The Interest Sensitivity of Corporate Cash

Xiaodan Gao Toni M. Whited Na Zhang*

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Abstract

We document a hump-shaped relationship between interest rates and corporate cash demand that contradicts conventional wisdom, and we develop a theoretical framework to rationalize this finding. The model features external-financing costs that are endogenously determined by interest rates. Interest rates affect corporate cash demand through two channels. First, forgone interest earnings imply an intuitive negative relation. Second, saved external borrowing costs imply a positive relation. The calibrated model quantitatively matches data features and reproduces the hump-shaped cash-interest relationship. This nonmonotonic corporate money demand schedule has important implications for monetary policy.

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*Zhang is sponsored by the Shanghai Pujiang Program. Gao is from the National University of Singapore; gao.xiaodan@nus.edu.sg. Whited is from the University of Michigan and NBER; twhited@umich.edu. Zhang is from Fudan University; nazhang@fudan.edu.cn.
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1. Introduction

Nonfinancial corporations in the United States hold more than 20% of the aggregate money stock ($M1$), and they account for approximately 50% of annual output. As such, the effectiveness of monetary policy and the relation between interest rates and money depends crucially on this source of money demand. Of particular interest is the sensitivity of the demand for corporate cash at low interest rates, as this sensitivity has important implications for the welfare cost of inflation and the design of optimal monetary policy (Lucas 2000; Ireland 2009; Rognlie 2015). Most studies of money demand have focused on household behavior (Mulligan and Sala-i-Martin 2000; Attanasio et al. 2002; Alvarez and Lippi 2009). Given that corporations hold a substantial fraction of the U.S. money stock, examining the interest sensitivity of corporate money demand has important policy implications.

We start by documenting a hump-shaped relationship between corporate cash demand and interest rates in both aggregate and firm-level data. On average, corporate cash demand rises with interest rates before reaching a peak at an interest rate of 6-7%, after which demand then declines. Our finding is robust to the use of different samples and various measures of interest rates. This evidence of a nonmonotonic relation contradicts the traditional view of an inverse relation between interest rates and money demand (Baumol 1952; Tobin 1956; Meltzer 1963). As such, our finding also naturally raises the question of how and why interest rates affect corporate cash demand.

To answer this question and rationalize the stylized fact of the hump-shaped relation between corporate cash and interest rates, we build a parsimonious model featuring endogenous debt financing costs that are determined by risk-free interest rates and default risk. In the model, firms combine labor and capital to produce output, they pay fixed operating costs in advance of production, and they face productivity shocks and financial frictions. To finance operating expenses and capital investments, firms can use internal cash or external funds, which can take the form of risky debt and equity issuance. Optimal financing decisions trade off an interest tax shield for debt, deadweight costs of default, and costs of issuing equity.

These imperfections in the capital markets generate two motives for holding cash. The first is the transaction/precautionary motive; that is, firms demand cash to avoid using costly external finance to fund their real operations. The second is what we call the balance-sheet dressing motive; that is, firms hold cash to shore up their net worth and thus obtain favorable rates on loans from external lenders.

In the model, these two motives interact with interest rates to affect corporate cash demand through three channels. The first is the traditional and intuitive cost channel whereby high interest rates raise the value of forgone interest earnings. Thus, instead of holding cash, firms can reallocate funds held as cash balances to other uses.

The second channel is more important, and it pertains *both* to cash balances held without interest and those held as risk-free assets. This channel works through the benefit of holding cash, which stems from its role of providing a cushion against the possibility of the firm having to fund either current or future outlays with costly external debt or equity. We show that at low interest rates, a rise in interest rates leads to a drop in firm value. The presence of fixed operating costs then translates this value loss into an increase in default risk, which, in turn, makes cost of debt rise above the risk-free interest rate. In response, firms demand more cash to facilitate operations and smooth capital investment in the face of higher external-financing costs.

A third channel reinforces the cost channel at high interest rates. If interest rates rise sufficiently, the combination of high financing costs and fixed operating costs exerts a strong negative income effect on firm asset accumulation, regardless whether the asset is cash or capital. Specifically, high financing costs cut resources available for capital investment. The ensuing reduction in investment spending implies a reduction in the need for a financial cushion to smooth this spending. We find strong support for this mechanism when we test it using a sample of Compustat industrial firms.

The net effect of interest rates on corporate cash demand then depends on which channels are most important. We find that the hump shaped relation between cash an interest rates arises because the second benefit channel dominates at low interest rates, while the combination of the first and third channels dominates at high interest rates.

We calibrate the model carefully and show that it quantitatively matches important features of our firm-level data in the period 1970-2013. Moreover, the model successfully reproduces a hump-shaped relationship between corporate money demand and interest rates, with the turning point at an interest rate of 6-7%.

Finally, we use our findings to revisit several important questions concerning money demand: the welfare cost of inflation, the transmission channels of monetary policy, and the U.S. corporate cash puzzle. First, the hump-shaped relationship implies a satiation level of corporate money demand in the neighborhood of a zero interest rate, which in turn suggests a moderate welfare cost of the Federal Reserve's low inflation policy. Second, the existence of corporate cash reserves results in the insensitivity of capital investment to interest-rate changes at low interest rates, thus dampening the effectiveness of monetary policy to boost the real economy by increasing lending and raising investment. Third, the hump-shaped relationship challenges the role of interest rates in resolving the corporate cash puzzle. During the 1990s and 2000s, when interest rates were relatively low, a decline in interest rates is expected to be associated with a decline in cash demand.

In this paper, we consider the opportunity-cost channel of interest rates, but we abstract from the allocation choice between cash and short-term marketable securities. We view this simplification as innocuous for several reasons. For example, under the business sweep programs started during the 1960s and 1970s and retail sweep programs that followed, the cost of holding cash relative to short-term marketable securities became small, as firms earn interest overnight on the cash sitting idle in their checking accounts. Moreover, the ratio of short-term marketable securities to assets has stayed constant at approximately 5% since the late 1980s, regardless of interest-rate movements over time. Finally, we extend the model and demonstrate that our main qualitative insights are robust to allowing cash balances to earn interest.

Our paper contributes to the literature in several ways. First, it focuses on corporate money demand. Meltzer (1963) highlights the importance of interest rates in determining firms' cash balances, and acknowledges the complexity of the problem. Mulligan (1997) and Bover and Watson (2005) empirically estimate the interest elasticity of firms' money demand using U.S. Compustat data from 1961-1992 and 1978-1992, respectively, and both find an inverse relationship. In this paper, we extend the sample to the more recent episode that features low interest rates, and we offer a more complete picture of the corporate money demand schedule. Our paper is also related to Stone et al. (2016) and Azar et al. (2016). Stone et al. (2016) uncover a positive relationship between interest rates and firms' cash balances using U.S. Compustat data from 1970-2014. They examine several possible explanations, but find that none explains the observed pattern. Azar et al. (2016) focus on more widely defined money (i.e., cash and short-term interest-bearing assets) held by firms and emphasize the costs of holding money in response to changes in interest rates.

Second, this paper provides insights into the welfare cost of inflation. Lucas (2000) and Ireland (2009) suggest two different money demand specifications. Their conflicting findings center on money demand behavior at low interest rates, which has significantly different implications for the welfare cost of a low but positive inflation. Our finding of a hump-shaped money demand function supports the existence of a satiation level of money demand under the Friedman rule, and suggests a modest welfare cost of the Fed's low-inflation policy.

Lastly, this paper helps to understand firms' cash policies. There is a growing literature on this topic. Several main holding motives have been identified and modeled, including the transaction motive (Baumol 1952), precautionary motive (Riddick and Whited 2009), tax motive (Armenter and Hnatkovska 2016), and agency motive (Nikolov and Whited 2014). Our paper complements this previous work by introducing the balance-sheet dressing motive for accumulating cash. Keeping cash on hand makes firms look stronger to external lenders and lowers interest rates on loans. This motive is widely recognized in practice but absent from the academic literature (Lins et al. 2010). In this paper, we capture this idea by allowing firms to pledge cash as collateral and endogenizing debt-financing costs.

The paper is organized as follows. Section 2 presents stylized facts on the hump-shaped relationship between interest rates and corporate cash holdings. Section 3 lays out the model to rationalize the empirical observation and characterizes optimal cash policies. Section 4 performs quantitative analyses, demonstrates the model's ability to deliver the hump-shaped cash-interest relationship. Section 5 discusses the implications for monetary policy. Section 6 concludes.

2. Corporate Cash and Interest Rates

In this section, we examine the empirical relationship between interest rates and corporate cash demand at both the aggregate level and disaggregated firm level. Our empirical money demand specification is based on (Ireland 2009), who finds a negative semi-elasticity in pre-crisis data. We deviate slightly from this traditional specification and estimate real money demand as a function of interest rates, real GDP and GDP growth. The last factor is included to control for economic fluctuations over the business cycle.

2.1 Aggregate Time-Series Evidence

For our analysis of aggregate data, we use the following regression model to investigate the corporate cash-interest rate relation at the aggregate level,

$$\text{cash}_t = \alpha_0 + \alpha_1 \,\text{interest}_t + \alpha_2 \,\text{interest}_t^2 + \alpha_3 \,\text{GDP}_t + \alpha_4 \,\text{GDP growth}_t + \epsilon_t, \tag{1}$$

where the subscript t refers to time. The dependent variable is the logarithm of the aggregate cash stock held by nonfinancial corporate business in the United States deflated by the GDP deflator. The independent variables include an interest rate, its square, the logarithm of real GDP, and the growth rate of real GDP. Data are collected from databases maintained by the Federal Reserve System, Bureau of Labor Statistics, and Bureau of Economic Analysis. We use quarterly data for estimation, with the sample covering the period from 1947Q2 to 2013Q2.

We present descriptive statistics in Table 1. Over the time period, the average log real corporate cash balance is 7.52, while log real GDP is 8.93. Cash is less volatile than real GDP. The average annualized three-month T-bill rate is 4.3%, with the lowest being 0.01% and the highest being greater than 15%. We also consider other measures of interest rates: one-year, five-year, and ten-year treasury constant maturity rates, as well as the federal funds effective rate.[1] The average one-year treasury constant maturity rate and federal funds effective rate are 5.2%.

Estimation results of the regression model (1) are reported in Table 2. In Column (1), we find a statistically significant hump-shaped relationship between corporate cash holdings and interest rates, with the turning point at an interest rate of 5.8%. This finding stands in contrast to the traditional view in monetary economics of an inverse relationship between interest rates and cash demand. Column (2) presents a specification of (1) in which we exclude real GDP growth and thus follow a more traditional money demand equation. Column (3) includes a time-trend term that allows cash demand to have a different trend from real GDP. Both modifications barely affect the hump-shaped cash-interest relation.

As a robustness check, we estimate the regression model (1) using alternative measures of interest rates and report the results in Table 3. Estimates confirm the findings in Table 2, although the implied cut-off point changes slightly and moves within the range [5.9%,

[1] Following Nagel (2016), we also use federal funds rates as an interest-rate measure, because the T-bill rate is an imperfect although good proxy for cash-holding costs.

6.8%], as shown in Figure 1. Finally, the sign of the coefficient on real GDP is broadly consistent with previous studies: the income elasticity is positive and moves within the range [0.144,0.249].

