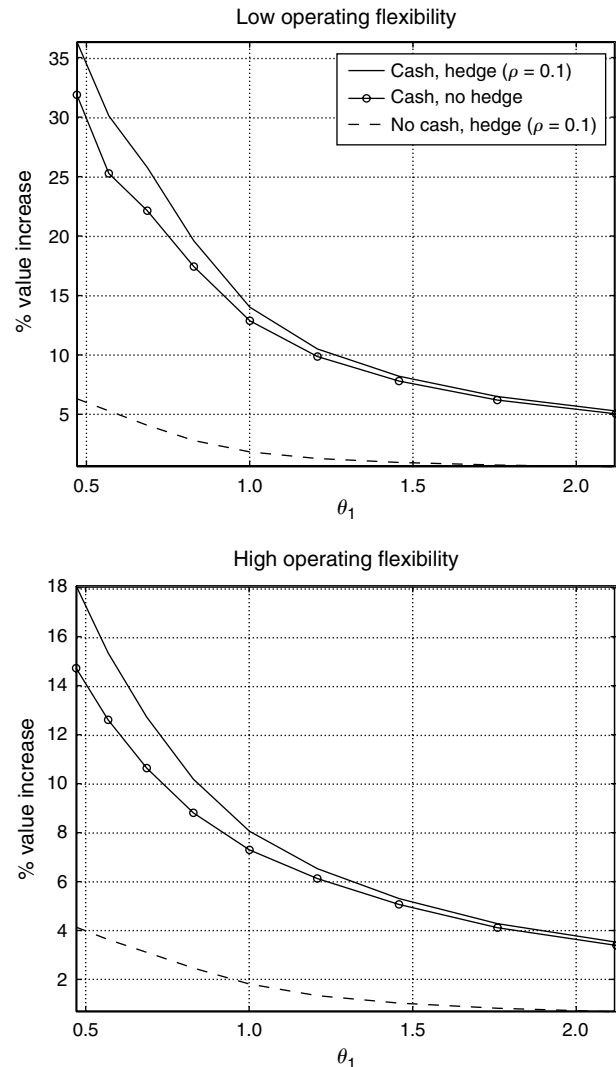
3.4. Contribution of Operating Flexibility to Risk Management

We now examine operating flexibility in detail, which is the third key component of the integrated risk management program in our framework. In particular, we focus on how this operational risk management mechanism interacts with liquidity and hedging (we will often group liquidity and hedging under the term financial risk management, or FRM).

Figure 6 shows the effect of operating flexibility on the value of financial risk management. The two panels illustrate that a higher level of operating flexibility (we set $K^c = 0.1$) reduces the benefit earned from either hedging or holding a cash balance, or both.²⁹ This result is consistent with a growing body of empirical evidence examining the interaction between financial hedging and operating flexibility across different industries, including Allayannis et al. (2001), Bartram (2008), Hankins (2011), and Pantzalis et al. (2001). However, note that FRM still adds significant value even in the presence of operating flexibility. This is true since operations are not completely flexible and the firm is still susceptible to losses, whose effects can be mitigated through FRM.

This substitution effect is by and large observed in Table 3, where we analyze the liquidity, hedging, and operating policies that emerge from our simulations. For instance, comparing the low and high operating flexibility cases, we note that cash is lower when there is higher flexibility. This is true as well if we allow for full operating flexibility where there are neither closing nor opening costs (note that operations are opened and closed with much greater frequency,

Figure 6 Effect of Operating Flexibility on Value of Financial Risk Management



Notes. This figure shows the effect of increasing operating flexibility on the value of hedging and liquidity. The top panel represents the base case of low operating flexibility ($K^o = 0.1$, $K^c = 0.3$), and the bottom panel represents the high operating flexibility case ($K^o = 0.1$, $K^c = 0$). In each case, we show the value increase attributable to financial risk management if there is (1) a dynamically managed cash balance and no swap, (2) a dynamically managed hedge and no cash balance, and (3) both cash balance and swap positions are dynamically managed. The plots are based on initial values of $h = 0$, $b = 0$, and $\theta_2 = 1$.

