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Cash Holdings, Capital Structure, and Financing Risk

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Abstract

This article quantifies a new motive of holding cash through the channel of financing risk. We show that if access to future credit is risky, firms may issue long-term debt now and save funds in cash to secure the current credit capacity for the future. We structurally estimate the model and find that this motive explains approximately 24% to 30% of cash holdings in the data. Counterfactual experiments indicate that the value of holding cash is approximately 8% of shareholder value.

I. Introduction

Holding cash is costly. However, in the data, U.S. public firms on average hold as high as 19% cash in their assets, particularly when they also hold 10% unused lines of credit, which could be substitutes for cash. Moreover, during the 2008 financial crisis, firms became increasingly cautious about their access to future credit, and they drew down existing credit lines and held the proceeds in cash even if there were no immediate financing needs (Ivashina and Scharfstein (2009)). So, why do firms stockpile cash?

In this article, we quantify a new motive of holding cash by developing a dynamic model of long-term debt with financing risk. We show that if the access to future credit is risky, firms may want to issue long-term debt right now and save the funds in cash, and they do so in order to secure the current credit capacity for the future. Further, we structurally estimate the model using a sample of U.S. public firms and find that this motive explains approximately 24% to 30% of total cash holdings in the data, even after controlling for transactional cash and unused lines of credit.

An innovation of the article is that we study firms' cash behaviors jointly with their capital structure decisions. Recent research shows that financial flexibility in

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the form of unused debt capacity plays an important role in the choice of the capital structure (see, e.g., DeAngelo, DeAngelo, and Whited (2011), Denis and McKeon (2012)). According to these articles, firms choose to borrow less (low leverage) to maintain the option of borrowing in the future. In this article, we show that under uncertain financing conditions, the unused debt capacity can disappear before the firm taps it. As a result, the risk of losing unused debt capacity would induce firms to borrow more now (high leverage) and keep the funds in cash.

This article is based on the assumption that firms have risky access to future credit. Specifically, we assume that the firm's total borrowing limit is captured by the value of its collateral assets, whereas the value of collateral depends stochastically on credit market conditions. Because the total borrowing limit may shrink in the future, the unused credit could also disappear. Thus, to hedge the risk that the option to borrow may go away in the future, the firm would execute the borrowing option earlier and save the proceeds in cash. This is the primary motivation in the article to explain why firms want to hold cash buffers.

In the quantitative analysis, we interpret the option to borrow, the difference between the potential borrowing limit and the actual debt, as unused lines of credit.[1] In that case, the model's assumption that unused credit is risky receives considerable support in the data. First, credit lines are short term. The rollover of credit lines is not guaranteed upon expiration. Second, access to lines of credit is contingent on the lender's ability or willingness to supply funds. Third, most credit lines come with a borrowing base formula that imposes a mark-to-market borrowing limit. The amount of available credit is directly linked to the market value of the firm's collateral assets. If the value of collateral assets fluctuates, so does the availability of credit lines.[2]

The model is an extension of the standard framework with investment and financing frictions (e.g., Gomes (2001), Cooley and Quadrini (2001)). We add three new ingredients. The first extension is to add a liquidity constraint to capture the cash-flow mismatch between financing and investing. We assume that the firm's cash flows are realized at the end of the period, which implies that the firm needs to hold liquidity (cash or unused credit) for inter-period payments associated with capital expenditures, expiring credit market liabilities, and dividend payout. Because of the stochastic nature of payments, the liquidity constraint is occasionally binding and generates a precautionary motive to hold liquid funds.

The second extension is to allow for long-term debt, which is important for distinguishing cash from negative debt. With only 1-period debt, there is no reason to borrow and hold cash because cash gives a lower direct return than the cost of debt. Firms will simply use all the available cash to reduce the liabilities that are due in the next period. With long-term debt, however, firms have incentives to borrow and temporarily hold cash to secure the current availability of credit for the future.

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[1] The precise difference between the borrowing limit and the actual debt is unused debt capacity. However, in the data, we observe the amount of unused lines of credit but not the total unused debt capacity. Thus, we use unused lines of credit as a lower-bound approximation of unused debt capacity.

[2] According to the data of a random sample of 600 Compustat firms hand-collected by Berrospide and Meisenzahl (2015), the average ratio of available credit to total credit is approximately 89%, and it declines significantly during the 2008 financial crisis.

This is possible because the long-term debt does not need to be repaid in full in the next period, even if the firm loses access to new credit.

The third extension is the consideration of shocks that affect the financial condition of firms, that is, their access to credit. This is in addition to a standard productivity or investment shock.

The model is solved numerically by a nonlinear approach, the projection method, and most model parameters are estimated by the simulated method of moments. We then conduct two counterfactual exercises. First, we examine the impact of each shock on firms' cash holdings. Because the model has two shocks, we can turn off one to study the impact of the other. In this counterfactual experiment, we find that financing risk is the key to understanding firms' cash behavior: It explains approximately 90% of precautionary cash in the benchmark model. The productivity risk, however, explains only 10%. The second counterfactual exercise is to shut down the channel of precautionary cash. In that case, we find that the shareholder value decreases by 8%, and we interpret this 8% as the value of holding precautionary cash.

We also use the model to study the impact of shocks that affect the financing conditions of firms and compare the prediction of the model to the real data. We find that in response to a credit crisis, firms reduce precautionary cash and unused lines of credit dramatically, whereas they do not cut investment much. This result is consistent with Duchin, Ozbas and Sensoy (2010), who show that firms used their cash holdings as buffers to smooth investment at the onset of the 2007–2008 credit crisis. In response to a credit boom, instead, firms not only keep most new credit as unused lines but also save cash out of borrowing. Such behavior demonstrates the precautionary motive of holding liquidity: Even if firms are in favorable market conditions, they are still cautious about the possibility of future adverse financing conditions.

Another quantitative exercise is to study the implications of an increase in credit uncertainty, or the volatility of the financial shock. In response to an increase in credit uncertainty, firms draw down credit lines and keep the proceeds in cash; that is, they shift the composition of liquidity from risky credit lines to safer cash holdings. This prediction is consistent with the finding of Ivashina and Scharfstein (2009) that firms increasingly drew down their credit lines in the second half of 2008, but drawdowns were not driven by firms' investment opportunities because drawdowns were held largely in cash.

This article relates to several strands of literature. The first strand of literature tries to explain why cash is different from negative debt. A feature shared by many dynamic corporate finance models is that holding cash is dominated by the use of cash to repay the outstanding debt.[3] To explain why cash is not negative debt, there are generally two approaches in the literature. The first approach is to impose debt-issuance costs, as in, for example, Gamba and Triantis (2008) and Boileau and Moyen (2016). Although those articles provide testable implications of firms'

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[3] For example, Cooley and Quadrini (2001), Hennessy and Whited (2005), (2007), Moyen (2004), DeAngelo et al. (2011), Bolton, Chen, and Wang (2011), Nikolov and Whited (2014), Hugonnier, Malamud, and Morellec (2015), and Eisfeldt and Muir (2016). Acharya, Almeida, and Campello (2007) develop a 3-period model to explain why cash is not negative debt.

choices between debt and cash holdings, the economic interpretation of the reduced-form debt-issuance cost is controversial.

The other approach is to allow different maturities between cash and debt. Chaderina (2013) develops a model with 2-period defaultable debt in which firms hold precautionary cash to hedge shocks that affect their future profitability prospects. The main difference between this article and that by Chaderina is that we consider multiperiod debt with enforcement constraints. Further, instead of studying the role of shocks that affect firms' future profitability prospects, we focus on the refinancing risk, that is, the risk of losing access to future credit.

Almeida, Campello, and Hackbarth (2011) study the role of cash and credit lines in mergers and acquisitions (M&As). They show that lines of credit can be an attractive source of financing acquisitions for profitable firms because these firms' lines of credit are less likely to be revoked. They focus on the revocability of credit lines caused by the firm's fundamentals, such as cash flows. In this article, we consider the availability of unused credit caused by the lender's financial status. Further, the purpose of holding liquidity in their model is to finance investment, given that acquisitions are forms of investment. In this article, the primary reason for holding liquidity is to hedge financing risk.

This article contributes to the recent literature studying the impacts of financial shocks on firms' investment and financing decisions. Jermann and Quadrini (2012) study the macroeconomic effects of financial shocks and show that standard productivity shocks can only partially explain the movements in real and financial variables. The addition of financial shocks brings the model closer to the data. Instead of focusing on the aggregate economy, this article focuses on individual firms, with special attention paid to publicly listed U.S. corporations. This allows us to show, from a micro-perspective as opposed to a macro-approach, that financial shocks play important roles in explaining firms' financing and investment decisions, especially for liquidity-management policies.

This article is also closely related to those by Bolton, Chen, and Wang (2013) and Eisfeldt and Muir (2016), who consider stochastic financing opportunities, and to that by Hugonnier et al. (2015), who adopt a similar interpretation of the credit-supply shocks.

The remainder of the article proceeds as follows: Section II introduces a simple 3-period model. We then extend the model in a dynamic manner in Section III. Section IV provides the model solution. In Section V, we conduct structural estimation and counterfactual experiments. Section VI describes model implications and provides robustness checks. Finally, Section VII concludes.

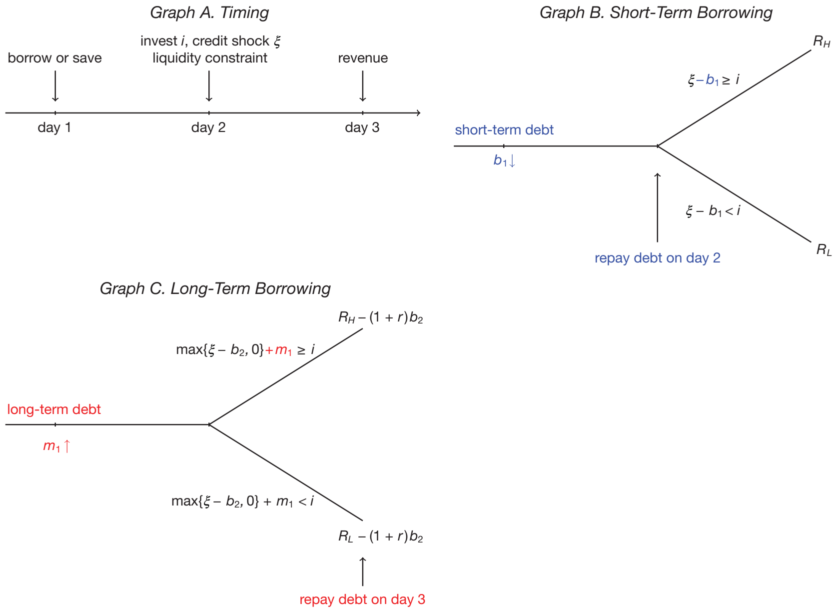
II. A 3-Period Model

To illustrate the central idea of the article, we start by presenting a simple 3-period model. The timing of the firm's decisions is summarized in Graph A of Figure 1. There are 3 days: day 1, day 2, and day 3. On day 1, a firm makes borrowing and saving decisions, and it has access to external financing up to a fixed borrowing limit $\overline{\xi}$. On day 2, the firm faces an investment opportunity of size i and still has access to the external financing but with a stochastic borrowing limit ξ.

FIGURE 1

Timing of Short-Term and Long-Term Borrowing

Figure 1 shows the sequences of investing and financing decisions.



The value of ξ is revealed at the beginning of day 2. On day 1, the firm knows that there are two possible realizations: ξ_H and ξ_L, with probabilities p_H and $1-p_H$, respectively. The expected credit limit is $\overline{\xi} = p_H\xi_H + (1-p_H)\xi_L$. To create a possible liquidity shortage on day 2, we assume that under adverse financing conditions, the firm cannot borrow enough funds to finance investment; that is, $\xi_L < i$. However, the expected credit limit is always greater than the investment; that is, $\overline{\xi} > i$.

