Disintegrating Risk Management

Andrea Gamba[*] Alexander J. Triantis[†]

September 18, 2009

ABSTRACT

We present a dynamic structural model of integrated risk management. Several motivations for managing risk are incorporated into the model, including costs associated with external financing, distress and bankruptcy, and convexities in both corporate and personal tax structures. Risk management is enabled through a coordination of operating flexibility, liquidity management, and hedging with derivatives. We analyze the value created by this integrated risk management structure, disintegrate this value in several ways, and examine why it falls short of the value associated with a perfect risk management contract that would return firm value to that in a frictionless world. We study the relative contribution of the various rationales for managing risk, and highlight the importance of distress costs, as well as a convexity due to personal taxes on equity income that has not been emphasized to date in the literature. We also isolate the marginal contributions of the different mechanisms to manage risk. We show that liquidity serves a critical role in risk management, despite the tax penalty associated with holding cash, which provides a rationalization for the high levels of cash observed in recent empirical studies. The value attributable to derivatives usage does not appear to be significant in the presence of other risk management mechanisms, though we identify circumstances where this value might be larger, thus helping to resolve conflicting empirical evidence on this issue. We also evaluate the impact of financial agency problems that may result in speculative derivatives positions, and examine the efficacy of imposing position limits in corporate risk management policies.

[*]Department of Economics, University of Verona, Verona, Italy and George Washington University School of Business, Washington, DC, USA

[†]Robert H. Smith School of Business, University of Maryland, College Park, MD, USA

Introduction

Risk management has become a critical dimension of corporate financial policy, particularly in light of the recent global financial and economic crisis. It is widely appreciated that companies can enhance their values if they are able to mitigate some of the costly effects of risk. However, there are several key unresolved questions regarding risk management that have formed the agenda for much of the research in this area, particularly with respect to the use of derivatives to manage risk. Why do (or should) firms use derivatives? How should hedges be optimally structured? How much value is created by hedging with derivatives? Do companies use derivatives to speculate rather than hedge? In this paper, we present a generalized dynamic setting that allows us to provide some new insights on these issues from a normative perspective. We focus not only on managing risk through the use of derivatives, but also explore the important roles that internal liquidity and operating flexibility play in an integrated risk management system. The key contributions of this paper are briefly outlined below.

First, we examine the simultaneous and relative impact of various motivations for risk management. Many of the rationales for reducing risk have been examined elsewhere in the risk management literature, but typically in isolation. These include: reducing expected tax payments (Graham and Smith (1999), Graham and Rogers (2002)), avoiding external financing costs (Froot, Scharfstein, and Stein (1993)), and mitigating financial distress and default costs (Smith and Stulz (1985)).[1] We also highlight another motivation for risk management that does not appear to have surfaced in the literature. We show that even if there are no direct costs of issuing equity, there is an indirect cost to having to tap equity markets since shareholders receive payouts net of personal tax, while they provide capital at gross value. This asymmetry leads to a convexity in personal tax on equity similar in nature to the convexity in corporate tax structure which is frequently discussed in the literature. We find that the value impact can be quite significant if outside equity must be frequently raised due to high income variability. Our model allows us to separate out the effect of this, as well as other conventional, drivers of risk management to better gauge their relative impact on firm value, and thus

[1] Our framework does not incorporate all potential rationales for risk management. We assume symmetric information, and thus issues of noisy measurement of managerial performance, such as in DeMarzo and Duffie (1991) and Breeden and Viswanathan (1996), do not arise in our setting. We also do not incorporate managerial agency problems, and thus we do not investigate the use of derivatives to either decrease risk as in Tufano (1996) and Han (1996), or increase risk as discussed in Geczy, Minton, and Schrand (2007), in order to improve managerial welfare. Finally, while our value function is non-linear, we do not explicitly focus on concave operating value functions as do MacKay and Moeller (2007).

the value gains from managing risk.[2] Our results suggest that distress costs may be the most critical driver of risk management.

Second, by allowing for operating flexibility, corporate liquidity, and derivatives hedging, 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, adjustment costs associated with managing operating flexibility, and potential agency costs associated with each risk management activity).[3] For instance, we show that there is some substitutability between liquidity, hedging, and operating flexibility as risk management mechanisms, but they are by no means redundant and should be coordinated to maximize value creation due to risk management.

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 by the use of derivatives in corporations. Based on a set of parameters that correspond to typical values found in the empirical literature, we estimate that hedging with derivatives, in the presence of alternative risk management mechanisms, is likely to increase firm value by no more than 2%. This is consistent with the lack of evidence of any value creation in several recent studies (e.g., Bartram, Brown, and Conrad (2008), Guay and Kothari (2003), and Jin and Jorion (2006)). However, we also find that for specific firms that may face a key exposure that can be more effectively hedged, the value creation attributable to hedging with derivatives could be higher, even more than 5%, which is consistent with findings in Haushalter (2000) (from the oil & gas industry), Carter, Rogers, and Simkins (2006) (from airlines), and Allayannis and Weston (2001) (from exporters using FX derivatives). We also explore the notion of a customized perfect hedge and show that the potential value gain from such an instrument can be significantly more valuable than using a simpler swap contract (particularly one with low correlation

[2]Empirical papers that examine which factors appear to drive the use of derivatives by corporations include: Allayannis and Ofek (2001), Allayannis, Brown, and Klapper (2003), Bartram (2000), Bartram, Brown, and Fehle (2009), Bodnar, Hayt, and Marston (1998), Geczy, Minton, and Schrand (1997), Guay and Kothari (2003), Haushalter (2000), Mayers and Smith (1982), Mian (1996), and Nance, Smith, and Smithson (1993).

[3]The notion of integrated risk management is certainly not new. Numerous papers have pointed out that there may be more than one type of mechanism to manage risk, including Shapiro and Titman (1986). The use of operating flexibility as a substitute or complement for financial hedging has been analyzed in a theoretical context by Mello, Parsons, and Triantis (1995) and empirically by Bartram, Brown, and Fehle (2009), Bartram (2008), Petersen and Thiagarajan (2000). Meulbroek (2001) and Meulbroek (2002) also point out the importance of integrating various risks in an organization as well as coordinating alternative ways of managing the resulting net exposure. A contemporaneous research effort by Bolton, Chen, and Wang (2009) also provides a dynamic model of corporate risk management that integrates both liquidity and hedging. Their setting differs from ours in several significant ways, and more importantly their paper's key results focus on the investment policy, marginal Tobin's q, and equity beta, of financially constrained firms.

with total firm risk), even if the swap position can be dynamically adjusted over time. This emphasizes that while risk management has the potential to be very valuable for many risky firms, the limited mechanisms typically used for managing risk mean that much of this potential value is unattainable.

Third, we emphasize that liquidity is an important, and in many circumstances the most effective, risk management mechanism. The value created through liquidity not only comes as a result of avoiding high costs of financial distress when a firm's risk cannot be completely hedged using derivatives, but also from helping to cover extraordinary costs (such as a costly restructuring of operations) that, while tied to operating profitability, may not be easily hedged through standard derivatives contracts. These results underscore the comparative advantage that firms with comfortable liquidity cushions had during the recent financial crisis where the costs of external financing spiked upward due to systemic financial distress, and firms simultaneously faced significant restructuring costs. Our results also provide theoretical support for the recent empirical findings of Bates, Kahle, and Stulz (2008). They document higher levels of cash held by firms during recent years, leading to net debt levels that are close to zero on average, and frequently negative.

Fourth, we evaluate the impact of financial agency problems that result in firms taking on speculative derivatives positions in some circumstances.[4] We show that the value loss from such behavior can be significant, particularly if the firm doesn't have sufficient liquidity and the hedging instruments are not highly correlated with the firm's risk exposure. However, if position limits, which are typically prescribed in corporate risk management policies, are carefully monitored, this can effectively restore much of the potential value gain attributable to the use of derivatives.

The next section presents our model. Section II provides our key results, including the effects of different drivers of risk management, the relative impact of liquidity and hedging on the value attributable to risk management, the contribution of operating flexibility to corporate risk management, and the effects of financial agency problems on risk management. Section III concludes the paper.

[4] Recent papers by Adam and Fernando (2006), Brown, Crabb, and Haushalter (2002), Faulkender (2005), Geczy, Minton, and Schrand (2007), Guay (1999), and Hentschel and Kothari (2001) attempt to determine to what extent firm usage of derivatives is geared towards speculation rather than hedging.

I. 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.[5] We use a discrete-time infinite-horizon framework.

A. Production technology

The firm has operating flexibility in that it can decide to start production if it is idle, or alternatively, it can temporarily cease operations. We denote m to be the status of the firm, where $m \in \{0, 1\}$, with 0 if operations are open/active, and 1 in the closed/idle status.

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:

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

where $\kappa_1 < 1$ is the persistence parameter, $\sigma_1 > 0$ is the conditional standard deviation, $\overline{x}_1 = \log \overline{\theta}_1$ is the long–term mean, and ε_1 are i.i.d. 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).

$$R(\theta_1, m) = \begin{cases} q(\theta_1 - A) & \text{if } m = 0 \\ 0 & \text{if } m = 1. \end{cases}$$

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

$$K(m, m') = \begin{cases} K^c & \text{if } m = 0 \text{ and } m' = 1 \\ K^o & \text{if } m = 1 \text{ and } m' = 0 \\ 0 & \text{otherwise.} \end{cases}$$

For brevity, we denote the net cash flow from the firm's operations as

$$g(\theta_1, m, m') = R(\theta_1, m) - K(m, m')$$

.

[5]For example, one can consider the classic setting of Brennan and Schwartz (1985) in which a mine can be opened and closed over time in reaction to changes in the commodity price.

B. Hedging

The firm can take a long position in a perpetual and putable swap contract issued by a bank.[6] The underlying asset of the swap is denoted θ_2, and $x_2 = \log \theta_2$ follows the process

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

where $\kappa_2 < 1$ and $\sigma_2 > 0$, and $\overline{x}_2 = \log \overline{\theta}_2$. Without loss of generality, we restrict the analysis to the case where the two state variables θ_1 and θ_2 have positive correlation, $\mathbb{E}[\varepsilon_1 \varepsilon_2] = \rho \geq 0$. When $0 < \rho < 1$, the swap offers an imperfect hedge of the risk of the firm. We will also examine the case where $\rho = 1$, where the firm may seemingly be able to eliminate all the firm's risk. For brevity, 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, i.e., 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 with $\theta_2 = \theta_2(t)$, is[7]

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

where $F_t(\theta_2, t+i) = \mathbb{E}_t\left[\theta_2(t+i)\right]$ 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 that (see Appendix A)

$$F_t(\theta_2, t+i) = \theta_2^{\kappa_2^i} \overline{\theta}_2^{(1-\kappa_2^i)} \exp\left(\frac{\sigma_2^2}{2} \frac{1-\kappa_2^{2i}}{1-\kappa_2^2}\right). \tag{4}$$

The firm can default on the swap obligation, and it also 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. Hence, the net payoff from the transaction is $h \cdot SP - h' \cdot SF$. We assume that each transaction (closing the old contract and opening the new one) also entails a negotiation cost, nc, proportional to the absolute value of the notional amount, so that the direct cost of adjusting the hedge is: $nc \cdot |h' + h|$.