with a change in operating mode about 17% of the time). Interestingly, however, when there is no operating flexibility whatsoever, which we proxy by setting the closing cost very high ($K^c = 10$), the cash balance is on average lower than in the low operating flexibility case. Recall that the cash balance is important in part to be able to cover extraordinary costs from restructuring operations. Since closing is not a viable option, the need for liquidity is reduced. This suggests that the relationship between liquidity and operating flexibility may not be monotonic, contrary to what

²⁸ The lower sensitivity of the marginal value of hedging as compared with that for liquidity also reflects to some degree the relatively smaller contribution of hedging versus liquidity to the overall value of integrated risk management.

²⁹ Consistent with this substitutability result, we also find that although operating flexibility greatly enhances firm value even with FRM mechanisms in place, the value due to operating flexibility is considerably higher if this is the only source of risk management.

Table 3 Effect of Operating Flexibility on Cash, Hedging, and Operating Policies

| | Cash/value | Hedge | Operate | Change |
|----------------------------|------------------|------------------|------------------|------------------|
| No operating flexibility | | | | |
| CB nH | 0.138 (0.123) | 0.000 (0.000) | 1.000 (0.000) | 0.000 (0.000) |
| nCB H | 0.000 (0.000) | 0.037 (0.058) | 1.000 (0.000) | 0.000 (0.000) |
| CB H | 0.135 (0.120) | 0.022 (0.039) | 1.000 (0.000) | 0.000 (0.000) |
| Low operating flexibility | | | | |
| CB nH | 0.208 (0.114) | 0.000 (0.000) | 0.597 (0.218) | 0.073 (0.038) |
| nCB H | 0.000 (0.000) | 0.041 (0.066) | 0.687 (0.214) | 0.054 (0.032) |
| CB H | 0.192 (0.113) | 0.030 (0.046) | 0.607 (0.214) | 0.071 (0.037) |
| High operating flexibility | | | | |
| CB nH | 0.178 (0.062) | 0.000 (0.000) | 0.500 (0.197) | 0.099 (0.041) |
| nCB H | 0.000 (0.000) | 0.055 (0.066) | 0.505 (0.198) | 0.098 (0.041) |
| CB H | 0.147 (0.065) | 0.023 (0.033) | 0.501 (0.197) | 0.098 (0.041) |
| Full operating flexibility | | | | |
| CB nH | 0.134 (0.055) | 0.000 (0.000) | 0.639 (0.165) | 0.175 (0.069) |
| nCB H | 0.000 (0.000) | 0.054 (0.064) | 0.639 (0.167) | 0.173 (0.070) |
| CB H | 0.103 (0.048) | 0.026 (0.028) | 0.640 (0.166) | 0.173 (0.069) |

Notes. This table shows the mean (and standard deviation) of four metrics: the level of cash balance normalized by the value of the firm (b/V); the hedge ratio (h); the operating mode (1 if operating, 0 if closed); and the frequency of change from one operating state to another. The four panels represent four different levels of operating flexibility: no operating flexibility ($K^o = 0.1$, $K^c = 10$); low operating flexibility ($K^o = 0.1$, $K^c = 0.3$); high operating flexibility ($K^o = 0.1$, $K^c = 0.1$); and full operating flexibility ($K^o = K^c = 0$). In each panel, there are three different cases shown: in the first row, a cash balance and no hedge ("CB, nH"), in the second row, no cash balance and a hedge ("nCB, H"), and in the third row, a cash balance and a hedge ("CB, H"). The hedge ("H") has a correlation ($\rho = 0.1$).

might be expected, pointing to caution when analyzing such relationships using empirical data.

Table 4 provides further insights into the combined effects of operating flexibility and financial risk management. Under the base case, as the operating flexibility increases, the cash balance decreases, as does the hedge ratio, as shown earlier. However, these decreases in FRM are proportionately larger when the effectiveness of the hedge, as measured by correlation, is higher. Since the hedge is more effective, and since there is greater operating flexibility, there is even less need for either of the financial risk management tools. This suggests that a stronger negative (substitution) relationship between operating flexibility and financial risk management will likely be observed in industries where hedging can be quite

effective given high correlation between available derivatives and the key risks those industries face.