On day 2, the firm faces two situations. In the first case, the total of available funds (cash plus unused credit) is larger than the investment. Therefore, the firm is able to make the investment. In the second situation, the available funds are insufficient to fund the investment, and the firm is unable to make the investment. On day 3, the firm receives the revenue R_H if it invested on day 2, or it receives R_L otherwise. Then, the firm pays off the debt. The remaining funds are paid out as dividends.

In this simple model, we assume that the discount factor is 1 and that the gross interest rate of 1-period debt is also 1. The gross interest rate of 2-period debt is $1+r$. We also assume that the revenue R_H is sufficiently larger than R_L so that if the firm has enough liquid funds on day 2, it would always take the investment project.

Let's first consider the scenario that cash and debt have the same maturity. In this case, cash is equivalent to negative 1-period debt. Graph B of Figure 1 illustrates the timing of short-term borrowing.

We use backward induction to study the firm's decisions. Consider the firm's choices on day 2: To take advantage of the investment opportunity, the firm has to satisfy the cash-in-advance constraint (liquidity constraint), such that $\xi - b_1 \geq i$. Here, the variable b_1 denotes the firm's net debt position on day 1. Given that ξ is the maximum amount the firm can borrow on day 2 and that b_1 is the amount of debt that needs to be repaid, the available funds for investment are $\xi - b_1$. Thus, the firm makes the investment only if $\xi - b_1 \geq i$.

Now, consider the firm's borrowing and saving decisions on day 1. On day 1, the borrowing limit ξ of day 2 is unknown. However, the firm knows that there are only two realizations: $\xi \in \{\xi_H, \xi_L\}$. Thus, given the assumption that the investment project is sufficiently profitable, on day 1, the firm wants to ensure that it will always have enough funds to finance the investment project on day 2, irrespective of the borrowing conditions it will encounter on day 2. As a result, to hedge the worst financing condition ξ_L on day 2, the firm would like to borrow negatively on day 1 ($b_1 < 0$) so that the cash-in-advance constraint on day 2 will always be satisfied ($\xi_L - b_1 \geq i$).

In the 3-period model considered here, the state variables at the beginning of day 1 are not specified. In the dynamic model we will consider later, the firm also holds debt outstanding at the beginning of day 1. Thus, in a dynamic framework, the model would imply that the firm will choose to reduce its debt balances on day 1 to hedge the adverse financing conditions on day 2.

To sum up, with only 1-period debt, although the firm can access $\overline{\xi}$ amount of external finance on day 1, it chooses not to tap it. Instead, the firm keeps $\overline{\xi} - b_1$ amount of unused credit. This is the *later-borrowing* motive that induces firms to hold unused lines of credit. In other words, the firm does not borrow now in order to be able to borrow later when the investment opportunity becomes available.

Now consider the scenario in which the firm can borrow with 2-period debt. Graph C of Figure 1 illustrates the timing. In this scenario, if the firm borrows on day 1, it does not need to pay back the debt on day 2. Instead, it repays the debt on day 3 with interest rate r. Now, to take advantage of the investment opportunity on day 2, the firm would tap the credit market on day 1 and save the proceeds in cash. Let b_2 denote the amount of 2-period debt that the firm borrows on day 1 and m_1 denote the amount of cash that the firm carries from day 1 to day 2. The cash-in-advance constraint on day 2 becomes $\max\{\xi - b_2, 0\} + m_1 \geq i$, where the term $\max\{\xi - b_2, 0\}$ is unused credit on day 2. To satisfy this cash-in-advance constraint even in the worst financing condition ξ_L, the firm would borrow positively and save cash on day 1: $b_2 = m_1 = i$. Notice that this is possible because of the assumption that $\overline{\xi} > i$. That is, the borrowing limit on day 1 is sufficient to finance the investment on day 2.

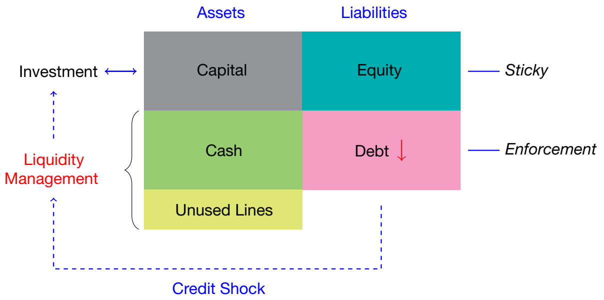
To sum up, when there is access to 2-period debt, the firm has the incentive to borrow earlier and save the proceeds in cash to hedge against adverse future credit conditions. This is the *pre-borrowing* motive that induces firms to borrow now and save the cash for the later period when investment opportunities become available. The goal of borrowing now is to secure enough funds in the later period, something that would not be guaranteed if the debt was only for 1 period.

The full dynamic model we describe in Section III features both the later-borrowing motive and the pre-borrowing motive. The presence of these two

FIGURE 2

A Sketch of the Dynamic Model

Figure 2 shows the structure of the model.



motives allows the model to generate the coexistence of cash and unused lines of credit in the optimal liquidity policies of firms.

III. The Dynamic Model

Figure 2 provides a sketch of the dynamic model. Consider a nonfinancial firm's balance sheet: On the assets side, it contains physical capital, cash holdings, and unused lines of credit;[4] on the liabilities side, it has equity and debt. In the model, equity is sticky, and debt is subject to enforcement constraints. The goal of the model is to understand how a credit shock affects a firm's investment decisions and how a firm manages its liquidity to hedge against the credit shock. In the following subsections, we discuss the elements of the balance sheet one by one.

A. Equity

Each firm is run by a manager who behaves in the interests of incumbent shareholders and maximizes the expected discounted present value of dividends. The firm's objective function is

$$V_t = \max : d_t + \mathbb{E}_t[\Lambda_{t+1} V_{t+1}], \tag{1}$$

where V_t represents the firm's equity value at the beginning of time t, d_t is the dividend payout during time t, and Λ_{t+1} is the shareholders' discount factor from time t to $t+1$. We assume a risk-neutral discount factor $\Lambda_{t+1} = \beta$ in the benchmark estimation and conduct robustness checks by allowing a stochastic discount factor.

B. Capital

The firm does not employ labor to produce goods. Capital is the only input. At each period t, the firm can access a production technology $F(z_t, k_t)$, in which k_t is capital, and z_t is a productivity shock.

Capital evolves according to

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[4] In the data, used lines of credit are debt obligations, whereas unused lines of credit remain off the balance sheet.

$$k_{t+1}-(1-\delta)k_t=\phi\left(\frac{i_t}{k_t}\right)k_t. \tag{2}$$

The variable δ is the capital depreciation rate, and the function $\phi(i_t/k_t)$ specifies the capital adjustment costs.

C. Long-Term Debt

The firm borrows in the form of long-term debt. We use a version of the exponential model introduced by Leland and Toft (1996) and recently used by Hackbarth and Mauer (2012) and Gourio and Michaux (2012), among others. In each period, the firm first repays a fixed proportion of its existing debt, and then it issues new debt with repayment rate δ_b and price $p_t(\delta_b)$. Specifically, with repayment rate δ_b, 1 unit of debt issued at time t receives a payment δ_b at time $t+1$, a payment $\delta_b(1-\delta_b)$ at time $t+2$, a payment $\delta_b(1-\delta_b)^2$ at time $t+3$, and so on.

Following the literature, we assume that the economy only contains a single type of maturity structure δ_b and that all debtholders have the same seniority without regard to when the debt was issued. Thus, in each period t, we only need to keep track of the total amount of debt instead of the distribution of debt with different maturity dates. Let b_t denote the debt balances at the beginning of period t, and then the total amount of repayment is $\delta_b b_t$.

The dynamics of long-term debt are given by

$$b_{t+1}=(1-\delta_b)b_t+n_t, \tag{3}$$

where b_t represents the debt balances at the beginning of period t, n_t represents the debt issuance during period t, and b_{t+1} denotes the debt balances at the end of period t. When $n_t>0$, the firm issues new debt after repayment; when $n_t<0$, the firm chooses to repay more than fraction δ_b of existing debt.

Firms do not default in the model. However, in each period t, firms are subject to the following enforcement constraint:

$$p_t b_{t+1}\leq \max\{\xi_t k_{t+1},(1-\delta_b)p_t b_t\}. \tag{4}$$

The variable ξ_t represents the collateral rate of capital and also reflects the market price of capital (credit market conditions). This enforcement constraint implies that the maximum amount of debt the firm holds at the end of period t should be either less than the value of collateral assets at the end of period t or less than the value of nonpaid debt of period t. In the Supplementary Material, we provide a micro-interpretation of this enforcement constraint.

If debt is 1-period debt, $\delta_b=1$, equation (4) becomes $p_t b_{t+1}\leq\xi_t k_{t+1}$, which is the collateral constraint in Kiyotaki and Moore (1997). However, if debt is multiple-period debt, $\delta_b<1$, the firm may hold debt more than the value of collateral assets *occasionally* (i.e., $p_s b_{s+1}\geq\xi_s k_{s+1}$, for some states s). This is due to the arrangement of long-term debt: In each period t, the firm is only obligated to repay δb_t amount of existing debt. After that, the lender cannot force the firm to repay more, even if the credit market condition (ξ_t) or the firm's credit quality ($\xi_t k_{t+1}$) decreases.

The pricing of long-term debt is straightforward. Define the debtholders' discount factor as $\Lambda_{t+1} = \beta$, the same as the shareholders', and then the price of long-term debt before the tax shield is

$$\widehat{p}_t = \mathbb{E}_t \left[\Lambda_{t+1}\delta_b + \Lambda_{t+1}(1-\delta_b)\widehat{p}_{t+1} \right]. \tag{5}$$

The current price of long-term debt is the sum of discounted future repayment and the discounted value of nonpaid debt.

Let τ denote the corporate tax rate, and then the price of long-term debt after the tax shield is

$$p_t = \frac{1}{1+(1-\tau)\left(\widehat{p}_t^{-1}-1\right)}. \tag{6}$$

Thus, the final price of long-term debt depends on the debt-repayment rate δ_b, the corporate tax rate τ, and the debtholders' discount factor β.

D. Unused Lines of Credit

The definition of unused lines of credit is based on the following assumption: The lender honors the firm's outstanding debt, but the lender cannot fully commit to the unused portion of credit lines.

In the model, the enforcement constraint in equation (4) is occasionally binding. We define the firm's unused lines of credit as the difference between the right side and the left side of the enforcement constraint: *the total borrowing capacity minus the actual borrowing*. Let l_t denote the amount of unused lines of credit during the period t, and then

$$l_t = \omega_{t+1} - p_t b_{t+1}, \tag{7}$$

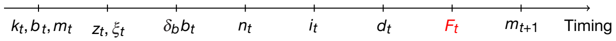
where the variable ω_{t+1} is the firm's total debt capacity, defined as $\omega_{t+1} = \max\{\xi_t k_{t+1}, (1-\delta_b)p_t b_t\}$. Notice that although the second term $(1-\delta_b)p_t b_t$ in the parentheses is precommitted, the first term $\xi_t k_{t+1}$ is contingent on the current credit market condition ξ_t and the size of the firm's capital assets k_{t+1}. Thus, the amount of unused credit during period t is not fully committed, and the actual availability of credit depends on the firm's credit quality $\xi_t k_{t+1}$.

This definition of unused lines of credit is designed to capture the following lending procedures in practice: First, the firm applies for a loan. Then, the bank evaluates the firm's collateral assets. After that, the bank issues a credit line to the firm based on the collateral assets. Given the credit line, the firm decides how much to borrow now and how much to save as unused lines. Finally, after these steps, the bank reevaluates the firm's collateral assets period by period and adjusts the credit limit accordingly.

The definition of unused lines of credit in this article is not exactly the same as the one used in the literature (e.g., Holmström and Tirole (1998), Acharya, Almeida, and Campello (2013)). First, for the simplicity of numerical computation, we assume that firms do not pay a commitment fee to secure a credit line. Second, a credit line is not a precommitment contract in the sense that the availability of a credit line is contingent on the firm's credit quality as well as the lender's financial health (credit market conditions). The bank only commits to the existing credit but not to the future credit. Third, to avoid high-dimensional computation problems and to highlight the risk of losing unused credit, we do not model lines of credit as state-contingent claims, as suggested by Rampini and Viswanathan (2010). Instead, we focus on the timing of credit-line usage: Given the access to a credit line with its limit depending on the firm's credit quality and the bank's willingness to supply funds, the firm makes choices about how much to draw down right now and how much to save as unused credit for future needs.

