Financial Heterogeneity and the Investment Channel of Monetary Policy *

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November 16, 2018

Abstract

We study the role of financial frictions and firm heterogeneity in determining the investment channel of monetary policy. Empirically, we find that firms with low default risk – those with low debt burdens, good credit ratings, and large “distance to default” – are the most responsive to monetary shocks. We interpret these findings using a heterogeneous firm New Keynesian model with default risk. In our model, low-risk firms are more responsive to monetary shocks because their marginal cost of finance is relatively flat. The aggregate effect of monetary policy therefore depends on the distribution of default risk, which varies over time.

*We thank Andy Abel, Adrien Auclert, Cristina Arellano, Neele Balke, Paco Buera, Simon Gilchrist, Chris House, Erik Hurst, Alejandro Justiniano, Greg Kaplan, Rohan Kekre, Aubhik Khan, John Leahy, Alisdair McKay, Fabrizio Perri, Felipe Schwartzman, Linda Tesar, Julia Thomas, Joe Vavra, Ivan Werning, Toni Whited, Christian Wolf, Arlene Wong, and Mark Wright for helpful conversations. We also thank seminar audiences at many institutions for valuable feedback. Finally, we thank Alberto Arredondo, Mike Mei, Richard Ryan, Samuel Stern, Yuyao Wang, and Liangjie Wu for excellent research assistance. This research was funded in part by the Initiative on Global Markets at the University of Chicago Booth School of Business and the Michigan Institute for Teaching and Research in Economics.
1 Introduction

Aggregate investment is one of the most responsive components of GDP to monetary shocks. Our goal in this paper is to understand the role of financial frictions in determining this investment channel of monetary policy. Given the rich heterogeneity in financial positions across firms, a key question is: which firms are the most responsive to changes in monetary policy? The answer to this question is theoretically ambiguous. On the one hand, financial frictions generate an upward-sloping marginal cost curve for investment, which dampens the response of investment to monetary policy for firms more severely affected by financial frictions. On the other hand, monetary policy may flatten out this marginal cost curve – for example, by increasing cash flows or improving collateral values – which amplifies the response of investment for affected firms. This latter view is the conventional wisdom of the literature, often informed by applying the financial accelerator logic across firms.

We address the question of which firms respond the most to monetary policy using new cross-sectional evidence and a heterogeneous firm New Keynesian model. Our empirical work combines monetary shocks, measured using the high-frequency event-study approach, with quarterly Compustat data. We find that firms with low default risk – those with low debt burdens, good credit ratings, and large “distance to default” – are significantly and robustly more responsive to monetary policy than other firms in our sample. Motivated by this evidence, our model embeds a heterogeneous firm investment model with default risk into the benchmark New Keynesian environment and studies the effect of a monetary shock. Monetary policy stimulates investment by directly increasing the expected return on capital – which drives the response of low-risk firms – and indirectly increasing cash flows and improving collateral values – which drives the response of high-risk firms. In our calibrated model, as in the data, low-risk firms are more responsive to monetary policy, indicating that the direct effects dominate the indirect ones. These heterogeneous responses imply that the aggregate effect of a given monetary shock is smaller when default risk in the economy is high.

Our baseline empirical specification estimates how the semi-elasticity of a firm’s investment with respect to a monetary policy shock depends on three measures of the firm’s
financial position: leverage, credit rating, and distance to default (which infers the probability of default from the values of equity and liability under certain assumptions). We control for firm fixed effects – to capture permanent differences across firms – and sector-by-quarter fixed effects – to capture differences in how sectors respond to aggregate shocks. Conditional on our set of controls, leverage is negatively correlated with credit rating and distance to default, and distance to default is positively correlated with credit rating. Therefore, we view low leverage, high credit rating, and large distance to default as proxies for low default risk.

Our main empirical result is that investment by firms with low default risk is significantly and persistently more responsive to monetary policy shocks. Our estimates imply that, one quarter after a monetary shock, a firm with one standard deviation more leverage than the average firm is about one third less responsive than the average firm and a firm with one standard deviation larger distance to default is about two thirds more responsive. In addition, very highly rated firms – those with a rating above “A” from Standard & Poor’s – are more than two times more responsive than other firms. These differences across firms persist up to three years after the shock and imply large differences in accumulated capital over time.

Although we believe that our interpretation of these heterogeneous responses reflecting default risk is natural, we also provide three pieces of evidence that they are not driven by other firm-level characteristics. First, the results are not driven by permanent heterogeneity in financial positions because they hold using only within-firm variation in financial position. Second, our results are not driven by differences in past sales growth, realized future sales growth, size, or liquidity. Third, other unobservable factors are unlikely to drive our results because we find similar results if we instrument financial position with past financial position (which is likely more weakly correlated with unobservables).1

In order to interpret these empirical results, we embed a model of heterogeneous firms facing default risk into the benchmark New Keynesian framework. There is a group of heterogeneous firms who invest in capital using either internal funds or external borrowing;
these firms can default on their debt, leading to an external finance premium. There is also a group of retailer firms with sticky prices, generating a New Keynesian Phillips curve linking nominal variables to real outcomes. We calibrate the model to match key features of firms’ investment, borrowing, and lifecycle dynamics in the micro data. Our model generates realistic behavior along non-targeted dimensions of the data, such as measured investment-cash flow sensitivities. The peak responses of aggregate investment, output, and consumption to a monetary policy shock are in line the peak responses estimated in the data by Christiano, Eichenbaum and Evans (2005).

In our calibrated model, firms with low default risk are more responsive to monetary policy shocks than firms with high default risk, consistent with the data. These heterogeneous responses depend crucially on how monetary policy shifts the marginal cost of capital. On the one hand, firms with high default risk face a steeper marginal cost curve than other firms, which dampens their response to the shock. On the other hand, the marginal cost curve shifts more strongly for high-risk firms due to changes in cash flows and collateral values, which amplifies their response. This latter force is dominated by the former force in our calibrated model. We estimate our empirical specification on panel data simulated from our model and find that the coefficient capturing heterogeneous responses in our model is within one standard error of its estimate in the data.

Finally, we show that the aggregate effect of a given monetary shock depends on the distribution of default risk across firms. We perform a simple calculation which exogenously varies the initial distribution of firms in the period of the shock. A monetary shock will generate an approximately 25% smaller change in the aggregate capital stock starting from a distribution with 50% less net worth than the steady state distribution. Under the distribution with low average net worth, more firms have a high risk of default and are therefore less responsive to monetary policy. More generally, this calculation suggests a potentially important source of time-variation in monetary transmission: monetary policy is less powerful when more firms have risk of default.

**Related Literature** Our paper contributes to four key strands of literature. The first studies the transmission of monetary policy to the aggregate economy. Bernanke, Gertler
and Gilchrist (1999) embed the financial accelerator in a representative firm New Keynesian model and find that it amplifies the aggregate response to monetary policy. We build on Bernanke, Gertler and Gilchrist (1999)’s framework to include firm heterogeneity. Consistent with their results, we find that the response of aggregate investment to monetary policy is larger in our model than in a model without financial frictions at all. However, among the 96% of firms affected by financial frictions in our model, those with low risk of default are more responsive to monetary policy than those with high risk of default, generating an additional source of state dependence.

Second, we contribute to the literature that studies how the effect of monetary policy varies across firms. A number of papers, including Kashyap, Lamont and Stein (1994), Gertler and Gilchrist (1994), and Kashyap and Stein (1995) argue that smaller and presumably more credit constrained firms are more responsive to monetary policy along a number of dimensions. We contribute to this literature by showing that firms with low default risk are also more responsive to monetary policy. These characteristics are not highly correlated with firm size in our sample. In addition, we use a different empirical specification, identification of monetary policy shocks, sample of firms, and time period.\(^2\)

Recent work by Jeenas (2018) performs a similar empirical exercise and finds that low-leverage firms are more responsive to monetary shocks upon impact, consistent with our findings. However, Jeenas (2018) argues that this pattern reverses over time and that high-leverage firms eventually become significantly more responsive to the shock, in contrast with our results. We show in Appendix A.4 that this reversal at long horizons is primarily driven by permanent heterogeneity in how firms respond to monetary shocks. We control for permanent heterogeneity in responsiveness in our specification, which eliminates these reversals, because firms in our model are ex-ante homogeneous. In addition, we focus on heterogeneity in default

\(^2\)In a recent paper, Crouzet and Mehrotra (2017) find some evidence of differences in cyclical sensitivity by firm size during extreme business cycle events. Our work is complementary to their’s by focusing on the conditional response to a monetary policy shock and using our economic model to draw aggregate implications.

\(^3\)Ippolito, Ozdagli and Perez-Orive (2017) study how the effect of high-frequency shocks on firm-level outcomes depends on firms’ bank debt. In order to merge in data on bank debt, Ippolito, Ozdagli and Perez-Orive (2017) must focus on the 2004-2008 time period. Given this small sample, Ippolito, Ozdagli and Perez-Orive (2017) do not consistently find significant differences in investment responses across firms. In addition, Ippolito, Ozdagli and Perez-Orive (2017) use a different empirical specification and focus on stock prices as the main outcome of interest.
risk while Jeenas (2018) focuses on heterogeneity in liquidity. Appendix A.4 shows that the results in our specification are not driven by differences in liquidity across firms; in fact, liquidity becomes insignificant once we control for distance to default, although statistical tests are relatively weak given the correlation structure of these variables.

Third, we contribute to the literature which studies how incorporating micro-level heterogeneity into the New Keynesian model affects our understanding of monetary transmission. To date, this literature has focused on how household-level heterogeneity affects the consumption channel of monetary policy; see, for example, Auclert (2017); McKay, Nakamura and Steinsson (2015); Wong (2016); or Kaplan, Moll and Violante (2017). We instead explore the role of firm-level heterogeneity in determining the investment channel of monetary policy. In contrast to the heterogeneous-household literature, we find that both direct and indirect effects of monetary policy play a quantitatively important role in driving the investment channel. The direct effect of changes in the real interest rates are smaller for consumption than for investment because households attempt to smooth consumption while firms do not smooth investment over time.

Finally, we contribute to the literature studying the role of financial heterogeneity in determining the business cycle dynamics of aggregate investment. Our model of firm-level investment builds heavily on Khan, Senga and Thomas (2016), who study the effect of financial shocks in a flexible price model. We contribute to this literature by introducing sticky prices and studying the effect of monetary policy shocks. In addition, we extend Khan, Senga and Thomas (2016)’s model to include capital quality shocks and a time-varying price of capital in order to generate variation in the implicit collateral value of capital, as in the financial accelerator literature. Khan and Thomas (2013) and Gilchrist, Sim and Zakrajsek (2014) study related flexible-price models of investment with financial frictions. Our model is also related to Arellano, Bai and Kehoe (2016), who study the role of financial heterogeneity in determining employment decisions.

**Road Map** Our paper is organized as follows. Section 2 provides the empirical evidence that the firm-level response to monetary policy varies with default risk. Section 3 develops our heterogeneous firm New Keynesian model to interpret this evidence. Section 4 provides a
theoretical characterization of the channels through which monetary policy drives investment in our model. Section 5 then calibrates the model and verifies that it is consistent with key features of the joint distribution of investment and leverage in the micro data. Section 6 uses the model to study the monetary transmission mechanism. Section 7 concludes.

2 Empirical Results

We document that firms with low default risk – proxied by low debt burdens, good credit ratings, and high measured “distance to default” – are significantly more responsive to changes in monetary policy than are other firms in the economy.

2.1 Data Description

Our sample combines monetary policy shocks with firm-level outcomes from quarterly Compustat data.

Monetary Policy Shocks We measure monetary shocks using the high-frequency, event-study approach pioneered by Cook and Hahn (1989). Following Gurkaynak, Sack and Swanson (2005) and Gorodnichenko and Weber (2016), we construct our shock $\epsilon_t^m$ as

$$\epsilon_t^m = \tau(t) \times (ffr_{t+\Delta_+} - ffr_{t-\Delta_-}),$$

where $t$ is the time of the monetary announcement, $ffr_t$ is the implied Fed Funds Rate from a current-month Federal Funds future contract at time $t$, $\Delta_+$ and $\Delta_-$ control the size of the time window around the announcement, and $\tau(t)$ is an adjustment for the timing of the announcement within the month.\(^4\) We focus on a window of $\Delta_- = fifteen minutes before the announcement and $\Delta_+ = forty five minutes after the announcement. Our shock series begins in January 1990, when the Fed Funds futures market opened, and ends in December

\(^4\)This adjustment accounts for the fact that Fed Funds Futures pay out based on the average effective rate over the month. It is defined as $\tau(t) \equiv \frac{\tau_m^d(t)}{\tau_m^d(t) - \tau_m^m(t)}$, where $\tau_m^d(t)$ denotes the day of the meeting in the month and $\tau_m^m(t)$ the number of days in the month.
Table 1

Summary Statistics of Monetary Policy Shocks

<table>
<thead>
<tr>
<th></th>
<th>high frequency</th>
<th>smoothed</th>
<th>sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean</td>
<td>-0.0185</td>
<td>-0.0429</td>
<td>-0.0421</td>
</tr>
<tr>
<td>median</td>
<td>0</td>
<td>-0.0127</td>
<td>-0.00509</td>
</tr>
<tr>
<td>std</td>
<td>0.0855</td>
<td>0.108</td>
<td>0.124</td>
</tr>
<tr>
<td>min</td>
<td>-0.463</td>
<td>-0.480</td>
<td>-0.479</td>
</tr>
<tr>
<td>max</td>
<td>0.152</td>
<td>0.233</td>
<td>0.261</td>
</tr>
<tr>
<td>num</td>
<td>164</td>
<td>71</td>
<td>72</td>
</tr>
</tbody>
</table>

Notes: Summary statistics of monetary policy shocks. “High frequency” shocks are estimated using event study strategy in (1). “Smoothed” shocks are time aggregated to the quarterly frequency using the weighted average (2). “Sum” refers to time aggregating by simply summing all shocks within a quarter.

2007, before the financial crisis.\(^5\) During this time there were 183 shocks with a mean of approximately zero and a standard deviation of 9 basis points.\(^6\)

We time aggregate the high-frequency shocks to the quarterly frequency in order to merge them with our firm-level data. We construct a moving average of the raw shocks weighted by the number of days in the quarter after the shock occurs.\(^7\) Our time aggregation strategy ensures that we weight shocks by the amount of time firms have had to react to them. Table 1 indicates that these “smoothed” shocks have similar features to the original high-frequency shocks. For robustness, we will also use the alternative time aggregation of simply summing all the shocks that occur within the quarter, as in Wong (2016). Table 1 shows that the moments of these alternative shocks do not significantly differ from the moments of the smoothed shocks.

\(^5\)We stop in December 2007 to study a period of conventional monetary policy, which is the focus of our economic model.

\(^6\)In our economic model, we interpret our measured monetary policy shock as an innovation to a Taylor Rule. An alternative interpretation of the shock, however, is that it is driven by the Fed providing information to the private sector. We argue that the information component of Fed announcements does not drive our results in Appendix A.

\(^7\)Formally, the monetary-policy shock in quarter \(q\) is defined as

\[ \varepsilon_q^m = \sum_{t \in J(q)} \omega^a(t) \varepsilon_t^m + \sum_{t \in J(q-1)} \omega^b(t) \varepsilon_t^m \]  

(2)

where \(\omega^a(t) = \frac{r^q(t) - r^q(t)}{r^q(t)}\), \(\omega^b(t) = \frac{r^d(t)}{r^q(t)}\), \(r^d(t)\) denotes the day of the monetary-policy announcement in the quarter, \(r^n_q(t)\) denotes the number of days in the monetary-policy announcement’s quarter, and \(J(q)\) denote the set periods \(t\) contained in quarter \(q\).
Firm-Level Variables  We draw firm-level variables from quarterly Compustat, a panel of publicly listed U.S. firms. Compustat satisfies three key requirements for our study: it is quarterly, a high enough frequency to study monetary policy; it is a long panel, allowing us to use within-firm variation; and it contains rich balance-sheet information, allowing us to construct our key variables of interest. To our knowledge, Compustat is the only U.S. dataset that satisfies these three requirements. The main disadvantage of Compustat is that it excludes privately held firms which are likely subject to more severe financial frictions.8 In Section 5, we calibrate our economic model to match a broad sample of firms, not just those in Compustat.

Our main measure of investment is \( \Delta \log k_{jt+1} \), where \( k_{jt+1} \) is the book value of the firm’s tangible capital stock of firm \( j \) at the beginning of period \( t + 1 \). We use this log-difference specification because investment is highly skewed, suggesting a log-linear rather than level-linear regression specification. We use the net change in log capital rather than the log of gross investment because gross investment often takes negative values. In Appendix A, we show that our results hold for other measures of investment as well.