Finally, we consider two cases not reported in tables. First, we examine the trade-off between a higher fixed cost ($A = 0.98$), which implies greater operating leverage, and higher operating flexibility ($K^c = 0.1$). This sensitivity was performed in such a way that the value trade-off was essentially neutral; that is, the firm would be indifferent from a value perspective between having higher flexibility with a higher fixed cost or lower flexibility with a lower fixed cost. This allowed us to see whether there were any effects on financial risk management policy from changing to the technology with higher operating flexibility but higher operating leverage. We find that the cash/value ratio decreases slightly from 0.192 in the base case to 0.186 with the higher operating leverage and higher operating flexibility. On one hand, higher operating flexibility lowers the need for liquidity; on the other hand, the higher operating fixed cost leads to the need for a higher cash balance due to potentially higher operating losses and longer periods of inactivity where debt needs to be serviced by using the cash balance rather than operating cash flow. While these effects largely offset each other, the same is not true for hedging. In that case, the higher operating flexibility leads to a lower hedge ratio (0.019 instead of 0.030 in the base case), and the fact that the firm is inactive more often in the presence of higher fixed costs and higher flexibility further reduces the hedge ratio. This suggests that empirical studies on liquidity and derivatives usage should jointly consider both operating flexibility as well as operating leverage, given the potential trade-off that may exist between the two.

Second, we examine the special case in our framework where the closing cost is negative. This case is analogous to the setup in Bolton et al. (2011), where reducing capacity not only reduces exposure but is also a source of cash. We examine the case where $K^o = 0.5$ and $K^c = -0.1$, so that the total "round-trip" cost of opening and closing is 0.4 as it is in the base case, where $K^o = 0.1$ and $K^c = 0.3$. We find that the hedging ratio decreases due to the ease of avoiding operating losses, and the cash balance decreases due to the cash made available when closing down. However, the firm still holds a substantial cash balance to help fund the costs of reopening, which is the main purpose of liquidity in the Bolton et al. (2011) model. In other words, it is more financial constraints than risk management that drive their results, pointing to an important distinction between our two approaches. From an empirical perspective, this highlights the importance of being able to carefully identify the nature of a firm's operating flexibility to understand the relationship to hedging and liquidity, suggesting

Table 4 Effect of Operating Flexibility and Hedging Correlation on Cash, Hedging, and Operating Policies

| | $\rho = 0.1$ | | | | $\rho = 0.5$ | | | |
|----------------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| | Cash/value | Hedge | Operations | Change | Cash/value | Hedge | Operations | Change |
| Low operating flexibility | | | | | | | | |
| nCB H | 0.000 (0.000) | 0.041 (0.076) | 0.687 (0.214) | 0.054 (0.032) | 0.000 (0.000) | 0.107 (0.111) | 0.642 (0.214) | 0.063 (0.033) |
| CB H | 0.192 (0.110) | 0.030 (0.060) | 0.607 (0.214) | 0.071 (0.037) | 0.192 (0.107) | 0.051 (0.073) | 0.606 (0.216) | 0.070 (0.036) |
| High operating flexibility | | | | | | | | |
| nCB H | 0.000 (0.000) | 0.055 (0.072) | 0.505 (0.198) | 0.098 (0.041) | 0.000 (0.000) | 0.093 (0.090) | 0.501 (0.196) | 0.099 (0.041) |
| CB H | 0.147 (0.064) | 0.023 (0.047) | 0.501 (0.197) | 0.098 (0.041) | 0.134 (0.060) | 0.036 (0.055) | 0.499 (0.195) | 0.098 (0.041) |

Notes. This table shows the mean (and standard deviation) of four metrics: the level of cash balance normalized by the value of the firm (b/V); the hedge ratio (h); the operating mode (1 if operating, 0 if closed); and the frequency of change from one operating state to another. The two panels represent low operating flexibility ($K^o = 0.1$, $K^c = 0.3$), and high operating flexibility ($K^o = 0.1$, $K^c = 0.1$). In each panel, there are two different cases shown: in the first row, no cash balance and a hedge ("nCB, H"), and in the second row, a cash balance and a hedge ("CB, H"). The hedge ("H") has a correlation $\rho = 0.1$ in the left four rows and a correlation $\rho = 0.5$ in the right four rows.

industry specific studies may be more appropriate so as to properly control for different levels of flexibility.