To further examine the effects of interest rates on corporate cash demand, we turn to a vector autoregression (VAR) model. We consider a specification that follows the ordering of GDP, interest rates and corporate cash holdings by including the change in log real GDP, interest rates, log real corporate cash balances, and a constant term in the analysis. We use the first difference of log real GDP to ensure stationarity of the VAR. We consider this ordering to account for the possibility that the joint dynamics of interest rates and corporate cash demand are driven by those changes in GDP that are not caused by monetary policy shocks. We use the Akaike Information Criterion (AIC) to select lag length. With the resulting specification, we then use the estimated VAR to examine the effect of the orthogonalized innovation in interest rates on corporate cash demand.

Given the result in Tables 2 and 3 that cash and interest rates have a hump-shaped relationship with a turning point approximately at the three-month T-bill rate of 6%, we divide our sample into two groups: the pre-1990 period (1951Q4-1990Q4) and the post-1990 period (1991Q1-2013Q2). We select the year 1990 because the three-month T-bill rates have been lower than 6% since then. In general, we can view pre-1990 as a high interest rate period and post-1990 as a low interest rate period.

Figure 2 plots the cumulative impulse responses of aggregate corporate cash holdings to interest rate shocks with a 95% confidence interval. Interest rate shocks are identified as innovations to the interest rate rule estimated from the VAR. The left panels show the reaction of corporate cash during the high interest rate period, and the right panels show its reaction during the low interest rate period. The results of VAR are in line with our finding of a hump-shaped corporate cash-interest rate relationship. In response to a positive interest rate shock (i.e., an interest rate hike), we find a significant decrease in cash holdings over time for the pre-1990 period and a significant increase in cash holdings within the first two years for the post-1990 period.[2]

2.2 Firm-level Evidence

In this subsection, we use firm-level data constructed from Compustat to provide additional evidence regarding the relationship between corporate cash and interest rates. The sample covers annual observations from 1970 to 2013 for nonfinancial nonutility U.S. public firms. Our basic regression specification is:

$$\begin{aligned} \text{cash}_{i,t} = \alpha_0 + \alpha_1 \text{interest}_t + \alpha_2 \text{interest}_t^2 + \alpha_3 \text{GDP}_t + \alpha_4 \text{GDP growth}_t + \alpha_5 \text{cash}_{i,t-1} \\ + \alpha_6\, t + \alpha_7\, t^2 + \alpha_8\, t^3 + year_{1987} + year_{1988} + \epsilon_{i,t}, \end{aligned} \tag{2}$$

where subscript i refers to a firm. The dependent variable is the logarithm of firm i's cash balance (item *ch* in Compustat) scaled by the GDP deflator for period t. We impose outlier rules on this variable by winsorizing it at the 1^{st} and 99^{th} percentiles. To control for the observed trend and possible changes in cash demand caused by factors other than interest rates and GDP, we include lagged cash holdings and a cubic time trend. This specification is motivated by the evidence in Bates et al. (2009), which documents a secular increase in firms' cash holdings. We also include dummy variables for 1987 and 1988 to control for the substantial change in cash during that period due to the adoption of SFAS 95.

Table 4 summarizes the estimation results for the regression model (2). Column (1) reports results from the regression in which we use three-month T-bill rates. These findings confirm those from our aggregate data. On average, there is a hump-shaped relation between cash and interest rates, with the turning point at an interest rate of 7.6%. Columns (2)-(5) present results for different measures of interest rates. A hump-shaped pattern is found in all cases, with the turning point varying between 7.8% and 9.2%. We plot the

[2] Patterns barely change when we include the price index in the VAR by considering a specification in which policy interest rates react to changes in the price level and real GDP. Results are available on request.

estimated nonlinear relation between cash and interests in Figure 3.

Next, we perform two robustness exercises. For our first, we use an alternative approach to control for the effect of the adoption of SFAS 95 on firms' cash holdings. In particular, we allow for a different interest-cash relationship during the transition period by adding a dummy that is one in 1986, 1987 and 1988 and zero otherwise, as well as its interaction with the interest rate and interest rate squared. Second, we use the double-difference method proposed by Han and Phillips (2010) to eliminate firm fixed effects. The results from these two exercises are reported in Tables 5 and 6, respectively. The estimates in Table 5 are quantitatively similar to those in the baseline model, while the double-difference estimates give a smaller turning point of 6.3%-8.2%. Although the statistical significance of some of the specifications falls, the overall picture is still of a significant, hump-shaped relationship.

We further allow the cash-interest relation to vary over time by including the interaction terms between three decade dummies and interest rates. We show these results in Table 7 and plot them in Figure 4. We find that corporate cash and interest rates exhibit a hump-shaped relationship in the 1970s and the 1990s, a U-shaped relationship in the 2000s, and an inverse relationship in the 1980s.

Although at first glance the cash-interest relationship appears to have different patterns during different time periods, taken as a whole, these patterns are consistent with the results obtained in Tables 2-6. The sensitivity of cash to interest rates varies over time because the *level* of interest rates is different during these various time periods. Thus, putting these separate intervals together produces a more complete picture of the cash-interest relation over a consecutive range of interest rates. As shown in Figure 4, when interest rates are low, cash demand initially drops slightly and then moves up. When interest rates take a middle range values, cash demand continues to increase and then starts to decline. When interest rates are high, cash demand falls with interest rates. These pieces together represent a hump-shaped relationship, which is largely consistent with the relationship shown in Figures 1 and 3.

2.3 Discussion

In summary, our aggregate-level and firm-level analyses show that corporate cash balances do not monotonically decrease with interest rates, as traditional theories predict. Instead, their relationship on average follows a hump-shaped pattern.

Our finding is broadly in line with previous studies. Mulligan (1997) uses U.S. Compustat data from 1961-1992 to examine the interest sensitivity of corporate cash demand and finds an inverse relationship.[3] During that period, nominal interest rates varied within the ranges of [2.4%, 14%]. Of those interest-rate observations, two thirds lie above the turning point, that is, in the negative-relationship region. A downward-sloping curve, therefore, can describe the cash-interest relationship during that sample period reasonably well. We derive the hump-shaped relationship because of the inclusion of more recent data, which feature a long period of relatively low interest rates. The interest sensitivity of corporate cash demand during the more recent episode is better described by a positive-sloping curve, which is also found in a contemporaneous paper by Stone et al. (2016).

We next present a parsimonious model featuring financial frictions and fixed operating costs to rationalize the stylized fact documented in this section.

3. Model

We examine a firm's problem in a partial equilibrium setting to analyze its cash-holding decision with respect to interest rates. In the model, the firm faces frictions in capital markets and uncertainty from demand and productivity. At each period, after observing the shock, the firm makes decisions about capital investment, debt borrowing, cash holdings, and dividend payment/equity issuance.

[3] See also Bover and Watson (2005) who use the sample period 1978-1992 to explore the cash-interest relationship.

We first specify the firm's production technology, capital accumulation process, and financing options, then present the firm's problem.

3.1 Technology

The firm combines labor, l, and capital, k, to produce output and faces and idiosyncratic productivity shock, z. Its production function is given by:

$$y = z^{\nu}(l^{1-\alpha}k^{\alpha})^{\theta}. \tag{1}$$

The parameter $\alpha \in (0,1)$ represents the capital share, and $\theta \in (0,1)$ captures a decreasing returns-to-scale technology. The parameter ν is normalized to be $1-(1-\alpha)\theta$, so the firm's profit function $\pi(z,k)$ is linear in the shock after optimizing over labor, which is a variable factor. The shock, z, follows an $AR(1)$ in logs:

$$\ln z' = \rho \ln z + \varepsilon_z', \qquad \varepsilon_z \sim N(0, \sigma_z^2), \tag{2}$$

where a prime denotes a variable in the subsequent period. The parameter ρ governs the persistence of z, and the innovation to z (ε_z) is normally distributed with variance σ_z^2.

3.2 Capital Investment

The firm augments its capital stock by capital investment, I, given by:

$$I = k' - (1-\delta)k.$$

The parameter $\delta \in (0,1)$ is the capital depreciation rate. The purchase or sale of capital incurs adjustment costs, which are defined by:

$$A(k, I) = \gamma_0 k \mathbf{1}_{I \neq 0} + \frac{\gamma_1}{2}\left(\frac{I}{k}\right)^2 k + (1-\gamma_2)|I|\mathbf{1}_{I<0}.$$

This specification includes nonconvex adjustment costs, $\gamma_0 > 0$, convex adjustment costs, $\gamma_1 > 0$, and partial irreversibility of capital, $\gamma_2 \in (0, 1)$.

3.3 Financing

The firm has four sources of funds to finance its expenditures: current-period cash inflows from sales, internal cash balances, risky debt, and equity issuance.

Cash balances, c, earn no interest. The cost of holding cash, therefore, is the interest rate, i.[4] The firm has access to credit markets. It can raise funds with risky debt, b, which it can repay in the subsequent period when the debt matures. The price of debt, q, depends on the uncertainty facing the firm and the firm's current-period decisions, namely, debt, cash holdings, and the capital stock.

In addition to debt financing, the firm can issue equity. Following Hennessy and Whited (2007), we denote $d \leq 0$ as equity issuance and $d > 0$ as a dividend payment, and we assume that issuing equity incurs both fixed costs, $\lambda_0 > 0$, and linear costs, $\lambda_1 > 0$.

3.4 The Firm's Problem

3.4.1. Timing

At the beginning of the current period, after observing the shock realization, z, the firm decides whether to default on its existing debt obligations b. Default leads to the liquidation of the firm's assets. The firm's internal resources are then distributed to creditors and the remaining unpaid debt is discharged. If the firm decides to continue, it pays off debt, pays fixed operating costs, c_f, prior to production, and produces output. Upon receiving the current-period revenue, the firm makes its capital investment and financial decisions. Fixed operating costs prior to production are included to augment the transactions demand for cash.

[4]Because firms earn interest on their cash balances under business sweep programs, we will relax this restriction in Section 4.5.2 to check the robustness of the model's main result.

3.4.2. Set-up

The firm is risk neutral. Its objective is to maximize its value, which is discounted at the risk-free interest rate. Each period, after observing the shock realization, and given the debt price schedule, the firm decides whether to default. If the firm is economically or financially distressed, that is, either the firm value drops below zero or there is no way to roll over the maturing debt, the firm defaults. We let firm value in the case of default equal zero, and the firm's problem is:

$$V(z,k,c,b) = \max\{0, V^c(z,k,c,b)\},$$

where $V^c(z,k,c,b)$ denotes the continuation value.