[6] We discuss in Section II the situation where derivative securities with non-linear payoff structures are used for hedging rather than swap contracts.

[7] In our results, we numerically compute the value of the swap by approximating the infinite summation in (3) with a finite summation with $T = 500$ terms.

At the inception of the swap agreement, the *fair value* of the contract, SF, 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. This also implies that there is an indirect cost associated with adjusting a swap position at a later date. 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 with $\theta_2 = \theta_2(t)$ is

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

where T_d is the default date for the firm, T_p is the date when the swap position is closed, and $RS(\cdot)$ is the bank's recovery value on the swap if the firm defaults.[8] In equation (5), $a \wedge b = \inf\{a, b\}$, and $\chi_{\{A\}}$ is the indicator function of the event A. In particular, $\{T_d \geq T_p\}$ 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.

Interpreting equation (5), the first line is the present value of the net payoff to the firm before either the firm exercises the option to close the swap agreement or default happens; the second part is the payoff to the bank if the firm terminates the swap agreement due to rebalancing of its hedge position, or if it defaults. The bank is paid the par value in the former case, and a reduced recovery value in the latter.

T_d and T_p are 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 as shown later in the context of the valuation problem.

Since the swap price, s, is fixed, SF (and SP) can be either positive or negative. Thus, as opposed to the typical swap contract where the swap price is set up so that $SF = 0$ at inception, here there may be an upfront payment: a cash inflow for the firm if $SF < 0$ or an outflow if $SF > 0$.[9] Because of the credit charge and the possibility of renegotiating the hedging contract, we can anticipate that in general $SF \neq SP$.

[8] $RS(\cdot)$ depends on the value of the firm, as will be soon shown.

[9] We choose to fix the swap price at a constant level, rather than setting the price to yield a zero swap value, in order to simplify our model. However, as a robustness check, we have rerun our numerical results using different swap price levels, and this does not affect our results.

C. Financial policy

We assume that the firm has issues a non-redeemable defaultable consol bond with face value d. The firm pays a coupon rate r on the debt at the end of every period.

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. The firm strategically manages its financial flexibility by setting the appropriate cash balance at each state over time. The 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 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 equityholders.

D. Personal and corporate taxes

Corporate pre-tax 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 $w(\theta, m, b, h, m', b', h')$:

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

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 τ_e on payments to equityholders, and τ_d on payments to bondholders. With respect to taxes on payouts to equityholders, we do not distinguish between dividends and equity repurchases (nor do we separately consider the capital gains of selling shareholders).

The value of the debt contract at time t, with $\theta = \theta(t)$ is

$$D(\theta) = \mathbb{E}_t \left[\sum_{i=1}^{T_d} \frac{rd(1 - \tau_d)}{(1 + r(1 - \tau_d))^i} \right] + \mathbb{E}_t \left[\chi_{\{T_d < \infty\}} \frac{RD(\theta(t + T_d))}{(1 + r(1 - \tau_d))^{T_d}} \right],$$

where $RD(\cdot)$ is the recovery value to debt holders in the case of default. This is defined later on (together with the default policy), as it depends on the optimal policy of the firm. Notice that we discount after personal tax cash flows with after personal tax returns.

E. Financial distress and default

If the after–corporate–tax cash flow from operations, net of the payoff from the swap contract and from a change in the hedging policy, plus current cash balance is lower than the interest payment on net debt,

$$\begin{aligned} rd > g(\theta_1, m, m') + (1+r)b + h(s - \theta_2) \\ + \left(hSP(\theta_1) - h'SF(\theta, m', b', h') - nc|h' + h|\right)\chi_{\{h' \neq h\}} - \tau_c(w), \end{aligned}$$

or $w - \tau_c(w) + b < 0$, the firm is in a liquidity crisis. We model financial distress costs as a proportion, dc, of the cash shortfall from the coupon payment. In addition to raising cash from equityholders to cover the shortfall (which has an effective cost of $(dc + \lambda)|w - \tau_c(w) + b|$ in this case of distress), the firm may decide to raise further capital to create a positive liquidity balance going forward. If it does so, the additional amount raised from equityholders is subject only to the standard proportional cost of λ.

If $w - \tau_c(w) + b < 0$, and the equityholders choose not to make up this shortfall, the firm is in default. We assume that in this case the swap contract has priority over the debt contract.[10] This means that the bankruptcy proceeds, net of proportional verification costs, γ, are first used to pay the bank (swap counterparty) if the swap values is negative, and debtholders 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 debtholders.[11]

F. The value of the firm

The cash flow to equity holders at t is

$$e_t = e(\theta, m, b, h, m', b', h') = \max\{cfe, 0\}(1 - \tau_e) + \min\{cfe, 0\}(1 + \lambda)$$

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 equityholders is taxed at the personal tax rate τ_e, or negative, in which case equity is raised, subject to the flotation cost λ. The

[10] 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 giving them effective priority over debt.

[11] In some cases, there may be "walk-away" clauses in the swap agreement that prevent this, but lenders often prohibit borrowers from entering into agreements with such provisions (see Gooch and Klein (2002)).

cash flow depends on the current state, (θ, m, b, h), as well as the decisions regarding next period's operating state, m', cash balance level, b', and swap position, h'.

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

$$E(\theta, m, b, h) = \max_{\{(m_i, b_i, h_i), i=1,\dots T_d\}} \mathbb{E}_t \left[\sum_{i=0}^{T_d} \beta^i e_i \right] \tag{6}$$

where $\beta = (1 + r_z(1-\tau_e))^{-1}$ is the discount factor for valuing equity flows, with $r_z = r(1-\tau_d)/(1-\tau_e)$ denoting the certainty equivalent rate of return on equity (see Sick (1990)).

The Bellman equation for the solution to (6) is

$$E(\theta, m, b, h) = \max \left\{ \max_{(m', b', h')} \left\{ e(\theta, m, b, h, m', b', h') + \beta \mathbb{E}_{\theta,m,b,h} \left[E(\theta', m', b', h') \right] \right\}, 0 \right\}. \tag{7}$$

where (m', b', h') denotes the firm's decision made at the beginning of the period, soon after the current state, θ, is observed, θ' is the unknown state at the end of the period, and $\mathbb{E}_{\theta,m,b,h}[\cdot]$ is the expectation conditional on (θ, m, b, h). When the firm is not solvent, the value of equity is maximized by exercising the limited liability option, i.e., $E(\theta, m, b, h) = 0$.

We denote the firm's policy as $\varphi(\theta, m, b, h)$. In our analysis, we will consider two possible goals: either firm value (i.e., first best) maximization, or equity value (i.e., second best) maximization. The optimal choice is $(m^*, b^*, h^*) = \varphi(\theta, m, b, h)$ if the firm is solvent. In the case of default, the firm is turned into an unlevered concern, i.e., all the cash balance is paid out and a new cash balance is set at $b = d$), the swap contract is liquidated ($h = 0$), and the operating policy is left unchanged (i.e., in default, the optimal policy is $(m, d, 0)$). We denote $\delta(\theta, m, b, h)$ as the default indicator function, that is, the indicator of the event $E(\theta, m, b, h) = 0$.

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

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

The first two lines of this equation represent the case where the firm is solvent. The first term in this expression is the standard cash flow from the swap; the second term is the par value of the swap which is paid (or received) if the position in the swap will be changed ($h'' \neq h'$); the third term is the new swap value in case the notional amount is unchanged, based on the firm's operating and cash policies, m'' and b'', respectively. $SF(\theta', m'', b'', h')$ 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 third line of the equation is the payoff in case 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 $h'' = 0$. Notice that in the definition of the cash flow to the swap, we incorporate φ to reflect that the end of period value depends on the future decisions $(m'', b'', h'') = \varphi(\theta', m', b', h')$.

From the above, 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

$$SF(\theta, m', b', h') = \beta_0 \mathbb{E}_{\theta,m,b,h}\left[cfs(\theta', m', b', h', \varphi)\right], \tag{8}$$

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

Using the same valuation principle we applied for the swap, the value of corporate debt is

$$D(\theta, m', b', h') = \beta \mathbb{E}_{\theta,m,b,h}\left[cfd(\theta', m', b', h', \varphi)\right], \tag{9}$$

where this time $\beta = (1 + r(1-\tau_d))^{-1}$ reflects the personal tax rate on debt, and the end of period after personal tax cash flow to debt holders is

$$\begin{aligned} cfd(\theta', m', b', h', \varphi) = {} & (1 - \delta(\theta', m', b', h'))\left(rb'(1-\tau_d) + D(\theta', m'', b'', h'')\right) \\ & + \delta(\theta', m', b', h') \min\{rb'(1-\tau_d) + d, \\ & \max\{0, b' + (1-\gamma)E(\theta', m', d, 0) + h\left((s - \theta_2') + SP(\theta_2')\right)\}\}. \end{aligned}$$

The first line 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 and third lines are the residual payoff to bond holders, considering their lower priority with respect to the swap. Note that, if θ_2' is such that $(s - \theta_2') + SP(\theta_2') > 0$ (typically when θ_2 is low), then the bond holders receive more than the unlevered going concern value of the firm net of bankruptcy costs (although less than d). Otherwise, they receive less than $b' + (1-\gamma)E(\theta', m', d, 0)$ due to their lower priority at default.

Under firm value maximization, we solve the program

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

when equity value is positive, with the condition that $D(\cdot)$ satisfies (9). If at the optimal solution the firm is solvent, then the optimal policy is (m^*, b^*, h^*). Otherwise the firm is in default and hence $(m, d, 0)$ is the optimal solution. Under equity value maximization, the solution of the valuation problem is found by solving the system of simultaneous equations (7) and (9). The numerical technique we use is value function iteration on a discretized version of the continuous state problem. Appendix B describes the approach we used to find a discrete–state approximation of the Markov process $\{\theta(t)\}$.

II. Results

In this section, we explore the impact of the underlying drivers of risk management, analyze the marginal and joint contributions of liquidity, hedging and operating flexibility to manage risk, and explore the potential impact of agency problems due to speculation.

A. Parameter values

The base case parameters for our analysis are shown in Table I. These parameters were selected to correspond to typical values found in the empirical literature and/or to obtain simulated moments for key metrics such as leverage that are consistent with those in recent studies. The simulation procedure we use is detailed in Appendix C. We discuss each parameter selection below.

The volatility and persistence of the log of the product price (or revenue, since production quantity is equal to one) are set to $\sigma_1 = 15\%$ and $\kappa_1 = .80$, which are consistent with the range of values used in recent articles with similar processes (e.g., Hennessy and Whited (2005) and Zhang (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., $\overline{x}_1 = 0$), the fixed production cost $A = .95$, and the closing and opening costs ($K^c = .3$ and $K^o = .1$). These values lead to a simulated volatility of ROE (using the market value of equity) of 0.26, which is within the range of values reported in empirical papers based on samples taken from different time periods.[12] 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 in the special case of perfect correlation), and the fixed swap price $s = 1$ for simplicity. Likewise, the production rate equals one.