E. Cash

The timing of a firm's decision is as follows: In each period t, the firm starts with capital assets k_t, debt outstanding b_t, and cash holdings m_t. Then the firm observes the period t productivity z_t and credit condition ξ_t. After that, the firm first repays fraction δ_b of its debt outstanding b_t and then decides the amount of new debt issuance n_t, investment i_t, dividend payout d_t, and finally, cash savings m_{t+1}.



However, the firm's revenues $F(z_t,k_t)$ are realized at the end of period t, whereas payments need to be made at the beginning of the period. Thus, at the beginning of period t, the firm faces a cash-in-advance constraint (liquidity constraint); The sources of funds must be sufficient to support the uses of funds:

$$\underbrace{m_t}_{\text{cash holdings}} + \underbrace{p_t n_t}_{\text{debt issuance}} \geq \underbrace{\delta_b b_t}_{\text{debt repayment}} + \underbrace{i_t}_{\text{investment}} + \underbrace{d_t}_{\text{payout}}. \tag{8}$$

The left side of equation (8) includes the financing sources, cash holdings and debt issuance, and the right side of the equation represents the financing needs, debt repayment, investment, and dividend payout. In this section, we assume that the firm cannot issue equity (or pay negative dividends). That is, $d_t \geq 0$. But we will relax this assumption in the quantitative analysis.

To sum up, given the rigidities of adjusting the financing needs (i.e., mandatory debt repayment, nonnegative dividend payout, and capital adjustment costs), to satisfy the period t cash-in-advance constraint, the firm has two choices in period $t-1$: either to accumulate cash or to reserve unused credit.

All the firm's decisions are subject to the budget constraint:

$$F(z_t,k_t) + m_t + p_t n_t = p_t^m m_{t+1} + \delta_b b_t + i_t + d_t, \tag{9}$$

where the variable p_t^m is the price of cash. After combining this budget constraint with the cash-in-advance constraint, the cash-in-advance constraint can be rewritten as

$$p_t^m m_{t+1} \geq F(z_t,k_t). \tag{10}$$

This cash-in-advance constraint is occasionally binding in the model, and when it does not bind, we define the precautionary cash as

$$c_t = p_t^m m_{t+1} - F(z_t, k_t). \tag{11}$$

When the precautionary cash $c_t > 0$, the cash balances carried into the next period are larger than the cash generated from cash flows in the current period.

To sum up the model, we recall a firm's balance sheet:

Assets	Liabilities
Capital k_{t+1}	Equity V_t
Cash m_{t+1}	Debt b_{t+1}

The firm considers three trade-offs: i) On the assets side of the balance sheet, the firm makes choices between cash and capital. Although cash earns a lower rate of return than capital, cash is more liquid than capital because the firm faces capital adjustment costs. ii) On the liabilities side, the firm prefers debt finance to equity finance, given the tax shield of debt. However, debt finance is limited by the enforcement constraints. iii) Between the assets side and the liabilities side, cash is not negative debt because of the maturity differences. Although cash helps to smooth the funds from long-term borrowing between periods, holding cash incurs an opportunity cost.

These three trade-offs imply two motivations for holding liquidity: i) the later-borrowing motive, in which, given the rigidities of adjusting the financing needs, the firm chooses to keep a distance from the borrowing limit and save unused credit to hedge future credit contractions, and ii) the pre-borrowing motive, in which, given the maturity mismatch between cash and debt, the firm also chooses to borrow more with long-term debt and save funds in cash, and it does so as insurance against future credit contractions.

Let $V(k,m,b;s)$ be the firm's equity value at the beginning of period t, where s represents the exogenous state variables z and ξ. The firm's problem $\mathcal{P}$ can be written down recursively:

$$V(k,m,b;s) = \max_{k',m',b',d} \{d + \mathbb{E}[\Lambda' V(k',m',b';s')]\}, \tag{12}$$

$$\text{subject to:}$$

$$p^m m' \geq F(z,k), \tag{13}$$

$$F(z,k) + m + pn = p^m m' + \delta_b b + i + d, \tag{14}$$

$$d \geq 0, \tag{15}$$

$$k' - (1-\delta)k = \phi\left(\frac{i}{k}\right)k, \tag{16}$$

$$b' = (1-\delta_b)b + n, \tag{17}$$

$$pb' \leq \max\{\xi k', (1-\delta_b)pb\}. \tag{18}$$

The manager maximizes the equity value of the firm subject to 6 constraints: the cash-in-advance constraint, the budget constraint, the nonnegative dividend constraint, the capital accumulation equation, the dynamics of long-term debt, and the enforcement constraint. We summarize two propositions of the firms' problem and their proofs in the Supplementary Material.

Proposition 1. If the debt repayment rate $\delta_b = 1$, the cash-in-advance constraint is always binding, and precautionary cash $c_t = 0$.

Proposition 2. There exists a cutoff $\delta_b^* < 1$ such that if $\delta_b < \delta_b^*$, the cash-in-advance constraint is occasionally binding, and precautionary cash $c_t > 0$.

The economic intuition of these two propositions is as follows: When the debt-repayment rate $\delta_b = 1$, cash is the same as negative debt. As a result, firms do not hold precautionary cash because they can always save interest expenses by using cash to reduce debt. However, when the repayment rate $\delta_b < \delta_b^*$, the benefit of holding cash can be larger than the direct costs of holding cash. This is because if the firm borrows with long-term debt today and saves the funds in cash, it can insure itself against future credit contractions.

IV. Model Solution

The model is solved numerically by the projection method, and the numerical procedures are discussed in the Supplementary Material.

A. Normalized Optimization Problem

To keep the model computation tractable, we detrend all firm-level variables by capital k, using the assumption of linear technology $F(z,k) = zk$. After detrending, the firm's optimization problem becomes:

$$\widetilde{V}\left(\widetilde{m},\widetilde{b};s\right) = \max_{g',\widetilde{m}',\widetilde{b}',\tilde{d}} \left\{\widetilde{d} + g'\mathbb{E}\left[\Lambda'\widetilde{V}\left(\widetilde{m}',\widetilde{b}';s'\right)\right]\right\}, \tag{19}$$

subject to :

$$p^m \widetilde{m}' g' \geq z, \tag{20}$$

$$z + \widetilde{m} + p\widetilde{n} = p^m \widetilde{m}' g' + \delta_b \widetilde{b} + \widetilde{i} + \varphi\left(\widetilde{d}\right), \tag{21}$$

(22)
$$g' - (1-\delta) = \phi\left(\widetilde{i}\right),$$

(23)
$$p\widetilde{b}' g' = (1-\delta_b)p\widetilde{b} + p\widetilde{n},$$

(24)
$$p\widetilde{b}' g' \leq \eta\xi g' + (1-\eta)(1-\delta_b)p\widetilde{b}.$$

where $g' = k'/k$ is the growth rate of capital, $\widetilde{m} = m/k$ and $\widetilde{b} = b/k$ are detrended state variables, and $\widetilde{x} = x/k$ denotes other detrended variables. In this normalized optimization problem, there are only two state variables left, the cash-to-capital ratio $\widetilde{m}$ and the debt-to-capital ratio $\widetilde{b}$, and this makes the numerical computation much easier.

In the quantitative analysis, we relax the assumption of a nonnegative dividend payout. Instead of imposing the nonnegative-dividend constraint of equation (15), we introduce a smooth equity adjustment cost function $\varphi(\widetilde{d})$ in the budget constraint of equation (21) to capture the frictions in adjusting equity. For numerical purposes, we also replace the debt-enforcement constraint in equation (18) with its stochastic version, equation (24), in which we take away the term "max" and introduce a refinancing probability η. In the Supplementary Material, we show that these two enforcement constraints, equations (18) and (24), are equivalent.

B. Functional Forms

In this section, we discuss the functional forms of capital and equity adjustment cost and the assumptions on the process of the shocks.

The capital adjustment cost function $\phi(i_t/k_t)$ is given by

(25)
$$\phi\left(\frac{i_t}{k_t}\right) = \frac{a_1}{(1-\zeta)}\left(\frac{i_t}{k_t}\right)^{1-\zeta} + a_2.$$

This function is concave in i_t and decreasing in k_t. The concavity of $\phi(\cdot)$ captures the idea that it is more costly to change the capital stock quickly. The value $1/\zeta$ is the elasticity of the investment–capital ratio with respect to the marginal q. The parameters $a_1 = \delta^{\zeta}$ and $a_2 = (-\zeta/1-\zeta)\delta$ are set so that in the steady state, the capital adjustment cost is 0, and the marginal q is equal to 1. This adjustment cost function has been widely used in the investment and production-based asset pricing literature (see, e.g., Jermann (1998)).

As in Jermann and Quadrini (2012), the equity adjustment cost function $\varphi(\widetilde{d})$ is given by

(26)
$$\varphi(\widetilde{d}) = \widetilde{d} + \kappa\left(\widetilde{d} - \widetilde{d}_{\text{target}}\right)^2,$$

where κ is a parameter measuring the rigidities of adjusting equity, and $\widetilde{d}_{\text{target}}$ is a long-term targeted dividend-payout ratio calibrated to match the average dividend-payout ratio in the data. This equity adjustment cost function implies that if the firm pays a dividend at its long-term target ratio, it does not incur any cost; however, if the firm deviates from its long-term target ratio, it needs to pay an additional cost, and particularly, if the firm wants to pay a negative dividend, that is, to issue equity, it needs to pay a cost that is convex in the amount of issuance.[5]

The productivity shock z_t follows a first-order autoregressive (AR(1)) process

$$\log(z_t) = \mu_z + \rho_z \log(z_{t-1}) - \sigma_z^2/2 + \sigma_z u_t, \tag{27}$$

where u_t is independent and identically distributed (IID) innovation with a standard normal distribution $N(0,1)$. The variable μ_z refers to the drift of the process $\log(z_t)$, ρ_z refers to the persistence, and σ_z refers to the volatility. The model allows large-scale shocks. Thus, given the log-normal specification, the impact of volatility σ_z on the conditional expectation of the productivity shock z_t cannot be ignored. Following Gilchrist, Sim, and Zakrajšek (2014), we subtract the term $\sigma_z^2/2$ in equation (27) to remove this second-order impact. Because u_t is distributed normally, simple algebra shows that $E(e^{-\sigma_z^2/2+\sigma_z u_t}|\sigma_z) = 1$. Thus, increases in volatility σ_z represent a mean-preserving spread to the conditional distribution of productivity z_t. For numerical purposes, we approximate the AR(1) process in equation (27) with a finite-state Markov chain.

The refinancing probability η_t in equation (24) is stochastic, and we refer to it as *financing shock* or *credit shock*. Similar to the productivity shock, the financing shock η_t follows an AR(1) process:

$$\eta_t = \overline{\eta} + \rho_\eta(\eta_{t-1} - \overline{\eta}) + v_t, \tag{28}$$

where the variables $\overline{\eta}$ and ρ_η are, respectively, the mean and the persistence of process η_t. The variable v_t is IID innovation with the distribution $N(0,\sigma_\eta^2)$, and σ_η refers to the volatility of the financing shock. Also, we approximate this AR(1) process with a finite-state Markov chain in the quantitative analysis.

V. Estimation

In this section, we conduct a structural estimation of the model. We start by describing the data and then discuss the estimation procedures and results.