If the firm decides to continue to operate, its problem can be viewed in two stages: the pre-production stage and the post-production stage. In the pre-production stage, the firm repays debt and pays fixed operating costs in advance of production. It can issue new debt and roll over existing debt. If funds remain insufficient to cover expenses, the firm can issue equity. Unused funds at this stage will be carried forward to the post-production stage. In the post-production stage, the firm produces output and makes capital investment and financial decisions. If current-period revenue is insufficient to meet investment expenditures, the firm issues equity; otherwise, the firm distributes dividends. The firm's optimization problem can be summarized by:

$$V^c(z,k,c,b) = \max_{I,b',c'} \Big\{ \phi_{d_1}[d_1 + \phi_{d_1}(-\lambda_0 + \lambda_1 d_1)] + [d_2 + \phi_{d_2}(-\lambda_0 + \lambda_1 d_2)] + \frac{1}{1+i}\mathbb{E}V(z',k',c',b') \Big\}$$

subject to budget constraints:

$$d_1 = c + qb' - b - c_f,$$

$$d_2 = \pi(z,k) + (1-\phi_{d_1})d_1 - I - A(k,I) - c',$$

$$b' \geq 0,$$

$$c' \geq 0,$$

$$\phi_{d_j} = \begin{cases} 1 & \text{if } d_j \leq 0 \\ 0 & \text{otherwise,} \end{cases}$$

at all dates. Here, d_j represents the net equity flow in stage $j \in \{1, 2\}$ at the current period, ϕ_{d_j} is an indicator function, and q is the debt price, which we discuss below.

3.4.3. Debt Pricing

Finally, we consider the debt pricing schedule required to solve the firm's problem. We assume that the firm borrows from a competitive, risk-neutral lender. The lender provides a state-contingent contract that compensates for the loss that occurs with default.

More specifically, the firm completely pays off the debt b' if it continues to operate in the subsequent period, but it pays the lender $c' + \chi(1-\delta)k'$ in case of default. The parameter $\chi \in (0, 1)$ is the recovery rate and governs the magnitude of bankruptcy costs. A zero profit condition, therefore, implies the following pricing expression:

$$qb' = \left(\frac{1}{1+i}\right) \mathbb{E}\{\mathbf{1}_{V'>0} b' + \mathbf{1}_{V' \leq 0}[c' + \chi(1-\delta)k']\}, \tag{3}$$

where $\mathbf{1}_{V'>0}$ is an indicator function that equals one if equity value is positive and zero otherwise. Equation (3) can be rewritten as:

$$q = \left(\frac{1}{1+i}\right) \mathbb{E}\left\{\mathbf{1}_{V'>0} + \mathbf{1}_{V' \leq 0}\left[\frac{c' + \chi(1-\delta)k'}{b'}\right]\right\}.$$

Note that we abstract from strategic default in the model. That is, the firm defaults only if it has negative firm value, or, more importantly, it fails to roll over maturing debt.

3.5 Interest Rates and Cash Holdings

In this subsection, we characterize the firm's optimal cash policy and develop the intuition behind the equation that links cash holdings with interest rates.

Solving the firm's problem, we derive the condition for optimal cash holdings as follows:

$$1 + \phi_{d_2}\lambda_1 = \frac{1}{1+i}\mathbb{E}\{\mathbf{1}_{V'>0}\Lambda'\} + \Lambda q_{c'} b' + \mu, \tag{2}$$

where $\Lambda = \phi_{d_1}(1 + \phi_{d_1}\lambda_1) + (1 - \phi_{d_1})(1 + \phi_{d_2}\lambda_1)$, and $q_{c'}$ is the first derivative of the bond price with respect to cash balances.

The left side of equation (2) gives the marginal cost of carrying one additional dollar of cash into the subsequent period. If dividends are positive, this cost is the cost of forgone dividends. If dividends are negative, that is, if the firm issues equity, this cost is given by the linear and fixed costs of equity issuance.

The right side represents the marginal benefit and has three components. The first is embodied in the term, $\frac{1}{1+i}\mathbb{E}[\mathbf{1}_{V'>0}\Lambda']$, which represents the expected present value of an additional dollar of cash. In turn, this extra dollar serves to lower the probability of default and thus relax financial constraints in the future. In other words, firms hold cash to avoid external financing costs in those states in which they experience liquidity shortages and therefore need to issue equity. This motive for accumulating cash echoes the precautionary motives in dynamic models such as the one in (Riddick and Whited 2009).

The second component on the right side of equation (2), $\frac{1}{1+i}\mathbb{E}[\mathbf{1}_{V'>0}\Lambda']$, reflects the beneficial effect of increased internal liquidity on cost of debt, $q_{c'}$. Naturally, optimal borrowing, $q_{c'}b'$, is higher and can be used to avoid expensive equity issuance in the current period. This extra motive for holding cash is missing in previous cash studies, yet it is consistent with managers' stated policies. According to Lins et al. (2010), CFOs indeed view the "ability to issue debt at a 'fair' price when funds are needed" as one of the key factors that drive their cash decisions. The last component is embodied in the Lagrange multiplier on the nonnegativity constraint on cash holdings, μ.

Multiplying both sides of equation (2) by the gross interest rate $1+i$, we can rewrite the optimal condition in a form that is easier to interpret. In the case of an interior solution with positive cash balances (i.e., $\mu = 0$), equation (2) becomes:

$$(1+i)(1+\phi_{d_2}\lambda_1) = \mathbb{E}[\mathbf{1}_{V'>0}\Lambda'] + \Lambda \frac{\partial \mathbb{E}\{\mathbf{1}_{V'>0} + \mathbf{1}_{V'\leq 0}\frac{c'+\chi(1-\delta)k'}{b'}\}}{\partial c'} b'. \tag{3}$$

Here, we see that interest rates affect firms' cash holdings in a nontrivial way. Conventional wisdom highlights the interest rate as a cost of holding cash, which is captured by the left side of equation (3) and implies a negative relationship. That is, as the interest rate increases, forgone interest earnings rise and therefore firms have weaker incentives to accumulate cash.

Nevertheless, the terms on the right side of equation (3) suggest that interest rates also have an impact on the benefit of holding cash. First, interest rates affect discount rates. As the interest rate increases, firm value, V', which is the discounted value of expected future dividends, falls. The drop in firm value drives up the default probability ($\mathbb{E}\mathbf{1}_{V'\leq 0}$), which in turn affects the benefit of holding cash in two ways. On the one hand, a higher default probability pushes up cash-holding benefits. As default risk rises, keeping cash on hand can more effectively lower the cost of debt, thereby allowing firms to issue more debt instead of costly equity in the current period. On the other hand, higher default risk implies a lower survival probability. As such, it becomes less likely that firms will continue operating and need cash to avoid external financing costs in the subsequent period. This second channel reduces the benefit of holding cash.

The discussion above suggests that the interest rate has an impact on both the costs and benefits of holding cash. Deriving the relationship between interest rates and corporate cash demand therefore requires a careful quantitative analysis, which we perform and discuss below.

4. Calibration

In this section, we apply the model described in Section 3 to data. We start by parameterizing the model and show that our model is able to deliver the hump-shaped relationship between interest rates and corporate cash holdings. We then perform a number of sensitivity analyses to demonstrate the robustness of the result.

4.1 Calibration

To derive the interest-cash relationship, we calibrate the model with a sample of nonfinancial nonutility firms from 1970 to 2013 constructed from Compustat. Then we examine how firms manage their cash policies in response to changes in interest rates.

We solve the model at an annual frequency and set the interest rate i equal to 5% which is the average during the sample period. To calibrate the profit function, $\pi(z, k)$, and the process for the idiosyncratic productivity shock, z, we estimate the regression model specified below:

$$Y_{i,t} = \beta_0 + \beta_1 k_{i,t} + \text{firm}_i + \text{year}_t + \epsilon_{i,t}. \tag{4}$$

The dependent variable $Y_{i,t}$ is the logarithm of operating income (item *oibdp*) for firm i scaled by the GDP deflator during period t. The independent variables include a constant term, the logarithm of the capital stock (item *ppent*) scaled by GDP deflator, firm dummies, and time dummies. The error term, $\epsilon_{i,t}$, corresponds to the logarithm of the idiosyncratic productivity shock $z_{i,t}$ in the model. The coefficient on the capital stock corresponds to the curvature of the profit function $\pi(z, k)$, with $\beta_1 = \frac{\alpha\theta}{1-\theta+\alpha\theta}$. Estimating equation (4) yields $\hat{\beta}_1 = 0.54$. We set the capital share, α, to 0.3, which implies that $\theta = 0.80$. We then collect the fitted residuals and estimate the following $AR(1)$ model to calibrate the persistence, ρ, and volatility, σ_z, that govern the shock process:

$$\hat{\epsilon}_{i,t} = \beta_2 \hat{\epsilon}_{i,t-1} + \varepsilon_{i,t}.$$

Estimation results yield $\rho = \hat{\beta}_2 = 0.41$ and $\sigma_z = 0.54$, where the latter is the standard deviation of the residual $\hat{\varepsilon}_{i,t}$.

We choose the resale price of capital, γ_2, to be 0.5, following Bloom (2009) and Gilchrist et al. (2014), and we set the capital depreciation rate, δ, equal to 0.13 which is the average of the ratio of depreciation (dp) to capital in our sample. Parameters related to financial frictions are chosen as follows. We set the debt recovery rate, χ, to be 0.5, which is the lower bound of the range [0.5, 0.7] suggested by Bris et al. (2006) and Acharya et al. (2007). We follow Gomes (2001) to choose the fixed equity-issuance costs $\lambda_0 = 0.1$.

The remaining parameters (γ_0, γ_1, λ_1 and c_f) are calibrated jointly by minimizing the distance between a list of selected moments constructed from model-simulated data and those computed with actual data. We choose the following five moments to match: the average cash-to-assets ratio, the average debt-to-assets ratio, the average investment-to-assets ratio, the average equity issuance-to-assets ratio, and the standard deviation of the investment-to-assets ratio.

More specifically, the average cash ratio is informative about the fixed operating costs, c_f. A larger fixed operating cost drives up cash holdings because its presence leads firms to accumulate internal cash to facilitate operations. The average and standard deviation of the capital investment ratio help to identify the linear and quadratic capital adjustment costs, γ_0 and γ_1. An increase in linear adjustment costs pushes up the real price of capital and affects the level of investment, while an increase in quadratic adjustment costs encourages firms to smooth capital investment and lowers the variance of investment. Lastly, the linear equity issuance costs λ_1 influence firms' choice between debt and equity. The average debt and equity ratios thus contain information about λ_1.

Table 8 summarizes the parameter estimates. The estimated linear and quadratic capital adjustment costs, γ_0 and γ_1, are 0.050 and 0.366, respectively, which lie within the range of the estimates reported by previous studies (Gilchrist and Himmelberg 1995; Cooper and Haltiwanger 2006). The estimated linear equity issuance cost λ_1 is 0.062. This value lies within the range of estimates reported by Hennessy and Whited (2005) and Hennessy and Whited (2007). The fixed operating cost c_f is 0.059, which is chosen to match the average cash ratio and amounts to roughly 16% of steady-state sales.

4.2 Model Validation

Table 9 reports the model predictions along with the corresponding data moments, including the first and second moments of cash holdings, debt financing, capital investment, and equity issuance.

We construct data moments using a sample of nonfinancial, unregulated U.S. firms in Compustat from 1970 to 2013. We define cash in the model as the $M1$ money stock and accordingly measure it by cash (item *ch*). Debt is defined as the total debt and measured as the sum of short-term debt (item *dlc*) and long-term debt (item *dltt*). Capital investment and equity issuance are measured by the items *capx* and *sstk*, respectively. To minimize the effect of outliers, we winsorize all variables at the bottom and top 1% level. To obtain model moments, we solve the model numerically.