4. Conclusions

Our results highlight, among other things, that hedging with derivatives may have a limited contribution to the value created through risk management, that liquidity management serves as a key risk management tool, and that distress costs are a key motivation for managing risk. Furthermore, given the costs associated with holding cash, the inability of derivatives to hedge significant drivers of firm risk and to cover extraordinary expenses such as adjustment costs, and the potential speculative use of derivatives, firms may fall quite short of achieving their risk management goal of eliminating the negative impacts of frictions on firm value.

The challenges of designing an integrated risk management system extend beyond the issues that have been incorporated into our model. Most notably, we have not considered asymmetric information and agency problems. Given the significant value potential associated with optimal risk management programs, further normative research into risk management design should be of high priority, coupled with empirical research informed by insights from this line of research.

Acknowledgments

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Appendix. A Simple Example

To illustrate the essence of our results in the simplest way possible, we construct a one-period numerical example with some of the key features of our general model. An unlevered firm can produce one unit of output subject to a cost of \$10, and with revenue X of either \$14 or \$8, with equal probability. If the resulting cash flow is negative, the firm faces a distress cost equal to 20% of the deficit. We assume a zero discount rate. The value of the firm is thus equal to $0.5(14 - 10) + 0.5(8 - 10) - 0.5(0.2(8 - 10)) = 2 - 1 - 0.2 = \0.8 , where the expected distress cost of \$0.2 represents a loss of 20% of the firm value in the absence of such frictions (i.e., the first-best value of the firm).

If the firm has access to a hedging instrument, it can increase firm value by eliminating or mitigating the distress costs. Assume first that there is a swap contract on an underlying variable Y that is perfectly correlated with the product price, or most simply, $Y = X$. The swap price is $\mathbb{E}(Y) = \$11$, and the firm will take a short position so that for one unit of the swap contract it would receive \$3 when $Y = 8$ and would pay \$3 when $Y = 14$. The firm can enter into a fraction of a unit of the short swap position, as measured by $h \in [0, 1]$. As long as $h \in [2/3, 1]$, the profit on the swap will offset (or more than offset) the loss of \$2 from production in the low state, and thus there will be no distress cost and firm value equals \$1.

Since in practice a firm's risk will never be fully hedged, we now explore the possibility that the correlation between X and Y , ρ_{XY} , is less than one. We examine the cases where ρ_{XY} can equal 0, 0.2, or 0.6 (as well as the perfectly correlated case). These correspond to different state probabilities for the four states of (X, Y) , as shown in Table A.1.³⁰

³⁰ In practice, rather than there being a swap on an underlying instrument that is less than perfectly correlated with the overall risk of the firm, it is likely that there are derivative contracts that are near perfectly correlated with certain risks that the firm faces, but a lack of derivative instruments to hedge other corporate risks. One can transform the framework we present into such a setting. For

Table A.1 Bivariate Binomial Example with Different Correlations

| State | X | Y | State probabilities for | | | | Payoff |
|-------|----|----|-------------------------|-----|-----|-----|------------------------------------|
| | | | $\rho = 0$ | 0.2 | 0.6 | 1 | |
| 1 | 14 | 14 | 0.25 | 0.3 | 0.4 | 0.5 | $4 - 3h$ |
| 2 | 14 | 8 | 0.25 | 0.2 | 0.1 | 0 | $4 + 3h$ |
| 3 | 8 | 14 | 0.25 | 0.2 | 0.1 | 0 | $(-2 - 3h)(1 + 0.2)$ |
| 4 | 8 | 8 | 0.25 | 0.3 | 0.4 | 0.5 | $-2 + 3h + 0.2 \min\{-2 + 3h, 0\}$ |

Note. This table shows the four states for (X, Y) and corresponding probabilities and payoffs in the presence of possible distress costs and under different correlation values.