[12] Campbell, Lettau, Malkiel, and Xu (2001), Pastor and Veronesi (2003), and Wei and Zhang (2006) document, and provide potential explanations for, the change in volatility of ROE and stock returns over the recent decades.

The base case value for the correlation, ρ, between the product price and the price of the underlying asset of the swap is assumed to be 0.1, but we will also explore cases where the correlation is equal to .5 or 1. The perfect correlation case allows us to analyze an extreme case where the firm's risk exposure should be perfectly hedged through proper use of the swap, thus providing an upper bound for the value created by such hedging. This will also permit us to highlight some limitations of hedging with derivatives. However, it is unlikely in practice that a firm will have the ability to hedge its entire risk exposure using derivatives. Most firms face multiple sources of risks, many of which are idiosyncratic and can therefore not be hedged with derivatives, as well as systematic risks for which well-established derivatives markets do not yet exist (e.g., macroeconomic factors). If we interpret the source of risk in our model more broadly as representing the entire risk exposure of a firm, the correlation can be loosely interpreted the extent to which a company's total risk exposure can be hedged using derivatives. We use a correlation of 0.1 for the base case, which seems to be a reasonable measure of the this extent of hedging for a (non-financial) company. The case with correlation of 0.5 is used for robustness to explore a situation where a company's primary risks (commodity price, foreign exchange, and interest rates) can all be reasonably well hedged. Since even firms in the commodities business are subject to significant idiosyncratic and otherwise non-hedgeable risks, and do not appear to fully hedge the exposures they can hedge, this likely represents a generous upper bound even for this class of firms.[13]

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_b) is set at 25%, consistent with Hennessy and Whited (2005), but somewhat less than that in Graham (2000). The corporate tax rate on income (τ_c^+) is set to the current marginal tax rate of 35%, and, due to limited carrybacks and carryforwards, the effective tax on losses (τ_c^-) is assumed to be somewhat lower at 30%. This convexity is roughly consistent with the corporate tax function applied in Hennessy and Whited (2005). Overall, the effective tax benefit (or penalty) from interest payments on debt (or return on 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 very consistent with empirical studies that directly estimate these costs (e.g., Altinkilic and Hansen (2000)) as well as those that indirectly estimate them through structural models (Hennessy and Whited (2005) and Hennessy and Whited (2007)).

[13]Tufano (1996) finds that few gold mining companies hedge more than half of their three–year forward production, and the mean "delta–percentage" is closer to 25%. Bartram, Brown, and Minton (2009) 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 hedgable. Carter, Rogers, and Simkins (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 is likely that it represents a higher percent of the total risk exposure.

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 mode, or to assume costly terms in agreements for capital infusions (e.g. during Fall 2008, banks and other distressed companies issued preferred stock with large dividends and attached warrants). Pulvino (1998)) estimates that the costs associated with fire-sales average around 14%, which is close to the 15% we assume. Distress costs assumed by other authors in related models start as low as 5% (the lowest point of a range of 5-25% assumed by Strebulaev (2007)) to 200% in Fehle and Tsyplakov (2005) (Hennessy and Whited (2005) assume a 40% distress cost).

The cost associated with a bankruptcy restructuring (γ) is assumed to be 10% of the value of the newly unlevered firm. While there is significant variation in estimates of bankruptcy costs provided in the literature, depending on sample selection as well as method of estimation, 10% appears to be a reasonable level. It is slightly higher than the mean bankruptcy costs reported in Bris, Welch, and Zhu (2006) and the estimate produced in Hennessy and Whited (2007), but towards the bottom end of the range estimated in Andrade and Kaplan (1998) based on highly leveraged transactions. As we will report later, 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 aggregate 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 value 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. However, our results do not appear to be sensitive to this cost within a reasonable range of values.

Finally, we set the debt level (d) equal to .4. Based on the resulting simulated leverage values, we find an average quasi-market leverage ratio of 24%, and an average net leverage ratio close to 0 (our simulated average value of b is 0.42). These values are reasonably consistent with the recent evidence presented in Bates, Kahle, and Stulz (2008). 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.

B. 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 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 in the model (based on the parameters in Table I). The value of risk management is calculated as the percentage increase in firm value from dynamically managing both cash balance and swap positions (with $\rho = .1$ between the swap's underlying asset and the product price), relative to the firm value when neither of these risk management controls are present. A first-best (firm value maximization) setting is used for now, and we later explore the effect of potential agency problems. We also later 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., $K^o = .1$ and $K^c = .3$).

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 θ_1 value of 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, it becomes very large (over 35%), but this is largely due to the fact that there are very small firm values for low θ_1 values, and 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 a derivative but also the contribution of managing an internal cash balance, can be a key contributor to 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 what the value of risk management is when there are no issuance, distress and bankruptcy costs, and when personal and corporate taxes are perfectly linear (i.e., $\tau_c^+ = \tau_c^- = .40$, and $\lambda = -\tau_e = -.12$). As expected, there is no value associated with the ability to hold a cash balance and to use a swap (neither are used in this case despite being available), because there are no penalties associated with the firm having negative income or being in distress or bankruptcy.

The other curves in Figure 1 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 two more significant drivers appear to be distress costs and convex personal taxes (i.e., the fact that equity outflows are taxed while inflows receive no tax subsidy).

The impact of distress costs (which are shown together with equity issuance costs, since both are incurred in the event of distress) is related to the penalty assumed for distress. 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.[14]

The role of convex personal taxes is interesting and appears not to be highlighted to date in the the risk management literature. 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 since they are taxed on income but yet 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. While 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 of course consistent with what we know from the empirical literature on payout and issuance policies in that firms don't pay out all available cash in part because this might leave them needing to raise equity capital in a subsequent period, and as a result equity issuance is also found to be relatively rare for firms that are not in a high-growth stage. In the context of our dynamic model, 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).

We should note that the relative impact of the various motivations for risk management clearly depends to some extent on the parameter assumptions, and thus will be situational specific for each firm. A firm's shareholder clientele may lead to a higher or lower effective "personal" tax rate on equity than the 12% assumed here, thus affecting the magnitude of the convex personal tax effect. Similarly, different firms may have more or less ability to carry forward or back net operating losses, affecting the convexity of corporate taxes, or may face higher or lower distress costs depending on the nature of the business and the degree of systemic distress at a point in time. Nevertheless, our results provide some useful insight into the relative importance of various motivations for risk management. Finally, note that summing 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.

[14] If bankruptcy costs are singled out as the only friction, risk management does not add any value in the current context where firm value is being optimized. The firm will raise the necessary financing (at no cost) rather than incur bankruptcy costs. Therefore, we do not include this curve in Figure 1.

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 uncertainty coupled with frictions and tax convexities. We will then examine the contribution of operating flexibility to risk management, taking into account that the firm can also manage its liquidity and hedging positions.

C. Relative Contributions of Liquidity, Hedging and Operating Flexibility to the Value of Risk Management

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 can't hedge with a swap; 2) the firm can dynamically manage a swap position, but can't keep a liquidity balance; and 3) the firm has both a liquidity balance and swap position that can be optimized over time. We continue to assume for now that $\rho = 0.1$ (i.e., the underlying asset of the swap, θ_2, has correlation of 0.1 with the firm's risk exposure, θ_1), and thus the case with both liquidity balance and swap is simply the base case curve which was shown in Figure 1). As discussed earlier, the swap and liquidity positions are dynamically managed to maximize firm value.

Maintaining a cash balance is clearly essential for the firm in our framework. Since the firm will experience losses when the firm is operating and the product price, θ_1, is lower than .97 (the fixed production cost of .95 plus the interest of $r * d = .05 * .4 = .02$), and also has to make interest payments even when production is closed, the existence of liquidity inside the firm is essential to avoid costly distress and equity issuance. 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.

The value of the derivatives hedge (with $\rho = 0.1$), whether measured in the absence or presence of a cash balance, ranges from 0 to 7% of firm value, 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 in recessionary industries or periods. 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.[15] In contrast, Allayannis and Weston (2001) estimate that

[15] However, Jin and Jorion (2006) note that their sample of oil and gas firms may bias their results towards lower value creation from the use of derivatives since investors in those firms might prefer that these firms not hedge away the risk exposure.

hedging with foreign exchange derivatives increases value by approximately 5% on average for their sample of non-financial multinationals (a value which Guay and Kothari (2003) view as excessive given the extent of hedging and its resulting effect on cash flows), and Carter, Rogers, and Simkins (2006) estimate value increases between 5-10% 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 $\rho = .1$, which can be loosely viewed as a firm being able to hedge about 10% of its risk exposure. Some firms may be able to hedge more than this percentage of their exposure, particularly those in industries where certain key risk factors are present, such as a commodity output or a highly volatile input factor (e.g., fuel cost for airlines). In Figure 3, we plot the percentage value increase attributable to risk management as in Figure 2, but explore the effect of higher correlations between θ_1 and θ_2 of either 0.5 or 1. Going from the case of $\rho = .1$ to that of $\rho = .5$, the value increase attributable to risk management does become larger as expected, but rather incrementally (less than .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 non-linear.

As discussed earlier, we believe it is unlikely that firms can hedge more than half of their risk exposure using derivatives, even in industries where there is one key uncertainty driving profitability that can be hedged. Thus it may well be, as Jin and Jorion (2006) and others have argued, that the high levels of value increase attributed to hedging may in fact reflect other endogenous factors. These factors may include additional risk management efforts beyond simply hedging with derivatives, or 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 percentage of a firm's risk exposure that 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 only considered one type of derivative, namely a swap contract. As Adam (2002), Adam (2009), Brown and Toft (2002) and others have shown, option contracts may be more effective hedging instruments for some companies than linear derivative contracts such as forwards and swaps. Thus, by focusing only on the use of a swap contract, we may be understating the true value that could be created using alternative non-linear derivatives contracts. Note, however, that the swap position in our model can be dynamically adjusted at relatively low cost, so the hedging profile is effectively non-linear and quite flexible. Nonetheless, it is useful to consider the value that would be created by an optimal customized derivatives contract, i.e., a "perfect hedge." This contract would cover the loss in any period such that the firm would never be in distress or in need of issuing equity, nor subject to the effects of convex corporate taxes.[16]

Figure 4 shows that the value added due to the customized contract is higher than that from dynamically rebalancing a cash balance and a swap position (with $\rho = 1$). To fully appreciate this result, first note from comparing the bottom two curves in Figure 4 that having 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 the profit will be locked in at .02 ($\approx (1 - .35) * (1 - .95 - .02)$), but this is not enough to pay the closing cost if it is optimal to close production.[17] Similarly, in states where the production is closed, the firm doesn't have cash flow to pay for opening costs if profitability returns and it is optimal to re-open 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.