We use three different measures of a firm’s financial position to proxy for default risk. First, we measure leverage as the firm’s debt-to-asset ratio \( \ell_{jt} \), where debt is the sum of short term and long term debt and assets is the book value of assets. Second, we measure the firm’s credit rating \( cr_{jt} \) using S&P’s long-term issue rating of the firm. For most of the paper, we will summarize the firm’s credit rating using an indicator variable for whether it is at least an A rating, \( 1 \{ cr_{jt} \geq A \} \). Third, we measure the firm’s “distance to default” \( dd_{jt} \) following Gilchrist and Zakrajšek (2012). This measure uses the firm’s equity value to infer its asset value; given the value of liabilities and assumptions on firm-level shocks, it then backs out the implied probability of default. Distance to default \( dd_{jt} \) has been shown by Schaefer and Strebulaev (2008) to account well for variation in corporate bond prices and is widely used in the finance industry.

Appendix A.1 provides details of our data construction, which follows standard practice in

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8Crouzet and Mehrotra (2017) construct a non-public, high-quality quarterly panel using micro data from the Quarterly Financial Reports. A key advantage of this dataset is that covers a much broader set of firm sizes than Compustat. However, it only covers the manufacturing sector and only follows small firms for eight quarters, which limits the ability to use within-firm variation.
### Table 2
**Summary Statistics of Firm-Level Variables**

#### (a) Marginal Distributions

<table>
<thead>
<tr>
<th>Statistic</th>
<th>$\Delta \log k_{jt+1}$</th>
<th>$\ell_{jt}$</th>
<th>$I{cr_{jt} \geq A}$</th>
<th>$dd_{jt}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.005</td>
<td>0.267</td>
<td>0.024</td>
<td>5.744</td>
</tr>
<tr>
<td>Median</td>
<td>-0.004</td>
<td>0.204</td>
<td>0.000</td>
<td>4.704</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.093</td>
<td>0.361</td>
<td>0.154</td>
<td>5.032</td>
</tr>
<tr>
<td>95th Percentile</td>
<td>0.132</td>
<td>0.725</td>
<td>0.000</td>
<td>14.952</td>
</tr>
</tbody>
</table>

#### (b) Correlation Matrix (raw variables)

<table>
<thead>
<tr>
<th></th>
<th>$\ell_{jt}$</th>
<th>$I{cr_{jt} \geq A}$</th>
<th>$dd_{jt}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\ell_{jt}$</td>
<td>1.00</td>
<td></td>
<td>(0.00)</td>
</tr>
<tr>
<td>$I{cr_{jt} \geq A}$</td>
<td>-0.02</td>
<td>1.00</td>
<td>(0.00)</td>
</tr>
<tr>
<td>$dd_{jt}$</td>
<td>-0.46</td>
<td>0.21</td>
<td>1.00</td>
</tr>
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</table>

#### (c) Correlation matrix (residualized)

<table>
<thead>
<tr>
<th></th>
<th>$\ell_{jt}$</th>
<th>$I{cr_{jt} \geq A}$</th>
<th>$dd_{jt}$</th>
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</thead>
<tbody>
<tr>
<td>$\ell_{jt}$</td>
<td>1.00</td>
<td></td>
<td>(0.00)</td>
</tr>
<tr>
<td>$I{cr_{jt} \geq A}$</td>
<td>-0.02</td>
<td>1.00</td>
<td>(0.00)</td>
</tr>
<tr>
<td>$dd_{jt}$</td>
<td>-0.38</td>
<td>0.05</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Notes: summary statistics of firm-level outcome variables. $\Delta \log k_{jt+1}$ is the change in the capital stock. $\ell_{jt}$ is the ratio of total debt to total assets. $I\{cr_{jt} \geq A\}$ is an indicator variable for whether the firm’s credit rating is above an A. $dd_{jt}$ is the firm’s “distance to default,” constructed following Gilchrist and Zakrajšek (2012). Panel (a) computes the mean, median, standard deviation, and 95th percentile of each of these variables in our un-winsorized sample. Panel (b) computes the pairwise correlations between the measures of financial position $\ell_{jt}$, $I\{cr_{jt} \geq A\}$, and $dd_{jt}$. Panel (c) computes the pairwise correlations of the residuals from the regression

$$y_{jt} = \alpha_j + \alpha_{st} + \Gamma'_{1} Z_{jt-1} + e_{jt},$$

where $y_{jt} \in \{\ell_{jt}, I\{cr_{jt} \geq A\}, dd_{jt}\}$, where $\alpha_j$ is a firm fixed effect, $\alpha_{st}$ is a sector-by-quarter fixed effect, and $Z_{jt-1}$ is a vector of firm-level controls containing leverage, sales growth, size, current assets as a share of total assets, and an indicator for fiscal quarter.

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The investment literature. Panel (a) of Table 2 presents simple summary statistics of the final sample used in our analysis. The mean capital growth rate is roughly 0.5% quarterly with a standard deviation of 9.3%. The mean leverage ratio is approximately 27% with a cross-sectional standard deviation of 36%. The mean distance to default is implies a six standard deviation shock drives the average firm to default, in line with Gilchrist and Zakrajšek (2012). We winsorize our sample at the top and bottom 0.5% of observations of investment, leverage, and distance to default in order to ensure our results are not driven by outliers.

Panel (b) of Table 2 shows the cross-correlation structure of leverage, credit rating, and
distance to default. Higher leverage is positively correlated with lower credit ratings and a smaller distance to default, indicating that higher debt burdens are associated with higher default risk. Firms with higher distance to default also have higher credit ratings, consistent with the idea that credit ratings partly proxy for default risk. Panel (c) of Table 2 shows that these results are all also true conditional on the controls in our baseline regression specification (3) below.

2.2 Heterogeneous Responses to Monetary Policy

We will estimate variants of the baseline empirical specification

$$\Delta \log k_{jt+1} = \alpha_j + \alpha_{st} + \beta y_{jt-1} \varepsilon_t^m + \Gamma' Z_{jt-1} + e_{jt},$$

(3)

where $\alpha_j$ is a firm $j$ fixed effect, $\alpha_{st}$ is a sector $s$ by quarter $t$ fixed effect, $\varepsilon_t^m$ is the monetary policy shock, $y_{jt} \in \{\ell_{jt}, \mathbb{1} \{cr_{jt} \geq A\}, dd_{jt}\}$ is the firm’s leverage ratio, credit rating, or distance to default, $Z_{jt}$ is a vector of firm-level controls, and $e_{jt}$ is a residual.\(^9\) Our main coefficient of interest is $\beta$, which measures how the semi-elasticity of investment $\Delta \log k_{jt+1}$ with respect to monetary shocks $\varepsilon_t^m$ depends on the firm’s financial position $y_{jt}$.\(^10\) This coefficient estimate is conditional on a number of controls that may simultaneously affect investment and leverage, but which are outside the scope of our economic model in Section 3. First, firm fixed effects $\alpha_j$ capture permanent differences in investment behavior across firms. Second, sector-by-quarter fixed effects $\alpha_{st}$ capture differences in how broad sectors are exposed to aggregate shocks. Finally, the firm-level controls $Z_{jt}$ include the level of the financial position variable $y_{jt}$, total assets, sales growth, current assets as a share of total assets, and a fiscal quarter dummy. We cluster standard errors two ways in order to account for correlation within firms and within quarters. This clustering strategy is conservative, effectively leaving 71 time-series observations.

\(^9\)The sectors $s$ we consider are: agriculture, forestry, and fishing; mining; construction; manufacturing; transportation communications, electric, gas, and sanitary services; wholesale trade; retail trade; and services. We do not include finance, insurance, and real estate or public administration.

\(^10\)We lag both financial position $y_{jt-1}$ and the controls $Z_{jt-1}$ to ensure they are predetermined at the time of the monetary shock. Note that both $k_{jt+1}$ and $y_{jt}$ measure end-of-period values. We denote the end-of-period capital stock with $k_{jt+1}$ rather than $k_{jt}$ to be consistent with the standard notation in our economic model in Section 3.
Table 3

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
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<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
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</thead>
<tbody>
<tr>
<td>leverage $\times$ ffr shock</td>
<td>-0.66**</td>
<td>-0.52**</td>
<td>-0.50*</td>
<td>-0.47</td>
<td>-0.24</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>(0.27)</td>
<td>(0.25)</td>
<td>(0.25)</td>
<td>(0.39)</td>
<td>(0.38)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mathbb{1}{cr_{jt} \geq A} \times$ ffr shock</td>
<td>2.69**</td>
<td>2.41**</td>
<td></td>
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<tr>
<td></td>
<td>(1.16)</td>
<td>(1.19)</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>dd $\times$ ffr shock</td>
<td>1.06**</td>
<td>0.70</td>
<td>1.07**</td>
<td></td>
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<tr>
<td></td>
<td>(0.45)</td>
<td>(0.44)</td>
<td>(0.52)</td>
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<tr>
<td>ffr shock</td>
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</tr>
</tbody>
</table>

Observations            | 239259 | 239259 | 239259 | 151433 | 239259 | 151433 | 151433 |
$R^2$                   | 0.108 | 0.119 | 0.116 | 0.137 | 0.119 | 0.139 | 0.126 |
Firm controls           | no      | yes   | yes   | yes   | yes   | yes   | yes   |
Time sector FE          | yes     | yes   | yes   | yes   | yes   | yes   | no    |
Time clustering         | yes     | yes   | yes   | yes   | yes   | yes   | yes   |

Notes: results from estimating variants of the baseline specification

\[ \Delta \log k_{jt+1} = \alpha_j + \alpha_{st} + \beta y_{jt-1} \varepsilon^m_t + \Gamma' Z_{jt-1} + \epsilon_{jt}, \]

where $\alpha_j$ is a firm fixed effect, $\alpha_{st}$ is a sector-by-quarter fixed effect, $y_{jt} \in \{\ell_{jt}, \mathbb{1}\{cr_{jt} \geq A\}, dd_{jt}\}$ is either the firm’s leverage ratio, credit rating, or distance to default, $\varepsilon^m_t$ is the monetary shock, and $Z_{jt-1}$ is a vector of firm-level controls containing leverage, sales growth, size, current assets as a share of total assets, and an indicator for fiscal quarter. Standard errors are two-way clustered by firms and quarters. We have normalized the sign of the monetary shock $\varepsilon^m_t$ so that a positive shock is expansionary (corresponding to a decrease in interest rates). We have standardized leverage $\ell_{jt}$ and distance to default $dd_{jt}$ over the entire sample, so their units are in standard deviations relative to the mean.

Table 3 reports the results from estimating the baseline specification (3). We perform two normalizations to make the estimated coefficient $\beta$ easily interpretable. First, we standardize the firm’s leverage $\ell_{jt}$ and distance to default $dd_{jt}$ over the entire sample, so their units are standard deviations relative to their mean value in our sample. Second, we normalize the sign of the monetary shock $\varepsilon^m_t$ so that a positive value corresponds to a cut in interest rates.

The first four columns in Table 3 show that firms with lower proxies for default risk – lower leverage, better credit ratings, and higher distance to default – are more responsive to the monetary shocks $\varepsilon^m_t$. Column (1) reports the coefficient on leverage without the firm-level controls $Z_{jt-1}$ and implies that a firm with one standard deviation more leverage than the average firm has approximately a 0.65 units lower semi-elasticity of investment to monetary policy. Adding firm-level controls $Z_{jt-1}$ in Column (2) does not significantly change this point estimate, suggesting our results are not driven by unobserved heterogeneity that is...
correlated with our controls. Therefore, we focus on specifications with firm-level controls $Z_{jt-1}$ for the remainder of the paper. Column (3) shows that a firm with a credit rating greater than $A$ has a more than 2.5 units greater semi-elasticity. Finally, Column (4) shows that a firm with one standard deviation higher distance to default has an approximately 1 unit higher semi-elasticity.

Columns (5) and (6) in Table 3 show that these conclusions hold conditional on various combinations of financial position, but statistical power falls due to the correlated nature of the variables. Column (5) shows that jointly including leverage and credit rating only slightly changes their interaction coefficients, consistent with their low correlation in Table 2. In contrast, Column (6) shows that the coefficients on both leverage and distance to default become marginally insignificant once we jointly include both include leverage and distance to default, consistent with their strong correlation in Table 2.

A natural way to assess the economic significance of our estimated interaction coefficients $\beta$ is to compare them to the average effect of a monetary policy shock. However, in our baseline specification (3), the average effect is absorbed by the sector-by-quarter fixed effect $\alpha_{st}$. We relax this restriction by estimating

$$
\Delta \log k_{jt+1} = \alpha_j + \gamma \epsilon_{jt}^m + \beta y_{jt-1} \varepsilon_{jt}^m + \Gamma_1' Z_{jt-1} + \Gamma_2' Y_{t-1} + \varepsilon_{jt};
$$

where $Y_t$ is a vector of aggregate controls for GDP growth, the inflation rate, and the unemployment rate. Column (7) of Table 3 shows that the average investment semi-elasticity is roughly 1.6.$^{11}$ Hence, our interaction coefficients in the previous columns imply an economically meaningful degree of heterogeneity.

**Within-Firm Variation** In the economic model that we develop in Section 3, firms are ex-ante homogeneous and heterogeneity in default risk is generated ex-post due to lifecycle dynamics and idiosyncratic shocks. However, it is possible that the empirical results presented in Table 3 are instead driven by permanent heterogeneity in how firms respond to monetary

---

11Assuming an annual depreciation rate of $\delta = 0.1$, this estimated coefficient implies that a one percentage point cut in the interest rate increases annualized investment by 16%, in line with the upper end of estimated user-cost elasticities in the literature, for example, Zwick and Mahon (2017).
Table 4
Heterogeneous Responses Estimated Using Within-Firm Variation

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
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<tr>
<td>leverage × ffr shock</td>
<td>-0.81**</td>
<td>-0.68**</td>
<td>-0.33</td>
<td>-0.21</td>
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<tr>
<td></td>
<td>(0.31)</td>
<td>(0.28)</td>
<td>(0.37)</td>
<td>(0.38)</td>
<td></td>
</tr>
<tr>
<td>dd × ffr shock</td>
<td></td>
<td>1.10***</td>
<td>0.89**</td>
<td>1.12**</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.39)</td>
<td>(0.38)</td>
<td>(0.47)</td>
<td></td>
</tr>
<tr>
<td>ffr shock</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.64**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.77)</td>
</tr>
<tr>
<td>Observations</td>
<td>219702</td>
<td>219702</td>
<td>151433</td>
<td>151433</td>
<td>151433</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.113</td>
<td>0.124</td>
<td>0.137</td>
<td>0.139</td>
<td>0.126</td>
</tr>
<tr>
<td>Firm controls</td>
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<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
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<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Time clustering</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

Notes: results from estimating
\[
\Delta \log k_{jt+1} = \alpha_j + \alpha_{st} + \beta(y_{jt-1} - \mathbb{E}_j[y_{jt}])\varepsilon^m_t + \beta_2(y_{jt-1} - \mathbb{E}_j[y_{jt}])Y_{t-1} + \Gamma Z_{jt-1} + \varepsilon_{jt},
\]
where $\alpha_j$ is a firm fixed effect, $\alpha_{st}$ is a sector-by-quarter fixed effect, $y_{jt} \in \{\ell_{jt}, \text{dd}_{jt}\}$ is leverage or distance to default, $\mathbb{E}_j[y_{jt}]$ is the average of $y_{jt}$ for firm $j$ in the sample, $\varepsilon^m_t$ is the monetary shock, $Y_{t-1}$ is lagged GDP growth, and $Z_{jt-1}$ is a vector of firm-level controls containing leverage, sales growth, size, current assets as a share of total assets, and an indicator for fiscal quarter. Standard errors are two-way clustered by firms and quarter. We have normalized the sign of the monetary shock $\varepsilon^m_t$ so that a positive shock is expansionary (corresponding to a decrease in interest rates). We have standardized within-firm leverage $(\ell_{jt} - \mathbb{E}[\ell_{jt}])$ and within-firm distance to default $(\text{dd}_{jt} - \mathbb{E}[\text{dd}_{jt}])$ over the entire sample, so their units are in standard deviations relative to the mean.

policy according to their financial position $y_{jt}$, breaking the tight link between default risk and shock responsiveness in our model. In order to ensure our results are not driven by permanent heterogeneity, we estimate the specification:

\[
\Delta \log k_{jt+1} = \alpha_j + \alpha_{st} + \beta(y_{jt-1} - \mathbb{E}_j[y_{jt}])\varepsilon^m_t + \Gamma_1 Z_{jt-1} + \Gamma_2(y_{jt-1} - \mathbb{E}_j[y_{jt}])Y_{t-1} + \varepsilon_{jt},
\]
where $\mathbb{E}_j[y_{jt}]$ is the average value of financial position $y_{jt}$ of firm $j$ in our sample and $Y_{t-1}$ is lagged GDP growth.$^{12}$ Permanent heterogeneity in financial position is differenced out of the interaction $(y_{jt-1} - \mathbb{E}_j[y_{jt}])\varepsilon^m_t$ and the heterogeneous responses are identified from temporary variation in financial position within a firm.$^{13}$

\[\text{Note: Our sample selection focuses on firms with at least forty quarters of data in order to precisely estimate the within-firm mean } \mathbb{E}_j[y_{jt}].\]

\[\text{Note: We add the interaction of } (y_{jt-1} - \mathbb{E}_j[y_{jt}]) \text{ with lagged GDP growth } Y_{t-1} \text{ in order to control for differences in cyclical sensitivities across firms. While this control is unimportant for the impact effect of the shock, we show below that there are significant differences in cyclical sensitivities at longer horizons. Not controlling}\]
Table 4 shows that the heterogeneous responses become stronger when using within-firm variation in financial position. We estimate the specification (5) only for leverage $\ell_{jt}$ and distance to default $dd_{jt}$ because the within-firm variation in credit rating is small. We standardize the demeaned variables $(y_{jt} - E[y_{jt}])$ so that their units are comparable to the previous specification (3). Column (2) shows that a firm with a one standard deviation within-firm increase in leverage has a 0.68 units lower semi-elasticity, compared to 0.52 in the baseline specification (3). Column (3) shows that a firm with a one standard deviation within-firm increase in distance to default has a 1.1 units higher semi-elasticity, compared to 1.06 in the previous specification. Furthermore, Column (4) shows that controlling for distance to default renders the coefficient on leverage insignificant. This result indicates that the heterogeneous responses within-firm are primarily driven by distance to default, which we view as our most direct measure of default risk.