The payoffs in each state are also shown in Table A.1. In the first two states, the firm will never have a negative cash flow for $h \in [0, 1]$. In the third state where the output price is low and the swap's underlying value is high, the hedge works particularly poorly and thus a large distress cost is incurred and increases with the size of the hedge. In the fourth state, the short swap position can produce a cash flow that more than offsets the operating loss as long as $h > 2/3$. A hedge ratio higher than $2/3$ will exacerbate the losses in the third state without any further benefit in the fourth state, so in this bivariate binomial example, the firm will choose an optimal $h^* = 2/3$, unless $\rho_{XY} = 1$, in which case any hedge ratio between $2/3$ and 1 maximizes firm value. The optimal hedge ratios are shown in Table A.2, together with the resulting expected loss. When $\rho_{XY} = 0$, there is no benefit to hedging (a flat value surface for $h \in [0, 2/3]$ and then decreasing for higher h), and thus there is a loss of 20% of firm value due to the expected distress cost. This loss is reduced by 2% for each 0.1 increase in ρ_{XY} , and goes to zero in the case of the perfectly correlated swap.

Table A.2 also shows what the hedge ratio would be if the objective were to minimize the variance of the payoff. In this case, $h^* = \rho_{XY}$, which is lower than the optimal hedge under firm value maximization. The minimum variance hedge ratio is thus suboptimal, and the resulting value loss is correspondingly higher.

Now, consider the case where the firm has operating flexibility that allows it to shut down production in the low output price state before incurring any production costs, thus mitigating any operating loss. However, there are switching costs of \$1 associated with exercising this shut down option, so there is still a loss of \$1 in the low price states, which would trigger an expected distress cost of \$0.10. The firm can reduce the expected distress costs by hedging with the swap. Specifically, the firm should select $h^* = 1/3$. If $\rho_{XY} = 1$, there would be no distress cost. For lower $\rho_{XY} = 1$ values, there would still be expected distress costs due to positive probability of state 3 occurring, where X is low and Y is simultaneously high. However, given that the potential loss

instance, the firm's revenue may be decomposed into $X = 0.5Z + 0.5Y$, where Z and Y are independent, and Y can be perfectly hedged with the swap while Z is not hedgeable. In this case, the values for Z would be 14, 20, 2, and 8 in states 1, 2, 3, and 4, respectively, so as to get the correspondence between X and Y shown in Table A.1.

Table A.2 Optimal Hedge Policy and Impact on Expected Distress Costs

| ρ | Firm value max | | Payoff variance min | |
|--------|----------------|---------------------------|---------------------|---------------------------|
| | h^* | $\mathbb{E}[\text{loss}]$ | h^* | $\mathbb{E}[\text{loss}]$ |
| 0 | $[0, 2/3]$ | 0.20 | 0 | 0.20 |
| 0.2 | $2/3$ | 0.16 | 0.2 | 0.188 |
| 0.6 | $2/3$ | 0.08 | 0.6 | 0.092 |
| 1 | $[2/3, 1]$ | 0 | 1 | 0 |

Note. This table shows the optimal hedge (h^*) and resulting expected distress cost ($\mathbb{E}[\text{loss}]$) assuming either firm value maximization or cash flow variance minimization, under different correlation values.

is \$1, rather than \$2, in the presence of operating flexibility, the expected distress costs will be half of the expected value loss shown in Table A.2. Note that the presence of operating flexibility not only mitigates distress costs but also significantly increases firm value. Since the firm can decrease the operating loss when $X = 8$ from \$2 to \$1, the firm value increases by 0.5. Other forms of risk management can reduce the impact of frictions, but cannot raise the overall value of the firm in the same way.