As shown in Table 9, our model explains the data reasonably well. The targeted moments used for estimation—the mean of each variable and the standard deviation of investment—match their data counterparts closely, except that the model overshoots the average investment. Adding an extra friction to investment would help lower investment rates, which, however, would lower model-implied cash and leverage ratios due to weaker financing needs and move them further apart from data.

We also assess model performance by reporting the nontargeted moments, including the standard deviation of variables of particular interest, their correlation with sales, and the frequency of equity issuance. The model-implied cyclical behavior of cash holdings, debt financing and investment is qualitatively consistent with data. In response to a positive productivity shock, the firm tends to invest more in capital, hold more cash out of revenue to pay fixed operating costs and facilitate operation in future, and lower debt financing. The model-implied cash, debt, and equity ratios are less volatile than they are in the data. The low volatility is caused by the high fixed operating costs in the model—that is, a constant amount of liquidity is required to facilitate operation each period, which smooths out the volatility of internal and external financing.

Overall, the model is able to reproduce key features of the data. This result strengthens the reliability of using the parameterization in Table 8 to examine the relationship between interest rates and firms' money demand.

4.3 The Relationship between Interest Rates and Corporate Cash

In this subsection, we use the calibrated model to examine how firms' cash-holding decisions respond to changes in interest rates. We let interest rates take the values of equally spaced points in the interval [0.01,0.09] and keep other parameters the same as those in the benchmark model. The comparative statics results are plotted in the upper left panel of Figure 5. To facilitate interpretation, we also plot the responses of firms' capital investment decisions to interest rates in the upper right panel, and the responses of cash and capital investments to interest rates in the case of zero fixed operating costs ($c_f = 0$) in the lower two panels. To control for the scale effect on real money demand, we focus on the behavior of the cash-to-assets ratio.

As shown in the upper left panel of Figure 5, corporate cash exhibits a hump-shaped relationship with interest rates. This result is generated by the interaction between financial frictions and fixed operating costs. The former generates the demand for cash as a buffer against the need to turn to costly external financing sources in the case of liquidity shortages, while the latter largely determines the probability of experiencing a liquidity shortage.

Specifically, as interest rates increase, in the presence of high operating costs, firm value V' (present value of expected future dividends) falls and the probability of default ($\mathbb{E}\mathbf{1}_{V' \leq 0}$) rises. The increase in default risk enlarges the wedge between the cost of debt and risk-free interest rates and generates stronger demand for cash. As such, this mechanism induces cash holdings to increase with interest rates.

However, firms also adjust capital investment in response to interest rate changes, which in turn affects cash demand. A higher cost of debt financing implies fewer proceeds raised with the same amount of debt issuance, and this decrease implies cuts to resources available for capital investment, in addition to the cuts imposed by fixed operating costs. To fund these fixed operating costs and continue to operate in the market, firms choose to reduce investment spending at high interest rates. Put differently, fixed operating costs crowd out investment when firms face severe credit market frictions. Weak capital investment needs significantly lower the demand for cash, as liquidity shortfalls become less likely. Furthermore, low capital investment deteriorates firms' capacity to generate internal cash flow, which is the key source of cash holdings in tight credit markets. The significant drop in both the demand for and supply of cash holdings contributes to the reduction in cash stock at high interest rates. Putting these pieces together produces a hump-shaped relationship between cash demand and interest rates.

There are three points to note here. First, the reason for the negative relationship between interest rates and cash holdings at high interest rates differs from traditional intuition based on the opportunity cost of holding cash. Instead, the negative relationship is mainly driven by the weak investment that results from high fixed operating costs and financial frictions, rather than the high forgone interest earnings, as conventional wisdom maintains.

Second, our benchmark model's prediction about the sensitivity of firms' capital investments to interest rates is consistent with the survey evidence provided by Sharpe and Suarez (2015), which finds that firms do not adjust their capital investment in response to interest-rate changes when interest rates are low. We find similar behavior in our model either because of the low cost of debt or adequate cash on hand. The similarity between our model and this external evidence lends support to the validity of our model.

Third, the cash-holding benefit generated by financial frictions in the model overturns traditional monetary theory's prediction on the monotonically negative relationship between cash and interest rates. This nonmonotonicity persists even if we remove fixed operating costs, as shown in the lower two panels of Figure 5. In the absence of a transaction motive for cash demand induced by fixed operating costs ($c_f = 0$), budget constraints are occasionally binding. Firms keep a low and constant level of cash holdings as a precaution and invest at the first-best level regardless of interest-rate changes.

4.4 Suggestive Evidence

In this subsection, we provide suggestive evidence to support the model's central insight on the role of fixed operating costs in generating the hump-shaped interest sensitivity as shown in Figure 5.

To test our proposed explanation, we rank firms based on their fixed operating costs which are proxied by their previous-period operating leverage and measured as the ratio of their selling, general and administrative costs (item $SG\&A$) over sales. We classify firms in the top third of the distribution as the ones with high operating leverage and those in the bottom third as the ones with low operating leverage. We then examine whether and how the relationship between interest rates and corporate cash varies when operating leverage changes.

Our model predicts that the cash demand of firms that face high operating leverage displays a hump-shaped relationship with interest rates, while the cash demand of firms with low operating leverage is unresponsive to interest rates. Estimation results presented in Table 10 are in accordance with model predictions: The hump-shaped pattern is only found for the former group, which provides strong evidence in support of the mechanism suggested by our model to explain the cash-interest relationship observed in the data.

4.5 Sensitivity Analysis

Next, we demonstrate the robustness of the hump-shaped cash-interest relationship obtained above with respect to the three preset parameters—the fixed equity issuance costs (λ_0), the resale price for disinvestment (γ_2), and the debt recovery rate (χ). We also investigate the model assumption about zero interest income earned on cash holdings. We make one modification at a time and present our results in Figure 6.

4.5.1. Parameterization

The effect of fixed equity issuance costs λ_0 on the interest-cash relationship is plotted in the upper left panel. As shown, the relationship remains hump shaped. When λ_0 falls to 0.05, firms face less severe financial frictions and therefore have a weaker precautionary motive for holding cash, which shifts the whole money demand schedule downward except at low interest rates, yet the nonmonotonicity remains intact.

The response of the money demand curve to the resale price for disinvestment is plotted in the upper right panel. When we remove partial irreversibility by setting $\gamma_2 = 1$, the overall shape of the curve is unchanged. A higher resale price of capital reduces firms' cash demand at high interest rates. Specifically, when the interest rate and therefore borrowing costs are high, firms optimally want to disinvest. Selling capital at a higher resale price then generates more liquidity, leading to a weaker need for holding cash to fund fixed operating costs relative to the benchmark model.

Changes in the debt recovery rate, χ, also have little effect on the shape of the corporate money demand curve. However, the debt recovery rate naturally affects the cash level, as shown in the bottom left panel. A higher recovery rate, $\chi = 0.75$, implies a smaller loss in the event of default and weakens the importance of cash in reducing the cost of debt when default risk is high. The average cash ratio, therefore, decreases with the debt recovery rate, χ.

4.5.2. Business Sweep Programs

In the benchmark model, we assume zero interest income on cash holdings. In reality, however, firms earn interest on their cash reserves under business sweep programs.[5] To accommodate this institutional feature, we next relax the model restriction on zero interest on cash balances. To ensure the existence of an upper bound on optimal cash holdings, interest income is taxed at a rate of 35%.

Allowing firms to earn interest, i, on their cash balances has no impact on the shape of corporate money demand, as shown in the bottom right panel. This invariance arises because the hump shape is not driven by the level of interest on cash balances but by two, by now familiar, countervailing forces: the rise in external financing costs driven by default risk and weak external borrowing needs caused by low capital investment at high interest rates. Paying interest on cash balances does lower the level of cash holding costs, which then translate into more resources available in the future, so firms accumulate less cash relative to the benchmark model. This mechanism operates when interest rates are either high or low.

When interest rates are high, another mechanism by which business sweep programs affect cash policy is present. At high interest rates, borrowing is expensive and internal liquidity becomes a more desirable source of funds. Earning interest on cash effectively reduces the value of capital which can be sold to generate cash flow. Firms therefore choose to hold more cash to fund fixed operating costs, leading to a higher cash ratio compared to the benchmark model.

[5]Business sweep programs, similar to NOW accounts, were initiated by commercial banks during the 1960s and 1970s. In these programs, money in business checking accounts was swept overnight into interest-earning assets. The primary intention was to allow firms to earn interest overnight on demand deposits, which was prohibited under the Banking Acts of 1933 and 1935.

Overall, although changes in parameters and cash-holding costs have significant effects on the level of cash demand, they have only a slight influence on the shape of corporate money demand, and therefore do not alter the model's central result.

5. Model Implications

In this section, we study the implications of the hump-shaped cash-interest relationship for the welfare cost of inflation, monetary policy, and the corporate cash-hoarding puzzle. In particular, we revisit three important questions regarding money demand: the welfare cost of inflation, the transmission channels of monetary policy, and the U.S. corporate cash puzzle.

5.1 Welfare Cost of Inflation

A classic question concerning money demand is the welfare cost of inflation. Bailey (1956) measures the welfare cost of inflation by calculating the area under the inverse money demand curve over a given segment of real money balances. Different money demand curves, therefore, imply different estimates for the welfare cost.

Despite a long line of research on this question, no clear consensus has been reached on the magnitude of the cost. One source of the discrepancy in the estimates arises from money demand behavior at low interest rates. Lucas (2000) shows that U.S. historical real balances from 1900 to 1994 are well predicted by a log-log function. This demand specification implies an arbitrarily large money demand, and thus a sizeable welfare cost of inflation as the interest rate approaches zero. Ireland (2009) extends the analysis and considers more recent data. He finds that a semi-log curve better fits U.S. money demand behavior. This result suggests a finite level of real balances when the interest rate is close to zero, which in turn implies a moderate level for the welfare cost of inflation.

Our finding of a hump-shaped corporate money demand speaks to the question of whether a satiation level in money demand exists at zero interest rates, so our finding also sheds light on the magnitude of the welfare cost of inflation. When interest rates fall, the low cost of holding cash in terms of forgone interest earnings is offset by its low benefit from reduced borrowing costs, so cash demand is weak. This low demand implies a modest welfare cost of the low and stable inflation policy pursued by the Federal Reserve, supporting the view put forward by Mulligan and Sala-i-Martin (2000) and Ireland (2009).

5.2 Monetary Policy

One of the central questions in monetary economics is the transmission mechanism of monetary policy. The response of investment to interest rates derived in Section 4.3 has important implications for this issue.

Our model suggests that as a result of low borrowing costs or sufficient cash on hand, firms invest at the first-best level and do not respond to interest-rate changes when interest rates are low. This behavior challenges two often-discussed channels through which monetary policy stimulates the real economy: the interest rate channel and the balance sheet channel.[6] Both channels boost output by increasing lending and raising investment. However, the existence of corporate cash reserves reduces the likelihood of financial distress and underinvestment in capital and, therefore, dampens the importance of both transmission mechanisms at low interest rate levels.