Returning to the "perfect hedge", this contract covers deficits due not only to operating losses but also to the adjustment costs (K^o and K^c), since it is designed to avoid all potential circumstances that would otherwise lead to equity issuance or distress. While a cash balance, coupled with hedging using a perfectly correlated swap, can manage much of the risk of a firm, even a substantial cash balance position will gradually be depleted if the firm continues to suffer losses over a sufficiently long period of time. Thus, even the cash and perfect hedge position will still trigger issuance and/or distress costs with some probability, though this can be minimized with a high cash balance. However, the firm may not have a sufficient string of positive outcomes to build such a large cash balance without issuing equity, and the tax penalty associated with holding a high cash balance can be very significant over time. In contrast, the perfect hedge can always cover any

---

[16] We calculate the value in this case by simply eliminating all frictions, i.e., zero issuance, distress and bankruptcy costs, and using linear functions for both personal equity tax ($\lambda = -\tau_e$) and corporate tax ($\tau_c^+ = \tau_c^-$). Since a perfect hedge prevents a firm from incurring any such costs (or being in the lower part of the convex tax function), this no-frictions case is conceptually the same as the perfect hedge case. Implicit here is that the perfect hedge provides exactly the state-contingent payout necessary to avoid any negative cash flows, not only due to operating losses, but also those incurred when adjusting the operating policy, and that the firm makes state-contingent payments whose present value is equal to the present value of the payouts received.

[17] 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. 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.

deficits, whether due to operating losses or adjustment costs, without any associated tax penalty.

Note that the value increase from the perfect hedge in Figure 4 relative to the case of having cash but no hedge (in Figure 2) is quite significant, of the order of 20%. Thus, while the marginal benefit of having a swap contract when the firm also optimally manages its cash balance may not be that high (particularly if ρ is low), as we discussed earlier, the situation would be quite different if there were in fact a perfect hedge. However, it would clearly be difficult to design such a product in practice that would provide a blanket cover for all of a firm's risk exposure, including occasional extraordinary costs such as those due to restructuring. These products would obviously have significant transaction costs due to their customized nature, and would also potentially be susceptible to other problems such as moral hazard, and we do not incorporate these offsetting costs associated with the perfect hedge here. Regardless, our exploration of the perfect hedge provides a mechanism to bound the value attributable to risk management.

To better understand the relative contribution of liquidity and hedging to value creation, particularly from a marginal perspective of how each contributes in the presence of the other, we examine the value surfaces shown in Figure 5. Each graph illustrates firm value for a particular current state (θ_1, θ_2, m, b, h) against possible selections of new cash balance (b') and hedge (h') levels. In each graph, there is an optimal (b', h') pair that maximizes firm value (i.e., corresponds to the peak of the value surface), and these values are shown above each graph. The optimal production policy is also shown above each graph as m', which equals 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 shown in Figure 5 are organized to show the effects of both current profitability as well as existing cash balance and hedge levels, as follows. The top row assumes $\theta_1 = 1$, while 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 ($b = h = 0$), while the right column assumes $b = 0.4$ and $h = .03$, which are approximately the steady-state average levels for the base case from our simulations (these statistics will be discussed in greater detail later in the results section).[18] In all cases, we choose the asset value underlying the swap, θ_2, to be equal to 0.8, in order to have a zero fair value of the swap.[19]

[18]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.

[19]While the fixed swap price, s, received each period is equal to one, and thus the periodic cash flow $s - \theta_2$ equals zero when $\theta_2 = 1$, the non-linearity of the swap valuation captured in Equation (5) (due to the distributional assumptions and 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 one can see that that the marginal values of liquidity and hedging are quite state specific, reflecting a variety of factors. For instance, comparing the top two graphs, one can see that when the firm starts with no cash, it accumulates what it makes in the current period, but doesn't increase the cash balance further given the high cost of doing so through issuing equity, whereas 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, and thus it is willing to issue equity in order 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, so this situation presents yet another distinct set of marginal values.

One can also see from the graphs that the marginal value of hedging appears to be 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, i.e., 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. The lower sensitivity of the marginal value of hedging as compared to that for liquidity also reflects to some degree the relatively smaller contribution of hedging versus liquidity to the overall value of integrated risk management.

We now turn to examine operating flexibility, which is the third key component of the integrated risk management program in our framework. We focus in particular on how this risk management tool interacts with the financial risk management (FRM) mechanisms, namely liquidity and hedging. Table II addresses this issue, showing value creation due to risk management under varying scenarios.

The first row of Table II shows the value increase due to FRM if there is no operating flexibility (so the firm must always remain open). These values are shown for a selection of θ_1 values around the long-term mean.[20] The second row also shows the value increase due to FRM, but where there already is operating flexibility (i.e., $K^c = .3$). The values of FRM are lower in the second row than in the first row, since operating flexibility also exists. In other words, there is some substitutability between the two forms of risk management, but yet FRM still adds significant value even in the presence of operating

[20]Note that in looking at percentage value increases, these increases become extremely high for small θ_1 values given that firm values can be very low in those cases, particularly when there is no FRM or operating flexibility.

flexibility. This is true since production is not completely flexible and the firm is still susceptible to losses, whose effects can be mitigated by using liquidity and hedging.

In the second set of rows, we see similar effects by turning the relationship around, examining the value of operating flexibility with and without FRM. We find that operating flexibility can greatly enhance firm value even if financial risk management mechanisms are in place. However, the value due to operating flexibility is considerably higher if this is the only source of risk management. Finally, in the last row we show the total potential of having an integrated risk management system comprised of both operating flexibility and financial risk management relative to the value of the firm when it is completely exposed to the impact of uncertainty without any tools to control the value loss associated with such risk. The values can clearly be quite high, though keep in mind that the percentage value increases for low θ_1 values reflect the very low firm values when there is no form of risk management mechanism at work.

D. Agency Problems due to Speculation

Much attention in the academic literature and in practice has been paid to the fact that derivatives can be readily used for speculative purposes within a corporation. In this section, we investigate the value impact of speculative behavior that might arise as a result of risk-shifting incentives driven by financial agency problems. We examine situations where this problem is of greatest concern, and discuss the extent to which position limits that can be effectively imposed and monitored can mitigate such problems.

In the top panel of Figure 6, we examine the percentage increase in firm value due to having a cash balance and a swap with $\rho = 0.1$, under three scenarios: 1) equity value maximization ("SB" for second-best); 2) equity value maximization, but with h capped at 0.5 ("constrained"); and 3) firm value maximization ("FB" for first-best, which was also shown in Figure 2). One can see that the value created is significantly lower when decisions are made to maximize equity value rather than firm value. Given that θ_1 and θ_2 have low correlation, there are cases where the firm may increase the hedge position beyond the level which would serve to maximize firm value, in order to increase risk and take advantage of the positive effect of risk on shareholder value. However, if position limits can be placed on h (and effectively monitored), this can help to significantly mitigate this agency problem due to speculation. The dashed line in the top panel illustrates that this position limit can almost restore the firm to its first-best value.

In the lower panel of Figure 6, the bottom two curves capture the firm value and equity value maximization cases when there is no cash balance. Without cash to provide some buffering effect on firm risk and at least a temporary reduction in net debt, equityholders use the swap even more aggressively. Not only does the firm not benefit from the risk management value of hedging, it loses value as a result of the speculative behavior of shareholders. The top three curves show a contrasting case where the firm holds a cash balance, and also has access to a swap with $\rho = 1$. In this case, speculation is much less likely given that the swap clearly aligns with the risk of the firm (and we do not permit $h < 0$ or $h > 1$). Some speculation is still possible, for instance if the firm is closed and yet it continues to hold a swap position, and indeed we see some value loss comparing the second-best and first-best cases. However, if a position limit of $h < 0.5$ is imposed (the "constrained" case), then firm value is restored to the first-best value (the curves are identical in the graph).

Thus, Figure 6 shows that the extent and impact of speculative use of derivatives on firm value will depend on, among other factors, the degree to which the derivatives instruments are correlated with firm risk, the ability to set and enforce position limits, and the extent to which the firm has cash, which provides a buffer against risks and ultimately represents value that would be foregone by shareholders in the event of a derivatives-induced loss.

These effects are also highlighted in Table III, where we show the mean and standard deviation (in parentheses) of the cash and hedging positions under both firm value and equity value maximization. These values are generated based on the simulation described in detail in Appendix C. Note that in the first row (corresponding to the top panel of Figure 6), the hedge level (and its standard deviation) is higher in the equity value maximization case than under firm value maximization. This increased hedge level is even more pronounced in the last row where there is no cash, consistent with the larger value loss due to speculative behavior noted above.

In contrast, when $\rho = 1$, the opportunity to speculate and drive the firm's risk higher is limited, as noted earlier. As a result, we find that the hedge ratio statistics in the third row of Table III are virtually identical in the first-best and second-best cases, consistent with the similar values observed in the top three curves in the bottom panel of Figure 6.

Finally, note in Table III that the cash position increases as the hedge becomes less effective (particularly dropping from $\rho = 1$ to $\rho = 0.5$), and that the cash position does not appear to be affected by financial agency problems. Similarly, while the probability of being open (the "Operate" column) differs somewhat from case to case, it is not greatly affected by agency conflicts, other than equityholders appearing to keep production open longer since they are less willing to incur the closing cost given that they may soon exercise their limited liability option. Overall, it is clear that the swap presents the best opportunity for equityholders to risk shift, and this incentive must be appropriately constrained by position limits that are carefully monitored.

III. Conclusions

Our framework incorporates several rationales for managing risk and examines the coordination of three important risk management mechanisms in a dynamic setting. 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 managerial 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 these investigations.

A. Derivation of Equation (4)

From equation (2), omitting the subscript for simplicity, we have

$$x(t+i) = \kappa^i x(t) + \overline{x}(1-\kappa)\sum_{j=0}^{i-1}\kappa^j + \sigma\sum_{j=0}^{i-1}\kappa^j\varepsilon(t+i-j).$$

Hence, the average of $x(t+i)$ conditional on $x(t)$ is

$$\mathbb{E}_t\left[x(t+i)\right] = \kappa^i x(t) + \overline{x}(1-\kappa)\sum_{j=0}^{i-1}\kappa^j = \kappa^i x(t) + \overline{x}(1-\kappa^i)$$

and the variance of $x(t+i)$ conditional on $x(t)$ is

$$\mathrm{Var}_t\left[x(t+i)\right] = \sigma^2\sum_{j=0}^{i-1}\kappa^{2j} = \sigma^2\frac{1-\kappa^{2i}}{1-\kappa^2}.$$

The future price as of t, given the current value $\theta_2(t) = \theta_2 = e^{x(t)}$, for delivery at $t+i$ is

$$\begin{aligned}
F_t(\theta_2, t+i) &= \exp\left\{\mathbb{E}_t\left[x(t+i)\right] + \frac{1}{2}\mathrm{Var}_t\left[x(t+i)\right]\right\}\\
&= \exp\left\{\kappa^i x(t)\right\}\cdot\exp\left\{\overline{x}(1-\kappa^i)\right\}\cdot\exp\left\{\frac{\sigma^2}{2}\frac{1-\kappa^{2i}}{1-\kappa^2}\right\}\\
&= \theta_2^{\kappa^i}\overline{\theta}_2^{(1-\kappa^i)}\exp\left\{\frac{\sigma^2}{2}\frac{1-\kappa^{2i}}{1-\kappa^2}\right\},
\end{aligned}$$

where $\overline{\theta}_2 = e^{\overline{x}}$.