Dynamics In order to estimate the dynamics of these differential responses across firms, we run the Jorda (2005)-style local projection of specification (5):

$$\log k_{jt+h} - \log k_{jt} = \alpha_{jh} + \alpha_{sth} + \beta_h (y_{jt-1} - E[y_{jt}])\varepsilon_t^{th} + \Gamma_{1h} Z_{jt-1} + \Gamma_{2h} (y_{jt-1} - E[y_{jt}])Y_{t-1} + \varepsilon_{jth}, \tag{6}$$

where $h \geq 1$ indexes the forecast horizon. The coefficient $\beta_h$ measures how the cumulative response of investment in quarter $t + h$ to a monetary policy shock in quarter $t$ depends on the firm’s financial position $y_{jt}$ in quarter $t - 1$. We estimate the local projection (6) separately for demeaned leverage $\ell_{jt}$ and demeaned distance to default $dd_{jt}$.

Figure 1 shows that firms with low-leverage and high-distance to default are consistently more responsive to the shock up to three years after the shock. Panel (a) shows that the peak of the differences by leverage occurs after four quarters and the differences disappear after twelve quarters. Panel (b) shows that the differences by distance to default are larger and significantly more persistent than for leverage. However, in both cases the long-run differences are imprecisely estimated with large standard errors. We focus on the impact effect of the shock for the rest of the paper because it is precisely estimated and is robust to for these interactions does not significantly affect the point estimates of the dynamics but leads to wider standard errors. See Appendix A.3 for details.
**Figure 1: Dynamics of Differential Response to Monetary Shocks**

(a) Leverage  
(b) Distance to Default

Notes: dynamics of the interaction coefficient between leverage and monetary shocks over time. Reports the coefficient \( \beta_h \) over quarters \( h \) from

\[
\log k_{j,t+h} - \log k_{j,t} = \alpha_j + \alpha_{sth} + \beta_h(y_{jt-1} - \mathbb{E}[y_{jt}])\varepsilon_{jt}^{m} + \Gamma_{j,t-1}^{m}Z_{jt-1} + \Gamma_{j,t}^{m}(y_{jt-1} - \mathbb{E}[y_{jt}])Y_{t-1} + \epsilon_{jt},
\]

where \( \alpha_j \) is a firm fixed effect, \( \alpha_{sth} \) is a sector-by-quarter fixed effect, \( y_{jt} \in \{\ell_{jt}, dd_{jt}\} \) is either the firm’s leverage ratio or distance to default, \( \mathbb{E}[y_{jt}] \) is the average of \( y_{jt} \) for firm \( j \) in the sample, \( \varepsilon_{jt}^{m} \) is the monetary shock, \( Z_{jt-1} \) is a vector of firm-level controls containing leverage, sales growth, size, current assets as a share of total assets, and an indicator for fiscal quarter, and \( Y_{t-1} \) is GDP growth. Standard errors are two-way clustered by firms and time. Dashed lines report 90% error bands. We have normalized the sign of the monetary shocks \( \varepsilon_{jt}^{m} \) so that a positive shock is expansionary (corresponding to a decrease in interest rates). We have standardized within-firm leverage \( (\ell_{jt} - \mathbb{E}[\ell_{jt}]) \) and within-firm distance to default \( (dd_{jt} - \mathbb{E}[dd_{jt}]) \) over the entire sample, so their units are in standard deviations relative to the mean.

a broader set of modeling choices than are the dynamics.

Recent work by Jeenas (2018) performs a similar empirical exercise and argues that low-leverage firms become significantly less responsive to monetary policy over time, in contrast with the insignificant dynamics in Figure 1. Appendix A.4.1 replicates the spirit of his result and argues that the difference between our results is accounted for by permanent heterogeneity in responsiveness across firms. Jeenas (2018) sorts firms based on their average leverage over the past year, which averages over high-frequency variation in leverage and implies that the estimated high-order dynamics are largely driven by permanent heterogeneity. While such permanent heterogeneity in responsiveness is certainly interesting to study, it is outside the scope of the economic model in this paper. Ultimately, we focus most of our analysis on the heterogeneous responses upon impact, which are robustly estimated in both our specification and Jeenas (2018).\(^{14}\)

\(^{14}\)Appendix A.4 also shows that our results are robust to two additional concerns raised by Jeenas (2018)’s
Ruling Out Alternative Drivers of Heterogeneous Responses  
We have interpreted the results so far to show that heterogeneity in default risk is a key driver of the heterogeneous responses to monetary policy across firms. Appendix A.2 provides evidence against two competing hypotheses. First, it shows that our results continue to hold when we control for the interaction of the monetary policy shock with firms’ sales growth, future sales growth, size, or liquidity, ruling out the possibility that our results are driven by some other observable that is simply mechanically correlated with default risk. Second, it shows that our results are stronger when we instrument current leverage or distance to default with their lagged values, providing evidence against the possibility that unobservables which are contemporaneously correlated with leverage drive our results.

Additional Results  
Appendix A.3 contains three sets of results that provide additional analysis of the results presented in this section. The first set of additional results shows robustness with respect to our measure of the monetary policy shock $\varepsilon_t^m$. First, we show that the heterogeneous responses are driven by expansionary rather than contractionary shocks, although the two are not statistically distinguishable from each other. Second, it argues that our results are driven by the effect of monetary announcements on the realized short rate – as in our economic model – and not on expectations of the path of future rates. Third, it shows that our results hold in the post-1994 sample, after which the Fed began making formal policy announcements. Fourth, it shows that our results are robust to an alternative time-aggregation of the shocks.

The second set of additional results shows robustness with respect to our measure of firm-level characteristics. First, it shows that the results are robust to controlling for lagged investment. Second, it shows that the results hold for various definitions of leverage based on debt net of current assets, leverage computed using only short-term debt, using only long-term debt, or using only other liabilities. Third, it explores heterogeneity in responses by other common measures of financial constraints: size, cash flows, dividend payments, and

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*analysis. First, Appendix A.4.2 shows that our results are not driven by heterogeneity in liquidity across firms; in fact, once we control for distance to default, we find that there are no significant differences by liquidity in our specification, although statistical tests are weak given the two variables are positively correlated. Second, Appendix A.4.3 shows that our results are not driven by outliers or non-standard choices about trimming the data.*
liquidity. Overall, the interaction between these variables is weaker than the interactions with leverage and credit ratings. Nonetheless, larger firms, firms with higher cash flows, dividend-paying firms, and firms with high liquidity – characteristics typically associated with less severe financial frictions – are more responsive to monetary policy shocks. Fourth, it shows that our results also hold when using an extensive margin measure of investment.

The third set of additional results shows that the heterogeneous responses are not driven by differences in cyclical sensitivities across firms. However, as mentioned in Footnote 13, we do find that there are nevertheless significant differences in cyclical sensitivities at longer horizons (which we control for in Figure 1). We show that not controlling for these differences does not significantly affect our point estimate of the dynamics but leads to even wider standard errors.

3 Model

We now develop a heterogeneous firm New Keynesian model in order to interpret the cross-sectional evidence in Section 2 and draw out aggregate implications. We describe the model in three blocks: an investment block, which captures heterogeneous responses to monetary policy; a New Keynesian block, which generates a Phillips curve; and a representative household, which closes the model.

3.1 Investment Block

The investment block contains a fixed mass of heterogeneous production firms that invest in capital subject to financial frictions. It builds heavily on the flexible-price model developed in Khan, Senga and Thomas (2016). Besides incorporating sticky prices, we extend Khan, Senga and Thomas (2016)’s framework in three additional ways. First, we add idiosyncratic capital quality shocks, which help us match observed default rates. Second, we incorporate aggregate adjustment costs in order to generate time-variation in the relative price of capital. Third, we assume that new entrants have lower initial productivity than average firms, which helps us match lifecycle dynamics.
**Production firms**  Time is discrete and infinite. There is no aggregate uncertainty; in Sections 4 and 6 below, we study the transition path in response to an unexpected monetary shock. Each period, there is a fixed mass 1 of production firms.\(^\text{15}\) Each firm \(j \in [0, 1]\) produces an undifferentiated good \(y_{jt}\) using the production function

\[
y_{jt} = z_{jt} (\omega_{jt} k_{jt})^\theta n_{jt}^\nu,
\]

where \(z_{jt}\) is an idiosyncratic total factor productivity shock, \(\omega_{jt}\) is an idiosyncratic capital quality shock, \(k_{jt}\) is the firm’s capital stock, \(n_{jt}\) is the firm’s labor input, and \(\theta + \nu < 1\). The idiosyncratic TFP shock follows an log-AR(1) process

\[
\log z_{jt+1} = \rho z_{jt} + \varepsilon_{jt+1}, \text{ where } \varepsilon_{jt+1} \sim N(0, \sigma^2).
\]

The capital quality shock is i.i.d. across firms and time and follows the log-normal process\(^\text{16}\)

\[
\log \omega_{jt} \sim N\left(-\frac{\sigma^2}{2}, \sigma^2\right).
\]

The capital quality shock also affects the value of the firm’s undepreciated capital at the end of the period, \((1 - \delta)\omega_{jt} k_{jt}\).

The timing of events within period is as follows.

(i) With probability \(\pi_d\) the firm receives an i.i.d. exit shock and must exit the economy after producing. Firms that do not receive the exit shock will be allowed to continue into the next period.

(ii) The firm decides whether or not to default. If the firm defaults it immediately and permanently exits the economy. In the event of default, lenders recover a fraction of the firm’s capital stock (described in more detail below) and the remaining capital is transferred lump-sum to the household. In order to continue, the firm must pay back

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\(^\text{15}\) We describe the entry and exit process below, which keeps the total mass of firms fixed.

\(^\text{16}\) We additionally assume that the idiosyncratic shock processes are bounded, which is important in our definition of unconstrained firms below. The idiosyncratic TFP shock is constrained to be in the interval \([-2.5\sigma_{zt}, 2.5\sigma_{zt}]\) and the capital quality shock is in the interval \([-2.5\sigma_{\omega}, 2.5\sigma_{\omega}]\).
the face value of its outstanding debt, \( b_{jt} \), and pay a fixed operating cost \( \xi \) in units of the final good.

(iii) Continuing firms produce using the production function (7). In order to produce, firms hire labor \( n_{jt} \) from a competitive labor market with real wage \( w_t \). Firms sell their output to retailers (described below) in a competitive market at relative price \( p_t \). At this point, firms that received the i.i.d. exit shock sell their undepreciated capital and exit the economy.

(iv) Continuing firms purchase new capital \( k_{jt+1} \) at relative price \( q_t \). Firms have two sources of investment finance, each of which is subject to a friction. First, firms can issue new nominal debt with real face value \( b_{jt+1} = \frac{B_{jt+1}}{\Pi_{t+1}} \), where \( B_{jt+1} \) is the nominal face value and \( \Pi_{t+1} \) is realized inflation on the final good (which is our numeraire, described below). Lenders offer a price schedule \( Q_t(z_{jt}, k_{jt+1}, b_{jt+1}) \). The price schedule is decreasing in the amount of borrowing \( b_{jt+1} \) because firms may default on this borrowing (we derive this price schedule below). Second, firms can use internal finance by lowering dividend payments \( d_{jt} \) but cannot issue new equity, which bounds dividend payments \( d_{jt} \geq 0 \).\(^{17}\)

We write the firm’s optimization problem recursively. The individual state variable of a firm is its total factor productivity \( z \) and “cash on hand”

\[
x = \max_n p_t z(\omega k)^\theta n^\nu - w_t n + q_t(1 - \delta) \omega k - b - \xi.
\]

Cash on hand \( x \) is the total amount of resources available to the firm other than additional borrowing. Conditional on continuing, the real equity value \( v_t(z, x) \) solves the Bellman equa-

\(^{17}\)The non-negative dividend constraint captures two key facts about external equity documented in the corporate finance literature. First, firms face significant costs of issue new equity, both direct flotation costs (see, for example, Smith (1977)) and indirect costs (for example, Asquith and Mullins (1986)). Second, firms issue external equity very infrequently (DeAngelo, DeAngelo and Stulz (2010)). The specific form of the non-negativity constraint is widely used in the macro literature because it allows for efficient computation of the model in general equilibrium. Other potential assumptions include proportional costs of equity issues (e.g., Gomes, 2001; Cooley and Quadrini, 2001; Hennessy and Whited, 2005; Gilchrist, Sim and Zakrajsek, 2014) and quadratic costs (e.g., Hennessy and Whited, 2007).
\[ v_t(z, x) = \max_{k', b'} x - q_t k' + Q_t(z, k', b') b' + \mathbb{E}_t \left[ \Lambda_{t+1} \left( \pi_d \chi^1 (x') x' + (1 - \pi_d) \chi^2_{t+1} (z', x') v_{t+1}(z', x') \right) \right] \]

such that \( x - q_t k' + Q_t(z, k', b') b' \geq 0 \) \hspace{1cm} (9)

\[ x' = \max_{n'} p_{t+1} z'(\omega' k')^{\theta}(n')^\nu - w_{t+1} n' + q_{t+1} (1 - \delta) \omega' k' - \frac{b'}{\Pi_{t+1}} - \xi, \]

where \( \chi^1 (x) \) and \( \chi^2_{t}(z, x) \) are indicator variables for default conditional on the realization of the exit shock.

**Proposition 1.** Consider a firm at time \( t \) that is eligible to continue into the next period, has idiosyncratic productivity \( z \), and has cash on hand \( x \). The firm’s optimal decision is characterized by one of the following three cases.

(i) **Default**: there exists a threshold \( \underline{x}_t (z) \) such that the firm defaults if \( x < \underline{x}_t (z) \).

(ii) **Unconstrained**: there exists a threshold \( \bar{x}_t (z) \) such that the firm is financially unconstrained if \( x > \bar{x}_t (z) \). Unconstrained firms follow the “frictionless” capital accumulation policy \( k'_t(z, x) = k^*_t(z) \). Unconstrained firms are indifferent over any combination of \( b' \) and \( d \) such that they remain unconstrained for every period with probability one.