A. Data

We obtain data from the Compustat annual files, except for the data on unused lines of credit. Data on unused lines of credit are not available in Compustat, and most existing research manually collects the credit-line data from firms' U.S. Securities and Exchange Commission (SEC) 10-K filings (e.g., Sufi (2009), Yun (2009)). For this article, we use the data from the Capital IQ database, which contains a large sample of unused lines of credit from 2002 to 2010. In Capital IQ,

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[5] There are several interpretations for why there are rigidities through equity-adjustment costs. i) Equity issuance cost: The firm pays an additional cost when it issues equity to shareholders, and the cost is convex in the sense that underwriting fees display increasing marginal cost in the size of the offering (e.g., Altınkılıç and Hansen (2000)). ii) Dividend smoothing: The firm has a long-term targeted payout ratio, and it actively adjusts the payout ratio when the ratio deviates from the target. iii) Dividend tax: Shareholders need to pay income tax on the dividends they received.

the variable "unused lines of credit" refers to *total undrawn credit*, which includes undrawn revolving credit, undrawn commercial paper, undrawn term loans, and other undrawn credit. Ippolito and Pérez Orive (2012) provide a detailed description of total undrawn credit in the Capital IQ database.

Following the literature, we exclude financial firms and utilities with SIC codes in the intervals 4900–4949 and 6000–6999 and firms with SIC codes greater than 9000. We also exclude firms with a missing value for book value of assets, debt, cash, unused line, investment, payout, and cash flow. We winsorize all variables at the 2.5th and 97.5th percentiles to limit the influence of outliers. All variables are deflated by the Consumer Price Index. The final sample for the structural estimation is a balanced panel of 1,999 firms over 9 years from 2002 to 2010. Table 1 provides the definitions and sources of the variables used in the structural estimation. Notice that based on the model, we define CASH as cash holdings minus short-term debt, and we define DEBT as long-term debt.

B. Parameters and Target Moments

The choice of model parameters is guided by the simulated method of moments (SMM). The basic idea of SMM is to choose the model parameters so that the moments generated by the model are as close as possible to the corresponding real data moments. The detailed estimation procedures are discussed in the Supplementary Material.

Panel A in Table 2 lists the 14 target moments used in the estimation. The choice of target moments is based on the following principle: First, to estimate most of the parameters in the model, we choose the mean and the standard deviation of all 6 key variables in the model, except the standard deviation of investment, which is replaced by the autocorrelation of investment.[6] Second, to identify the persistence of shocks, we also include the autocorrelation of cash and the autocorrelation of cash flows.

Panel B in Table 2 lists the 10 parameters estimated by the SMM. They are the drift, persistence, and standard deviation of the productivity shock μ_z, ρ_z, and σ_z, respectively; the persistence and standard deviation of credit shock, ρ_η and σ_η, respectively; the capital depreciation rate δ; the collateral rate ξ; the equity rigidity parameter κ; the capital adjustment parameter ζ; and the price of cash p^m.

Panel 3 in Table 2 lists the 3 parameters that are calibrated directly from the data. We set the subjective discount rate $\beta = 0.97$ such that the implied 1-period interest rate is approximately equal to the average of the real interest rate 1.03 over the sample period 2002–2010. We use the effective corporate tax rate $\tau = 0.15$, as in the literature (e.g., Hackbarth and Mauer (2012)). The debt-repayment rate $\delta_b = 0.31$ is set to match the average long-term debt-retirement rate in the data.

C. Sensitivity Test

Before going to the estimation results, we briefly discuss how the model parameters are identified by the data moments. In the estimation, parameters are jointly identified by moments, and the number of moments is larger than the number of

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[6] The model is unable to match the standard deviation of investment without the addition of investment shock. We introduce investment shock in Section VII.

TABLE 1

Variable Definitions in the Structural Estimation

Table 1 reports the variable definitions.

Variable	Model	Detrended Model	Data
Cash/assets	$\frac{p^m m_{t+1}}{k_t+m_t}$	$\frac{p^m \widetilde{m}_{t+1} g_{t+1}}{1+\widetilde{m}_t}$	(Cash and short-term investments (CHE$_t$) − total debt in current liabilities (DLC$_t$)) /total assets (AT$_{t-1}$). From Compustat.
Debt/assets	$\frac{p_t b_{t+1}}{k_t+m_t}$	$\frac{p_t \widetilde{b}_{t+1} g_{t+1}}{1+\tilde{m}_t}$	Total long-term debt (DLTT$_t$) /total assets (AT$_{t-1}$). From Compustat.
Investment/assets	$\frac{i_t}{k_t+m_t}$	$\frac{\widetilde{i}_t}{1+\tilde{m}_t}$	Capital expenditures (CAPX$_t$) /total assets (AT$_{t-1}$). From Compustat.
Payout/assets	$\frac{d_t : d_t > 0}{k_t+m_t}$	$\frac{\widetilde{d}_t : \widetilde{d}_t > 0}{1+\tilde{m}_t}$	(Purchase of common and preferred stock (PRSTKC$_t$) + preferred/preference dividends (DVP$_t$) + common/ordinary dividends (DVC$_t$)) /total assets (AT$_{t-1}$). From Compustat.
Cash flow/assets	$\frac{z_t k_t}{k_t+m_t}$	$\frac{z_t}{1+\tilde{m}_t}$	Operating income before depreciation (OIBDP$_t$) /total assets (AT$_{t-1}$). From Compustat.
Unused line/assets	$\frac{l_t}{k_t+m_t}$	$\frac{\widetilde{l}_t}{1+\tilde{m}_t}$	TOTAL_UNDRAWN_CREDIT$_t$/total assets (AT$_{t-1}$). From Capital IQ and Compustat.

TABLE 2

Benchmark Estimation

In Table 2, empirical moments are based on a balanced panel of nonfinancial, unregulated firms from Compustat annual files from 2002 to 2010. Panel A reports the target moments in the estimation, Panel B lists point estimates and standard errors (SE) (in parentheses), and Panel C reports parameters estimated directly from the data.

Panel A. Target Moments	Data	Model
Mean of cash/assets	0.189	0.154
Mean of unused line/assets	0.100	0.047
Mean of debt/assets	0.162	0.184
Mean of investment/assets	0.050	0.053
Mean of payout/assets	0.029	0.041
Mean of cash flow/assets	0.098	0.093
Std. dev. of cash/assets	0.116	0.046
Std. dev. of unused line/assets	0.055	0.074
Std. dev. of debt/assets	0.082	0.091
Std. dev. of payout/assets	0.027	0.025
Std. dev. of cash flow/assets	0.070	0.033
Autocorrelation of cash/assets	0.188	0.191
Autocorrelation of investment/assets	0.205	0.220
Autocorrelation of cash flow/assets	0.297	0.315
Panel B. Estimated Parameters	Estimates	SE
Drift of productivity shock, μ_z	0.041	(0.007)
Persistence of productivity shock, ρ_z	0.466	(0.086)
Volatility of productivity shock, σ_z	0.421	(0.077)
Persistence of credit shock, ρ_η	0.410	(0.063)
Volatility of credit shock, σ_η	0.457	(0.054)
Capital depreciation rate, δ	0.087	(0.012)
Collateral rate, ξ	0.456	(0.041)
Equity-rigidity parameter, κ	0.533	(0.118)
Capital adjustment cost, ζ	0.779	(0.199)
Price of cash, p^m	0.975	(0.023)
Panel C. Calibrated Parameters		
Subjective discount factor, β		0.97
Corporate effective tax rate, τ		0.15
Debt-repayment rate, δ_b		0.31

parameters. Thus, there is no one-to-one mapping between moments and parameters. To have a clear idea about the identification of the model parameters, we conduct a sensitivity test to find out the relationship between the target moments and the model parameters. In the test, we first use the estimated parameters as benchmark parameters to compute the moments. Then, we adjust the parameters one by one to examine the sensitivity of each moment with respect to the change of parameters. Table 3 reports the results, and Figures 3 and 4 illustrate the identification of shocks.

According to the sensitivity test, the main identification of parameters is as follows: First, consider the identification of two shocks in the model. The drift of productivity shock μ_z can be identified by the mean of investment. This is because increases in μ_z raise the marginal profit of investment and therefore the level of investment. The persistence of productivity shock ρ_z is mainly identified by the autocorrelation of cash flows, and the standard deviation σ_z is identified by the standard deviation of cash flows. As can be seen from Graphs A and C of Figure 3, the autocorrelation of cash flows is monotonically increasing in ρ_z but is not sensitive to σ_z. Graphs B and D show that the standard deviation of cash flows is insensitive to ρ_z but is monotonically increasing in σ_z. Similarly, the persistence of the credit shock ρ_η is mainly identified by the autocorrelation of cash, and the standard deviation of credit shock σ_η is identified by the standard deviation of cash. Please also refer to Figure 4 for a graphical illustration.

A change in the capital deprecation rate δ affects the level of cash, the level of debt, the level of investment, and the level of cash flows, and therefore the parameter δ is pinned down by these 4 moments. The collateral rate ξ is mainly identified by the level of debt because increases in ξ raise the level of debt uniquely.

The next set of parameters is about frictions. The equity rigidity parameter κ measures the rigidities of adjusting equity. It is mainly identified by the standard deviation of payout. The second friction parameter, the capital adjustment cost parameter ζ, is identified by the autocorrelation of investment.

The price of cash p^m measures the opportunity cost of holding cash. Increases in the price of cash reduce the level of cash but raise the level of unused credit lines. Thus, the parameter p^m can be jointly identified by two moments: the level of cash and the level of unused credit lines.

D. Estimation Results

Table 2 reports the estimation results. The model matches the data quite well, except for 3 moments: the mean of unused lines of credit, the standard deviation of cash, and the standard deviation of cash flows. The model is unable to match these 3 moments for the following reasons: On the one hand, to generate a higher standard deviation of cash or cash flows, the model requires a lower capital adjustment cost. On the other hand, the model needs a higher capital adjustment cost to match the level of unused lines of credit. There is thus a tension between matching the level of the firm's liquidity holdings and matching the standard deviation of the firm's real decisions.

Panel B in Table 2 shows the estimated value of the model parameters. The estimated standard deviation of productivity shock is 0.466, and the persistence is 0.421. Compared with the literature (e.g., DeAngelo et al. (2011)), the estimated

TABLE 3

Sensitivity Test of Estimated Parameters

Table 3 shows the results of the sensitivity test of the estimated parameters. The first column lists the benchmark moments simulated by the parameters estimated in Table 2. The rest of the columns show the results of the sensitivity test by changing the value of 1 parameter each time. The parameters are as follows: the drift of productivity shock μ_z, the persistence of productivity shock ρ_z, the volatility of productivity shock σ_z, the persistence of credit shock ρ_η, the volatility of credit shock σ_η, the capital depreciation rate δ, the collateral rate ξ, the equity-rigidity parameter κ, the capital adjustment cost ζ, and the price of cash p^m. We increase each parameter by 33% to test its sensitivity, except the price of cash p^m, which we increase from 0.975 to 0.98.

	Benchmark	μ_z	ρ_z	σ_z	ρ_η	σ_η	δ	ξ	κ	ζ	p^m
Mean of cash/assets	0.154	0.156	0.149	0.147	0.156	0.172	0.173	0.168	0.152	0.155	**0.107**
Mean of unused line/assets	0.047	0.044	0.044	0.049	0.053	0.066	0.045	0.068	0.061	0.047	**0.129**
Mean of debt/assets	0.184	0.189	0.184	0.180	0.170	0.146	0.179	**0.229**	0.167	0.184	0.088
Mean of investment/assets	0.053	**0.056**	0.040	0.052	0.052	0.052	0.067	0.052	0.053	0.056	0.055
Mean of payout/assets	0.041	0.038	0.044	0.045	0.041	0.044	0.046	0.040	0.041	0.038	0.046
Mean of cash flow/assets	0.093	0.093	0.088	0.086	0.092	0.091	**0.112**	0.091	0.094	0.092	0.098
Std. dev. of cash/assets	0.046	0.047	0.046	0.046	0.046	**0.056**	0.045	0.054	0.042	0.046	0.032
Std. dev. of unused line/assets	0.074	0.073	0.073	0.078	0.085	0.105	0.074	0.102	0.086	0.075	0.124
Std. dev. of debt/assets	0.091	0.093	0.092	0.093	0.103	0.128	0.090	0.112	0.089	0.093	0.071
Std. dev. of payout/assets	0.025	0.024	0.027	0.027	0.026	0.029	0.026	0.026	**0.022**	0.024	0.025
Std. dev. of cash flow/assets	0.033	0.034	0.035	**0.041**	0.033	0.033	0.040	0.033	0.034	0.034	0.035
Autocorrelation of cash/assets	0.191	0.199	0.219	0.174	**0.256**	0.174	0.172	0.185	0.175	0.191	0.146
Autocorrelation of investment/assets	0.220	0.213	0.393	0.257	0.264	0.164	0.249	0.203	0.280	**0.190**	0.095
Autocorrelation of cash flow/assets	0.315	0.312	**0.445**	0.304	0.310	0.292	0.292	0.317	0.305	0.309	0.262

standard deviation of productivity shock is higher, whereas the persistence is lower. The reason is that the data we considered include the recent financial crisis. Thus, it is reasonable to find that firms' decisions are more volatile in our estimation.