To obtain a price of the swap consistent with the one under Model I (one-factor, mean reverting process in continuous time) in Schwartz (1997), although in discrete time, the long term mean must be $\overline{x} - \frac{1}{2}\sigma^2/(1-\kappa)$ in place of $\overline{x}$.

B. Approximation of the stationary distribution of the state variable

Given the dynamics in (1) and (2), using a vector notation we have a VAR of the form

$$x(t) = c + \mathcal{K}x(t-1) + \varepsilon(t)$$

where $\varepsilon = (\varepsilon_1, \varepsilon_2)$ is a bivariate Normal variate with zero mean and covariance matrix Σ,

$$c = \begin{pmatrix} (1-\kappa_1)\overline{x}_1 \\ (1-\kappa_2)\overline{x}_2 \end{pmatrix}, \qquad \mathcal{K} = \begin{pmatrix} \kappa_1 & 0 \\ 0 & \kappa_2 \end{pmatrix}, \qquad \Sigma = \begin{pmatrix} \sigma_1^2 & \sigma_1\sigma_2\rho \\ \sigma_1\sigma_2\rho & \sigma_2^2 \end{pmatrix},$$

where, differently from the approach proposed in Tauchen (1986), Σ may be non–diagonal and singular (when $\rho = 1$).

Given this different assumption on the error covariance matrix, we follow an efficient approach first proposed by Knotek and Terry (2008) based on numerical integration of the multivariate Normal distribution. In particular, the continuous–state process $x(t)$ is approximated by a discrete–state process $\widehat{x}(t)$, which varies on the finite grid $\{X_1, X_2, \dots, X_n\} \subset \mathbb{R}^2$. Define a partition of $\mathbb{R}^2$ made of n non–overlapping 2–dimensional intervals $\{\mathcal{X}_1, \mathcal{X}_2, \dots, \mathcal{X}_n\}$ such that $X_i \in \mathcal{X}_i$ for all $i = 1, \dots, n$ and $\cup_{i=1}^n \mathcal{X}_i = \mathbb{R}^2$. The $n \times n$ transition matrix Π is defined as

$$\begin{aligned} \Pi_{i,j} &= \text{Prob}\left\{\widehat{x}(t+1) \in \mathcal{X}_j \mid \widehat{x}(t) = X_i\right\} \\ &= \text{Prob}\left\{c + \mathcal{K}x(t) + \varepsilon(t+1) \in \mathcal{X}_j\right\} \\ &= \text{Prob}\left\{\varepsilon(t+1) \in \mathcal{X}'_j\right\} = \int_{\mathcal{X}'_j} f(x, 0, \Sigma)dx \end{aligned}$$

where $\mathcal{X}'_j = \mathcal{X}_j - c - \mathcal{K}x(t)$, and $f(x, 0, \Sigma)$ is the density of the bivariate Normal with mean zero and covariance matrix Σ. The integral on the last line of the above equation is computed numerically following the Monte–Carlo integration approach by Genz (1992) (extended to the singular covariance matrix case by Genz and Kwong (2000)).[21] As for the choice of the grid, we follow Tauchen (1986) using a uniformly spaced scheme.

C. Monte Carlo simulation

Given the optimal policy function $\varphi(\cdot)$ from the solution of the valuation problem (either first or second best), we use Monte Carlo simulation to generate a sample of Ω possible future paths for our firm. In particular, we obtain the simulated dynamics of the state variable $\theta = (\theta_1, \theta_2)$ under the actual (as opposed to the risk–neutral) probability by application of the recursive formula

$$x(t) = c^* + \mathcal{K}x(t-1) + \varepsilon(t)$$

where $\varepsilon(t)$ are independent sample for a bivariate Normal distribution, with covariance matrix Σ,

$$c^* = \begin{pmatrix} (1-\kappa_1)x_1^* \\ (1-\kappa_2)x_2^* \end{pmatrix}, \qquad \mathcal{K} = \begin{pmatrix} \kappa_1 & 0 \\ 0 & \kappa_2 \end{pmatrix}, \qquad \Sigma = \begin{pmatrix} \sigma_1^2 & \sigma_1\sigma_2\rho \\ \sigma_1\sigma_2\rho & \sigma_2^2 \end{pmatrix},$$

[21] We use both Genz's and Knotek and Terry's routines for this part of the program.

and $x_i^* = \overline{x}_i + RP_i$, for $i = 1, 2$. The risk premia are $RP_1 = 6\%$ and $RP_2 = .6\%$ (consistent with $\rho = 0.1$). Then we compute $\theta_i(t) = e^{x_i(t)}$, for $i = 1, 2$.

We set as initial points for our simulation $x_1(0) = x_2(0) = 0$, and $m_0 = 0$, $b_0 = 0$, $h_0 = 0$. Based on this, we determine the optimal choice $(m_1, b_1, h_1) = \varphi(\theta_0, m_0, b_0, h_0)$. Then for the specific realization $\theta_1(\omega)$, if the firm is not in default, we apply the optimal policy function obtaining: $(m_2, b_2, h_2) = \varphi(\theta_1(\omega), m_1, b_1, h_1)$. Otherwise, if the firm is in default, $(m_2, b_2, h_2) = (m_1, d, 0)$.

The subsequent steps are a recursive application of the same principle:

$$(m_{t+1}, b_{t+1}, h_{t+1}) = \varphi(\theta_t(\omega), m_t, b_t, h_t)$$

if the firm is solvent and

$$(m_{t+1}, b_{t+1}, h_{t+1}) = (m_t, d, 0)$$

in case of default, for $t = 1, \ldots, T$ and for $\omega = 1, \ldots, \Omega$. Given the realized state $(\theta_t(\omega), m_t, b_t, h_t)$, we determine all the quantities of interest (e.g., value of equity, level of cash balance) from the simulated sample.

In our numerical experiments, we generate simulated samples with $\Omega = 10,000$ paths and $T = 150$ years (steps). To limit the dependence of our results from the initial point, we drop the first 50 steps.

References

Adam, T., 2002, Why firms use non-linear hedging strategies, Working paper, HKUST.

Adam, T., 2009, Capital expenditures, financial constraints, and the use of options, Working paper, MIT Sloan School of Management.

Adam, T., and C. Fernando, 2006, Hedging, speculation, and shareholder value, *Journal of Financial Economics* 81, 283–309.

Allayannis, G., G. Brown, and L. Klapper, 2003, Capital structure and financial risk: Evidence from East Asia, *Journal of Finance* 58, 2667–2709.

Allayannis, G., and E. Ofek, 2001, Exchange rate exposure, hedging, and the use of foreign currency derivatives, *Journal of International Money and Finance* 20, 273–296.

Allayannis, G., and J. P. Weston, 2001, The use of foreign currency derivatives and firm market value, *Review of Financial Studies* 14, 243–276.

Altinkilic, O., and R. S. Hansen, 2000, Are there economies of scale in underwriting fees? Evidence of rising external financing costs, *Review of Financial Studies* 13, 191–218.

Andrade, G., and S. Kaplan, 1998, How costly is financial (not economic) distress? Evidence from highly leveraged transactions that became distressed, *Journal of Finance* 53.

Bartram, S.M., 2000, Corporate risk management as a lever for shareholder value creation, *Financial Markets, Institutions, and Instruments* 9, 279–324.

Bartram, S.M., 2008, What lies beneath: Foreign exchange rate exposure, hedging and cash flows, *Journal of Banking and Finance* 32, 1508–1521.

Bartram, S.M., G. Brown, and J. Conrad, 2008, The effects of derivatives on firm risk and value, Working paper, University of North Carolina.

Bartram, S.M., G. Brown, and Fehle, 2009, International evidence on financial derivatives usage, *Financial Management* 38, 185–206.

Bartram, S.M., G. Brown, and B. Minton, 2009, Resolving the Exposure Puzzle: The Many Facets of Exchange Rate Exposure, *Journal of Financial Economics* forthcoming.

Bates, T.W., K.M. Kahle, and R. M. Stulz, 2008, Why do U.S. firms hold so much more cash than they used to?, Working paper, Ohio State University.

Bodnar, G.M., G.S Hayt, and R.C. Marston, 1998, 1998 Wharton Survey of Financial Risk Management by US Nonfinancial Firms, *Financial Management* 27, 70–91.

Bolton, P., H. Chen, and N. Wang, 2009, A unified theory of Tobin's q, corporate investment, financing, and risk management, Working paper, Columbia University.

Breeden, D., and S. Viswanathan, 1996, Why do firms hedge? An asymmetric information model, Working paper, Duke University.

Brennan, Michael J., and Eduardo Schwartz, 1985, Evaluating Natural Resource Investments, *Journal of Business* 58, 135–157.

Bris, A., I. Welch, and N. Zhu, 2006, The costs of bankruptcy: Chapter 7 Liquidation versus Chapter 11 Reorganization, *Journal of Finance* 61, 1253–1303.

Brown, G., P. Crabb, and D. Haushalter, 2002, Are firms successful at selective hedging?, *Journal of Business*.

Brown, G., and K. B. Toft, 2002, How firms should hedge, *Review of Financial Studies* 15, 1283–1324.

Campbell, J.Y., M. Lettau, B.G. Malkiel, and Y. Xu, 2001, Have individual stocks become more volatile? An empirical exploration of idiosyncratic risk, *Journal of Finance* 56.

Carter, D.A., D.A. Rogers, and B. J. Simkins, 2006, Does fuel hedging make economic sense? The case of the US airline industry, *Financial Management* pp. 5–28.

DeMarzo, P, and D. Duffie, 1991, Corporate financial hedging with proprietary information, *Journal of Economic Theory* 53, 261–286.

Faulkender, M., 2005, Hedging or market timing? Selecting the interest rate exposure of corporate debt, *Journal of Finance* 60, 931–962.

Fehle, F., and S. Tsyplakov, 2005, Dynamic risk management: Theory and evidence, *Journal of Financial Economics* 78, 3–47.

Froot, K. A., D. Scharfstein, and J. C. Stein, 1993, Risk Management: Coordinating corporate investment and financing policies, *Journal of Finance* 48, 1629–1658.

Geczy, C., B. A. Minton, and C. Schrand, 1997, Why firms use currency derivatives, *Journal of Finance* 52, 1323–1354.

Geczy, C., B. A. Minton, and C. Schrand, 2007, Taking a View: Corporate speculation, governance and compensation, *Journal of Finance* 62.

Genz, A., 1992, Numerical Computation of Multivariate Normal Probabilities, *Journal of Computational and Graphical Statistics* 1, 141–149.