(iii) **Constrained**: firms with \( x \in [\underline{x}_t (z), \bar{x}_t (z)] \) are financially constrained. Constrained firms’ optimal investment \( k'_t(z, x) \) and borrowing \( b'_t(z, x) \) decisions solve the Bellman equation (9). Constrained firms also pay zero dividends, which implies

\[ q_t k' = x + Q_t(z, k', b'). \]

**Proof.** See Appendix B.1.

Proposition 1 characterizes the decision rules which solve this Bellman equation. Firms with low cash on hand \( x < \underline{x}_t (z) \) default because they cannot satisfy the non-negativity condition\(^{18}\)

\(^{18}\)Firms which receive the exogenous exit shock have simple decision rules. Those that do not default simply sell their undepreciated capital after production. Since these firms cannot borrow, they default whenever cash on hand \( x < 0 \).
constraint on dividends \( d \geq 0 \). Firms with high cash on hand \( x > \pi_t(z) \) are \textit{financially unconstrained} in the sense that they have no probability of default, which implies that any combination of external financing \( b' \) and internal financing \( d \) which leaves them unconstrained is optimal. Finally, firms with cash on hand \( x \in [\pi_t(z), \pi_t(z)] \) are \textit{financially constrained} in the sense that they affected by default risk. These firms set \( d = 0 \) because the value of resources inside the firm, used to lower borrowing costs, is higher than the value of resources outside the firm. Over 96% of firms in our calibration are affected by default risk in this way. Below, we focus our analysis on how these firms respond to monetary policy, since the analysis of the unconstrained firms is fairly standard. It is important to note that these constrained firms can be either \textit{risky constrained} – have a positive probability of default in the next period – or \textit{risk-free constrained} – have no probability of default in the next period yet not be financially unconstrained.

**Lenders** There is a representative financial intermediary that lends resources from the representative household to firms at the firm-specific price schedule \( Q_t(z, k', b') \). If the firm defaults on the loan in the following period, the lender recovers a fraction \( \alpha \) of the market value of the firm’s capital stock \( q_{t+1}\omega'k' \). The price schedule prices this default risk competitively:

\[
Q_t(z, k', b') = E_t \left[ \Lambda_{t+1} \left\{ \frac{1}{\Pi_{t+1}} - \left( \pi_d \chi^1(x') + (1 - \pi_d) \chi^2_{t+1}(z', x') \right) \left( \frac{1}{\Pi_{t+1}} - \min \left\{ \frac{\alpha q_{t+1}(1 - \delta) \omega'k'}{b'/\Pi_{t+1}}, 1 \right\} \right) \right\},
\]

where \( x' = \max_n p_{t+1} z(\omega'k')^\theta (n')^\nu - w_t n' + q_{t+1}(1 - \delta) \omega'k' - b' - \xi \) is the cash on hand implied by \( k', b' \), and the realization of \( z' \).

**Entry** Each period, a mass \( \Pi_t \) of new firms enter the economy. We assume that the mass of new entrants is equal to the mass of firms that exit the economy so that the total mass of production firms is fixed in each period \( t \). Each of these new entrants \( j \in [0, \Pi_t] \) draws an idiosyncratic productivity shock \( z_{jt} \) from the time-invariant distribution

\[
\mu_{\text{ent}}(z) \sim \log N \left( -m \frac{\sigma}{\sqrt{(1 - \rho^2)}}, s \frac{\sigma}{\sqrt{(1 - \rho^2)}} \right),
\]
where \( m \geq 0 \) and \( s \geq 0 \) are parameters. We calibrate these parameters to match the average size and growth rates of new entrants, motivated by the evidence in Foster, Haltiwanger and Syverson (2016) that young firms have persistently low levels of measured productivity.\(^{19}\) New entrants also draw capital quality from its ergodic distribution, are endowed with \( k_0 \) units of capital from the household, and have zero units of debt. They then proceed as incumbent firms.

### 3.2 New Keynesian Block

The New Keynesian block of the model is designed to parsimoniously generate a New Keynesian Phillips curve relating nominal variables to the real economy. Following Bernanke, Gertler and Gilchrist (1999), we keep the nominal rigidities separate from the investment block of the model.

**Retailers and Final Good Producer** There is a fixed mass of retailers \( i \in [0, 1] \). Each retailer produces a differentiated variety \( \widetilde{y}_{it} \) using the heterogeneous production firms’ good as its only input:

\[
\widetilde{y}_{it} = y_{it},
\]

where \( y_{it} \) is the amount of the undifferentiated good demanded by retailer \( i \). Retailers set a relative price for their variety \( \widetilde{p}_{it} \) but must pay a quadratic price adjustment cost

\[
\frac{\gamma}{2} \left( \frac{\widetilde{p}_{it}}{\bar{p}_{it-1}} - 1 \right)^2 Y_t,
\]

where \( Y_t \) is the final good. The retailers’ demand curve is generated by the representative final good producer, who has production function

\[
Y_t = \left( \int \frac{\gamma - 1}{\gamma} \frac{\gamma - 1}{\gamma} \frac{\gamma - 1}{\gamma} \frac{\gamma - 1}{\gamma} \right),
\]

where \( \gamma \) is the elasticity of substitution over intermediate goods. The final good is the numeraire.

The retailers and final good producers aggregate into the familiar New Keynesian Phillips

\(^{19}\)Foster, Haltiwanger and Syverson (2016) argue that these low levels of measured productivity among young firms demand across firms rather than physical productivity. We remain agnostic about the interpretation of TFP in our model. Without the assumption that entrants have lower average productivity than existing firms, default risk would be disproportionately concentrated in a small group of young firms.
Curve:

\[
\log \Pi_t = \frac{\gamma - 1}{\varphi} \log \frac{p_t}{p^*} + \beta \mathbb{E}_t \log \Pi_{t+1},
\]  

(11)

where \( \Pi_t \) is gross inflation of the final good and \( p^* = \frac{\gamma - 1}{\varphi} \) is the steady state relative price of the heterogeneous production firm output.\(^{20}\) The Phillips Curve links the New Keynesian block to the investment block through the relative price \( p_t \). When aggregate demand for the final good \( Y_t \) increases, retailers must increase production of their differentiated goods because of the nominal rigidities; this force increases demand for the production firms good \( y_{it} \), which increases its relative price \( p_t \) and generates inflation through the Phillips Curve (11).

**Capital Good Producer**  There is a representative capital good producer who produces aggregate capital \( K_{t+1} \) using the technology

\[
K_{t+1} = \Phi\left( \frac{I_t}{K_t} \right) K_t + (1 - \delta) K_t,
\]  

(12)

where \( \Phi\left( \frac{I_t}{K_t} \right) = \left( \frac{I_t}{K_t} \right)^{\frac{\delta^1}{1-\phi}} - \frac{\delta}{\phi-1} \) and \( I_t \) are units of the final good used to produce capital.\(^{21}\) Profit maximization pins down the relative price of capital as

\[
q_t = \frac{1}{\Phi\left( \frac{I_t}{K_t} \right)} = \left( \frac{I_t/K_t}{\delta} \right)^{1/\phi}.
\]  

(13)

**Monetary Authority**  The monetary authority sets the nominal risk-free interest rate \( R^\text{nom}_t \) according to the Taylor rule

\[
\log R^\text{nom}_t = \log \frac{1}{\beta} + \varphi_\pi \log \Pi_t + \varepsilon^m_t, \text{ where } \varepsilon^m_t \sim N(0, \sigma^2_m),
\]

where \( \varphi_\pi \) is the weight on inflation in the reaction function, and \( \varepsilon^m_t \) is the monetary policy shock.

\(^{20}\)We focus directly on the linearized formulation for computational simplicity.

\(^{21}\)We use external adjustment costs rather than internal adjustment costs for two reasons. First, external adjustment costs generate time-variation in the price of capital, which allows us to study changes in the collateral value of capital. Second, because capital is liquid at the firm level, we can reduce the number of individual state variables, which is useful in the computation of the model.
3.3 Representative Household and Equilibrium

There is a representative household with preferences over consumption $C_t$ and labor supply $N_t$ represented by the expected utility function

$$E_0 \sum_{t}^{\infty} \beta^t (\log C_t - \Psi N_t),$$

where $\beta$ is the discount factor and $\Psi$ controls the disutility of labor supply. The household owns all firms in the economy. The stochastic discount factor and nominal interest rate are linked through the Euler equation for bonds, $\Lambda_{t+1} = \frac{1}{R_{t, t+1}}$.

An equilibrium involves a set of value functions $v_t(z, x)$; decision rules $k_t'(z, x)$, $b_t'(z, x)$, $n_t(z, x)$; measure of firms $\mu_t(z, \omega, k, b)$; debt price schedule $Q_t(z, k', b')$; and prices $w_t, q_t, p_t, \Pi_t, \Lambda_{t, t+1}$ such that (i) all firms optimize, (ii) lenders price default risk competitively, (iii) the household optimizes, (iii) the distribution of firms is consistent with decision rules, and (iv) all markets clear. Appendix B.2 precisely defines an equilibrium of our model.

4 Channels of Monetary Transmission

Before performing the quantitative analysis, we theoretically characterize the channels through which monetary policy affects investment in our model. This exercise identifies the key sources of heterogeneous responses across firms, which motivates our calibration in Section 5.

Monetary policy experiment We study the effect an unexpected innovation to the Taylor rule $\varepsilon_t^m$ followed by a perfect foresight transition back to steady state. This approach allows for clean analytical results because there is no distinction between ex-ante expected real interest rates and ex-post realized real interest rates. We focus on financially constrained firms as defined in Proposition 1, which make up more than 96% of the firms in our calibration.
Impact on decision rules  The optimal choice of investment $k'$ and borrowing $b'$ satisfy the following two conditions:

$$ q_t k' = x + \frac{1}{R_t(z, k', b')} b' \tag{14} $$

$$ \left(q_t - \varepsilon_{R,k'}(z, k', b') \frac{b'}{k'} \right) \frac{R_{t+1}^p(z, k', b')}{1 - \varepsilon_{R,b'}(z, k', b')} = \frac{1}{R_t} \mathbb{E}_t [\text{MRPK}_{t+1}(z', k')] \tag{15} $$

where $R_t$ is the risk-free rate between $t$ and $t + 1$, $R_t(z, k', b') = R_t(z, k', b')/R_t$ is a measure of the borrowing spread, $\varepsilon_{R,k'}(z, k', b')$ is the elasticity of the interest rate schedule with respect to investment $k'$, $R_{t+1}^p(z, k', b') = R_t(z, k', b')/R_t$ is a measure of the borrowing spread, $\varepsilon_{R,b'}(z, k', b')$ is the elasticity of the debt price schedule with respect to borrowing, $\text{MRPK}_{t+1}(z, k', b') = \frac{\partial}{\partial k'} (\max_{n'} p_{t+1} z' (\omega' k')^q (n')^q - w_{t+1} n' + q_{t+1} (1 - \delta) \omega' k')$ is the return on capital to the firm, $\lambda_t(z, k, b)$ is the Lagrange multiplier on the non-negativity constraint on dividends, and $\underline{z}_t(k, b)$ is the default threshold in terms of productivity (which inverts the cash-on-hand threshold defined in Proposition 1). Condition (14) is the non-negativity constraint on dividends, which implies that capital expenditures $q_t k'$ must be financed either by internal resources $x$ or new borrowing $\frac{1}{R_t(z, k', b')} b'$. Condition (15) is the intertemporal Euler equation, which equates the marginal cost of new capital $k'$ on the left-hand side with the marginal benefit on on the right-hand side. The expectation and covariances in this expression are only taken over the states in which the firm does not default.

The marginal cost of capital is the product of two terms. The first term, $q_t - \varepsilon_{R,k'}(z, k', b') \frac{b'}{k'}$, is the relative price of new investment $q_t$ net of the interest savings due to higher capital, $\varepsilon_{R,k'}(z, k', b') \frac{b'}{k'}$. The interest savings result from the fact that, all else equal, higher capital decreases expected losses due to default to the lenders. The second term in the marginal cost of capital is related to borrowing costs, $\frac{R_{t+1}^p(z, k', b')}{1 - \varepsilon_{R,b'}(z, k', b')}$. Borrowing costs enter the marginal cost of capital because borrowing is the marginal source of investment finance for these constrained firms. A higher interest rate spread or slope of that spread result in higher borrowing costs.
The marginal benefit of capital is the sum of three terms. The first term, $\frac{1}{R_t}E_t [\text{MRPK}_{t+1}(z', k')]$, is the expected return on capital discounted by the real interest rate.\(^{22}\) The second term,$\frac{1}{R_t} \frac{\text{Cov}_t(\text{MRPK}_{t+1}(z', k'), 1+\lambda_{t+1}(z', k', b'))}{E_t[1+\lambda_{t+1}(z', k', b')]}$, captures the covariance of the return on capital with the firm’s shadow value of resources; capital is more valuable to the firm if it pays a high return when the firm values additional resources. The third term, $\frac{1}{R_t} v_t^0(\bar{z}_{t+1}(k', b')) g(\bar{z}_{t+1}(k', b'))\left( \frac{\partial \bar{z}_{t+1}(k', b')}{\partial k'} - \frac{\partial \bar{z}_{t+1}(k', b')}{\partial b'} \right)$, captures how the additional investment affects the firm’s default probabilities and, therefore, the value of the firm. In our calibration, this term is negligible because the value of the firm close to the default threshold, $v_t^0(\bar{z}_{t+1}(k', b'))$, is essentially zero.

Figure 2 plots the marginal benefit and marginal cost schedules as a function of capital accumulation $k'$. In order to illustrate the key economic mechanisms, we compare how these curves shift following an expansionary monetary policy shock for two polar examples of firms. These firms share the same level of productivity but differ in their initial cash on hand; the first firm has high cash on hand and is currently risk-free (though it is still constrained in the sense of Proposition 1), while the second has low cash on hand and is risky constrained.

\(^{22}\)Firms discount using the risk-free rate because there is no aggregate risk.
**Risk-Free Firm**  The left panel of Figure 2 plots the two schedules for the risk-free firm. The marginal cost curve is flat when capital accumulation \( k' \) can be financed without incurring default risk and becomes upward sloping when investment is so large that the borrowing required creates default risk and therefore a credit spread. The marginal benefit curve is downward sloping due to diminishing returns of capital. In the initial equilibrium, the firm is risk-free because the two curves intersect in the flat region of the marginal cost curve.

The expansionary monetary shock shifts both the marginal benefit and marginal cost curves. The marginal benefit curves shifts out for two reasons. First, the shock decreases the real interest rate, which decreases the firm's discount rate \( R_t \) and therefore increases the discounted return on capital. Second, the shock also changes the relative price of output \( p_{t+1} \), the real wage \( w_t \), and the relative price of undepreciated capital \( q_{t+1} \) due to general equilibrium. In our calibration, these changes increase the return on capital \( MRPK_{t+1}(z, k', b') \) and therefore further shift out the marginal benefit curve.\(^{23}\)

The expansionary shock also shifts up the marginal cost curve because the increase in investment demand increases the relative price of capital \( q_t \). In the new equilibrium, the firm has increased its investment and remains risk-free because the marginal benefit and marginal cost curves still intersect along the flat region of marginal cost.

**Risky Firm**  The right panel of Figure 2 plot how the marginal benefit and marginal cost schedules shift for the risky firm. Because this firm has low initial cash on hand \( x \), it needs to borrow more than the risk-free firm to achieve the same level of investment. Hence, its marginal cost curve is upward-sloping over a larger region of the state space.

The key difference between the risky and the risk-free firm is how monetary policy shifts the marginal cost curve. As for the risk-free firm, the curve shifts up because the relative price of capital \( q_t \) increases, but there are two additional effects for the risky firm. First, monetary policy increases cash on hand \( x \), which decreases the amount the firm needs to borrow to finance any level of investment and therefore extends the flat region of the marginal cost.

\(^{23}\)The shock also affects the covariance term and the change in default threshold, which are difficult to analytically characterize.
curve. Monetary policy increases cash on hand according to:

\[
\frac{\partial \log x}{\partial \varepsilon_t^m} = \frac{1}{1 - \nu - \theta} \left( \frac{\partial \log p_t}{\partial \varepsilon_t^m} - \nu \frac{\partial \log w_t}{\partial \varepsilon_t^m} \right) \frac{\nu t(z, k)}{x} + \frac{\partial \log q_t}{\partial \varepsilon_t^m} \frac{q_t(1 - \delta)\omega k}{x} + \frac{\partial \log \Pi_t}{\partial \varepsilon_t^m} \frac{b/\Pi_t}{x},
\]

where \( \nu t(z, k) = \max_n p_t z^k n^\nu - w_t n \). This expression (16) contains three ways that monetary policy affects cash flows. First, monetary policy affects current revenues by changing the relative price of output \( p_t \) net of real labor costs \( \nu w_t \). Second, monetary policy affects the value of firms’ undepreciated capital stock by changing the relative price of capital \( q_t \). Finally, monetary policy changes the real value of outstanding nominal debt through inflation \( \Pi_t \).