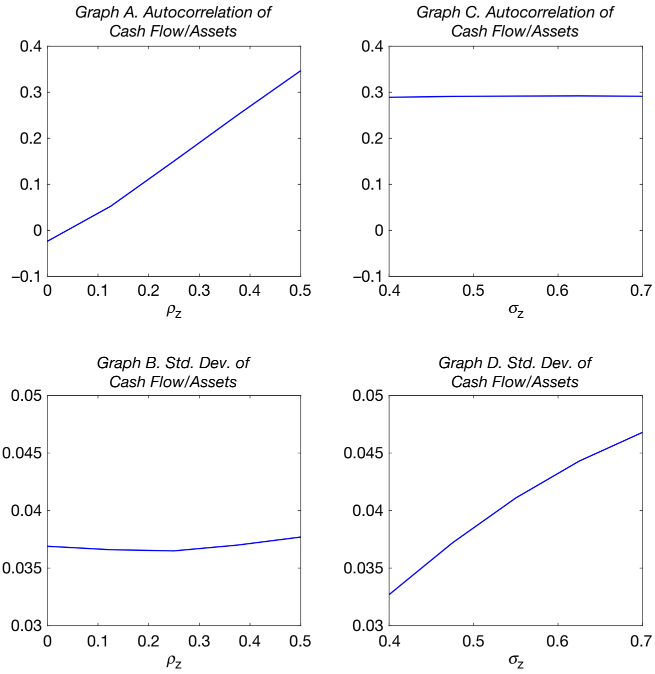
The estimated standard deviation of credit shock is 0.457, and the persistence is 0.410. Because these two estimates of credit shocks are new in the literature, it is useful to explain the magnitude of the shocks. Suppose that during normal periods, the firm can refinance its debt with a probability of 50%; then the estimated magnitude means that if the firm is hit by the worst credit shock, it cannot refinance its debt anymore, whereas if the firm receives the best credit shock, it can refinance its debt with a probability of 100%.

The estimated collateral rate is 0.456, which implies that the firm can borrow up to 45.6% of its capital assets. The equity-rigidity parameter κ is 0.533, which means that for a firm with a 10 book value of assets, if the firm issues 1 in equity, its issuance cost is 5% of the proceeds; if the firm issues 2 in equity, its issuance cost doubles to 10% of the proceeds. That is, the equity-issuance cost is convex. The capital adjustment cost ζ is 0.779, which implies that the elasticity of the investment–capital ratio with respect to the marginal q is 1.28.

FIGURE 3

The Key Identification of Productivity Shock z

Figure 3 shows the sensitivity of cash-flow moments to the productivity shock. Graphs A and B show the sensitivity with respect to the persistence of productivity shock ρ_z, and Graphs C and D show the sensitivity with respect to the standard deviation of productivity shock σ_z.



The estimated price of cash p^m is 0.975, which is higher than the price of 1-period debt of 0.97. The difference between the price of cash and the price of 1-period debt can be interpreted as the opportunity cost of holding cash, or the liquidity premium. In terms of return, the interest rate earned on cash is $1/0.975 \approx 1.026$, whereas the interest rate paid on debt is 1.03. Thus, the estimated liquidity premium is approximately 40 basis points (bps).

E. Subsample Estimation

In this section, we estimate the model by separating the data sample used in Table 2 into 2 subsamples: small firms versus large firms.[7] Ex ante, one would expect that small firms are more likely to be financially constrained, and they also face higher productivity or financing risks. Thus, if our model is identified, we would be able to find that the estimated parameters of small firms are economically different from those of large firms.

Table 4 reports the results of the subsample estimation. First, in terms of empirical moments, from Panel A, we can observe that small firms have a higher cash-to-assets ratio (small firms = 0.261 vs. large firms = 0.117), lower unused-credit

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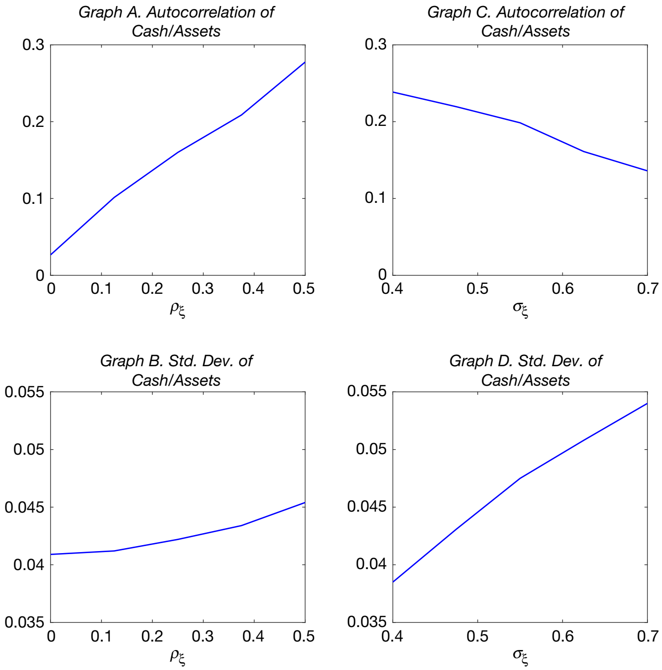
[7] We thank the anonymous referee for making this suggestion.

FIGURE 4

The Key Identification of Credit Shock ξ

Figure 4 shows the sensitivity of cash moments to the credit shock. Graphs A and B show the sensitivity with respect to the persistence of credit shock ρ_ξ, and Graphs C and D show the sensitivity with respect to the standard deviation of credit shock σ_ξ.



ratio (0.087 vs. 0.114), lower debt ratio (0.096 vs. 0.228), lower investment ratio (0.047 vs. 0.054), and lower payout ratio (0.024 vs. 0.035), indicating that small firms are more likely to be financially constrained. At the same time, we also find that small firms have higher cash-flow volatility (0.094 vs. 0.047) and higher cash volatility (0.155 vs. 0.076), suggesting that small firms potentially face higher risks.

Second, in terms of estimated parameters, Panel B of Table 4 shows that small firms indeed face higher risks, particularly the credit risk. For small firms, not only is the persistence of credit shock higher (0.281 vs. 0.218), but the volatility of credit shock is more than 2 times that of large firms (0.633 vs. 0.301). Furthermore, small firms have a lower estimated collateral rate (0.287 vs. 0.569), higher equity adjustment cost parameter (0.962 vs. 0.461), and higher capital adjustment cost parameter (1.434 vs. 0.409), indicating that small firms face tighter financial constraints and more rigidities in adjusting financial structure.

F. Counterfactual Exercises

Given the estimated model, we conduct a counterfactual exercise to identify which type of risk is better in explaining the firm's liquidity policies: financing risk or productivity risk. We first simulate the model using the estimated parameters to generate benchmark moments, and then we remove the productivity shock from the

TABLE 4

Estimation: Small Versus Large

In Table 4, we structurally estimate the model by separating the full sample used in Table 2 into 2 subsamples: small firms versus large firms. We sort firms into 2 groups based on each firm's average asset size during the sample period. Panel A reports the target moments in the estimation, and Panel B lists point estimates and standard errors (SE) (in parentheses).

	Small Firms		Large Firms	
Panel A. Target Moments	Data	Model	Data	Model
Mean of cash/assets	0.261	0.136	0.117	0.112
Mean of unused line/assets	0.087	0.056	0.114	0.086
Mean of debt/assets	0.096	0.097	0.228	0.240
Mean of investment/assets	0.047	0.041	0.054	0.054
Mean of payout/assets	0.024	0.032	0.035	0.045
Mean of cash flow/assets	0.050	0.071	0.145	0.109
Std. dev. of cash/assets	0.155	0.038	0.076	0.044
Std. dev. of unused line/assets	0.058	0.083	0.053	0.081
Std. dev. of debt/assets	0.073	0.086	0.091	0.074
Std. dev. of payout/assets	0.026	0.017	0.028	0.024
Std. dev. of cash flow/assets	0.094	0.035	0.047	0.046
Autocorrelation of cash/assets	0.188	0.192	0.186	0.214
Autocorrelation of investment/assets	0.151	0.149	0.257	0.241
Autocorrelation of cash flow/assets	0.283	0.272	0.310	0.257
Panel B. Estimated Parameters	Estimates	SE	Estimates	SE
Drift of productivity shock, μ_z	0.057	(0.606)	0.080	(0.752)
Persistence of productivity shock, ρ_z	0.395	(0.037)	0.490	(0.017)
Volatility of productivity shock, σ_z	0.618	(0.085)	0.514	(0.048)
Persistence of credit shock, ρ_η	0.281	(0.142)	0.218	(0.213)
Volatility of credit shock, σ_η	0.633	(0.060)	0.301	(0.042)
Capital depreciation rate, δ	0.061	(0.029)	0.101	(0.017)
Collateral rate, ξ	0.287	(0.027)	0.569	(0.044)
Equity-rigidity parameter, κ	0.962	(0.498)	0.461	(0.324)
Capital adjustment cost, ζ	1.434	(0.612)	0.409	(0.223)
Price of cash, p^m	0.975	(0.030)	0.983	(0.124)

model and simulate a new set of moments as a comparison. Similarly, we also remove the financing shock from the model and simulate another set of moments.

Table 5 shows the results of the experiment. First, compared with the data (column 1), the benchmark model (column 2) explains 67% of precautionary cash and 47% of unused lines of credit as observed in the data.[8] Second, the model with only financing shock (column 3) generates 63% of precautionary cash and 33% of unused lines of credit as observed in the data. Third, the model with only productivity shock (column 4) generates 4% of precautionary cash and 10% of unused lines of credits as observed in the data. Thus, this counterfactual exercise implies that the financing risk is the driving force for firms to hold liquidity, particularly for the precautionary cash. Furthermore, the precautionary cash generated by the financing risk accounts for $0.057/0.189 \approx 30\%$ of the total cash holdings in the data.

A second counterfactual exercise is to examine the value of holding liquidity. We run the following 3 experiments: In the first experiment, we shut down both the channel of holding precautionary cash and the channel of holding unused lines of credit. That is, we assume that both the cash-in-advance constraint and the debt-enforcement constraint are always binding in the model. In the second experiment, we shut down only the channel of holding unused lines of credit, and in the third

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[8] According to the model, the precautionary cash of period t is defined as cash holdings at the beginning of period $t+1$ minus cash flows at the end of period t.

TABLE 5

Counterfactual Exercise I: The Role of Shocks

The first column of Table 5 reports the moments observed in the data. The second column reports the benchmark moments of the model with both the financing shock and the productivity shock. The third column reports the moments of the model with only the financing shock. The fourth column reports the moments of the model with only the productivity shock.