5.3 U.S. Corporate Cash Puzzle

The last few decades have witnessed substantial cash accumulation in the economy. The average cash-to-assets ratio for the U.S. corporate sector has increased steadily from 4.1% in 1984 to 21.1% in 2013. Puzzled by the trend and concerned about potential resource misallocation within firms from high-productivity assets to cash, there is a rapidly growing number of studies that aim to understand this phenomenon.

[6] Mishkin (1996) provides a summary of the channels for monetary transmission.

Azar et al. (2016) argue that the corporate cash-hoarding phenomenon can be rationalized by the reduction in interest rates since the 1980s. More specifically, interest rates are positively associated with the cost of holding cash. A fall in interest rates implies a drop in the carrying cost of cash, and therefore can explain the secular trend in corporate cash balances. Boileau and Moyen (2016) reach a similar conclusion that an economy-wide reduction in the cost of holding liquidities is responsible for the rise in cash holdings.

In this paper, we emphasize the cash-holding benefit, which co-moves with interest rates. Our findings challenge the cost-based explanation proposed by Azar et al. (2016). Instead, we offer an alternative explanation. The increase in cash holdings from 1984 to 1991 can be attributed to a drop in interest rates, yet for a different reason. Interest rates fell significantly from 9.5% to 5.4% during that period. Lower borrowing costs encourage investment spending and then generate strong demand for cash. Moreover, the drop in interest rates from 5.4% to 0.06% from 1991 to 2013 is unlikely to have contributed to the secular increase in corporate cash reserves during that period. Instead, the interest-rate cuts would reduce borrowing costs and cash-holding benefits, thus leading to a decline in cash ratios.

6. Conclusion

This paper investigates the relationship between interest rates and corporate cash demand. We first document a hump-shaped relationship that holds in both aggregate and firm-level data. This finding is at odds with the literature on monetary economics, which suggests an inverse relationship between cash and interest rates that reflects the opportunity cost of holding cash.

We then develop a structural framework to rationalize this observed fact. The model features endogenous debt financing costs that co-move with risk-free interest rates. As interest rates increase, firm value drops, thus raising default risk and the cost of debt. The increased credit spread prompts firms to demand more cash, as higher external financing costs induce firms to build a liquidity cushion to support their operations and capital investments. This mechanism generates the upward-sloping part of the corporate cash demand schedule. As interest rates continue to rise, high debt-financing costs imply fewer proceeds raised with the same amount of debt issuance. In combination with fixed operating costs, this financial friction significantly tightens firms' budgets and results in capital investment cuts. Consequently, lower capital investment needs contribute to a lower demand for cash. When interest rates are very high, this second mechanism dominates, and cash holdings decline with interest rates.

We then explore the policy implications of the hump-shaped relationship between interest rates and corporate cash demand. First, the corporate money demand schedule implies a satiation level of cash holdings at zero interest rates. This feature of demand in turn implies that low inflation, for example, a modest departure from the Friedman rule, generates moderate welfare losses. Second, the hump shape suggests that using interest-rate cuts at low interest rates to boost economic activity may not be effective, as a result of adequate cash held by firms. Third, the U.S. corporate cash puzzle cannot be attributed to a drop in interest rates over time.

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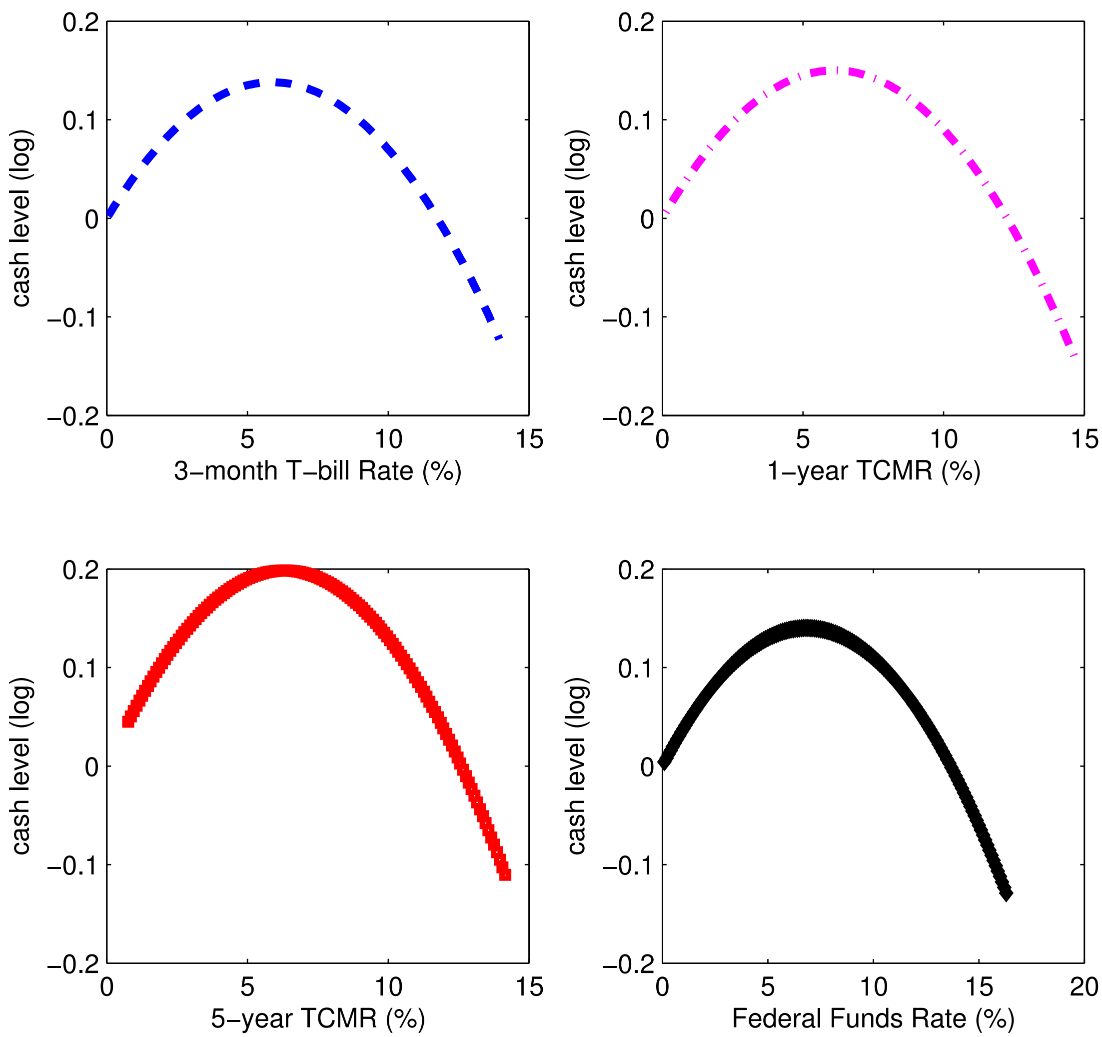

Figure 1: **Cash and Nominal Interest Rates: Aggregate-level Facts (Quarterly).** The figure plots the estimated relationship between the logarithm of aggregate corporate cash stock and nominal interest rates using regression model (1). The sample is constructed from Flow of Funds, covering the period from 1951Q4 to 2013Q2. We use four measures of interest rates: three-month T-bill rates (upper-left panel), one-year treasury constant maturity rates (upper-right panel), five-year treasury constant maturity rates (lower-right panel), and federal funds effective rates (lower-right panel).

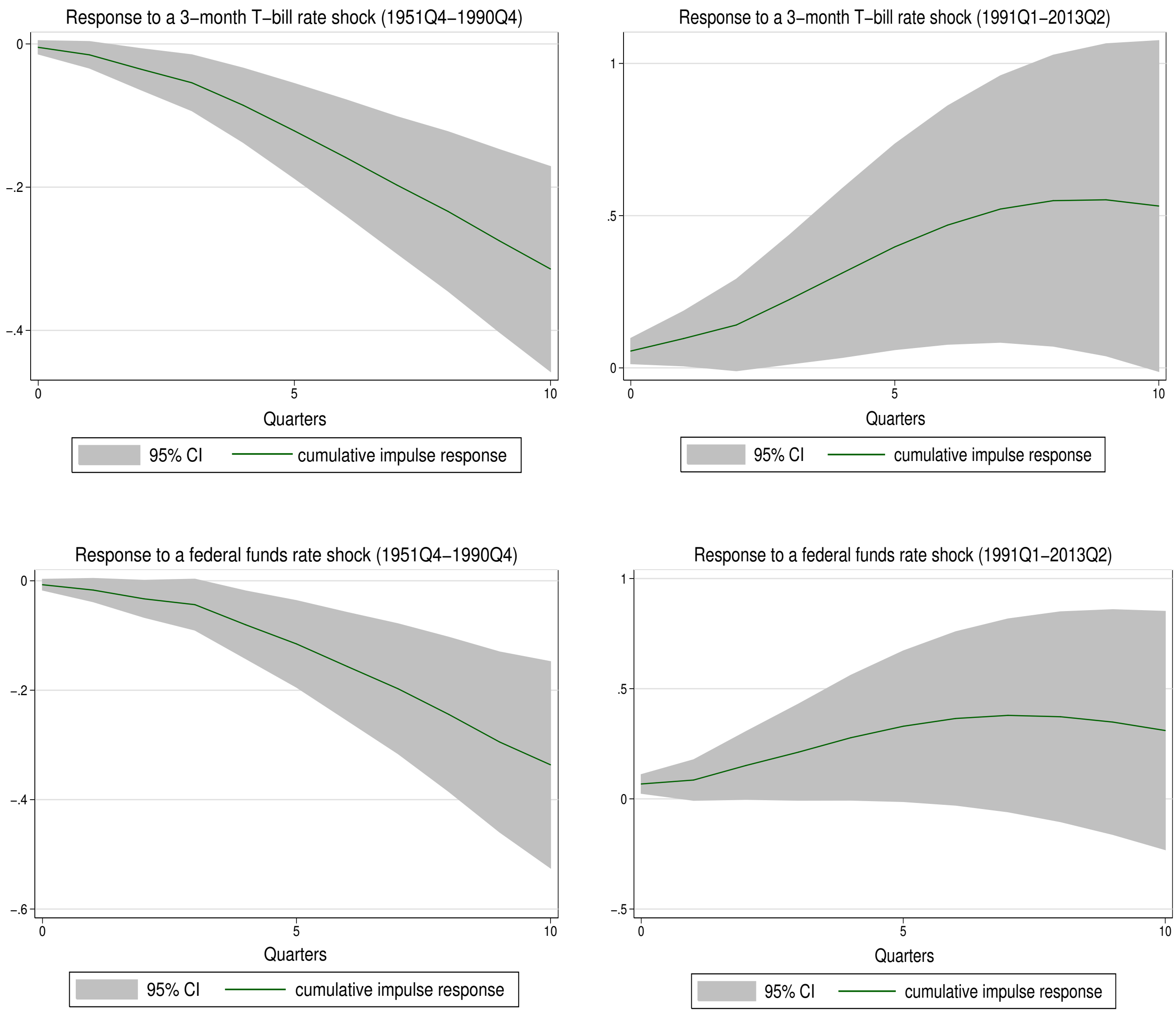

Figure 2: **Cumulative Impulse Responses of Aggregate Corporate Cash Holdings to Interest Rate Shocks (Quarterly).** The figure plots the cumulative impulse response of the aggregate corporate cash stock to interest rate shocks during the first 10 quarters. The sample is constructed from Flow of Funds, covering the period from 1951Q4 to 2013Q2. The left panels plot the reaction of corporate cash to a positive interest rate shock during the high interest rate period (pre-1990), and the right panels show the reaction during the low interest rate period (post-1990). The gray-shaded area indicates a 95% confidence interval. We use two measures of policy interest rates: three-month T-bill rates (upper panels) and federal funds effective rates (lower panels).