The second key difference in how monetary policy affects the risky firm’s marginal cost curve is that it flattens the upward-sloping region, reflecting reduced credit spreads. Credit spreads fall because the expansionary shock decreases the expected losses from default to the lender. Recall that, in the event of default, lenders recover \( \alpha q_{t+1} \omega_{jt+1} k_{jt+1} \) per unit of debt; since the shock increases the relative price of capital \( q_{t+1} \), it also increases the recovery rate. In addition, monetary policy also decreases the probability of default, although this effect is quantitatively small in our calibration.

Whether the risky firm is more or less responsive than the risk-free firm depends crucially on the size of these two shifts in the marginal cost curve. Theoretically, they may or may not be large enough to induce the risky firm to be more responsive to monetary policy than the risk-free firm. The goal of our calibration is to quantitatively discipline these shifts using our model of investment under default risk.

## 5 Parameterization

We now calibrate the model and verify that its steady state behavior is consistent with key features of the micro data. In Section 6, we use the calibrated model to quantitatively study the effect of a monetary policy shock \( \varepsilon_t^m \).
Table 5: Fixed Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Household</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\beta$</td>
<td>Discount factor</td>
<td>0.99</td>
</tr>
<tr>
<td><strong>Firms</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\nu$</td>
<td>Labor coefficient</td>
<td>0.64</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Capital coefficient</td>
<td>0.21</td>
</tr>
<tr>
<td>$\delta$</td>
<td>Depreciation</td>
<td>0.026</td>
</tr>
<tr>
<td><strong>New Keynesian Block</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\phi$</td>
<td>Aggregate capital AC</td>
<td>4</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>Demand elasticity</td>
<td>10</td>
</tr>
<tr>
<td>$\varphi_\pi$</td>
<td>Taylor rule coefficient</td>
<td>1.25</td>
</tr>
<tr>
<td>$\varphi$</td>
<td>Price adjustment cost</td>
<td>90</td>
</tr>
</tbody>
</table>

Notes: Parameters exogenously fixed in the calibration.

5.1 Calibration

We calibrate the model in two steps. First, we exogenously fix a subset of parameters. Second, we choose the remaining parameters in order to match moments in the data.

**Fixed Parameters** Table 5 lists the parameters that we fix. The model period is one quarter, so we set the discount factor $\beta = 0.99$. We set the coefficient on labor $\nu = 0.64$. We choose the coefficient on capital $\theta = 0.21$ to imply a total returns to scale of 85%. Capital depreciates at rate $\delta = 0.026$ quarterly to match the average aggregate investment rate of nonresidential fixed investment reported in Bachmann, Caballero and Engel (2013).

We choose the elasticity of substitution in final goods production $\gamma = 10$, implying a steady state markup of 11%. This choice implies that the steady state labor share is $\frac{1-\nu}{\gamma} \approx 58\%$, close to the current U.S. labor share reported in Karabarbounis and Neiman (2013). We choose the coefficient on inflation in the Taylor rule $\varphi_\pi = 1.25$, in the middle of the range commonly considered in the literature. Finally, we set the price adjustment cost parameter $\varphi = 90$ to generate the slope of the Phillips Curve equal to 0.1, as in Kaplan, Moll and Violante (2017).
### Table 6
**Fitted Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Idiosyncratic shock processes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\rho$</td>
<td>Persistence of TFP</td>
<td>0.86</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>SD of innovations to TFP</td>
<td>0.03</td>
</tr>
<tr>
<td>$\sigma_\omega$</td>
<td>SD of capital quality</td>
<td>0.04</td>
</tr>
<tr>
<td><strong>Financial frictions</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\xi$</td>
<td>Operating cost</td>
<td>0.02</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Loan recovery rate</td>
<td>0.91</td>
</tr>
<tr>
<td><strong>Firm lifecycle</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$m$</td>
<td>Mean shift of entrants’ prod.</td>
<td>2.92</td>
</tr>
<tr>
<td>$s$</td>
<td>SD of entrants’ prod</td>
<td>1.11</td>
</tr>
<tr>
<td>$k_0$</td>
<td>Initial capital</td>
<td>0.46</td>
</tr>
<tr>
<td>$\pi_d$</td>
<td>Exogeneous exit rate</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Notes: Parameters chosen to match the moments in Table 7.

**Fitted Parameters** We choose the parameters listed in Table 6 to match the empirical moments reported in Table 7. The first set of parameters govern the idiosyncratic shocks: $\rho$ and $\sigma$ control the AR(1) process for TFP and $\sigma_\omega$ controls the i.i.d. process for capital quality. The second set of parameters govern the frictions to external finance: the fixed operating cost $\xi$ controls how often firms default and the recovery rate $\alpha$ controls the credit spread conditional on default. The final set of parameters govern the firm lifecycle: the parameters $m$ and $s$ control the productivity distribution of new entrants, $k_0$ controls the initial capital stock of new entrants, and $\pi_d$ is the probability of receiving an exogenous exit shock.

We target four key sets of statistics in our calibration.\(^{24}\) First, we target the dispersion of plant-level investment rates in Census microdata reported by Cooper and Haltiwanger (2006).\(^{25}\) The dispersion of investment rates places discipline on the degree of idiosyncratic risk faced by firms. Cooper and Haltiwanger (2006)’s sample is a balanced panel of plants that have survived at least sixteen years; to mirror this sample selection in the model, we

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\(^{24}\)At each step of this moment-matching process, we choose the disutility of labor supply $\Psi$ to generate a steady state employment rate of 60%.

\(^{25}\)An issue with this empirical target is that production units in our model correspond more closely to firms than to plants. We prefer to use the plant-level data from Cooper and Haltiwanger (2006) because it carefully constructs measures of retirement and sales of capital to measure negative investment, which is important in our model because capital is liquid.
condition on firms that have survived for twenty years, and our calibration results are robust
to different choices of this cutoff.

The second set of moments we target are related to firms’ use of external finance. Following
Bernanke, Gertler and Gilchrist (1999), we target a mean default rate of 3% as estimated
in a survey of businesses by Dun and Bradstreet. We target an average annual credit spread
implied by BAA rated corporate bond yields to the ten-year Treasury yield. Finally, we
target the average firm-level gross leverage ratio of 34.4% from the microdata underlying the
Quarterly Financial Reports, as reported in Crouzet and Mehrotra (2017).

The final two sets of moments are informative about firm lifecycle dynamics. We target
the average size of firms one year old and two years old relative to the average size of all firms
in the economy. The relative size of one year old firms is informative about the size of new
entrants, and the difference between the sizes of one and two year old firms is informative
about how quickly young firms grow. We also target the average exit rate and the share of
firms in the economy at age one and two. The difference in shares of age one and two firms
is informative about the exit rate of young firms. All of these statistics are computed from
the Business Dynamics Statistics (BDS), the public-release sample of statistics aggregated
from the Census’ Longitudinal Business Database (LBD).

Table 7 shows that our model matches the targeted moments reasonably well. The
model closely matches the dispersion of investment rates, which captures the degree of id-
iosyncratic risk faced by firms. The model also closely matches the average gross leverage
ratio and the average credit spreads, but it underpredicts the mean default rate. Firms in
our model grow too quickly relative to the data, which is not surprising because we do not
include other frictions to firm growth such as capital adjustment costs or customer accumu-
lation. Finally, the model underpredicts the total amount of firm exit (due to the fact that
it underpredicts the average default rate), but it does provide a good match of the ratio of

---

26 We target credit spreads because the debt price schedule is central to the economic mechanisms in our
model. To the extent that observed credit spreads are driven by risk premia rather than risk-neutral pricing
of default risk, we may overstate the importance of default risk in our calibration. We do not believe this is a
major concern because our calibrated debt recovery rate is broadly in line with estimated loss in default from
the corporate finance literature. For robustness, we also directly targeted estimates of the cost of default
from this literature, rather than the level of spreads, and found similar steady state behavior.

27 We do not match the moments exactly because our model is nonlinear. We use simulated annealing to
minimize the weighted sum of squared errors implied by these moments.
Table 7
Calibration Targets and Model Fit

<table>
<thead>
<tr>
<th>Moment</th>
<th>Description</th>
<th>Data</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Investment behavior (annual)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma \left( \frac{i}{k} \right)$</td>
<td>SD investment rate</td>
<td>33.7%</td>
<td>31.8%</td>
</tr>
<tr>
<td><strong>Financial behavior (annual)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mathbb{E}[\text{default rate}]$</td>
<td>Mean default rate</td>
<td>3.00%</td>
<td>2.01%</td>
</tr>
<tr>
<td>$\mathbb{E}[\text{credit spread}]$</td>
<td>Mean credit spread</td>
<td>2.35%</td>
<td>2.54%</td>
</tr>
<tr>
<td>$\mathbb{E} \left[ \frac{b}{k} \right]$</td>
<td>Mean gross leverage ratio</td>
<td>34.4%</td>
<td>33.6%</td>
</tr>
<tr>
<td><strong>Firm Growth (annual)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mathbb{E}[n_1]/\mathbb{E}[n]$</td>
<td>Size of age 1 firms (relative to mean)</td>
<td>28%</td>
<td>42%</td>
</tr>
<tr>
<td>$\mathbb{E}[n_2]/\mathbb{E}[n]$</td>
<td>Size of age 2 firms (relative to mean)</td>
<td>36%</td>
<td>66%</td>
</tr>
<tr>
<td><strong>Firm Exit (annual)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mathbb{E}[\text{exit rate}]$</td>
<td>Mean exit rate</td>
<td>8.7%</td>
<td>7.88%</td>
</tr>
<tr>
<td>$\mathbb{E}[M_1]/\mathbb{E}[M]$</td>
<td>Share of firms at age 1</td>
<td>10.5%</td>
<td>7.4%</td>
</tr>
<tr>
<td>$\mathbb{E}[M_2]/\mathbb{E}[M]$</td>
<td>Share of firms at age 2</td>
<td>8.1%</td>
<td>6.1%</td>
</tr>
</tbody>
</table>

Notes: Empirical moments targeted in the calibration. Investment behavior drawn from the distribution of plant-level investment rates in Census microdata, 1972-1988, reported in Cooper and Haltiwanger (2006). These investment moments are drawn from a balanced panel; we mirror this sample selection in the model by computing investment moments for firms who have survived at least twenty years. The mean default rate is from Dun and Bradstreet survey, as reported by Bernanke, Gertler and Gilchrist (1999). The average firm-level gross leverage ratio is taken from the micro data underlying the Quarterly Financial Reports, and is reported in Crouzet and Mehrotra (2017). The average credit spread is measured as the yield on BAA rated corporate bonds relative to a ten-year Treasury bond. The mean exit rate is computed from the Business Dynamics Statistics (BDS). The average size of firms age one and two is relative to the average size of firms the economy, and also drawn from the BDS. The shares of firms at age one and two are also drawn from the BDS.

exit rates of age 1 to age 2 firms.

The calibrated parameters in Table 6 are broadly comparable to existing estimates in the literature. Idiosyncratic TFP shocks are less persistent and more volatile than aggregate productivity shocks, consistent with direct measurements of plant- or firm-level productivity. The calibrated loan recovery rate is 91%, in line with the low estimated costs of default in the literature. New entrants start with significantly lower productivity and capital than the average firm.
5.2 Financial Heterogeneity in the Model and the Data

Appendix B.3 analyzes firms’ decision rules in the stationary distribution and identifies two key sources of financial heterogeneity across firms. The first source is lifecycle dynamics; firms are born below their optimal scale, i.e. \( k_0 < k^*(z) \), and need to grow to accumulate capital. These young firms initially borrow in order to accumulate capital, increasing their risk of default and therefore borrowing costs. The second source of financial heterogeneity is TFP shocks \( z \); a positive shock increases the firm’s optimal scale \( k^*(z) \), which again induces debt-financed capital accumulation.

Appendix B.3 also compares the behavior of the model to three key non-targeted dimensions of the data that are informative about these sources of financial heterogeneity. First, we find that firms in our model reach their average size after five years, which is faster than in the data. This rapid speed of convergence is not surprising because our model abstracts from other sources of lifecycle dynamics, such as firm-level adjustment costs or customer base concerns. Second, we show that the joint distribution of investment and leverage rates in our model is comparable to Census and Compustat data. Finally, we show that measured investment-cash flow sensitivities in our model are roughly in line with the data.

6 Monetary Policy Analysis

We now quantitatively analyze the effect of a monetary policy shock \( \varepsilon_i^m \). Section 6.1 begins the analysis by computing the aggregate impulse responses to an expansionary shock in our calibrated model. Section 6.2 studies the heterogeneous effects of monetary policy across firms and shows that, consistent with the empirical results from Section 2, risky firms are less responsive to monetary policy. Finally, Section 6.3 shows that the aggregate effect of monetary policy depends on the distribution of net worth.

The economy is initially in steady state and unexpectedly receives a \( \varepsilon_i^m = -0.0025 \) innovation to the Taylor rule which reverts to 0 according to \( \varepsilon_{t+1}^m = \rho_m \varepsilon_t^m \) with \( \rho_m = 0.5 \). We compute the perfect foresight transition path of the economy as it converges back to steady state.\(^{28}\)

\(^{28}\)Allowing for persistence in the monetary policy shocks themselves is a simple way to create inertia in
Notes: Aggregate impulse responses to a $c_m^0 = -0.0025$ innovation to the Taylor rule which decays at rate $\rho_m = 0.5$. Computed as the perfect foresight transition in response to a series of unexpected innovations starting from steady state.

### 6.1 Aggregate Response to Monetary Policy

Figure 3 plots the responses of key aggregate variables to this expansionary shock. The shock lowers the nominal interest rate; because prices are sticky, this also lowers the real interest rate. The lower real interest rate stimulates investment demand for the reasons discussed in Section 4. It also stimulates consumption demand from the household through the Euler equation. Higher aggregate demand for goods raises inflation. This process increases investment by 1.6%, output by 0.5%, and consumption by 0.35% for a 0.4% change in the annualized nominal interest rate, broadly in line with the peak effect of monetary policy estimated in Christiano, Eichenbaum and Evans (2005).²⁹

²⁹Our model does not generate the hump-shaped aggregate responses emphasized by Christiano, Eichenbaum and Evans (2005). We could do so by incorporating adjustment costs to investment rather than capital. However, we prefer to focus on capital adjustment costs because they are a parsimonious way to capture movements in the relative price of capital.
Table 8
Regression Results

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<tr>
<td>(1) (2)</td>
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<td>leverage × ffr shock</td>
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<td>-0.955</td>
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<td>R²</td>
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<td>0.216</td>
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<tr>
<td>Firm controls</td>
<td>no</td>
<td>yes</td>
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</table>

Notes: Results from running the baseline specification \( \Delta \log k_{jt} = \alpha_j + \alpha_t + \beta \ell_{jt-1} \varepsilon_t^m + \Gamma' Z_{jt-1} + \varepsilon_{jt} \) on model-simulated data, where \( \alpha_j \) is a firm fixed effect, \( \alpha_t \) is a sector-by-quarter fixed effect, \( \ell_{jt-1} \) is the firm’s leverage, \( \varepsilon_t^m \) is the monetary shock, and \( Z_{jt-1} \) is a vector of firm-level controls containing leverage and size. We have normalized the sign of the monetary shock \( \varepsilon_t^m \) so that a positive shock is expansionary (corresponding to a decrease in interest rates). We have standardized leverage \( \ell_{jt} \) over the entire sample, so its units are in standard deviations relative to the mean. The sample period is four quarters before the monetary shock through ten quarters after the shock. To mirror the sample selection into Compustat, we condition on firms that have survived at least ten years. “Data” refers to results in Table 3.

6.2 Heterogeneous Responses to Monetary Policy

We now study the heterogeneous responses to monetary policy across firms in our model and show that they are consistent with the data.

Model-Implied Regression Coefficients In order to directly compare our model to the data, we simulate a panel of firms in response to the monetary shock and estimate the regression specification (3) on the simulated panel. We mirror the sample selection into Compustat by conditioning on firms that have survived at least ten years. We identify the innovation to the Taylor rule \( \varepsilon_t^m \) with the high-frequency shocks that we measure in the data.\(^{30}\) We estimate the regression using data from one year before the shock to ten quarters after the shock.