	Data	Benchmark Model	Financing Shock	Productivity Shock
Mean of precautionary cash/assets	0.091	0.061	0.057	0.004
Mean of unused line/assets	0.100	0.047	0.033	0.010
Mean of cash/assets	0.189	0.154	0.151	0.103
Mean of debt/assets	0.162	0.184	0.204	0.258
Mean of investment/assets	0.050	0.053	0.056	0.057
Mean of payout/assets	0.029	0.041	0.038	0.033
Mean of cash flow/assets	0.098	0.093	0.094	0.098
Std. dev. of cash/assets	0.116	0.046	0.039	0.031
Std. dev. of unused line/assets	0.055	0.074	0.054	0.017
Std. dev. of debt/assets	0.082	0.091	0.084	0.025
Std. dev. of payout/assets	0.027	0.025	0.024	0.021
Std. dev. of cash flow/assets	0.070	0.033	0.004	0.035
Autocorrelation of cash/assets	0.188	0.191	0.115	0.207
Autocorrelation of investment/assets	0.205	0.220	−0.053	0.020
Autocorrelation of cash flow/assets	0.297	0.315	0.258	0.256

TABLE 6

Counterfactual Exercise II: The Value of Liquidity

The first column of Table 6 reports the moments of the benchmark model. The second through fourth columns report the moments of the experimental models. Model 1 is the model without any liquidity holdings, Model 2 is the model without the channel of holding unused lines of credit, and Model 3 is the model without the channel of holding precautionary cash. To draw comparisons between different models, we normalize the value of the firm in the benchmark model to 1. Also, we set the value of capital and the value of debt to be the same in these models so that firms in different models are identical except for having different channels of holding liquidity.

	Benchmark Model	Model 1 Neither	Model 2 No Lines	Model 3 No Prec. Cash
Normalized value of cash flow	0.110	0.110	0.110	0.110
Normalized value of debt	0.245	0.245	0.245	0.245
Normalized value of precautionary cash	0.063	0.000	0.103	0.000
Normalized value of unused credit line	0.077	0.000	0.000	0.138
Normalized value of the firm	1.000	0.798	0.996	0.937
Normalized value of equity	0.755	0.553	0.751	0.692
Normalized costs of adjusting capital	0.101	0.322	0.117	0.108
Normalized costs of adjusting equity	0.023	0.219	0.069	0.014
Normalized value of equity payout	0.042	0.044	0.041	0.036
Normalized volatility of equity payout	0.034	0.110	0.061	0.020

experiment, we shut down only the channel of holding precautionary cash. Finally, we compare the firms' performances under these 3 experiments to the benchmark model.

When comparing the firms' performance under these 3 experiments, we set the value of capital and the value of debt in the experimental models to be the same as in the benchmark model.[9] Thus, the firms in these experiments are identical except for having different channels of holding liquidity.

Table 6 shows the results of these 3 experiments. Compared with the benchmark model, in the model without any liquidity holdings (model 1), the equity value decreases by $(0.755-0.553)/0.755 \approx 27\%$. The economic explanation behind this result is simple: In the case of no liquidity holdings, the firm needs to adjust equity or

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[9] This can be done by recalibrating the mean of productivity shock and financing shock such that the simulated mean of capital and debt are the same as in the benchmark model. However, the persistence and volatility of shocks remain the same.

capital very frequently, which in turn causes large value losses in the presence of adjustment costs.

In model 2 of Table 6, the channel of holding unused lines of credit is closed, and therefore the firm holds more precautionary cash as a substitute for unused credit lines. However, the equity value barely changes. This implies that the firm is doing a good job of substituting unused lines of credit with cash holdings.

In model 3 of Table 6, the firm is not allowed to hold precautionary cash. Intuitively, in this case, the firm increases unused lines of credit as a substitute for cash. Interestingly, however, the shareholder value decreases by $(0.755-0.692)/0.746 \approx 8\%$, which is smaller than the decrease in model 1 but larger than that in model 2. Thus, this experiment suggests that unused lines of credit cannot be perfect substitutes for cash holdings.

G. Comparative Statics of Debt Maturity

In this section, we study the comparative statics of the firm's cash holdings and financing dynamics with respect to the exogenous changes of debt maturity.

Graph A in Figure 5 shows the firm's cash-to-assets ratio as a function of debt maturity. The solid line represents the model, and the dashed line represents the data. As can be seen from the graph, the firm's cash-to-assets ratio decreases with the maturity of debt, both in the data and in the model. This is because long-term debt provides more stable funds than short-term debt, and hence, when the maturity of debt is long, firms need less liquidity to hedge against refinancing risks. Thus, this result is consistent with the finding of Harford, Klasa, and Maxwell (2014) that firms increased their cash holdings to mitigate the refinancing risk caused by shortening debt maturity over the 1980–2008 period.

Moreover, the model-predicted cash-to-asset ratio is quite close to the one observed in the data. Notice that in the model, there is only a single type of debt maturity, whereas in the data, there are multiple structures of debt maturity; thus, the comparison here between the model and the data can be taken as an out-of-sample test.

A key implication of the model is that firms have incentives to issue long-term debt and save funds in cash to hedge against future credit contractions. Further, this motive for holding cash increases with the maturity of debt. Thus, the model predicts that the correlation between cash accumulation and debt issuance is positive, and the strength of the correlation increases with the maturity of debt.

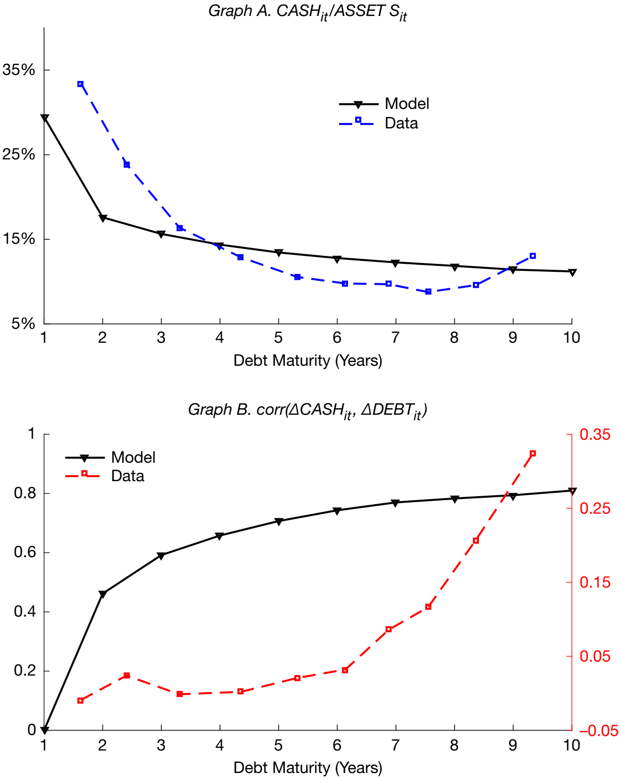
Graph B in Figure 5 depicts the correlation between cash accumulation and debt issuance as a function of debt maturity. The solid line represents the model, and the dashed line represents the data. As shown in the figure, both in the data and in the model, the correlation is positive and increases in the maturity of debt. Thus, the model's key mechanism is supported by the data.

However, the predicted correlation is much higher than the one observed in the data. The explanation for this discrepancy is as follows: In the model, there are no frictions to prevent firms from saving cash out of debt issuance, and therefore the correlation between cash saving and debt issuance is strong, whereas in the data, there are restrictions on the use of the proceeds from debt issuance. Another caveat is that in the data, we use the maturity of outstanding debt to approximate the

FIGURE 5

Comparative Statics of Debt Maturity

Figure 5 shows the comparative statics of debt maturity. The solid lines represent the model prediction, and the dashed lines represent the real data. Graph A depicts the cash-to-assets ratio, and Graph B depicts the correlation between cash accumulation and net long-term debt issuance. We classify firms into 10 groups based on the maturity of outstanding debt. In the data, we define the maturity of debt as follows: MATURITY = (0.5DD1 + 1.5DD2 + 2.5DD3 + 3.5DD4 + 4.5DD5 + 10(DLTT − DD2 − DD3 − DD4 − DD5))/(DLTT + DD1), where Compustat items DD1, DD2, DD3, DD4, and DD5 represent, respectively, the dollar amount of long-term debt maturing during the first year after the annual report, during the second year after the report, and so on; item DLTT represents the dollar amount of long-term debt that matures in more than 1 year. In the model, the maturity of debt is defined as the inverse of the debt-repayment rate. However, in the model, when the maturity of debt equals 1, there will be no difference between cash and unused credit lines, and in that case, we treat unused credit lines as cash.



maturity of new issued debt, but these two maturities are the same in the model, given that there is only a single type of debt structure.

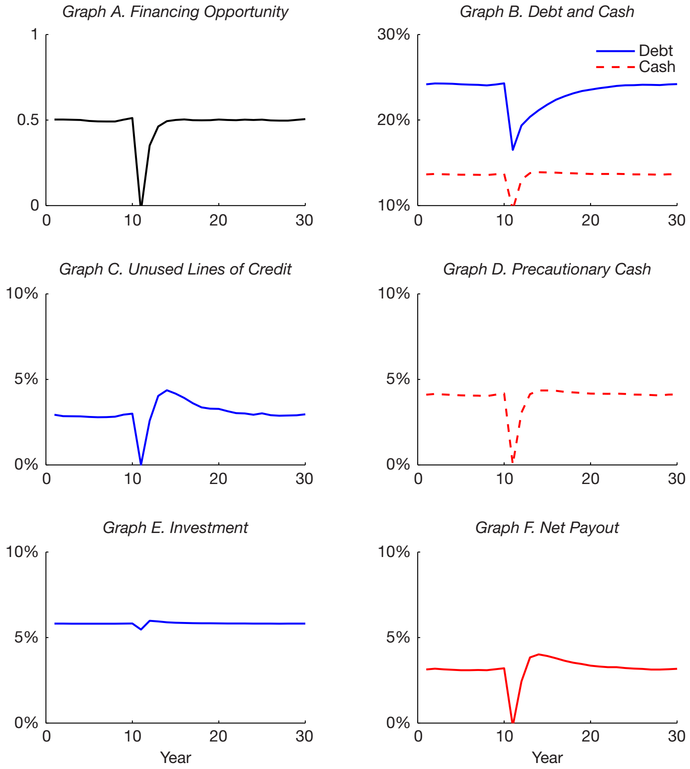
VI. Model Implications

In this section, we simulate the model to investigate the firm's response to different types of shocks. More specifically, we simulate three types of shocks to mimic three hypothetical scenarios: credit crisis, credit boom, and credit uncertainty. Because the model allows for large-scale shocks, the firm's responses to shocks are not linearized around the steady state; instead, they are the actual nonlinear transition paths after the shocks. When calculating the transition paths, we use the previously estimated structural parameters.

FIGURE 6

Credit Crisis

Figure 6 depicts the firm's transition path after a negative credit shock. The *x*-axis indicates time (year), and the *y*-axis represents the value of each variable (to assets ratio). Because the model is nonlinear and features large-scale shocks, we depict the actual transition path instead of showing the percentage deviations around the steady state. To get the transition paths, we simulate 10,000 firms, with each firm having 30 periods. For the first 10 periods, we simulate the firm using the estimated parameters. At period 11, we add an additional negative financing shock. From period 11 onward, we simulate each firm's transition paths and calculate the average of the transition paths across the 10,000 simulated firms.



A. Credit Crisis

Figure 6 shows the firm's transition paths after a negative credit shock/financing shock. Graph A plots the process of the negative credit shock. During the first 10 periods, the firm can access a lender with a probability of 0.5. In the 11th period, there is a negative credit shock, which reduces the probability of financing to 0. Here, the size of the shock is taken from the previously estimated value of the shock. From period 12 onward, the financing opportunity recovers according to the estimated AR(1) process of the shock.