Finally, consider the possibility of the firm holding cash as a precautionary measure to mitigate distress costs triggered in the low output price states. However, there is a cost to holding cash, potentially due to the structure of the tax code, and we assume this cost is 2% of the amount of cash held. If the firm holds \$2.04 of cash, then it can stave off any distress costs (the cash net of the cost of holding cash will offset the operating loss of \$2 in the low output price states). The value loss in this case is simply the cost of holding cash, which is \$0.04, thus reducing the loss due to the combination of frictions and uncertainty from 20% of firm value down to only 4%. As can be seen by the linear relationship between expected loss and correlation in Table A.2, only if $\rho_{XY} > 0.8$ in our example would the use of hedging dominate holding cash as a risk management tool. Thus, in most practical cases where significant parts of firm risk cannot be hedged, cash will emerge as a critical element of the risk management policy.

Of course, it is possible to combine multiple risk management mechanisms. If the firm is able to shut down production, and incur only the switching cost of \$1 in the low price states, and if the firm also held \$1.02 of cash, then distress costs would be avoided. The net value loss would simply be the \$0.02 cost of holding cash, lower than the \$0.04 in the absence of operating flexibility. In the absence of operating flexibility, the firm could combine hedging together with holding cash. The benefit of hedging is that the firm could potentially offset some of the operating loss at no cost, and thus perhaps hold less cash and avoid the associated carrying cost. However, in our example, unless $\rho_{XY} \geq 0.8$, the benefit from hedging to offset the operating loss in state 4 is lower than the net benefit of adding more cash to guarantee there will be no operating loss in both states 3 and 4.³¹ More

³¹ Of course, more general state spaces could yield hybrid solutions where hedging and cash are jointly used, and such strategies emerge from our general model in the paper.

importantly, note that even when $\rho_{XY} = 1$, the marginal benefit of hedging when cash is held is relatively small. Holding cash reduces the value loss from 20% down to 4%, and although hedging completely eliminates any value loss, this incremental benefit is only worth 4%.

Our more general model in the paper incorporates corporate and personal taxes, debt and bankruptcy costs, and equity issuance costs. Furthermore, it is dynamic with the ability to adjust cash, derivatives positions and operations over time, subject to some adjustment costs, thus leading to a richer set of insights.