Table 8 shows that the estimated interaction coefficient in the model is within one standard error of the empirical estimate. Hence, the shifts in the marginal cost curve for risky

\(^{30}\)In our model, the change in the nominal interest rate is smaller than the innovation to the Taylor rule because the monetary authority responds to the increased inflation. This fact may lead to an inconsistency between the monetary shocks in the model and the measured shocks in the data, which are based on changes in expected rates. Our implicit assumption is that the feedback effect through the Taylor rule takes sufficient time that it is not incorporated into the measure of the high-frequency shocks. Because we use the one-month futures, our assumption requires that the monetary authority respond to inflation with at most a one month lag.
Figure 4: Decomposition of Semi-Elasticity of Capital to Monetary Policy Shock

Notes: Semi-elasticity of capital and stationary distribution of firms conditional on idiosyncratic productivity one standard deviation below the mean. Left column plots over the entire state space while right column focuses on low levels of cash on hand $x$. “Direct effect” refers to only the real interest rate changes, holding all other prices fixed at steady state. “Adjustment cost” refers to changing the price of capital for new investment only. “Indirect effect” refers to changing all other prices.

firms discussed in Section 4 are not large enough to compensate for its upward slope. Column (1) estimates the regression (3) without any firm-level controls $Z_{jt}$. In both the model and the data, a firm with one standard deviation more leverage than the average firm has an investment semi-elasticity approximately one percentage point lower than the average firm. Columns (2) includes firm-level controls $Z_{jt}$ and shows that this conclusion does not substantially change. The $R^2$ of the regressions are higher in our model, indicating that the data contain more unexplained sources of variation in investment.\textsuperscript{31}

Channels Driving Heterogeneous Responses Figure 4 plots the semi-elasticity of investment $k'$ with respect to the monetary shock as a function of cash on hand $x$, and decomposes this elasticity into the three different categories: the direct effect, which works through changes in the real interest rate, the adjustment cost effect, which works through changes in the relative price of new capital, and the indirect effect, which works through all

\textsuperscript{31}Our results are somewhat sensitive to the number of periods we include in the regression. To investigate this sensitivity, we ran our baseline specification (3) using only the period of the shock. Because this specification only includes one quarter of data, we cannot estimate the fixed effects and the coefficient on leverage simply captures cross-sectional heterogeneity in how firms respond to the shock. Even in this much simpler setting, the estimated coefficient is strongly negative without controls. However, the coefficient significantly falls with controls because we exploiting different sources of variation than in our baseline specification.
other prices. We compute the contribution of each of these channels by feeding in the relevant series of prices to the firms in our model, holding all other prices fixed at their steady state values.

Both the direct and indirect effects have a strong stimulative effect on investment while the adjustment cost has a strong negative impact on investment. However, all these effects are dampened for risky firms relative to risk-free firms due to the upward-sloping marginal cost curve plotted in Figure 2. Completely financially unconstrained firms with $x > \pi_t(z)$ have a lower semi-elasticity than all these firms because they are less exposed to the indirect effects of monetary policy. In terms of the Euler equation (15), unconstrained firms have zero covariance between the shadow value of funds and the return on capital.

The fact that both the direct and indirect effects play a quantitatively important role in driving the investment channel of monetary policy contrasts with Auclert (2017)’s and Kaplan, Moll and Violante (2017)’s decomposition of the consumption channel. In the context of a household’s consumption-savings problem, they find that the contribution of the direct effect of lower real interest rates is small relative to the indirect general equilibrium effects of higher labor income. In our model, direct interest rate effects are stronger because firms are more price-sensitive than households. In fact, without any financial frictions at all, the partial equilibrium elasticity of investment with respect to interest rates would be nearly infinite (see House (2014)). Households are less price sensitive because of consumption-smoothing motives.

6.3 Aggregate Implications of Financial Heterogeneity

In this subsection, we study two ways in which financial heterogeneity matters for understanding the aggregate monetary transmission mechanism. First, we show that the aggregate effect of monetary policy is larger in our model than in a comparable version of the model without financial frictions (which collapses to a representative firm). Second, we show that the aggregate effect of a given monetary policy shock in our model significantly depends on the initial distribution of net worth.
Notes: Aggregate impulse responses to a $\epsilon_0^m = -0.0025$ innovation to the Taylor rule which decays at rate $\rho_m = 0.5$. Computed as the perfect foresight transition in response to a series of unexpected innovations starting from steady state. “Het agent” refers to calibrated heterogeneous firm model from the main text. “Rep agent” refers to a version of the model in which the heterogeneous production sector is replaced by a representative firm with the same production function and no financial frictions.

Comparison to Frictionless Model We eliminate financial frictions by removing the non-negativity constraint on dividends; in this case, the investment block of the model collapses to a financially unconstrained representative firm (see Khan and Thomas (2008) Appendix B). Figure 5 shows that the impact effect of monetary policy on investment is 25% larger in our full model than in the representative firm benchmark. Hence, despite the fact that risky constrained firms are less responsive than risk-free constrained firms, both types of constrained firms are more responsive than completely unconstrained firms.

To understand this result, Figure 6 plots the semi-elasticity of capital with respect to the monetary policy shock for firms in our model, assuming that they face the equilibrium path of prices from the representative firm model. By construction, the response of unconstrained firms with $x \geq \bar{x}(z)$ is the same as the representative firm in the frictionless benchmark. In contrast, both the risky and risk-free constrained firms are significantly more responsive than the unconstrained firms. Both types of constrained firms are more responsive because their marginal value of additional cash-on-hand is strictly larger than for completely unconstrained firms. Within constrained firms with low cash-on-hand, risky constrained firms are less responsive than risk-free constrained firms, consistent with the results in Section 6.2.
Notes: Left column plots the semi-elasticity of capital and stationary distribution of firms conditional on idiosyncratic productivity one standard deviation below the mean. Right column plots the same objects conditional on idiosyncratic productivity one standard deviation above the mean. The left y-axis measures the semi-elasticity of capital with respect to the monetary policy shock (measured in annual percentage points and absolute value). The right y-axis measures the stationary distribution of firms. Top row plots these functions over the entire space of cash on hand. Bottom row plots these functions for low levels of cash on hand only. Decision rules are computed given the equilibrium path of prices from the representative firm model.

Higher investment demand from constrained firms puts additional upward pressure on the relative price of capital $q_t$ in the general equilibrium of our full model. Unconstrained firms, who have a small positive response facing the representative firm model’s prices, now have a large negative response.

**State Dependence of Aggregate Transmission** We now show that the aggregate effect of monetary policy is smaller when the initial distribution of firms contains more risky firms. In order to illustrate the quantitative magnitude of this mechanism, we perform a simple calculation: we take the semi-elasticity of capital with respect to monetary policy as fixed and vary the initial distribution of firms.\(^{32}\)

\(^{32}\)This exercise does not allow for prices to vary with the initial distribution. However, the exercise is a nevertheless an important necessary condition for the general equilibrium model to generate state dependence. We perform the simple exercise of fixing the elasticities and varying the distribution for two reasons.
We vary the initial distribution of firms in production $\hat{\mu}(z, x)$ by taking the weighted average of two reference distributions. The first reference distribution is the steady-state distribution $\hat{\mu}^*(z, x)$. The second reference distribution $\tilde{\mu}(z, x)$ assumes that the conditional distribution of cash-on-hand for every level of productivity is equal to the distribution of cash-on-hand conditional on the lowest realization of productivity in steady state. We normalize the second reference distribution so that the marginal distribution of productivity is the same as in the steady state distribution. Hence, $\tilde{\mu}(z, x)$ is an example of a distribution in which firms of all productivity levels have a poor distribution of cash on hand. We then compute the initial distribution as a weighted average of these two reference distributions, $\hat{\mu}(z, x) = \tilde{\omega}\tilde{\mu}(z, x) + (1 - \tilde{\omega})\hat{\mu}^*(z, x)$. We vary $\tilde{\omega} \in [0, 1]$ to trace out linear combinations of distributions between the steady state ($\tilde{\omega} = 0$) and the low cash on hand ($\tilde{\omega} = 1$) distributions. We then compute the change in the aggregate capital stock in response to the monetary policy shock for each of these initial distributions.

The left panel of Figure 7 shows that the change in the aggregate capital stock is 30% smaller starting from the low-cash distribution $\tilde{\mu}(z, x)$ than starting from the steady state distribution $\hat{\mu}^*(z, x)$, and the response varies linearly in between these two extremes. Average cash-on-hand is 70% lower and there are twice as many risky constrained firms in the low-cash distribution than in the steady state distribution. The right panel of Figure 7 shows that this effect is due to the fact that the low-cash distribution $\tilde{\mu}(z, x)$ places more mass in the region of the state space where the elasticity of capital with respect to the monetary policy shock is low.

These results suggest a potentially powerful source of time-variation in the aggregate transmission mechanism: monetary policy is less powerful when net worth is low and default risk is high. A limitation of this analysis is that we have varied the initial distribution exogenously. The natural next step in this analysis is to incorporate with various business cycle...

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First, since we do not have to re-compute the equilibrium transition path for each initial distribution, we can investigate state dependence with respect to a large number of initial distributions. Second, this exercise clearly isolates the impact of varying the initial distribution from the additional changes to firms’ policy rules arising from changes in prices.

In this exercise, markets do not clear for a given initial distribution of cash-on-hand. We use the elasticities from the representative firm prices plotted in Figure 6 so that markets do not clear for any initial distribution. If we had used the equilibrium elasticities, markets would clear for some initial distributions and not others, potentially biasing our interpretation of the results.
Notes: Dependence of aggregate response on initial distribution. We compute the change in aggregate capital for different initial distributions using the response to monetary policy computed under the price path from the representative firm model. We vary the initial distribution of firms in production $\mu(z, x)$ by taking the weighted average of two reference distributions. The first reference distribution is the steady-state distribution $\mu^*(z, x)$. The second reference distribution $\tilde{\mu}(z, x)$ assumes that the conditional distribution of cash-on-hand for every level of productivity is equal to the distribution of cash-on-hand conditional on the lowest realization of productivity in steady state. We normalize the second reference distribution so that the marginal distribution of productivity is the same as in the steady state distribution. We then compute the initial distribution as a weighted average of these two distributions, $\tilde{\mu}(z, x) = \tilde{\omega}\mu(z, x) + (1 - \tilde{\omega})\mu^*(z, x)$. Left panel varies $\tilde{\omega} \in [0, 1]$ and plots the change in the aggregate capital stock upon impact against the average cash-on-hand of the initial distribution. Right panel plots the semi-elasticity of capital with respect to the shock over cash on hand for high productivity firms. The steady state distribution corresponds to $\tilde{\omega} = 0$ and the low-cash distribution corresponds to $\tilde{\omega} = 1$.

shocks into our model and study the types of distributions that actually arise in equilibrium.

7 Conclusion

In this paper, we have argued that financial frictions dampen the response of investment for firms with high default risk. Our argument had two main components. First, we showed in the micro data that firms with high leverage or low credit ratings invest significantly less than other firms following a monetary policy shock. Second, we built a heterogeneous firm New Keynesian model with default risk that is quantitatively consistent with these empirical results. In the model, monetary policy stimulates investment through a combination of direct and indirect effects. High-risk firms are less responsive to these changes because their marginal cost of investment finance is higher than for low-risk firms. The aggregate effect
of monetary policy is primarily driven by these low-risk firms, which suggests a novel form of state dependence: monetary policy is less powerful when default risk in the economy is greater.

Our results may be of independent interest to policymakers who are concerned about the distributional implications of monetary policy across firms. An often-discussed goal of monetary policy is to provide resources to viable but credit constrained firms. Many policymakers’ conventional wisdom, built on the financial accelerator mechanism, suggests that constrained firms will significantly increase their capital investment in response to expansionary monetary policy. Our results imply that, instead, expansionary policy will stimulate the less risky firms in the economy.
References


Appendix (For Online Publication Only)

A Empirical Appendix

This appendix describes the firm-level variables used in the empirical analysis of the paper, based on quarterly Compustat data. The definition of the variables and sample selection follow standard practices in the literature (see, for example, Whited, 1992; Gomes, 2001; Eisfeldt and Rampini, 2006; Clementi and Palazzo, 2015).

A.1 Data Construction

Variables

1. Investment, intensive margin (baseline measure): defined as $\Delta \log(k_{jt+1})$, where $k_{jt+1}$ denotes the capital stock of firm $j$ at the end of period $t$. For each firm, we set the first value of $k_{jt+1}$ to the level of gross plant, property, and equipment ($\text{ppegtq}$, item 118) in the first period in which this variable is reported in Compustat. From this period onwards, we compute the evolution of $k_{jt+1}$ using the changes of net plant, property, and equipment ($\text{ppentq}$, item 42), which is a measure net investment with significantly more observations than $\text{ppegtq}$ (net of depreciation). If a firm has a missing observation of $\text{ppentq}$ located between two periods with nonmissing observations we estimate its value using a linear interpolation with the values of $\text{ppentq}$ right before and after the missing observation; if two or more consecutive observations are missing we do not do any imputation. We only consider investment spells with 40 quarters or more in order to precisely estimate fixed effects.

2. Investment, extensive margin: defined as $1 \{ \frac{i_{jt}}{k_{jt}} > 1\% \}$, where $i_{jt} = k_{jt+1} - (1 - \delta_j)k_{jt}$ denotes gross investment. We measure $\delta_j$ using depreciation rates of Fixed Asset Tables from NIPA at the sector level.

3. Leverage: defined as the ratio of total debt (sum of $\text{dlc}$ and $\text{dltt}$, items 45 and 71) to total assets ($\text{at}$, item 44).
4. **Net leverage**: defined as the ratio of total debt minus net current assets \((\text{actq}, \text{item 40}, \text{minus } \text{lctq}, \text{item 49})\) to total assets.

5. **Real Sales Growth**: measured as log-differences in sales \((\text{saleq}, \text{item 2})\) deflated using CPI.

6. **Size**: measured as the log of total assets.

7. **Liquidity**: defined as the ratio of cash and short-term investments \((\text{cheq}, \text{item 36})\) to total assets.

8. **Cash flow**: measured as EBITDA divided by capital stock.

9. **Dividend payer**: defined as a dummy variable taking a value of one in firm-quarter observations in which the firm paid dividends to preferred stock of the company (constructed using \(\text{dvpq}, \text{item 24}\)).

10. **Tobin’s q**: defined as the ratio market to book value of assets. The market value of assets is measured as the book value, plus the market value of common stock, minus the book value of common stock \(\text{ceq}\), plus deferred taxes and investment tax credit (item \(\text{txditcq}, \text{item 52}\)). The market value of common stock is computed as the product of price at quarter close \((\text{prccq})\) and common shares outstanding \((\text{cshoq}, \text{item 61})\). We winsorize 1% of observations in each tail of the distribution.

11. **Sectoral dummies**. We consider the following sectors: (i) agriculture, forestry, and fishing: \(\text{sic} < 10\); (ii) mining: \(\text{sic} \in [10, 14]\); (iii) construction: \(\text{sic} \in [15, 17]\); (iv) manufacturing: \(\text{sic} \in [20, 39]\); (v) transportation, communications, electric, gas, and sanitary services: \(\text{sic} \in [40, 49]\); (vi) wholesale trade: \(\text{sic} \in [50, 51]\); (vii) retail trade \(\text{sic} \in [52, 59]\); (viii) services: \(\text{sic} \in [70, 89]\).

**Sample Selection**  Our empirical analysis excludes (in order of operation):

1. Firms in finance, insurance, and real estate sectors \((\text{sic} \in [60, 67])\) and public administration \((\text{sic} \in [91, 97])\).
2. Firms not incorporated in the United States.

3. Firm-quarter observations with acquisitions (constructed based on aqcy, item 94) larger than 5% percent of assets.

4. Firm-quarter observations that satisfy one of the following conditions, aimed at excluding extreme observations:
   
i. Investment rate is in the top and bottom 0.5 percent of the distribution.
   
  ii. Leverage higher than 10.
   
  iii. Net current assets as a share of total assets higher than 10 or below -10.
   
  iv. Quarterly real sales growth above 1 or below -1.

After applying these sample selection operations, we winsorize observations of leverage and distance to default at the top and bottom 0.5\% of the distribution.

A.2 Ruling Out Alternative Drivers of Heterogeneous Responses

In the main text, we argue that heterogeneity in default risk is a key source of heterogeneous responses to monetary policy across firms. In this appendix, we provide evidence against two competing hypotheses.