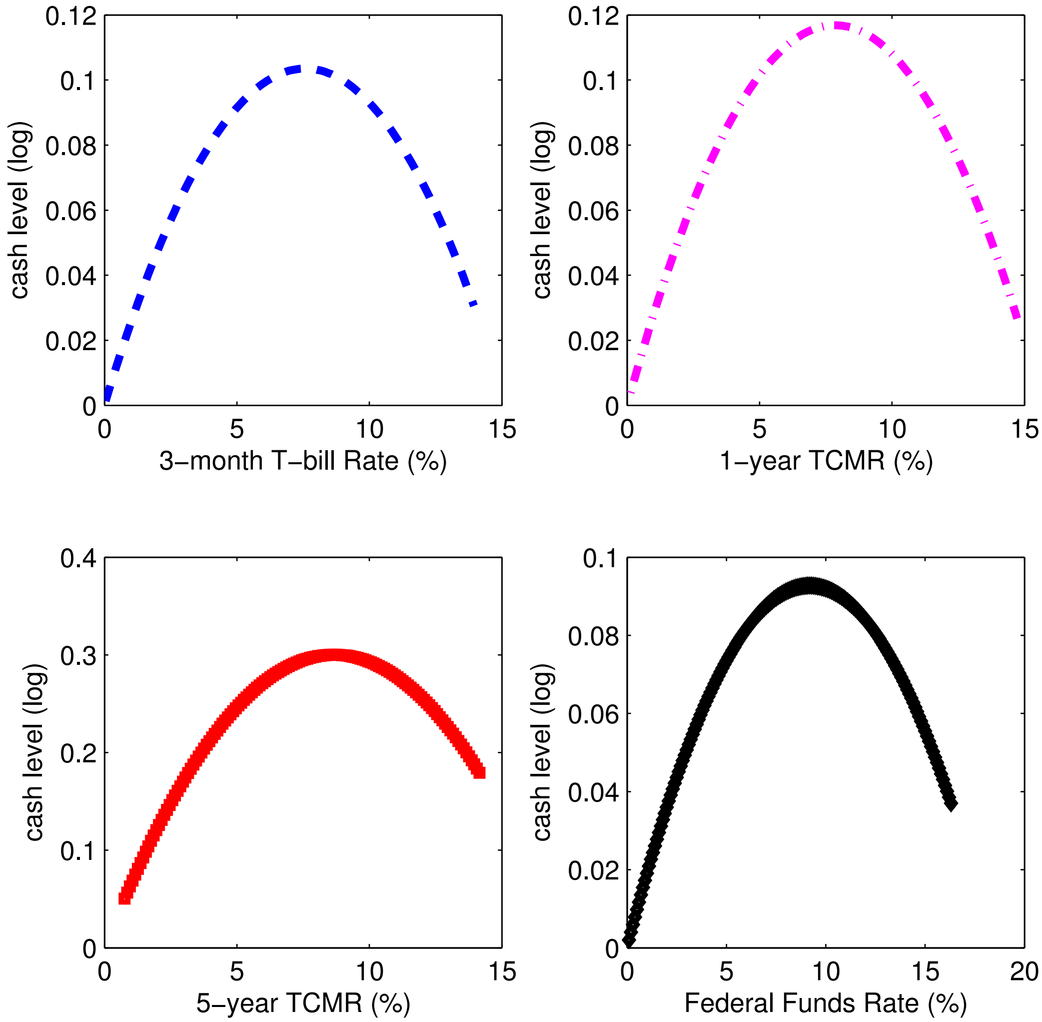

Figure 3: **Cash and Nominal Interest Rates: Firm-level Facts.** The figure plots the estimated relationship between the logarithm of cash holdings and nominal interest rates using regression model (2). The sample is constructed from Compustat, covering annual observations from 1970 to 2013 for nonfinancial nonutility firms. We plot estimation results of four measures of interest rates: three-month T-bill rates (top-left panel), one-year treasury constant maturity rates (top-right panel), five-year treasury constant maturity rates (bottom-left panel), and federal funds effective rates (bottom-right panel).

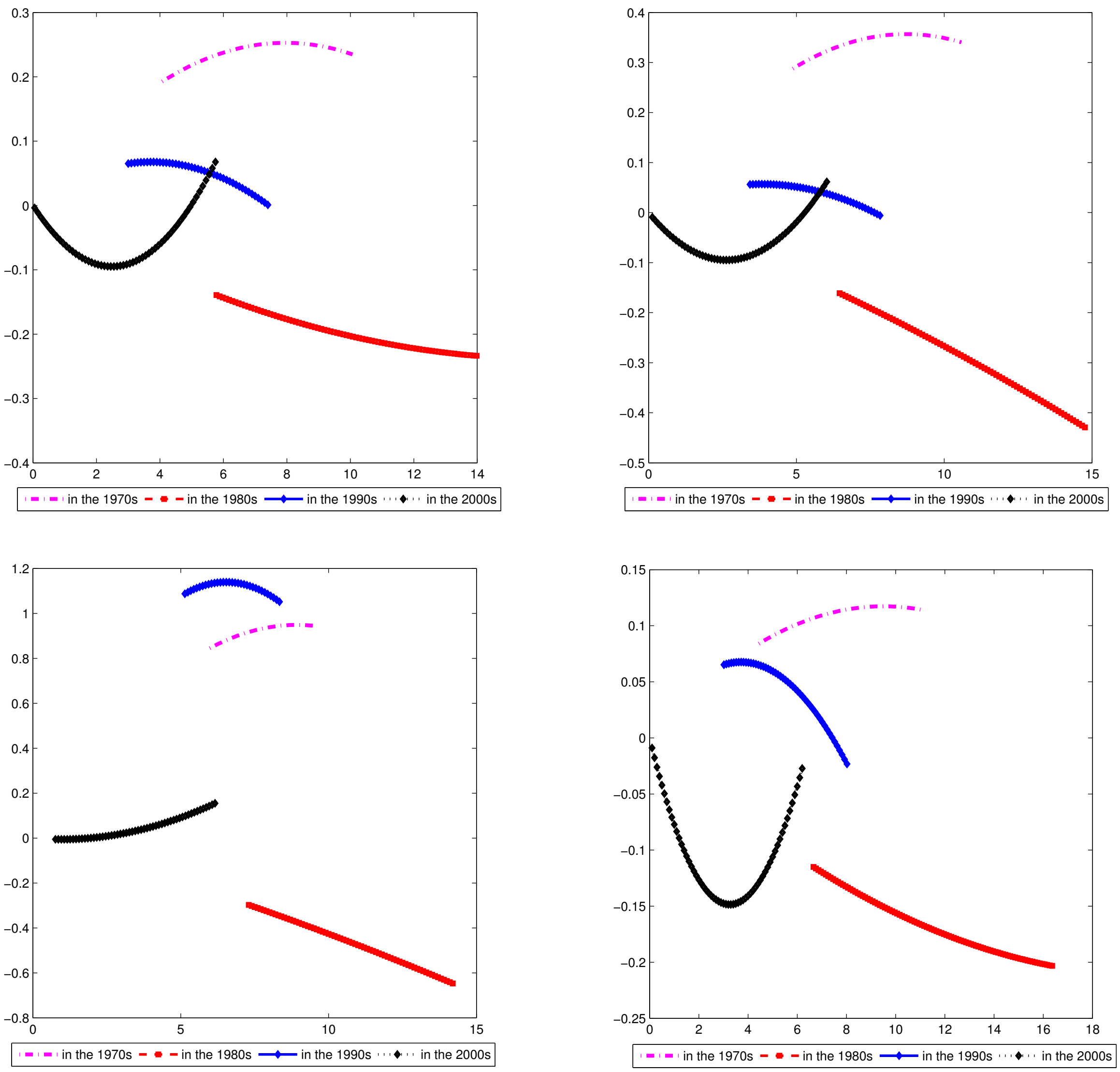

Figure 4: **Cash and Nominal Interest Rates: Firm-level Facts by Decade (1970-2013).** The figure plots the estimated relationship between the logarithm of cash holdings and nominal interest rates using regression model (2). The sample is constructed from Compustat, covering annual observations from 1970 to 2013 for nonfinancial nonutility firms. Estimates are reported in Table 7. We plot estimation results of four measures of interest rates: three-month T-bill rates (top-left panel), one-year treasury constant maturity rates (top-right panel), five-year treasury constant maturity rates (bottom-left panel), and federal funds effective rates (bottom-right panel).