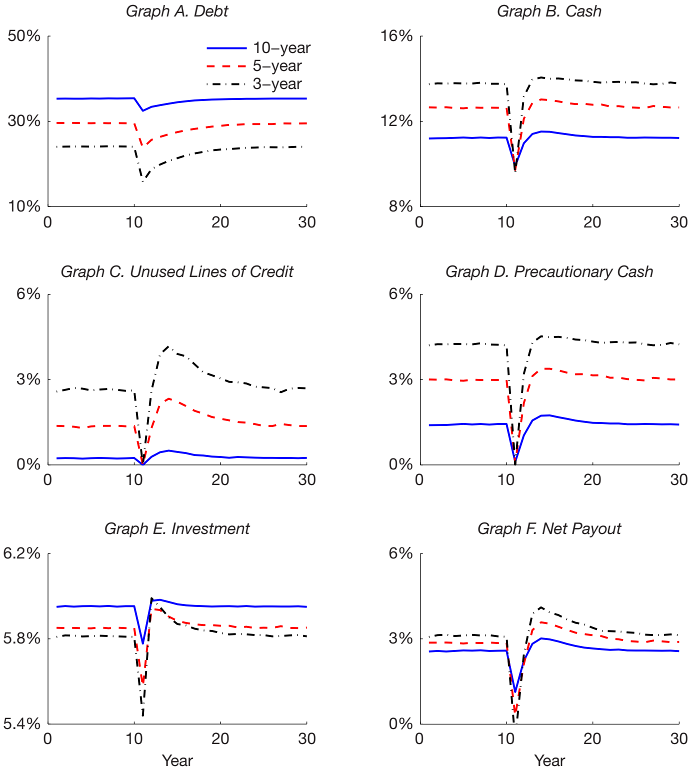
Graph B of Figure 6 depicts the transition paths of the debt-to-assets ratio and cash-to-assets ratio, and Graphs C–F describe the transition paths of the ratio of unused credit lines to assets, the ratio of precautionary cash to assets, the investment-to-assets ratio, and the ratio of net payout to assets, respectively.

As can be seen in Graph B of Figure 6, after a negative credit shock, the firm reduces debt as well as cash holdings. This is because a negative credit shock temporarily freezes the firm's access to credit markets. The firm needs to reduce

FIGURE 7

Long-Term Debt (with cash) Provides Financial Flexibility

Figure 7 shows the sensitivities of the firm's transition paths with respect to the debt-repayment rate δ_b. We consider 3 cases of the debt-repayment rate: $\delta_b = 0.10$, $\delta_b = 0.20$, and $\delta_b = 0.33$, which represent 10-year, 5-year, and 3-year debt maturity, respectively. The x-axis indicates time (year), and the y-axis represents the value of each variable (to assets ratio). Because the model is nonlinear and features large-scale shocks, we depict the actual transition path instead of showing the percentage deviations around the steady state. To get the transition paths, we simulate 10,000 firms, with each firm having 30 periods. For the first 10 periods, we simulate the firm using the estimated parameters. At period 11, we add an additional positive financing shock. From period 11 onward, we simulate each firm's transition paths and calculate the average of the transition paths across the 10,000 simulated firms.



external borrowing and rely on internal finance. At the same time, as shown in Graphs C and D, the firm reduces its liquidity holdings dramatically: Both unused lines of credit and precautionary cash hit the 0 bound when the firm has trouble accessing the credit market.

However, as shown in Graph E of Figure 6, the firm does not cut much of its investment because of its sizable liquidity holdings. This is consistent with the finding of Duchin et al. (2010) that firms used their cash holdings as buffers to smooth investment at the onset of the credit crisis of 2007–2008. Finally, the firm also reduces its net payout after the negative credit shock, which is shown in Graph F.

Figure 7 shows the sensitivity of the firm's transition paths with respect to the debt-repayment rate δ_b after a negative credit shock. We consider 3 cases of the debt-repayment rate: $\delta_b = 0.10$, $\delta_b = 0.20$, and $\delta_b = 0.33$, which represent 10-year, 5-year, and 3-year debt maturity, respectively. As shown in Figure 7, firms with 10-year debt maturity respond relatively less to the negative credit shock than firms with 5-year or 3-year debt maturity. This implies that long-term debt (with cash) provides insurance against credit shocks.

B. Credit Boom

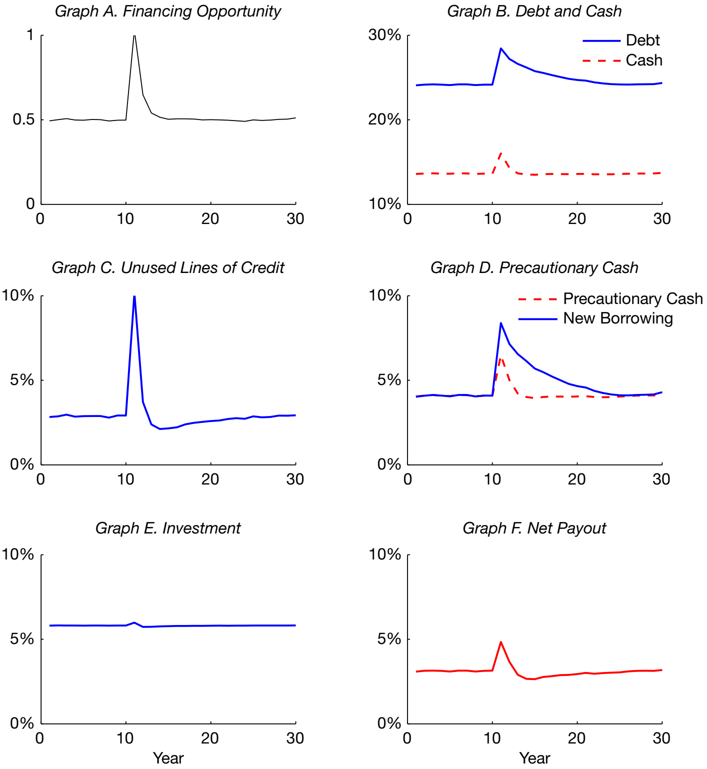
Figure 8 shows the firm's transition paths after a positive credit shock. Graph A plots the process of the positive credit shock. Graph B depicts the transition paths of debt and cash, and Graphs C–F depict the transition paths of unused lines of credit, precautionary cash, investment, and net payout, respectively.

Two takeaway results from Figure 8 are as follows: i) Although a credit boom provides better financing opportunities, the firm does not choose to borrow

FIGURE 8

Credit Boom

Figure 8 depicts the firm's transition path after a positive credit shock. The *x*-axis indicates time (year), and the *y*-axis represents the value of each variable (to assets ratio). Because the model is nonlinear and features large-scale shocks, we depict the actual transition path instead of showing the percentage deviations around the steady state. To get the transition paths, we simulate 10,000 firms, with each firm having 30 periods. For the first 10 periods, we simulate the firm using the estimated parameters. At period 11, we add an additional positive financing shock. From period 11 onward, we simulate each firm's transition paths and calculate the average of the transition paths across the 10,000 simulated firms.



all the available credit. Instead, the firm keeps most new credit as unused lines, which is shown in Graph C. ii) Given the amount of debt that the firm has borrowed during the credit boom, the firm saves some of the proceeds as precautionary cash. To draw a comparison between the new borrowing and the new cash savings, we also plot the changes in borrowing (solid line) in Graph D. As can be seen from Graph D, some of the new borrowing has been saved as precautionary cash.

These two results demonstrate the precautionary motive of holding liquidity: Even if firms are in favorable market conditions, they are still cautious about the possibility of future adverse financing conditions.

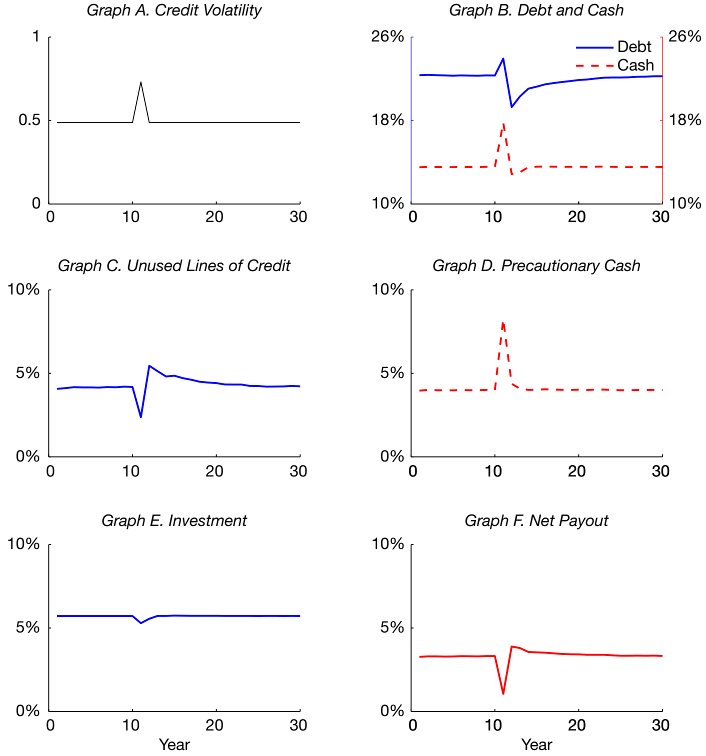
C. Credit Uncertainty

Figure 9 depicts the firm's transition path after a credit-uncertainty shock, that is, after an increase in credit volatility. In this exercise, we change only the second

FIGURE 9

Credit Uncertainty

Figure 9 depicts the firm's transition path after a credit uncertainty shock. The *x*-axis indicates time (year), and the *y*-axis represents the value of each variable (to assets ratio). Because the model is nonlinear and features large-scale shocks, we depict the actual transition path instead of showing the percentage deviations around the steady state. To get the transition path, we simulate 10,000 firms, with each firm having 30 periods. For the first 10 periods, we simulate the firm using the estimated value of credit volatility. From period 11 onward, we increase the credit volatility by 50%. We simulate each firm's transition paths and calculate the average of the transition paths across the 10,000 simulated firms.



moment of credit shock while leaving the expected level of credit shock unchanged. Graph A plots the change of the credit volatility. Graphs B–F depict the transition path for each variable.

As shown in Graph B of Figure 9, when credit volatility increases, the firm increases cash holdings immediately but cuts debt 1 period after the shock. This is because under the setting of long-term debt, reducing the current debt would shrink the next period's borrowing capacity, and hence the firm is hesitant to cut debt.

Graph C of Figure 9 shows that after the credit-uncertainty shock, the firm first reduces unused lines of credit and then rebuilds them. Graph D shows that the firm increases precautionary cash immediately after the shock. The economic interpretation is as follows: When credit uncertainty increases, the firm wants to prepare more liquidity for the future, through either cash or unused lines of credit. However, the increase in credit uncertainty also raises the chance that very bad credit conditions will prevail in the future, which in turn makes reserving unused credit lines less reliable than stockpiling cash because access to future credit lines depends on future credit conditions. As a result, when credit uncertainty increases, the firm wants to shift the funds under risky credit lines into safer cash holdings. This offers a plausible explanation for why firms wanted to draw down credit lines and stockpile cash during the recent financial crisis (e.g., Ivashina and Scharfstein (2009)): because of the increases in credit uncertainty.

Graph E of Figure 9 shows that the level of investment declines after the credit-uncertainty shock, and Graph F shows that the firm temporarily cuts the dividend payout to help build up cash reserves.

VII. Robustness Checks

A. Estimation with Stochastic Discount Factor

In this section, we check the model robustness by adding the investor's stochastic discount factor. Following the literature, we specify the investor's stochastic discount factor as[10]

$$\Lambda_{t+1} = \beta \left(\frac{z_{at+1}}{z_{at}} \right)^{-\gamma}, \tag{29}$$

where β is the subjective discount rate, γ is the risk-aversion coefficient, and z_{at} denotes the aggregate productivity level at time t.

This discount factor implies that the investors have a higher valuation of firms that pay out dividends (repay debt) in an economic downturn. To capture the aggregate business-cycle fluctuations in the data, following Warusawitharana and Whited (2016), we specify 2 aggregate states, an expansionary state $z_{aH} = 1.01$ and a recessionary state $z_{aL} = 0.97$, with transition matrix

$$\Gamma = \begin{bmatrix} 0.71 & 0.29 \\ 0.75 & 0.25 \end{bmatrix}.$$

We set the investor's risk-aversion coefficient $\gamma = 2$. We also assume that the aggregate productivity shock z_{at} is independent of the firm-level productivity shock z_t specified in Section III.B. Thus, the firm's total productivity can be written as $\widehat{z_t} = z_{at} z_t$.