Heterogeneity in Other Observable Firm Characteristics

Table 9 shows that our main results are not driven by differences in firms’ sales growth realized future sales growth, size, or liquidity. It expands the baseline specification using within-firm variation as:

\[
\Delta \log k_{jt+1} = \alpha_j + \alpha_{st} + \beta_y (y_{jt-1} - \mathbb{E}_j [y_{jt}]) \epsilon_t^m + \beta_z z_{jt-1} \epsilon_t^m + \Gamma_1 Z_{jt-1} + \Gamma_2 (y_{jt-1} - \mathbb{E}_j [y_{jt}]) Y_{t-1} + e_{jt},
\]

where \( z_{jt-1} \) is lagged sales growth, realized future sales growth in one year, lagged size, or lagged liquidity. In each case, the coefficients on leverage \( \ell_{jt-1} \) and distance to default \( dd_{jt-1} \) remain stable. Hence, firm-level shocks or characteristics that are correlated with

\[33\text{The results for the baseline specification (3) are very similar.}\]
Table 9

Interaction With Other Firm-Level Covariates

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<th>(4)</th>
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</table>

Observations                        219702  151433  208917  145073  219702  151433  219578  151353

$R^2$                               0.124   0.137   0.128   0.140   0.124   0.137   0.126   0.138

Firm controls                       yes     yes     yes     yes     yes     yes     yes     yes

Time sector FE                      yes     yes     yes     yes     yes     yes     yes     yes

Time clustering                     yes     yes     yes     yes     yes     yes     yes     yes

Notes: results from estimating variants of the baseline specification

$\Delta \log k_{jt+1} = \alpha_j + \alpha_{st} + \beta_y(y_{jt-1} - \mathbb{E}_j[y_{jt}])\varepsilon_t^m + \beta_z z_{jt-1} \varepsilon_t^m + \Gamma_1 Z_{jt-1} + \Gamma_2 (y_{jt-1} - \mathbb{E}_j[y_{jt}]) Y_{t-1} + \epsilon_{jt},$

where $\alpha_j$ is a firm fixed effect, $\alpha_{st}$ is a sector-by-quarter fixed effect, $y_{jt} \in \{\ell_{jt}, \text{dd}_{jt}\}$ is leverage or distance to default, $\mathbb{E}_j[y_{jt}]$ is the average financial position $y_{jt}$ of firm $j$ in our sample, $z_{jt-1}$ is the firm’s lagged sales growth, future sales growth, size, or liquidity, $\varepsilon_t^m$ is the monetary shock, $Y_{t-1}$ is lagged GDP growth, and $Z_{jt-1}$ is a vector of firm-level controls containing leverage, sales growth, size, current assets as a share of total assets, and an indicator for fiscal quarter. Standard errors are two-way clustered by firms and quarter. We have normalized the sign of the monetary shocks $\varepsilon_t^m$ so that a positive shock is expansionary (corresponding to a decrease in interest rates). We have standardized within-firm leverage $(\ell_{jt} - \mathbb{E}[\ell_{jt}])$ and within-firm distance to default $(\text{dd}_{jt} - \mathbb{E}[\text{dd}_{jt}])$ over the entire sample, so their units are in standard deviations relative to the mean.

these additional variables do not drive the heterogeneous responses by default risk that we document in the main text.\(^{34}\)

**Heterogeneity in Other Unobservable Firm Characteristics** Table 10 provides evidence that unobservable factors do not drive the heterogeneous responses either. We instrument demeaned leverage $\ell_{jt-1} - \mathbb{E}[\ell_{jt-1}]$ in our baseline specification (5) with an average of past demeaned leverage and instrument demeaned distance to default $\text{dd}_{jt-1} - \mathbb{E}_j[\text{dd}_{jt}]$ with

\(^{34}\)Our result that large firms are more sensitive to monetary policy shocks is broadly consistent with Kudlyak and Sanchez (2017), who find that, in Compustat, large firms are also more responsive to the 2007 financial crisis.
The table below presents the results of instrumenting financial position with past financial position. The table includes four columns, labeled (1) to (4), each representing different specifications of the relationship between financial position and monetary shocks.

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<td>$R^2$</td>
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Notes: IV results from estimating the baseline specification

$$
\Delta \log k_{jt+1} = \alpha_j + \alpha_{st} + \beta y(j_{jt-1} - E[j_{jt}])\epsilon^m_t + \Gamma_1' Z_{jt-1} + \Gamma_2 (y_{jt-1} - E[j_{jt}]) Y_{t-1} + e_{jt},
$$

where $\alpha_j$ is a firm fixed effect, $\alpha_{st}$ is a sector-by-quarter fixed effect, $y_{jt} \in \{\ell_{jt}, dd_{jt}\}$ is leverage or distance to default, $E[j_{jt}]$ is the average financial position of firm $j$ in our sample, $\epsilon^m_t$ is the monetary shock, $Y_{t-1}$ is lagged GDP growth, and $Z_{jt-1}$ is a vector of firm-level controls containing leverage, sales growth, size, current assets as a share of total assets, and an indicator for fiscal quarter. Within-firm financial position $y_{jt} - E[j_{jt}]$ is instrumented with the past four quarters or past eight quarters average financial position. Standard errors are two-way clustered by firms and quarter. We have normalized the sign of the monetary shock $\epsilon^m_t$ so that a positive shock is expansionary (corresponding to a decrease in interest rates). We have standardized within-firm leverage $(\ell_{jt} - E[\ell_{jt}])$ and within-firm distance to default $(dd_{jt} - E[dd_{jt}])$ over the entire sample, so their units are in standard deviations relative to the mean.

Past demeaned distance to default. If unobserved factors drive both leverage/distance to default and the response to monetary policy, and these factors are more weakly correlated with lagged leverage/distance to default, we would expect these instrumental variables coefficients to be smaller than our baseline results. Instead, Table 10 shows that the estimated coefficients generally increase in this instrumental variables specification. This result is consistent with measurement error creating attenuation bias in our baseline specification (3).

### A.3 Additional Results

This appendix contains a number of additional results referenced in the main text. We perform our robustness checks for the specification using only within-firm variation (5); the results in this section are very similar when using all variation in the baseline specification (3).


Table 11

<table>
<thead>
<tr>
<th>Expansionary vs. Contractionary Shocks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>(1) (2) (3) (4)</td>
</tr>
<tr>
<td>leverage × ffr shock                    -0.68**</td>
</tr>
<tr>
<td>(0.28)</td>
</tr>
<tr>
<td>leverage × pos ffr shock                -0.71**</td>
</tr>
<tr>
<td>(0.30)</td>
</tr>
<tr>
<td>leverage × neg ffr shock                -0.56</td>
</tr>
<tr>
<td>(0.96)</td>
</tr>
<tr>
<td>dd × ffr shock                         1.10***</td>
</tr>
<tr>
<td>(0.39)</td>
</tr>
<tr>
<td>dd × pos ffr shock                     1.38***</td>
</tr>
<tr>
<td>(0.50)</td>
</tr>
<tr>
<td>leverage × neg ffr shock                0.12</td>
</tr>
<tr>
<td>(0.77)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Observations</th>
<th>219702</th>
<th>219702</th>
<th>151433</th>
<th>151433</th>
</tr>
</thead>
<tbody>
<tr>
<td>R²</td>
<td>0.124</td>
<td>0.124</td>
<td>0.137</td>
<td>0.137</td>
</tr>
<tr>
<td>Firm controls</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Time sector FE</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Time clustering</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

Notes: results from estimating variants of the baseline specification

\[ \Delta \log k_{jt+1} = \alpha_j + \alpha_{st} + \beta_y (y_{jt-1} - E_j[y_{jt}])\varepsilon_t^m + \Gamma_1' Z_{jt-1} + \Gamma_2 (y_{jt-1} - E_j[y_{jt}]) Y_{t-1} + e_{jt}, \]

where \( \alpha_j \) is a firm fixed effect, \( \alpha_{st} \) is a sector-by-quarter fixed effect, \( y_{jt} \in \{\ell_{jt}, dd_{jt}\} \) is leverage or distance to default, \( E_j[y_{jt}] \) is the average financial position \( y_{jt} \) of firm \( j \) in our sample, \( \varepsilon_t^m \) is the monetary shock, \( Y_{t-1} \) is lagged GDP growth, and \( Z_{jt-1} \) is a vector of firm-level controls containing leverage, sales growth, size, current assets as a share of total assets, and an indicator for fiscal quarter. Columns (2) and (4) contain separate interactions for expansionary and contractionary shocks. Standard errors are two-way clustered by firms and quarters. We have normalized the sign of the monetary shock \( \varepsilon_t^m \) so that a positive shock is expansionary (corresponding to a decrease in interest rates). We have standardized within-firm leverage \( (\ell_{jt} - E[\ell_{jt}]) \) and within-firm distance to default \( (dd_{jt} - E[dd_{jt}]) \) over the entire sample, so their units are in standard deviations relative to the mean.

A.3.1 Robustness With Respect to Monetary Shock

The first set of robustness checks concerns our measured monetary policy shock \( \varepsilon_t^m \).

Expansionary vs. Contractionary Shocks Table 11 separately estimates heterogeneous responses for expansionary and contractionary shocks. Although the heterogeneous responses by leverage or distance to default are only significant for expansionary shocks, the differences between the two are marginally significant at best. This result is largely due to the fact that there are relatively few observations of contractionary shocks in our sample, creating large standard errors.
### Table 12
**Target vs. Path Decomposition**

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>leverage × ffr shock</td>
<td>-0.68**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.28)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>leverage × target shock</td>
<td>-0.98**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.45)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>leverage × path shock</td>
<td>-0.70</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1.30)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dd × shock</td>
<td>1.10***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.39)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dd × target shock</td>
<td>1.47**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.67)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dd × path shock</td>
<td>-0.41</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1.65)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Observations</th>
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<th>214301</th>
<th>151433</th>
<th>147986</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R^2$</td>
<td>0.124</td>
<td>0.125</td>
<td>0.137</td>
<td>0.138</td>
</tr>
<tr>
<td>Firm controls</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Time sector FE</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Time clustering</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

Notes: results from estimating variants of the baseline specification

\[
\Delta \log k_{jt+1} = \alpha_j + \alpha_{st} + \beta_y (y_{jt} - \mathbb{E}_j[y_{jt}])\varepsilon^m_t + \Gamma_1' Z_{jt-1} + \Gamma_2 (y_{jt-1} - \mathbb{E}_j[y_{jt}])Y_{t-1} + \epsilon_{jt},
\]

where $\alpha_j$ is a firm fixed effect, $\alpha_{st}$ is a sector-by-quarter fixed effect, $y_{jt} \in \{\ell_{jt}, dd_{jt}\}$ is leverage or distance to default, $\mathbb{E}_j[y_{jt}]$ is the average financial position $y_{jt}$ of firm $j$ in our sample, $\varepsilon^m_t$ is the monetary shock, $Y_{t-1}$ is lagged GDP growth, and $Z_{jt-1}$ is a vector of firm-level controls containing leverage, sales growth, size, current assets as a share of total assets, and an indicator for fiscal quarter. Columns (2) and (4) run separate interactions of financial position $y_{jt}$ with the target and path component of interest rates, as defined in Campbell et al. (2016). Standard errors are two-way clustered by firms and quarters. We have normalized the sign of the monetary shock $\varepsilon^m_t$ so that a positive shock is expansionary (corresponding to a decrease in interest rates). We have standardized within-firm leverage $(\ell_{jt} - \mathbb{E}[\ell_{jt}])$ and within-firm distance to default $(dd_{jt} - \mathbb{E}[dd_{jt}])$ over the entire sample, so their units are in standard deviations relative to the mean.

**Results Driven by Effect on Short Rates** Following Gurkaynak, Sack and Swanson (2005), we decompose monetary policy announcements into a “target” component that affects the level of the yield curve and a “path” component that affects the slope of the yield curve. Table 12 shows that the differential responses across firms we find in the main text are driven by the target component of the announcement, capturing the effect of the announcement on the level of the yield curve, rather than the path component of the announcement, capturing the effect on the slope of the yield curve. This result indicates that our results are primarily driven by the effect of Fed policy announcements on short-term interest rates rather than on...
Table 13
Post-1994 Estimates

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>leverage × ffr shock</td>
<td>-0.80**</td>
<td>-0.54</td>
<td>-0.55</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.37)</td>
<td>(0.49)</td>
<td>(0.52)</td>
<td></td>
</tr>
<tr>
<td>dd × ffr shock</td>
<td>0.80*</td>
<td>0.54</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.43)</td>
<td>(0.40)</td>
<td>(0.56)</td>
<td></td>
</tr>
<tr>
<td>ffr shock</td>
<td></td>
<td></td>
<td></td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(1.19)</td>
</tr>
<tr>
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<td>118782</td>
<td>118782</td>
<td>118782</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.138</td>
<td>0.150</td>
<td>0.152</td>
<td>0.137</td>
</tr>
<tr>
<td>Firm controls</td>
<td>yes</td>
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<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Time sector FE</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Time clustering</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

Notes: results from estimating variants of the baseline specification

$$\Delta \log k_{jt+1} = \alpha_j + \alpha_{st} + \beta_y (y_{jt-1} - \mathbb{E}_j[y_{jt}]) \varepsilon_t^m + \Gamma_1' Z_{jt-1} + \Gamma_2 (y_{jt-1} - \mathbb{E}_j[y_{jt}]) Y_{t-1} + e_{jt},$$

where $\alpha_j$ is a firm fixed effect, $\alpha_{st}$ is a sector-by-quarter fixed effect, $y_{jt} \in \{\ell_{jt}, dd_{jt}\}$ is leverage or distance to default, $\mathbb{E}_j[y_{jt}]$ is the average financial position $y_{jt}$ of firm $j$ in our sample, $\varepsilon_t^m$ is the monetary shock, $Y_{t-1}$ is lagged GDP growth, and $Z_{jt-1}$ is a vector of firm-level controls containing leverage, sales growth, size, current assets as a share of total assets, and an indicator for fiscal quarter. Only data after 1994 is used in the estimation. Standard errors are two-way clustered by firms and quarters. We have normalized the sign of the monetary shock $\varepsilon_t^m$ so that a positive shock is expansionary (corresponding to a decrease in interest rates). We have standardized within-firm leverage $(\ell_{jt} - \mathbb{E}[\ell_{jt}])$ and within-firm distance to default $(dd_{jt} - \mathbb{E}[dd_{jt}])$ over the entire sample, so their units are in standard deviations relative to the mean.

expectations of growth in the future, which would affect long-term rates more than short-term.

Post-1994 Sample Because the Fed began making formal policy announcements only after 1994, Table 13 estimates our baseline specification using post-1994 data. Low-leverage and high-distance to default firms continue to be more responsive in this specification. The average effect of monetary policy becomes insignificant because its variation is smaller in the post-1994 sample.

Alternative Time Aggregation Table 14 shows that our baseline results hold when we time-aggregate the high-frequency shocks by taking the simple sum within the quarter, rather than the weighted sum in the main text.
Table 14

ALTERNATIVE TIME AGGREGATION

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>leverage x ffr shock (sum)</td>
<td>-0.68***</td>
<td>-0.61**</td>
<td>-0.54**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.19)</td>
<td>(0.25)</td>
<td>(0.27)</td>
<td></td>
</tr>
<tr>
<td>dd x ffr shock (sum)</td>
<td>0.81***</td>
<td>0.54**</td>
<td>0.69**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.26)</td>
<td>(0.25)</td>
<td>(0.32)</td>
<td></td>
</tr>
<tr>
<td>ffr shock (sum)</td>
<td>0.47</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.53)</td>
</tr>
<tr>
<td>Observations</td>
<td>222475</td>
<td>153520</td>
<td>153520</td>
<td>151433</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.123</td>
<td>0.135</td>
<td>0.138</td>
<td>0.126</td>
</tr>
<tr>
<td>Firm controls</td>
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<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Time sector FE</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Time clustering</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

Notes: results from estimating variants of the baseline specification

$$\Delta \log k_{jt+1} = \alpha_j + \alpha_{st} + \beta_y (y_{jt-1} - \mathbb{E}_j[y_{jt}])\varepsilon_t^m + \Gamma_1' Z_{jt-1} + \Gamma_2 (y_{jt-1} - \mathbb{E}_j[y_{jt}])Y_{t-1} + \varepsilon_{jt},$$

where $\alpha_j$ is a firm fixed effect, $\alpha_{st}$ is a sector-by-quarter fixed effect, $y_{jt} \in \{\ell_{jt}, dd_{jt}\}$ is leverage or distance to default, $\mathbb{E}_j[y_{jt}]$ is the average financial position $y_{jt}$ of firm $j$ in our sample, $\varepsilon_t^m$ is the monetary shock, $Y_{t-1}$ is lagged GDP growth, and $Z_{jt-1}$ is a vector of firm-level controls containing leverage, sales growth, size, current assets as a share of total assets, and an indicator for fiscal quarter. Standard errors are two-way clustered by firms and quarters. We have normalized the sign of the monetary shock $\varepsilon_t^m$ so that a positive shock is expansionary (corresponding to a decrease in interest rates). We have standardized within-firm leverage ($\ell_{jt} - \mathbb{E}[\ell_{jt}]$) and within-firm distance to default ($dd_{jt} - \mathbb{E}[dd_{jt}]$) over the entire sample, so their units are in standard deviations relative to the mean. We time-aggregate the monetary shock by simply summing the high-frequency shocks that occur in a given quarter.