Genz, A., and K-S Kwong, 2000, Numerical Evaluation of Singular Multivariate Normal Probabilities, *Journal of Statistical Computation and Simulation* 68, 1–21.

Gooch, A.K., and L.B. Klein, 2002, *Documentation for Derivatives.* (Euromoney Institutional Investor London, UK) 4th edn.

Graham, J. R., 2000, How Big Are the Tax Benefits of Debt?, *Journal of Finance* 55, 1901–1941.

Graham, J. R., and D.A. Rogers, 2002, Do firms hedge in response to tax incentives, *Journal of Finance* 57, 815–839.

Graham, J. R., and C. W. Smith, 1999, Tax incentives to hedge, *Journal of Finance* 54, 2241–2263.

Guay, W., 1999, The impact of derivatives on firm risk: An empirical examination of new derivatives users, *Journal of Accounting and Economics* 26, 319–351.

Guay, W., and S. P. Kothari, 2003, How much do firms hedge with derivatives?, *Journal of Financial Economics* 70, 423–461.

Han, L. M., 1996, Managerial compensation and corporate demand for insurance, *Journal of Risk and Insurance* 63, 381–404.

Haushalter, D., 2000, Financing policy, basis risk, and corporate hedging: Evidence from oil and gas producers, *Journal of Finance* 55, 107–152.

Hennessy, C. A., and T. M. Whited, 2005, Debt Dynamics, *Journal of Finance* 60, 1129–1165.

Hennessy, C. A., and T. M. Whited, 2007, How Costly is External Financing? Evidence from a Structural Estimation, *Journal of Finance* 62, 1705–1745.

Hentschel, L., and S. P. Kothari, 2001, Are corporations reducing or taking risks with derivatives, *Journal of Finance and Quantitative Analysis* 36, 93–116.

Jin, Y., and P. Jorion, 2006, Firm value and hedging: Evidence from US oil and gas producers, *Journal of Finance* 61, 893–919.

Knotek, E. S., and S. Terry, 2008, Markov–Chain Approximations of Vector Autoregressions: Application of General Multivariate–Normal Integration, Working paper, 08-02 Federal Reserve Bank of Kansas City.

MacKay, P., and S. Moeller, 2007, The value of corporate risk management, *Journal of Finance* 62, 1379–1419.

Mayers, D., and C. W. Smith, 1982, On the corporate demand for insurance, *Journal of Business* 55, 281–296.

Mello, A., J. E. Parsons, and A. J. Triantis, 1995, An integrated model of multinational flexibility and financial hedging, *Journal of International Economics* 39, 27–51.

Meulbroek, L., 2001, A better way to manage risk, *Harvard Business Review*.

Meulbroek, L., 2002, The promise and challenge of integrated risk management, *Risk Management and Insurance Review* 5, 55–66.

Mian, S. L., 1996, Evidence of corporate hedging policy, *Journal of Financial and Quantitative Analysis* 31, 419–439.

Nance, D. R., C. W. Smith, and Smithson, 1993, On the determinants of corporate hedging, *Journal of Finance* 48, 267–284.

Pastor, L., and P. Veronesi, 2003, Stock valuation and learning about profitability, *Journal of Finance* 58, 1749–89.

Petersen, M. A., and S. R. Thiagarajan, 2000, Risk measurement and hedging: with and without derivatives, *Financial Management* 29, 5–30.

Pulvino, T. C., 1998, Do asset fire-sales exist? An empirical investigation of commercial aircraft transactions, *Journal of Finance* 53.

Schwartz, E. S., 1997, The Stochastic Behaviour of Commodity Prices: Implications for Valuation and Hedging, *Journal of Finance* 70, 923–973.

Shapiro, A. C., and S. Titman, 1986, An integrated approach to corporate risk management, in *The revolution in corporate finance*, ed. by J. M. Stern, and D. H. Chew. Basil Blackwell.

Sick, G., 1990, Tax-Adjusted Discount Rates, *Management Science* 36, 1432–1450.

Smith, C. W., and R. M. Stulz, 1985, The determinants of firms' hedging policies, *Journal of Financial and Quantitative Analysis* 20, 391–405.

Strebulaev, Ilya A., 2007, Do Tests of Capital Structure Theory Mean What They Say?, *Journal of Finance* 62, 1747–1787.

Tauchen, George, 1986, Finite State Markov-chain Approximations to Univariate and Vector Autoregressions, *Economics Letters* 20, 177–181.

Tufano, P., 1996, Who Manages Risk? An empirical examination of the risk management practices in the gold mining industry, *Journal of Finance* 52, 1097–1137.

Wei, S.X., and C. Zhang, 2006, Why did individual stocks become more volatile?, *Journal of Business* 79, 259–292.

Zhang, Lu, 2005, The Value Premium, *Journal of Finance* 55, 67–103.

$\overline{x}_1$	long-term mean of product price variable	0
$\overline{x}_2$	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	0.80
κ_2	persistence of x_2	0.80
ρ	correlation between product price and swap underlying	0.1
s	swap price	1
A	fixed production cost	.95
q	production rate	1
K^o	opening cost	.1
K^c	closing cost	.3
r	annual risk-free borrowing rate	5%
d	debt level	.4
τ_e	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%

Table I: **Base Case Parameter Values**

	Percentage Value Increase			
	$\theta_1 = .69$	$\theta_1 = .83$	$\theta_1 = 1.00$	$\theta_1 = 1.21$
Value of FRM, no OperFlex	60.7	28.8	16.0	10.5
Value of FRM, with OperFlex	25.8	19.6	14.1	10.5
Value of OperFlex, no FRM	74.6	33.1	17.6	11.2
Value of OperFlex, with FRM	36.6	23.6	15.6	11.2
Value of OperFlex and FRM	119.6	59.2	34.1	22.8

Table II: **Contribution of Operating Flexibility to the Value of Risk Management**. The table shows the interaction between the value of Financial Risk Management (FRM), i.e., the value gained by dynamically managing cash balance and swap positions, and the value of Operating Flexibility (OperFlex) gained from being able to close (and re-open) production subject to the base case value of $K^c = .3$ (and $K^o = .1$), relative to not having the option to close down. The first row shows the percentage value creation from having FRM if the firm does not have operating flexibility, while the second row shows this value increment of FRM if the firm does have operating flexibility. Similarly, the third and fourth rows show the percentage value addition from having operating flexibility if the firm does not have, or has, FRM, respectively. Finally, the fifth row shows the percentage value increase from having both operating flexibility and FRM relative to having neither. All values are shown for four representative θ_1 levels. The values are computed based on 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 I, and current values of $h = 0$, $b = 0$ and $\theta_2 = 1$.

	Firm Value Maximization			Equity Value Maximization		
	Cash	Hedge	Operate	Cash	Hedge	Operate
CB, H($\rho = .01$)	0.360	0.030	0.607	0.352	0.048	0.614
	(0.270)	(0.078)	(0.000)	(0.271)	(0.106)	(0.000)
CB, H($\rho = .05$)	0.358	0.051	0.606	0.333	0.069	0.617
	(0.265)	(0.086)	(0.000)	(0.257)	(0.112)	(0.000)
CB, H($\rho = 1$)	0.189	0.188	0.688	0.189	0.189	0.692
	(0.149)	(0.190)	(0.000)	(0.149)	(0.191)	(0.000)
CB, nH	0.396	0.000	0.597	0.398	0.000	0.601
	(0.287)	(0.000)	(0.000)	(0.287)	(0.000)	(0.000)
nCB, H($\rho = .01$)	0.000	0.041	0.678	0.000	0.174	0.680
	(0.000)	(0.091)	(0.000)	(0.000)	(0.198)	(0.000)

Table III: **Cash, Hedging and Operating Policies**. The table shows the mean and standard deviation (in parentheses) of the levels of cash balance (b), hedge (h) and operating activity (assumed to be 1 if operating, 0 if closed) for five different cases: the first three rows allow for a cash balance ("CB") and a hedge ("H") with correlation (ρ) of either 0.1, 0.5 or 1.0, respectively; the fourth row corresponds to the case with cash and no hedge ("nH"); the fifth row allows for a hedge with $\rho = 0.1$, but no cash balance ("nCB"). The first set of three columns corresponds to cases run under a first-best firm value optimization, while the second set of columns is for the second-best equity value maximization. The moments are based on the simulation described in Appendix C, using 10,000 runs. All other parameter values are shown in Table I.

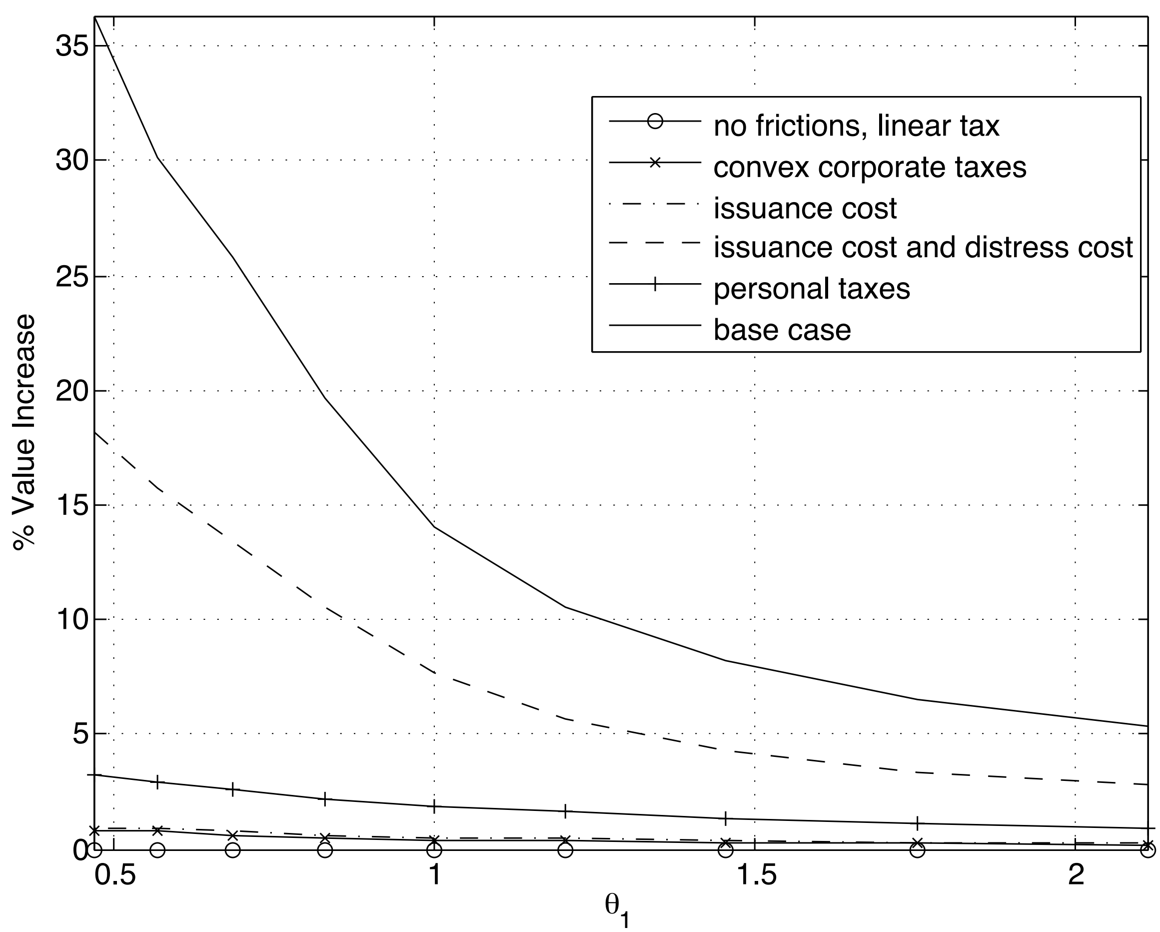


Figure 1: **Relative Impact of Various Motivations for Risk Management**. The figure shows the value of risk management when different underlying frictions are turned on and off, thus allowing the relative impact of each motivation of risk management to be analyzed. The Base Case shows the value of risk management when all frictions are present (using the parameter values in Table I). The case of "No Frictions, Linear Tax" has no distress, bankruptcy or issuance costs, and linear personal and corporate taxes (i.e., $\tau_c^+ = \tau_c^- = .40$, and $\lambda = -\tau_e = -.12$), confirming that there is no value associated with risk management in the absence of frictions. The other cases 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). 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 I, except as indicated otherwise above. The plots are based on initial values of $h = 0$, $b = 0$, and $\theta_2 = 1$.