References

- Acharya V, Davydenko S, Strebulaev I (2012) Cash holdings and credit risk. *Rev. Financial Stud.* 25:3572–3609.
- Allayannis G, Schill M (2010) Financial policies and hedging. Working paper, Darden School of Business, University of Virginia, Charlottesville.
- Allayannis G, Weston JP (2001) The use of foreign currency derivatives and firm market value. *Rev. Financial Stud.* 14:243–276.
- Allayannis G, Ihrig J, Weston JP (2001) Exchange-rate hedging: Financial vs. operating strategies. *Amer. Econom. Rev. Papers Proc.* 91:391–395.
- Altinkilic O, Hansen RS (2000) Are there economies of scale in underwriting fees? Evidence of rising external financing costs. *Rev. Financial Stud.* 13:191–218.
- Aretz K, Bartram SM (2010) Corporate hedging and shareholder value. *J. Financial Res.* 33:317–371.
- Bartram SM (2008) What lies beneath: Foreign exchange rate exposure, hedging and cash flows. *J. Banking Finance* 32:1508–1521.
- Bartram SM, Brown G, Minton B (2010) Resolving the exposure puzzle: The many facets of exchange rate exposure. *J. Financial Econom.* 95:148–173.
- Bates TW, Kahle KM, Stulz RM (2009) Why do U.S. firms hold so much more cash than they used to? *J. Finance* 64:1985–2021.
- Bolton P, Chen H, Wang N (2011) A unified theory of Tobin's q , corporate investment, financing, and risk management. *J. Finance* 66:1545–1578.
- Campello M, Giambona E, Graham JR, Harvey CR (2011) Liquidity management and corporate investment during a financial crisis. *Rev. Financial Stud.* 24:1944–1979.
- Campello M, Lin C, Ma Y, Zou H (2011) The real and financial implications of corporate hedging. *J. Finance* 66:1615–1647.
- Carter DA, Rogers DA, Simkins BJ (2006) Does fuel hedging make economic sense? The case of the US airline industry. *Financial Management* 1:5–28.
- Fehle F, Tsyplakov S (2005) Dynamic risk management: Theory and evidence. *J. Financial Econom.* 78:3–47.
- Froot KA, Scharfstein D, Stein JC (1993) Risk management: Coordinating corporate investment and financing policies. *J. Finance* 48:1629–1658.
- Gamba A, Triantis AJ (2008) The value of financial flexibility. *J. Finance* 63:2263–2296.
- Geczy C, Minton BA, Schrand C (1997) Why firms use currency derivatives. *J. Finance* 52:1323–1354.
- Geczy C, Minton BA, Schrand C (2007) Taking a view: Corporate speculation, governance and compensation. *J. Finance* 62:2405–2443.
- Graham JR (2000) How big are the tax benefits of debt? *J. Finance* 55:1901–1941.
- Graham JR, Rogers DA (2002) Do firms hedge in response to tax incentives? *J. Finance* 57:815–839.
- Guay W, Kothari SP (2003) How much do firms hedge with derivatives? *J. Financial Econom.* 70:423–461.
- Hankins K (2011) How do financial firms manage risk? Unraveling the interaction of financial and operational hedging. *Management Sci.* 57:2197–2212.
- Haushalter D (2000) Financing policy, basis risk, and corporate hedging: Evidence from oil and gas producers. *J. Finance* 55:107–152.
- Hennessy CA, Whited TM (2005) Debt dynamics. *J. Finance* 60:1129–1165.
- Hoyt R, Liebenberg A (2011) The value of enterprise risk management. *J. Risk Insurance* 78:795–822.
- Jin Y, Jorion P (2006) Firm value and hedging: Evidence from U.S. oil and gas producers. *J. Finance* 61:893–919.
- Larkin Y, Leary M, Michaely R (2013) Do investors value dividend smoothing stocks differently? Presentation, 48th Annual Conference of the Western Financial Association, June 17–20, Hyatt Regency, Lake Tahoe, NV.
- Lins K, Servaes H, Tufano P (2010) What drives corporate liquidity: An international survey of cash holdings and lines of credit. *J. Financial Econom.* 98:160–176.
- Mello A, Parsons JE (2000) Hedging and liquidity. *Rev. Financial Stud.* 13:127–153.
- Mello A, Parsons JE, Triantis AJ (1995) An integrated model of multinational flexibility and financial hedging. *J. Internat. Econom.* 39:27–51.
- Meulbroeck L (2001) A better approach to managing risk. *Harvard Bus. Rev.* 79:22–23.
- Meulbroeck L (2002) The promise and challenge of integrated risk management. *Risk Management and Insurance Rev.* 5:55–66.
- Pantazis C, Simkins BJ, Laux P (2001) Operational hedges and the foreign exchange exposure of U.S. multinational corporations. *J. Internat. Bus. Stud.* 32:793–812.
- Pulvino TC (1998) Do asset fire-sales exist? An empirical investigation of commercial aircraft transactions. *J. Finance* 53:939–978.
- Rampini A, Viswanathan S (2010) Collateral, risk management, and the distribution of debt capacity. *J. Finance* 65:2293–2322.
- Smith CW, Stulz RM (1985) The determinants of firms' hedging policies. *J. Financial Quant. Anal.* 20:391–405.
- Strebulaev IA (2007) Do tests of capital structure theory mean what they say? *J. Finance* 62:1747–1787.
- Terry SJ, Knotek ES (2011) Markov-chain approximations of vector autoregressions: Application of general multivariate-normal integration techniques. *Econom. Lett.* 110:4–6.
- Tufano P (1996) Who manages risk? An empirical examination of the risk management practices in the gold mining industry. *J. Finance* 52:1097–1137.
- Wei SX, Zhang C (2006) Why did individual stocks become more volatile? *J. Bus.* 79:259–292.