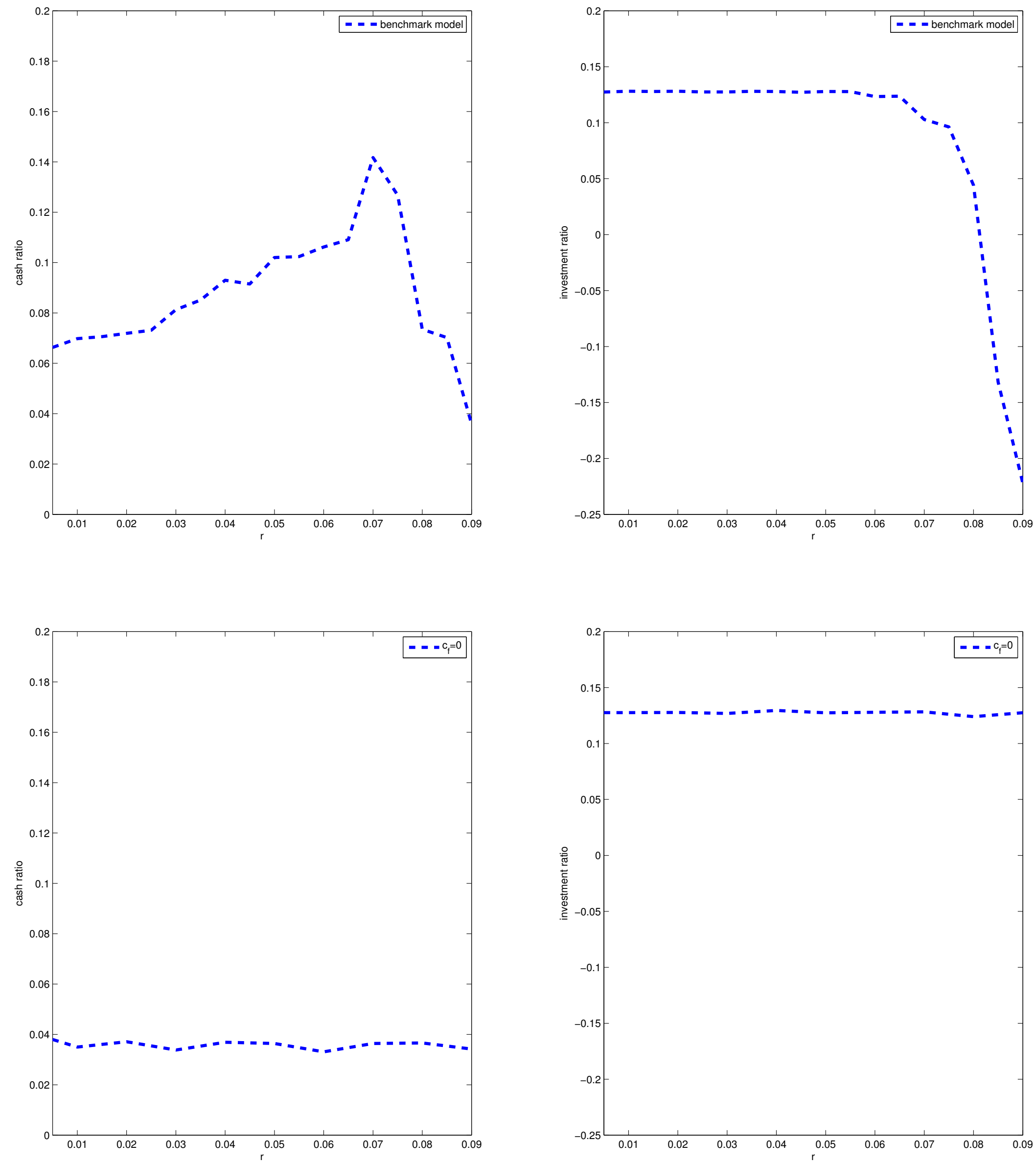

Figure 5: **Corporate Money Demand: Channel Exploration.** This figure plots the responses of firms' cash and investment ratios with respect to interest rates under different parameterizations to illustrate the mechanisms of the hump shapes relation between corporate cash demand and interest rates. The upper two panels plot the responses in the benchmark model, and the lower two panels show the responses in the case of zero fixed operating costs $c_f = 0$.

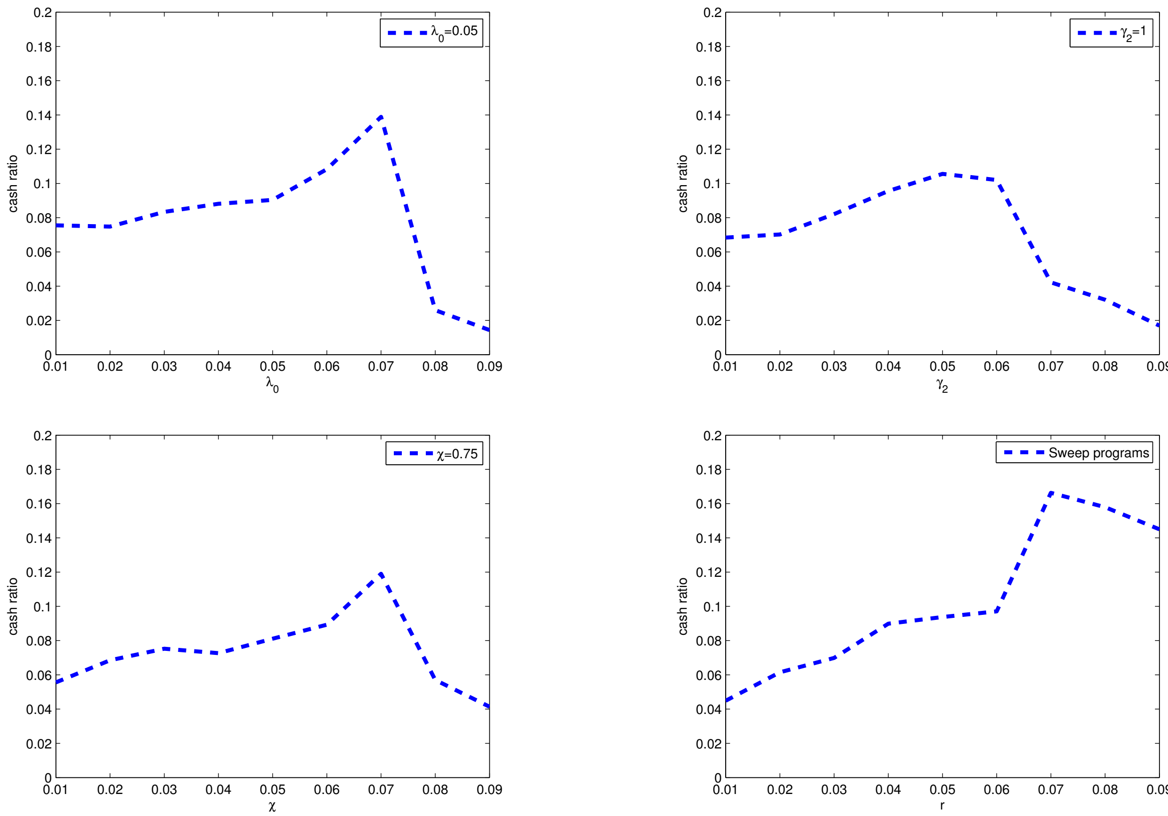

Figure 6: **Corporate Money Demand: Sensitivity Analysis.** This figure plots the responses of firms' cash ratios with respect to interest rates under different parameterizations (λ_0, γ_2, and χ) and model assumptions.

Table 1: Summary Statistics

	Mean	Std.	Min	Max	Obs.
Corporate Cash (log)	11.234	0.8291	9.5609	12.918	251
Real Corporate Cash (log)	7.5159	0.3206	4.9609	8.2516	251
Three-month T-bill (%)	4.3687	3.0162	0.0133	15.053	265
One-year TCMR (%)	5.2042	3.1766	0.1133	16.320	241
Five-year TCMR (%)	5.8499	2.9313	0.6667	15.427	241
Ten-year TCMR (%)	6.1330	2.7648	1.6433	14.847	241
Federal Funds Rate (%)	5.2032	3.4991	0.0733	17.780	236
Real GDP (log)	8.9341	0.6266	7.5654	9.6500	265
GDP growth rate (%)	0.7936	0.9740	-2.589	3.9856	265

Table 1 presents descriptive statistics for each variable used in regression equation (1) and reports the mean, standard deviation, minimum value, maximum value, and number of observations. The sample period covers 1947Q2 to 2013Q2.

Table 2: Corporate Cash and Interest Rates: Baseline

	(1)	(2)	(3)
3-month T-bill Rate	0.047*	0.055*	0.054*
	(0.024)	(0.028)	(0.032)
3-month T-bill Rate^2	-0.004***	-0.005***	-0.005**
	(0.002)	(0.002)	(0.002)
Real GDP	0.148***	0.136***	-0.079
	(0.035)	(0.040)	(0.633)
GDP growth	7.163**		7.342*
	(3.576)		(3.796)
Time trend	No	No	Yes
R-squared	0.1430	0.1019	0.1435
No. of Obs.	251	251	251

Table 2 reports estimation results of regression model (1) on interest rates, real GDP, and real GDP growth rates. Heteroskedasticity-consistent standard errors reported in parentheses. Significance levels are indicated by *, **, and *** for 10%, 5%, and 1%, respectively.

Table 3: Corporate Cash and Interest Rates: Robustness

	1-year TCMR	5-year TCMR	10-year TCMR	Federal Funds
Interest	0.049**	0.063**	0.077**	0.041*
	(0.023)	(0.030)	(0.034)	(0.022)
Interest^2	-0.004***	-0.005***	-0.006***	-0.003***
	(0.001)	(0.002)	(0.002)	(0.001)
Real GDP	0.163***	0.156***	0.144***	0.172***
	(0.034)	(0.039)	(0.044)	(0.033)
GDP growth	7.534*	7.653**	7.774**	8.454**
	(3.855)	(3.816)	(3.856)	(4.211)
R-squared	0.1481	0.1472	0.1461	0.1468
No. of Obs.	241	241	241	236

Table 3 reports estimation results of regression model (1) on interest rates, real GDP, and real GDP growth rates. Four alternative measures of nominal interest rates are considered: one-year, five-year, and ten-year treasury constant maturity rates, and federal funds effective rates. Heteroskedasticity-consistent standard errors reported in parentheses. Significance levels are indicated by *, **, and *** for 10%, 5%, and 1%, respectively.

Table 4: Corporate Cash and Interest Rates: Firm-Level Evidence

	(1) 3-month T-bill	(2) 1-year TCMR	(3) 5-year TCMR	(4) 10-year TCMR	(5) Federal Funds
Interest	0.0273*	0.0298*	0.0693**	0.1027**	0.0202
	(0.0165)	(0.0172)	(0.0332)	(0.0465)	(0.0144)
Interest^2	-0.0018**	-0.0019**	-0.0040**	-0.0057**	-0.0011*
	(0.0009)	(0.0009)	(0.0017)	(0.0023)	(0.0007)
Real GDP	-1.7431***	-1.7245***	-1.8375***	-1.7434***	-1.7511***
	(0.6626)	(0.6508)	(0.5955)	(0.5478)	(0.6823)
GDP growth	0.0169**	0.0163**	0.0175***	0.0181***	0.0174**
	(0.0071)	(0.0068)	(0.0063)	(0.0062)	(0.0074)
Lagged Cash	0.8845***	0.8845***	0.8844***	0.8844***	0.8845***
	(0.0077)	(0.0077)	(0.0077)	(0.0077)	(0.0077)
Cubic Time Trend	Yes	Yes	Yes	Yes	Yes
Year Dummy for 1987	Yes	Yes	Yes	Yes	Yes
Year Dummy for 1988	Yes	Yes	Yes	Yes	Yes
R-squared	0.7935	0.7936	0.7936	0.7936	0.7936
No. of Obs.	205798	205798	205798	205798	205798

Table 4 reports estimation results of regression model (2) on interest rates, real GDP, real GDP growth rates, lagged cash holdings, and cubic time trend. We also include dummy variables for 1987 and 1988 to control for the potential effects of the accounting change introduced by SFAS-95 on firms' cash choices. Heteroskedasticity-consistent standard errors reported in parentheses are two-way clustered by firm and year. Significance levels are indicated by *, **, and *** for 10%, 5%, and 1%, respectively.