Table 7 reports the estimation results when the stochastic discount factor is included. Compared with the results in Table 2, the predicted cash-to-assets ratio in Table 7 becomes lower, whereas the ratio of unused credit lines to assets is higher. This is because under the setting of the stochastic discount factor, firms are more risk averse toward borrowing, and hence they borrow less and hold more unused lines of credit. Further, because the firm borrows less, the cash savings from borrowing become less too. This explains why the cash-to-assets ratio decreases.

Table 8 reports the results of the counterfactual exercise of examining the role of shocks. The first column summarizes the moments simulated by the model using the estimated parameters in Table 7. The second and third columns show that conditional on the stochastic discount factor, financing risk, rather than productivity shock, is the driving force for the firm's liquidity holdings. The fourth column shows that without the stochastic discount factor, cash increases, whereas unused lines of credit decrease. This is consistent with the earlier observations that higher risk aversion increases unused lines of credit but reduces precautionary cash.

To sum up, the two takeaway results are as follows: i) A higher degree of shareholder risk aversion implies a relatively stronger later-borrowing motive

TABLE 7

Estimation with Stochastic Discount Factor

Table 7 reports the estimation results when the stochastic discount factor is included. Panel A reports the target moments, and Panel B lists point estimates and standard errors (SE) (in parentheses).

Panel A. Target Moments	Observed	Simulated
Mean of cash/assets	0.189	0.129
Mean of unused line/assets	0.100	0.072
Mean of debt/assets	0.162	0.143
Mean of investment/assets	0.050	0.047
Mean of payout/assets	0.029	0.029
Mean of cash flow/assets	0.098	0.076
Std. dev. of cash/assets	0.116	0.070
Std. dev. of unused line/assets	0.055	0.130
Std. dev. of debt/assets	0.082	0.121
Std. dev. of payout/assets	0.027	0.019
Std. dev. of cash flow/assets	0.070	0.022
Autocorrelation of cash/assets	0.188	0.463
Autocorrelation of investment/assets	0.205	0.229
Autocorrelation of cash flow/assets	0.297	0.230
Panel B. Estimated Parameters	Estimates	SE
Drift of productivity shock, μ_z	0.021	(0.004)
Persistence of productivity shock, ρ_z	0.399	(0.050)
Volatility of productivity shock, σ_z	0.342	(0.041)
Persistence of credit shock, ρ_η	0.302	(0.012)
Volatility of credit shock, σ_η	0.477	(0.016)
Capital depreciation rate, δ	0.061	(0.008)
Collateral rate, ξ	0.389	(0.046)
Equity-rigidity parameter, κ	0.742	(0.101)
Capital adjustment cost, ζ	0.801	(0.049)
Price of cash, p^m	0.977	(0.042)

TABLE 8

The Role of Shocks with Stochastic Discount Factor

The first column of Table 8 summarizes the benchmark moments simulated by the model using the estimated parameters in Table 7. The second column reports the moments simulated by the model with the financing shock and the stochastic discount factor. The third column reports the moments simulated by the model with the productivity shock and the stochastic discount factor, and the fourth column reports the moments simulated by the model with both the financing shock and the productivity shock but without the stochastic discount factor.

	With All Shocks	Financing Shock	Productivity Shock	Without Discount Factor
Mean of precautionary cash/assets	0.053	0.040	0.009	0.059
Mean of unused line/assets	0.072	0.069	0.024	0.041
Mean of debt/assets	0.143	0.146	0.232	0.187
Mean of investment/assets	0.047	0.047	0.049	0.045
Mean of payout/assets	0.029	0.030	0.026	0.029
Mean of cash flow/assets	0.076	0.077	0.079	0.076
Std. dev. of cash/assets	0.070	0.050	0.025	0.055
Std. dev. of debt/assets	0.121	0.122	0.050	0.089
Std. dev. of payout/assets	0.019	0.012	0.011	0.015
Std. dev. of cash flow/assets	0.022	0.004	0.023	0.022
Std. dev. of unused line/assets	0.130	0.123	0.034	0.085
Autocorrelation of cash/assets	0.463	0.536	0.542	0.428
Autocorrelation of investment/assets	0.229	0.240	0.757	0.135
Autocorrelation of cash flow/assets	0.230	0.533	0.216	0.263

of holding unused lines of credit but a relatively weaker pre-borrowing motive of saving precautionary cash, and ii) conditional on the stochastic discount factor, financing risk is still the primary determinant for firms to hold liquidity.

B. Adding Investment Shock

In the benchmark estimation (Table 2), we compare financing shock with productivity shock and find that financing shock, rather than productivity shock, is the key to understanding firms' liquidity holdings. In this section, for the robustness check, we consider another type of shock, investment shock, which is denoted by χ_t in the investment equation:

$$k_{t+1} - (1-\delta)k_t = \chi_t \phi\left(\frac{i_t}{k_t}\right)k_t. \tag{30}$$

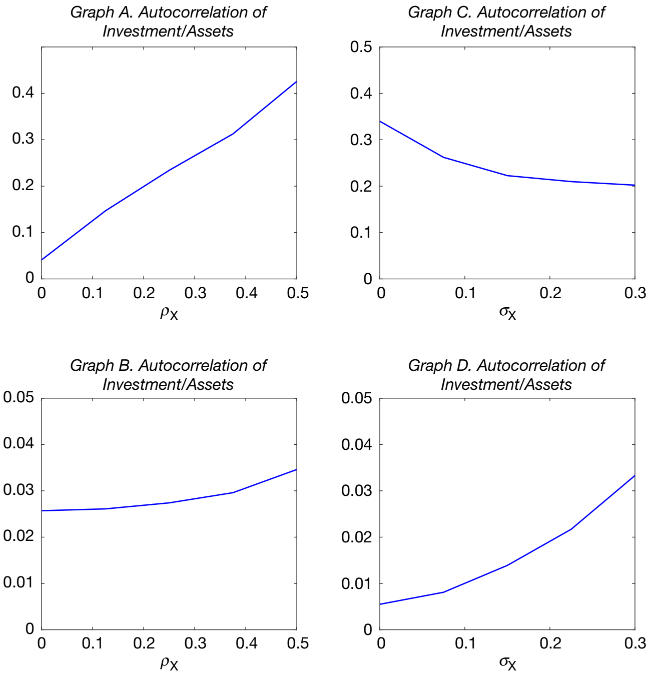
Whereas the productivity shock affects the firm's incentive to invest through the marginal productivity of capital, the investment shock directly affects the efficiency of investment. A higher χ_t means a higher efficiency of transforming final goods to capital goods, and hence the firm would invest more to accumulate capital. The investment shock is identified by the persistence and the standard deviation of the investment-to-assets ratio. See Figure 10 for a graphic illustration.

Table 9 reports the estimation results with 3 shocks. Panel A shows the targeted moments, and Panel B shows the estimated parameters. Compared with the benchmark estimation in Section V.D, the current estimation with 3 shocks fits the data better. With the addition of investment shock, the model is able to match the standard deviation of investment. As for the estimated parameters, the

FIGURE 10

The Key Identification of Investment Shock χ

Figure 10 shows the sensitivity of investment moments to the investment shock. Graphs A and B show the sensitivity with respect to the persistence of investment shock ρ_χ, and Graphs C and D show the sensitivity with respect to the standard deviation of investment shock σ_χ.



persistence of investment shock is 0.201, and the volatility of investment shock is 0.242.

We are particularly interested in the exercise of risk decomposition with 3 shocks, which can tell us the relative importance of each shock in explaining firms' liquidity holdings. Table 10 shows the results. The first column reports the moments simulated by the model with 3 shocks. The second through fourth columns report the results with only financing shock, productivity shock, and investment shock, respectively. As can be seen from the table, the financing shock is the most important shock to explain the firm's liquidity holdings (both cash and unused lines of credit). It can be calculated that financing shock can explain approximately $(0.054/0.189) = 24\%$ of the cash holdings observed in the data, whereas productivity shock and investment shock explain 5% and 2%, respectively.

TABLE 9

Estimation with 3 Shocks

Table 9 reports the estimation results with 3 shocks. Panel A reports the target moments, and Panel B lists the point estimates and standard errors (SE) (in parentheses).

	Data	Model
Panel A. Target Moments		
Mean of cash/assets	0.189	0.163
Mean of unused line/assets	0.100	0.038
Mean of debt/assets	0.162	0.174
Mean of investment/assets	0.050	0.060
Mean of payout/assets	0.029	0.038
Mean of cash flow/assets	0.098	0.094
Std. dev. of cash/assets	0.116	0.048
Std. dev. of unused line/assets	0.055	0.071
Std. dev. of debt/assets	0.082	0.096
Std. dev. of investment/assets	0.025	0.026
Std. dev. of payout/assets	0.027	0.024
Std. dev. of cash flow/assets	0.070	0.042
Autocorrelation of cash/assets	0.188	0.190
Autocorrelation of investment/assets	0.205	0.199
Autocorrelation of cash flow/assets	0.297	0.290
Panel B. Estimated Parameters	Estimates	SE
Drift of productivity shock, μ_z	0.055	(0.092)
Persistence of productivity shock, ρ_z	0.454	(0.152)
Volatility of productivity shock, σ_z	0.538	(0.142)
Persistence of credit shock, ρ_η	0.280	(0.578)
Volatility of credit shock, σ_η	0.595	(0.143)
Persistence of investment shock, ρ_χ	0.201	(0.196)
Volatility of investment shock, σ_χ	0.242	(0.096)
Capital depreciation rate, δ	0.092	(0.031)
Collateral rate, ξ	0.379	(0.120)
Equity-rigidity parameter, κ	0.363	(0.204)
Capital adjustment cost, ζ	0.552	(0.547)
Price of cash, p^m	0.975	(0.034)

TABLE 10

The Role of Shocks (with 3 shocks)

Table 10 reports the results of risk decomposition with 3 shocks. The first column summarizes the moments simulated by the model using the estimated parameters in Table 9. The second column reports the moments simulated by the model with only the financing shock. The third column reports the moments simulated by the model with only the productivity shock, and the fourth column reports the moments simulated by the model with only the investment shock.

	With All Shocks	Financing Shock	Productivity Shock	Investment Shock
Mean of precautionary cash/assets	0.069	0.045	0.009	0.003
Mean of unused line/assets	0.038	0.021	0.016	0.007
Mean of debt/assets	0.174	0.204	0.227	0.248
Mean of investment/assets	0.060	0.051	0.051	0.072
Mean of payout/assets	0.038	0.042	0.040	0.023
Mean of cash flow/assets	0.094	0.095	0.100	0.100
Std. dev. of cash/assets	0.048	0.033	0.037	0.004
Std. dev. of unused line/assets	0.071	0.043	0.024	0.010
Std. dev. of debt/assets	0.096	0.077	0.037	0.020
Std. dev. of investment/assets	0.026	0.003	0.003	0.031
Std. dev. of payout/assets	0.024	0.026	0.024	0.015
Std. dev. of cash flow/assets	0.042	0.003	0.044	0.001
Autocorrelation of cash/assets	0.190	0.057	0.232	−0.069
Autocorrelation of investment/assets	0.199	−0.143	0.115	0.205
Autocorrelation of cash flow/assets	0.290	0.187	0.247	0.078

VIII. Conclusion

In this article, we quantify a new motive of holding cash through the channel of financing risk. We show that if the access to future credit is risky, firms want to issue long-term debt right now and save the funds in cash, and they do so in order to secure the current credit capacity for the future. The main results are as follows: i) The liquidity premium of holding cash is approximately 40 bps; ii) the value of holding cash is approximately 8% of shareholder value; iii) financing risk, instead of productivity risk or investment risk, is the driving force for firms to hold liquidity; and iv) increases in credit uncertainty induce firms to draw down credit lines and hold the proceeds in cash.

An implication of the model is that firms manage liquidity jointly with capital structure decisions: On the one hand, to maintain the option to borrow in the future, firms borrow less in the current period and hold unused credit lines. On the other hand, to hedge the risk of losing the option to borrow, firms increase leverage today and save cash for future needs.

Supplementary Material

To view supplementary material for this article, please visit http://dx.doi.org/10.1017/S002210902000099X.

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