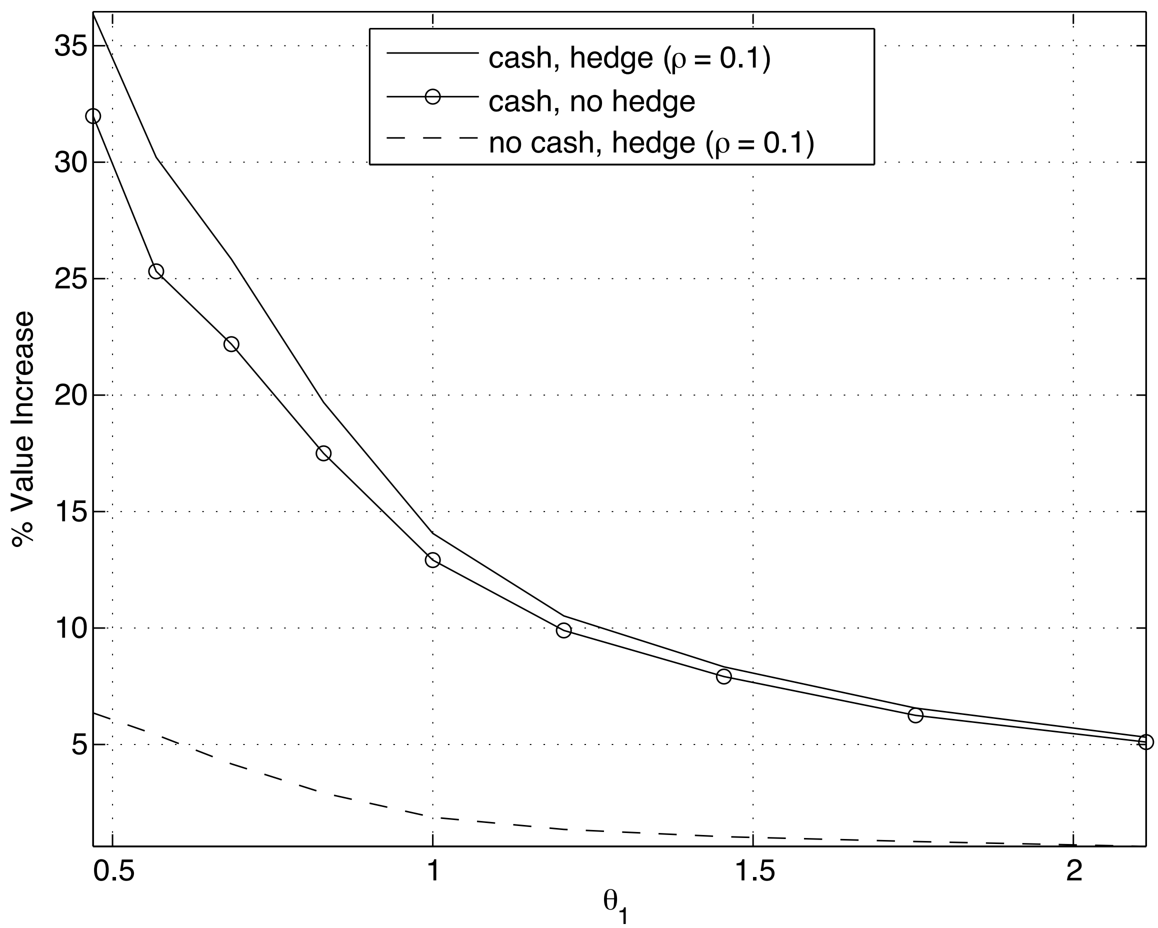


Figure 2: **Relative Contribution of Liquidity and Hedging to the Value of Risk Management**. The figure shows the value increase attributable to risk management under three different risk management scenarios: 1) dynamically managed cash balance and no swap; 2) dynamically managed hedge and no cash balance; and 3) both cash balance and swap positions are dynamically managed. The underlying asset for the swap (θ_2) has a correlation (ρ) of 0.1 with the product price (θ_1). The percentage increase in firm value from risk management is plotted against θ_1. 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 I. The plots are based on initial values of $h = 0$, $b = 0$, and $\theta_2 = 1$.

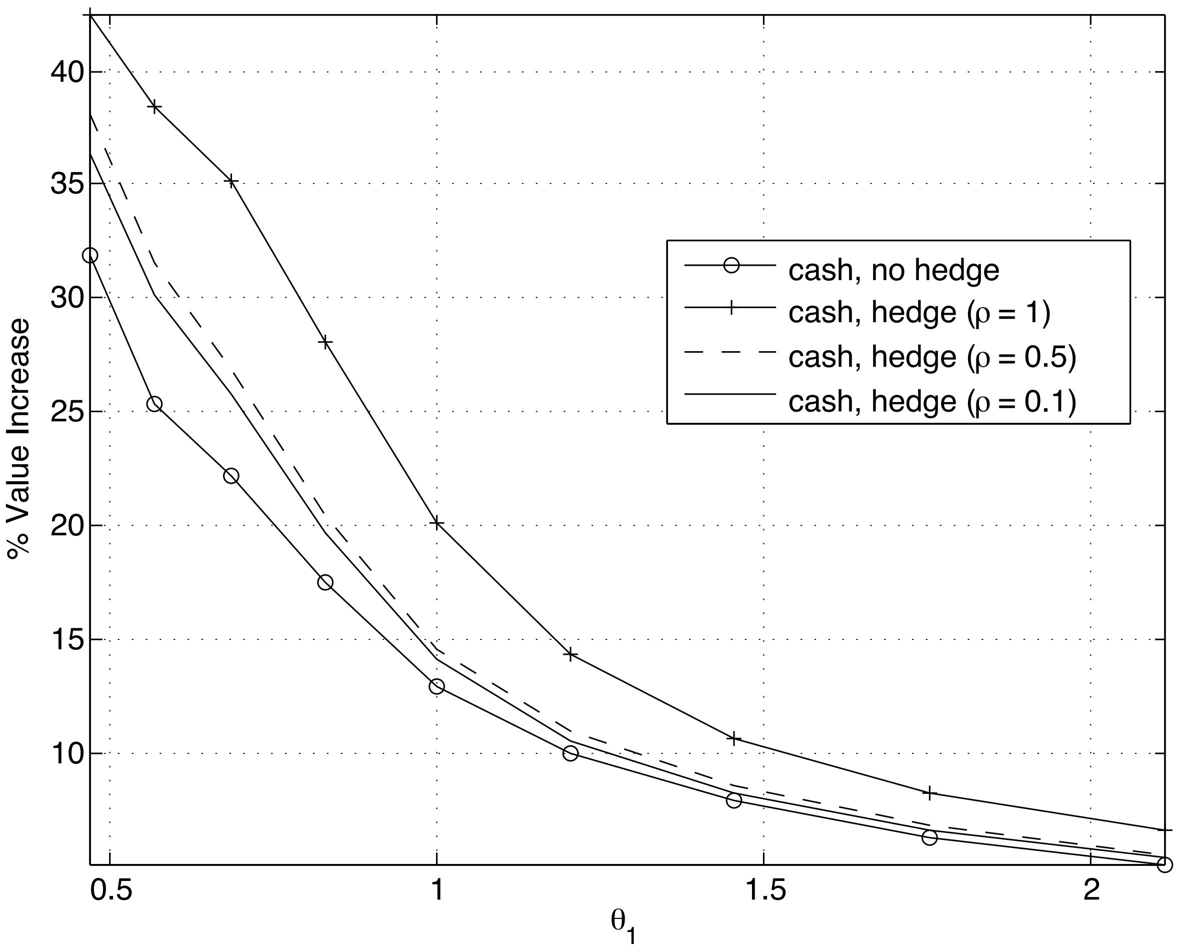


Figure 3: **Effect of Swap Correlation on Contribution of Hedging to the Value of Risk Management**. The figure shows the increase in firm value due to risk management assuming the firm holds an optimally rebalanced cash position, and either has no swap (lowest curve), or can dynamically manage a swap 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 product price (θ_1), represented by the successively higher curves on the graph. The percentage increase in firm value is plotted against θ_1. 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 I. The plots are based on initial values of $h = 0$, $b = 0$, and $\theta_2 = 1$.