Table 5: Corporate Cash and Interest Rates: Robustness I

	(1) 3-month T-bill	(2) 1-year TCMR	(3) 5-year TCMR	(4) 10-year TCMR	(5) Federal Funds
Interest	0.0273*	0.0297*	0.0690**	0.1022**	0.0202
	(0.0165)	(0.0172)	(0.0334)	(0.0471)	(0.0145)
Interest^2	-0.0018**	-0.0019**	-0.0040**	-0.0057**	-0.0011*
	(0.0009)	(0.0009)	(0.0017)	(0.0023)	(0.0007)
$\text{Interest} \times \text{dummy}_{1986-1988}$	-11.105***	-0.1043	-3.9502***	-5.3545***	-14.165***
	(1.1033)	(0.7916)	(0.6859)	(0.7504)	(1.7319)
$\text{Interest}^2 \times \text{dummy}_{1986-1988}$	0.9123***	0.0105	0.2664***	0.3391***	1.0128***
	(0.0875)	(0.0561)	(0.0435)	(0.0455)	(0.1207)
Real GDP	-1.7477***	-1.7218***	-1.8303***	-1.7366***	-1.7568**
	(0.6751)	(0.6535)	(0.6021)	(0.5531)	(0.6919)
GDP growth	0.0169**	0.0162**	0.0175***	0.0180***	0.0174**
	(0.0071)	(0.0068)	(0.0063)	(0.0063)	(0.0074)
Lagged Cash	0.8845***	0.8845***	0.8844***	0.8844***	0.8845***
	(0.0077)	(0.0077)	(0.0077)	(0.0077)	(0.0077)
Cubic Time Trend	Yes	Yes	Yes	Yes	Yes
Dummy for 1986 - 1988	Yes	Yes	Yes	Yes	Yes
R-squared	0.7935	0.7936	0.7936	0.7936	0.7935
No. of Obs.	205798	205798	205798	205798	205798

Table 5 reports estimation results of regression model (2) on interest rates, real GDP, real GDP growth rates, lagged cash holdings and cubic time trend. We allow for a different cash-interest relationship in 1987 and 1988 when there was an accouting change introduced by SFAS-95. Heteroskedasticity-consistent standard errors reported in parentheses are two-way clustered by firm and year. Significance levels are indicated by *, **, and *** for 10%, 5%, and 1%, respectively.

Table 6: Corporate Cash and Interest Rates: Robustness II

	(1) 3-month T-bill	(2) 1-year TCMR	(3) 5-year TCMR	(4) 10-year TCMR	(5) Federal Funds
Interest	0.0264	0.0307	0.0742**	0.1096**	0.0174
	(0.0223)	(0.0220)	(0.0343)	(0.0430)	(0.0204)
Interest^2	-0.0021	-0.0023**	-0.0048***	-0.0067***	-0.0013
	(0.0013)	(0.0011)	(0.0017)	(0.0021)	(0.0010)
Real GDP	-0.3835	-0.3842	-0.5917	-0.5132	-0.2876
	(1.0958)	(1.0886)	(0.9355)	(0.8347)	(1.1456)
GDP growth	0.0095	0.0088	0.0100	0.0097	0.0089
	(0.0075)	(0.0074)	(0.0071)	(0.0067)	(0.0079)
Lagged Cash	0.4660***	0.4659***	0.4657***	0.4654***	0.4659***
	(0.0296)	(0.0280)	(0.0060)	(0.0058)	(0.0311)
Cubic Time Trend	Yes	Yes	Yes	Yes	Yes
Year Dummy for 1987	Yes	Yes	Yes	Yes	Yes
Year Dummy for 1988	Yes	Yes	Yes	Yes	Yes
R-squared	0.0370	0.0371	0.0375	0.0377	0.0370
No. of Obs.	203683	203683	203683	203683	203683

Table 6 reports estimation results of regression model (2) on interest rates, real GDP, real GDP growth rates, lagged cash holdings, and cubic time trend. Heteroskedasticity-consistent standard errors reported in parentheses are two-way clustered by firm and year. Significance levels are indicated by *, **, and *** for 10%, 5%, and 1%, respectively.

Table 7: Corporate Cash and Interest Rates: Time Varying Firm-Level Evidence

	(1) 3-month T-bill	(2) 1-year TCMR	(3) 5-year TCMR	(4) 10-year TCMR	(5) Federal Funds
Interest	-0.0762**	-0.0718**	-0.0112	-0.0008	-0.0912***
	(0.0353)	(0.0336)	(0.0580)	(0.0718)	(0.0313)
Interest × 1970s	0.1398***	0.1537***	0.2237	0.2773	0.1159***
	(0.0476)	(0.0534)	(0.1656)	(0.2409)	(0.0376)
Interest × 1980s	0.0469	0.0501	-0.0244	-0.0192	0.0706
	(0.0516)	(0.0534)	(0.0874)	(0.1029)	(0.0435)
Interest × 1990s	0.1126	0.1016	0.3600	0.5553*	0.1276*
	(0.0980)	(0.1015)	(0.2904)	(0.2979)	(0.0775)
Interest^2	0.0153***	0.0136***	0.0059	0.0073	0.0158***
	(0.0047)	(0.0047)	(0.0063)	(0.0087)	(0.0039)
Interest^2 × 1970s	-0.0193***	-0.0183***	-0.0178	-0.0230	-0.0171***
	(0.0052)	(0.0053)	(0.0110)	(0.0156)	(0.0042)
Interest^2 × 1980s	-0.0144***	-0.0131***	-0.0052	-0.0074	-0.0153***
	(0.0052)	(0.0052)	(0.0071)	(0.0094)	(0.0043)
Interest^2 × 1990s	-0.0202**	-0.0175*	-0.0326	-0.0472*	-0.0207***
	(0.0095)	(0.0092)	(0.0210)	(0.0220)	(0.0071)
Real GDP	-0.8518	-0.9532	-1.1537**	-0.8973*	-0.5748
	(0.7849)	(0.7510)	(0.5486)	(0.4814)	(0.7886)
GDP growth	0.0093*	0.0093*	0.0132**	0.0127*	0.0074
	(0.0052)	(0.0054)	(0.0067)	(0.0072)	(0.0047)
Lagged Cash	0.8843***	0.8843***	0.8843***	0.8843***	0.8843***
	(0.0077)	(0.0077)	(0.0077)	(0.0077)	(0.0077)
Cubic Time Trend	Yes	Yes	Yes	Yes	Yes
Decade fixed effect	Yes	Yes	Yes	Yes	Yes
Year Dummy for 1987	Yes	Yes	Yes	Yes	Yes
Year Dummy for 1988	Yes	Yes	Yes	Yes	Yes
R-squared	0.7937	0.7937	0.7937	0.7937	0.7936
No. of Obs.	205798	205798	205798	205798	205798

Table 7 reports estimation results of regression model (2) on interest rates, real GDP, real GDP growth rates, lagged cash holdings, and cubic time trend. We allow for a time-varying cash-interest relation. Heteroskedasticity-consistent standard errors reported in parentheses are two-way clustered by firm and year. Significance levels are indicated by *, **, and *** for 10%, 5%, and 1%, respectively.

Table 8: Model Parameterization

Parameter	Value
technology and shocks	
capital share (α)	0.30
curvature of production function (θ)	0.80
persistence of productivity shock (ρ)	0.41
standard deviation of productivity shock (σ_z)	0.54
capital adjustment and depreciation	
linear capital adjustment costs (γ_0)	0.050
quadratic capital adjustment costs (γ_1)	0.366
resale price for disinvestment (γ_2)	0.50
capital depreciation rate (δ)	0.13
financial and operation frictions	
risk-free rate (r)	0.05
debt recovery rate (χ)	0.50
fixed equity issuance costs (λ_0)	0.10
linear equity issuance costs (λ_1)	0.062
fixed production costs (c_f)	0.059

Table 8 summarizes the parameter values used to solve the model. The sample period covers 1970 to 2013.

Table 9: Model Moments

Moments		data	model
(i) cash to assets ($c_{t+1}/(k_{t+1}+c_{t+1})$)			
	mean	0.111	0.100
	standard deviation	0.159	0.071
	correlation with sales	0.176	0.228
(ii) debt to assets ($b_t/(k_{t+1}+c_{t+1})$)			
	mean	0.298	0.275
	standard deviation	0.346	0.208
	correlation with sales	-0.187	-0.415
(iii) capital investment to assets ($I_t/(k_{t+1}+c_{t+1})$)			
	mean	0.071	0.116
	standard deviation	0.087	0.062
	correlation with sales	0.244	0.679
(iv) equity issuance to assets ($e_t/(k_{t+1}+c_{t+1})$ when $e_t < 0$)			
	mean	0.085	0.098
	standard deviation	0.232	0.216
	issuance frequency	0.364	0.225

Table 9 presents moments of particular interest. Data moments are calculated based on a sample of nonfinancial and nonutility firms over the period from 1970 to 2013.

Table 10: Corporate Cash and Interest Rates: Mechanism Test

	(1) 3-month T-bill	(2) 1-year TCMR	(3) 5-year TCMR	(4) 10-year TCMR	(5) Federal Funds
Panel A: Firms with High Operating Leverage					
Interest	0.0586***	0.0598**	0.1148**	0.1436**	0.0454**
	(0.0226)	(0.0244)	(0.0507)	(0.0729)	(0.0196)
Interest^2	-0.0031***	-0.0032**	-0.0063**	-0.0078**	-0.0020**
	(0.0012)	(0.0013)	(0.0027)	(0.0037)	(0.0009)
Real GDP	-2.6887**	-2.5553**	-2.4230**	-2.1191**	-2.7253**
	(1.1030)	(1.1068)	(1.0674)	(1.0127)	(1.1317)
GDP growth	0.0278**	0.0263**	0.0271**	0.0269**	0.0292**
	(0.0116)	(0.0112)	(0.0109)	(0.0110)	(0.0122)
Lagged Cash	0.8772***	0.8772***	0.8771***	0.8770***	0.8772***
	(0.0098)	(0.0098)	(0.0098)	(0.0098)	(0.0098)
Cubic Time Trend	Yes	Yes	Yes	Yes	Yes
Year Dummy for 1987	Yes	Yes	Yes	Yes	Yes
Year Dummy for 1988	Yes	Yes	Yes	Yes	Yes
R-squared	0.7732	0.7731	0.7732	0.7731	0.7731
No. of Obs.	76944	76944	76944	76944	76944
Panel B: Firms with Low Operating Leverage					
Interest	-0.0068	-0.0049	0.0115	0.0444	-0.0064
	(0.0162)	(0.0163)	(0.0316)	(0.0455)	(0.0141)
Interest^2	-0.0003	-0.0004	-0.0013	-0.0028	-0.0001
	(0.0009)	(0.0009)	(0.0016)	(0.0022)	(0.0007)
Real GDP	-0.7868	-0.8389	-1.1364**	-1.2743***	-0.7865
	(0.5563)	(0.5362)	(0.4933)	(0.4512)	(0.5709)
GDP growth	0.0070	0.0072	0.0081	0.0092*	0.0068
	(0.0058)	(0.0057)	(0.0056)	(0.0055)	(0.0058)
Lagged Cash	0.8859***	0.8859***	0.8858***	0.8858***	0.8868***
	(0.0062)	(0.0061)	(0.0062)	(0.0062)	(0.0062)
Cubic Time Trend	Yes	Yes	Yes	Yes	Yes
Year Dummy for 1987	Yes	Yes	Yes	Yes	Yes
Year Dummy for 1988	Yes	Yes	Yes	Yes	Yes
R-squared	0.7918	0.7918	0.7918	0.7918	0.7918
No. of Obs.	71219	71219	71219	71219	71219

Table 10 reports estimation results of regression model (2) on interest rates, real GDP, real GDP growth rates, lagged cash holdings, and cubic time trend. Heteroskedasticity-consistent standard errors reported in parentheses are two-way clustered by firm and year. Significance levels are indicated by *, **, and *** for 10%, 5%, and 1%, respectively.