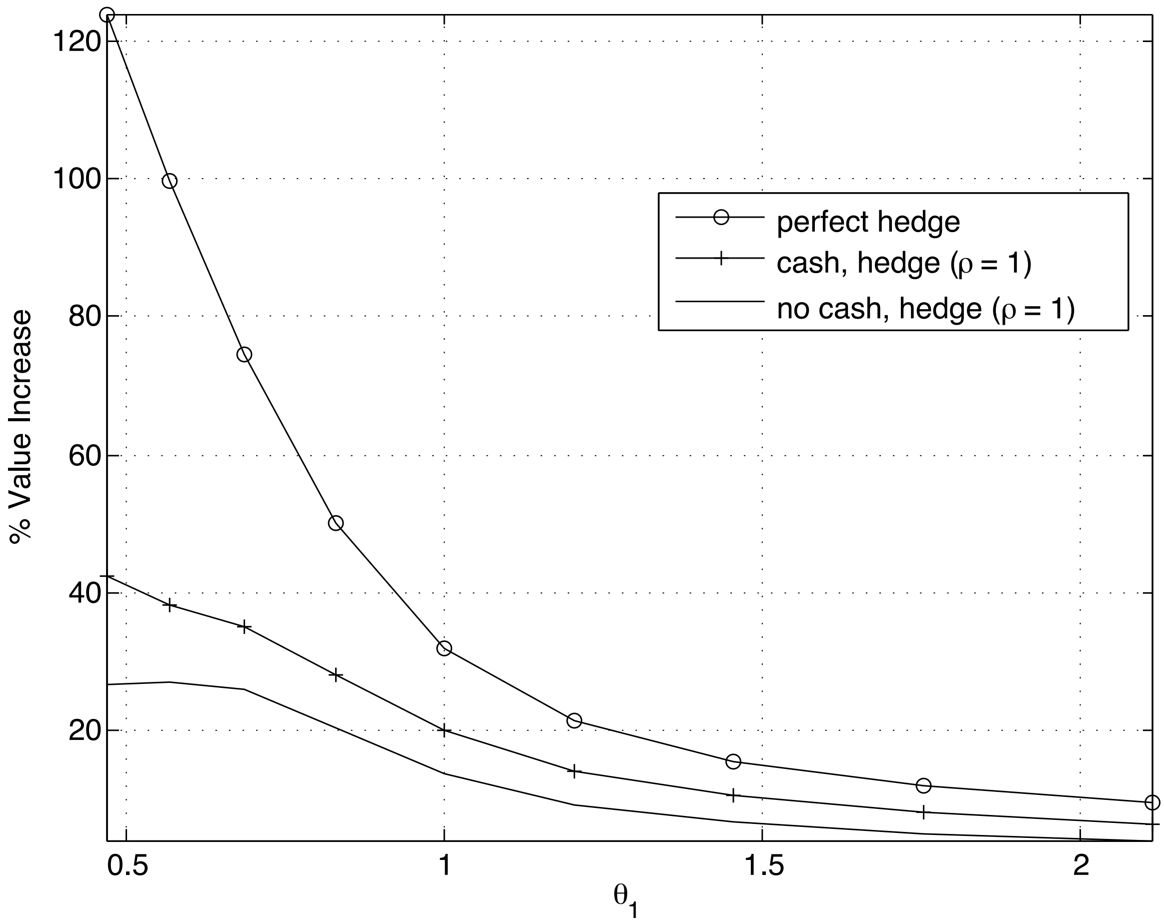


Figure 4: **Risk Management with a Perfectly Correlated Swap or with a Perfect Hedge**. The figure shows the percentage increase in firm value due to risk management under three different risk management scenarios: 1) no cash balance, but a swap with perfect correlation ($\rho = 1$); 2) cash balance, and a swap with $\rho = 1$; and 3) a "perfect hedge" (equivalent to the "no frictions" case, as explained in the text). The percentage increase in firm value is plotted against θ_1, the product price. 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 I. The plots are based on initial values of $h = 0$, $b = 0$, and $\theta_2 = 1$.

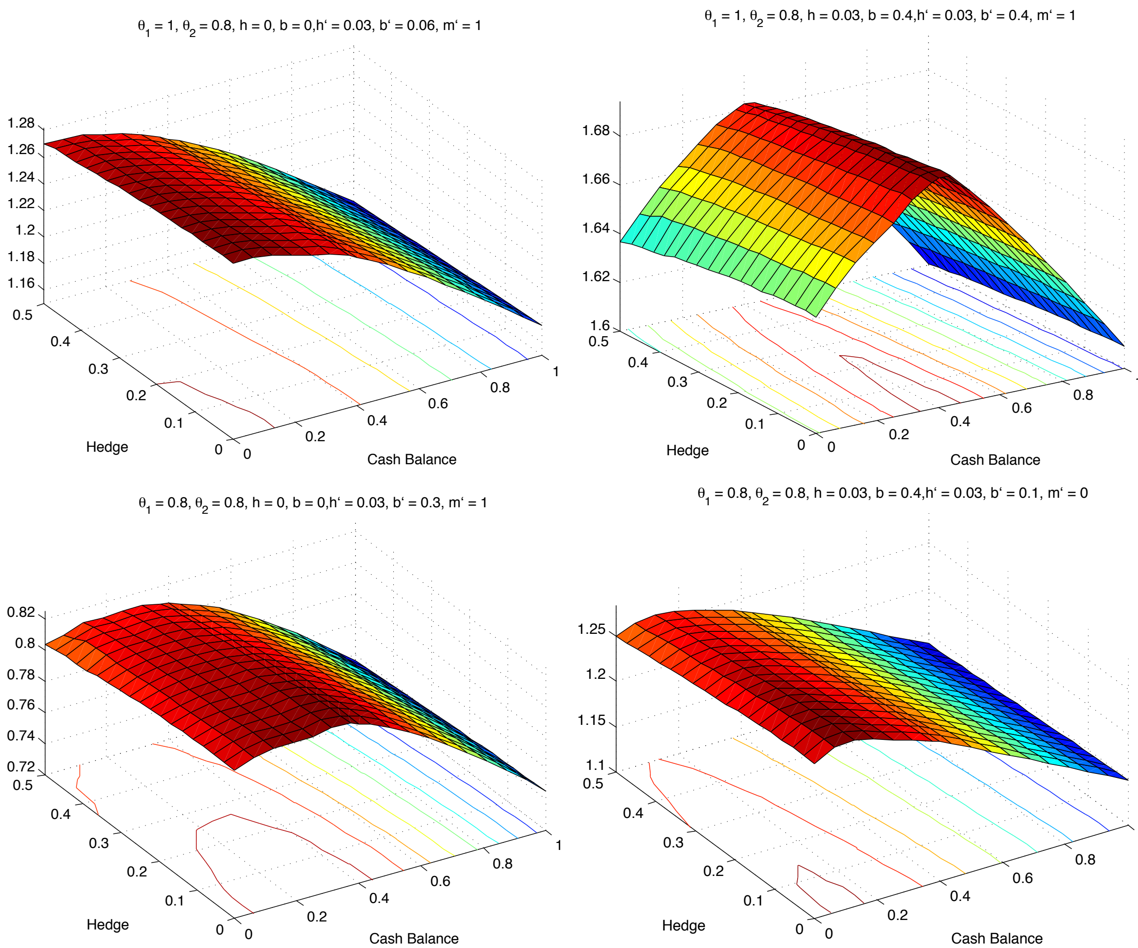
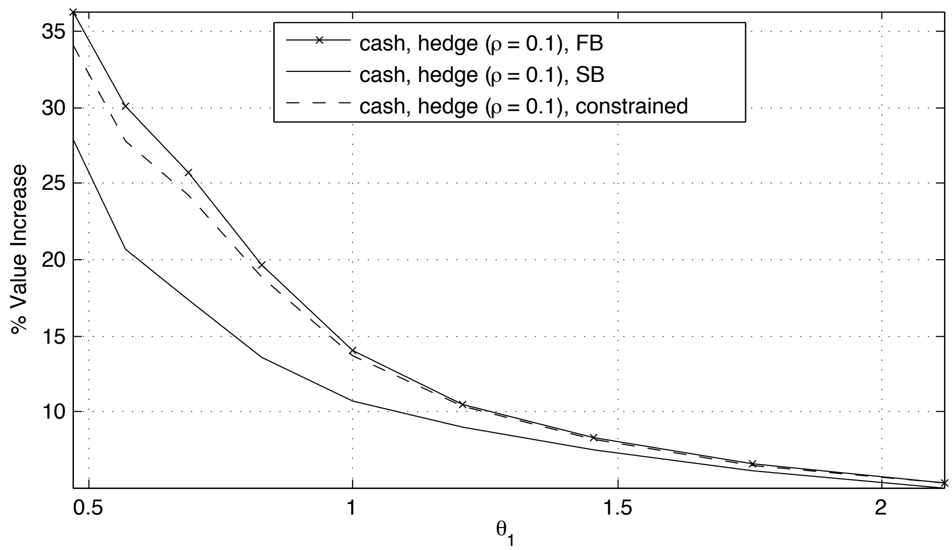


Figure 5: **Marginal Values of Liquidity and Hedging**. The four graphs show firm values plotted against potential new hedge ratio (h') and cash level (b') selections, assuming four different current states (i.e., four different (θ_1, θ_2, m, b, h) combinations). The top row assumes an average θ_1 value (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 is closed. 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 I.



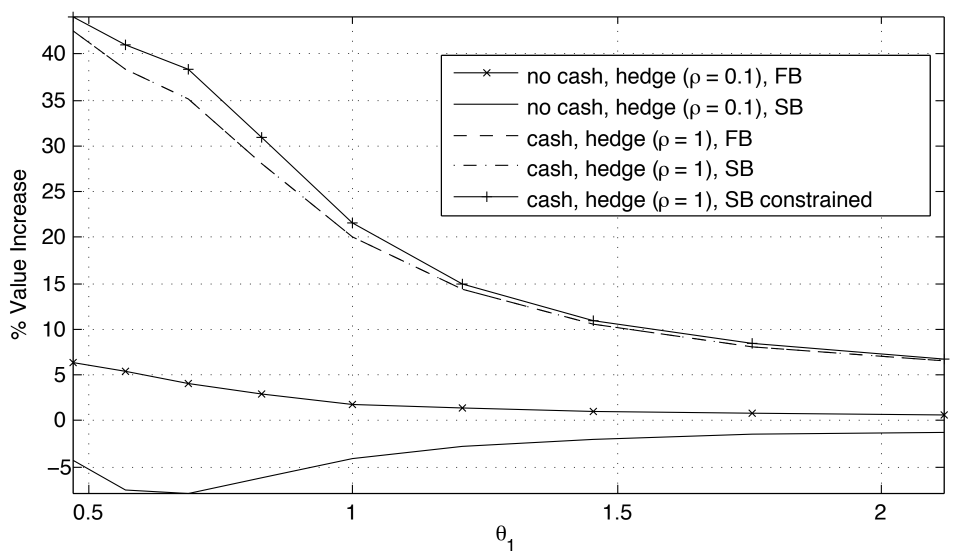


Figure 6: **Agency Costs Associated with Speculation**. This figure illustrates the impact of potential speculation with derivatives on firm value. In the upper panel, the firm manages a liquidity balance and a hedge with $\rho = 0.1$. The three curves correspond to: first-best firm value optimization ("FB"), second-best equity value maximization ("SB"), and second-best value if a position limit of $h < 0.5$ is imposed ("constrained"). In the lower panel, there are two sets of curves. The bottom two curves represent situations where the firm does not hold a cash balance, but has a hedge with $\rho = 0.1$, and either maximizes firm value ("FB") or equity value ("SB"). For the top three curves in the lower panel, the firm manages a cash balance and has a swap with $\rho = 1$, and the cases considered are the first-best, second-best, and constrained second-best case where $h < 0.5$. All percentage firm value increases due to risk management are plotted against θ_1. The values are from the numerical solution of the model using 9 points for each θ, 19 points for h, and 18 points for cb, based on the parameter values in Table I. The plots are based on initial values of $h = 0$, $b = 0$, and $\theta_2 = 1$.