A.3.2 Robustness With Respect to Firm-Level Characteristics

The next set of robustness checks concerns our measures of firm-level characteristics.

Lagged Investment Table 15 shows that the main results in Table 3 continue to hold when controlling for lagged investment. This exercise is motivated by results in Eberly, Rebelo and Vincent (2012), who show that the $R^2$ of a similar investment regression significantly increases when one includes lagged investment. However, Table 15 shows that there is only a modest increase in the $R^2$ for our sample. This difference is primarily due to the fact that we use quarterly data while Eberly, Rebelo and Vincent (2012) use annual data; the $R^2$ for long-horizon dynamics is substantially larger.
### Table 15

**Lagged Investment**

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>leverage \times\ ffr shock</td>
<td>-0.48*</td>
<td>-0.20</td>
<td>-0.10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.28)</td>
<td>(0.38)</td>
<td>(0.39)</td>
<td></td>
</tr>
<tr>
<td>dd \times\ ffr shock</td>
<td>0.88**</td>
<td>0.73**</td>
<td>0.93**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.37)</td>
<td>(0.35)</td>
<td>(0.42)</td>
<td></td>
</tr>
<tr>
<td>investment ,(t - 1)</td>
<td>0.20***</td>
<td>0.15***</td>
<td>0.15***</td>
<td>0.16***</td>
</tr>
<tr>
<td></td>
<td>(0.01)</td>
<td>(0.01)</td>
<td>(0.01)</td>
<td>(0.01)</td>
</tr>
<tr>
<td>ffr shock</td>
<td>1.14*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.65)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>219702</td>
<td>151433</td>
<td>151433</td>
<td>151433</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.159</td>
<td>0.156</td>
<td>0.158</td>
<td>0.148</td>
</tr>
<tr>
<td>Firm controls</td>
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<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Time sector FE</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Time clustering</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

Notes: results from estimating variants of the baseline specification

$$\Delta \log k_{jt+1} = \alpha_j + \alpha_{st} + \beta_y(y_{jt-1} - E_j[y_{jt}])\varepsilon_t^m + \Gamma'_1 Z_{jt-1} + \Gamma'_2 (y_{jt-1} - E_j[y_{jt}])Y_{t-1} + e_{jt},$$

where $\alpha_j$ is a firm fixed effect, $\alpha_{st}$ is a sector-by-quarter fixed effect, $y_{jt} \in \{\ell_{jt}, dd_{jt}\}$ is leverage or distance to default, $E_j[y_{jt}]$ is the average financial position $y_{jt}$ of firm $j$ in our sample, $\varepsilon_t^m$ is the monetary shock, $Y_{t-1}$ is lagged GDP growth, and $Z_{jt-1}$ is a vector of firm-level controls containing leverage, sales growth, size, current assets as a share of total assets, an indicator for fiscal quarter, and lagged investment $\Delta \log k_{jt}$. Standard errors are two-way clustered by firms and quarters. We have normalized the sign of the monetary shock $\varepsilon_t^m$ so that a positive shock is expansionary (corresponding to a decrease in interest rates).

We have standardized within-firm leverage $(\ell_{jt} - E[\ell_{jt}])$ and within-firm distance to default $(dd_{jt} - E[dd_{jt}])$ over the entire sample, so their units are in standard deviations relative to the mean.

**Decomposition of Leverage** Table 16 decomposes leverage into various types of debt and shows that our results hold for each of these types of debt.\(^{35}\) In addition, the table shows that our results hold when use leverage net of current assets.

**Heterogeneity by Other Measures of Financial Position** Table 17 computes heterogeneous responses by other measures of financial position – size, cash flows, dividend payments, and available liquid assets. It shows that larger firms, firms with higher cash flows, dividend-paying firms, and firms with more liquid assets are more responsive to monetary

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\(^{35}\)This decomposition sheds light on the role of the “debt overhang” hypothesis in driving our results. Under this hypothesis, equity holders of highly leveraged firms capture less of the return on investment; since equity holders make the investment decision, they will choose to invest less following the monetary policy shock. However, because investment is long lived, this hypothesis would predict much stronger differences by long term debt. We find that this is not the case; if anything, the differences across firms are stronger for debt due in less than one year.
Table 16
Decomposition of Leverage

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>leverage × ffr shock</td>
<td>-0.68**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.28)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>net leverage × ffr shock</td>
<td>-0.71**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.30)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST debt × ffr shock</td>
<td>-0.37</td>
<td>-0.44</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.31)</td>
<td>(0.31)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LT debt × ffr shock</td>
<td>-0.20</td>
<td>-0.35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.25)</td>
<td>(0.24)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>other liabilities × ffr</td>
<td>-0.23</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>shock</td>
<td>(0.28)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>liabilities × ffr shock</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.69**</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>(0.31)</td>
<td></td>
</tr>
</tbody>
</table>

Observations: 219702 219702 219702 219702 219702 219682 219682

R^2: 0.124 0.125 0.124 0.121 0.125 0.124 0.126

Firm controls: yes yes yes yes yes yes yes

Time sector FE: yes yes yes yes yes yes yes

Time clustering: yes yes yes yes yes yes yes

Notes: results from estimating variants of the baseline specification

\[ \Delta \log k_{jt+1} = \alpha_j + \alpha_{st} + \beta_y(y_{jt-1} - E_j[y_{jt}]) + \epsilon_t^m + \Gamma_1'Z_{jt-1} + \Gamma_2(y_{jt-1} - E_j[y_{jt}])Y_{t-1} + \epsilon_{jt}, \]

where \( \alpha_j \) is a firm fixed effect, \( \alpha_{st} \) is a sector-by-quarter fixed effect, \( y_{jt} \in \{ y_{jt}, dd_{jt} \} \) is leverage or distance to default, \( E_j[y_{jt}] \) is the average financial position \( y_{jt} \) of firm \( j \) in our sample, \( \epsilon_t^m \) is the monetary shock, \( Y_{t-1} \) is lagged GDP growth, and \( Z_{jt-1} \) is a vector of firm-level controls containing leverage, sales growth, size, current assets as a share of total assets, and an indicator for fiscal quarter. “Leverage” refers to leverage constructed as in the main text. “Net leverage” is leverage net of current assets. “Short term debt” is current debt (coming due in less than one year) divided by total assets. “Long term debt” is total debt minus current debt divided by total assets. “Other liabilities” is other liabilities divided by total assets. “Liabilities” is total debt plus other liabilities divided by total assets. Standard errors are two-way clustered by firms and quarters. We have normalized the sign of the monetary shock \( \epsilon_t^m \) so that a positive shock is expansionary (corresponding to a decrease in interest rates). We have standardized within-firm leverage \( (y_{jt} - E[y_{jt}]) \) and within-firm distance to default \( (dd_{jt} - E[dd_{jt}]) \) over the entire sample, so their units are in standard deviations relative to the mean.

shocks. However, none of these differences are statistically significant.

Extensive Margin Measure of Investment Table 18 shows that our baseline results hold for an indicator for the firm’s investment rate being greater than 1%, \( 1 \{ i_{jt} \geq 1\% \} \). This measure is motivated by the fact that many changes in micro-level investment occur along the extensive margin. Additionally, by focusing on large investment episodes, this measure is less prone to small measurement error in the capital stock. Quantitatively, firms with

56
### Table 17
**Interaction With Other Measures of Financial Positions**

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
<th>(8)</th>
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<tbody>
<tr>
<td>leverage × ffr shock</td>
<td>-0.68**</td>
<td>-0.67**</td>
<td>-0.68**</td>
<td>-0.73**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.28)</td>
<td>(0.28)</td>
<td>(0.28)</td>
<td>(0.28)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ddf × ffr shock</td>
<td>1.12***</td>
<td>1.09***</td>
<td>1.09***</td>
<td>1.13***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.39)</td>
<td>(0.39)</td>
<td>(0.39)</td>
<td>(0.39)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>size × ffr shock</td>
<td>0.37</td>
<td>0.56</td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>(0.29)</td>
<td>(0.40)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cash flows × ffr shock</td>
<td>-0.02</td>
<td>-0.35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.46)</td>
<td>(0.63)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I{dividends &gt; 0} × ffr shock</td>
<td>0.39</td>
<td>0.24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.60)</td>
<td>(0.64)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>liquidity × ffr shock</td>
<td></td>
<td></td>
<td>-0.24</td>
<td>-0.31</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.31)</td>
<td>(0.35)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Observations         | 219702  | 151433  | 218185  | 150350  | 219578  | 151353  |
| R²                   | 0.124   | 0.137   | 0.130   | 0.142   | 0.125   | 0.137   | 0.126   | 0.138   |
| Firm controls        | yes     | yes     | yes     | yes     | yes     | yes     | yes     | yes     |
| Time sector FE       | yes     | yes     | yes     | yes     | yes     | yes     | yes     | yes     |
| Time clustering      | yes     | yes     | yes     | yes     | yes     | yes     | yes     | yes     |

Notes: results from estimating variants of the baseline specification

\[
\Delta \log k_{jt+1} = \alpha_j + \alpha_{st} + \beta_y(y_{jt-1} - \mathbb{E}_j[y_{jt}])z^m_j + \Gamma_z^1 y_{jt-1} + \Gamma_z^2 (y_{jt-1} - \mathbb{E}_j[y_{jt}])Y_{t-1} + e_{jt},
\]

where \(\alpha_j\) is a firm fixed effect, \(\alpha_{st}\) is a sector-by-quarter fixed effect, \(y_{jt}\) is leverage, distance to default, size (measured by log of current assets), cash flows, an indicator for whether the firm pays dividends, or liquidity, \(\mathbb{E}_j[y_{jt}]\) is the average financial position \(y_{jt}\) of firm \(j\) in our sample, \(z^m_j\) is the monetary shock, \(Y_{t-1}\) is lagged GDP growth, and \(Z_{jt-1}\) is a vector of firm-level controls containing leverage, sales growth, size, current assets as a share of total assets, and an indicator for fiscal quarter. Standard errors are two-way clustered by firms and quarters. We have normalized the sign of the monetary shock \(z^m_j\) so that a positive shock is expansionary (corresponding to a decrease in interest rates). We have standardized each of the demeaned financial variables \(y_{jt} - \mathbb{E}_j[y_{jt}]\) over the entire sample, so their units are in standard deviations relative to the mean.

One cross-sectional standard deviation higher leverage are nearly 5% less likely to invest following an expansionary monetary policy shock, and firms with one standard deviation higher distance to default are over 5% more likely to invest.

### A.3.3 Robustness With Respect to Differences in Cyclical Sensitivities

Our final set of results shows that our results are not driven by differences in cyclical sensitivities across firms.
### Table 18

**Extensive Margin of Investment**

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>leverage × ffr shock</td>
<td>-2.81**</td>
<td>-4.12**</td>
<td>-3.69*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1.40)</td>
<td>(1.93)</td>
<td>(1.91)</td>
<td></td>
</tr>
<tr>
<td>dd × ffr shock</td>
<td>5.30***</td>
<td>3.44*</td>
<td>4.09*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1.70)</td>
<td>(1.74)</td>
<td>(2.32)</td>
<td></td>
</tr>
<tr>
<td>ffr shock</td>
<td></td>
<td></td>
<td></td>
<td>7.47</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(4.59)</td>
</tr>
<tr>
<td>Observations</td>
<td>219702</td>
<td>151433</td>
<td>151433</td>
<td>151433</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.223</td>
<td>0.234</td>
<td>0.235</td>
<td>0.222</td>
</tr>
<tr>
<td>Firm controls</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Time sector FE</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Time clustering</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

Notes: results from estimating variants of the baseline specification

$\mathbb{I}\{\frac{\ell_{jt}}{E_j[\ell_{jt}]} \geq 1\%\} = \alpha_j + \alpha_{st} + \beta_y(y_{jt-1} - E_{y_{jt}})\varepsilon_{mt} + \Gamma_1 Z_{jt-1} + \Gamma_2(y_{jt-1} - E_{y_{jt}})Y_{t-1} + \epsilon_{jt},$

where $\alpha_j$ is a firm fixed effect, $\alpha_{st}$ is a sector-by-quarter fixed effect, $y_{jt} \in \{\ell_{jt}, dd_{jt}\}$ is leverage or distance to default, $E_{y_{jt}}$ is the average financial position $y_{jt}$ of firm $j$ in our sample, $\varepsilon_{mt}$ is the monetary shock, $Y_{t-1}$ is lagged GDP growth, and $Z_{jt-1}$ is a vector of firm-level controls containing leverage, sales growth, size, current assets as a share of total assets, and an indicator for fiscal quarter. Standard errors are two-way clustered by firms and quarters. We have normalized the sign of the monetary shock $\varepsilon_{mt}$ so that a positive shock is expansionary (corresponding to a decrease in interest rates). We have standardized within-firm leverage $(\ell_{jt} - E[\ell_{jt}])$ and within-firm distance to default $(dd_{jt} - E[dd_{jt}])$ over the entire sample, so their units are in standard deviations relative to the mean.

**Impact Effects** Our baseline specification using within-firm variation (5) controls for different cyclical sensitivities across firms by including an interaction between demeaned financial position $y_{jt} - E_{y_{jt}}$ with lagged GDP growth. Table 19 shows that our robust to controlling for interactions with other cyclical variables: the inflation rate or the unemployment rate.

**Dynamics** Figure 8 plots the dynamics of the differential responses from specification (5) without controlling for differential responses to GDP growth as in the main text. Not controlling for these differences leaves the point estimates largely unchanged but increases the standard errors, suggesting that differences in cyclical sensitivities confound inference about the monetary shock. In any event, Figure 8 makes clear that our conclusion that long-run dynamics are imprecisely estimated is not due to controlling for differences in cyclical
### Table 19
**Controlling for Differences in Cyclical Sensitivities**

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>leverage × ffr shock</td>
<td>-0.68**</td>
<td>-0.64**</td>
<td>-0.36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.28)</td>
<td>(0.29)</td>
<td>(0.26)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dd × ffr shock</td>
<td></td>
<td>1.10***</td>
<td></td>
<td>1.12***</td>
<td></td>
<td>0.88**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.39)</td>
<td></td>
<td>(0.39)</td>
<td></td>
<td>(0.35)</td>
</tr>
<tr>
<td>leverage × dlog gdp</td>
<td>-0.14**</td>
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<td>-0.15***</td>
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<td></td>
</tr>
<tr>
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<td>(0.06)</td>
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<td>(0.06)</td>
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<tr>
<td>dd × dlog gdp</td>
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<td>0.11</td>
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<td>0.09</td>
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<tr>
<td></td>
<td>(0.11)</td>
<td></td>
<td>(0.11)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>leverage × dlog cpi</td>
<td></td>
<td></td>
<td>-0.12</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>(0.09)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>dd × dlog cpi</td>
<td></td>
<td></td>
<td>-0.09</td>
<td></td>
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<td></td>
<td>(0.12)</td>
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</tr>
<tr>
<td>leverage × ur</td>
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<td></td>
<td></td>
<td>0.00</td>
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<td>0.00</td>
</tr>
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<td></td>
<td>(0.00)</td>
<td></td>
<td>(0.00)</td>
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<tr>
<td>dd × ur</td>
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<td>219702</td>
<td>151433</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.124</td>
<td>0.137</td>
<td>0.124</td>
<td>0.137</td>
<td>0.124</td>
<td>0.137</td>
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<tr>
<td>Firm controls</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

Notes: results from estimating variants of the baseline specification

$$\Delta \log k_{jt+1} = \alpha_j + \alpha_{st} + \beta_y(y_{jt-1} - E_j[y_{jt}])\varepsilon^m_t + \Gamma'_1Z_{jt-1} + \Gamma'_2(y_{jt-1} - E_j[y_{jt}])Y_{t-1} + \epsilon_{jt},$$

where $\alpha_j$ is a firm fixed effect, $\alpha_{st}$ is a sector-by-quarter fixed effect, $y_{jt} \in \{\ell_{jt}, dd_{jt}\}$ is leverage or distance to default, $E_j[y_{jt}]$ is the average financial position $y_{jt}$ of firm $j$ in our sample, $\varepsilon^m_t$ is the monetary shock, $Y_{t-1}$ is GDP growth (dlog gdp), the inflation rate (dlog cpi), or the unemployment rate (ur), and $Z_{jt-1}$ is a vector of firm-level controls containing leverage, sales growth, size, current assets as a share of total assets, and an indicator for fiscal quarter. We have normalized the sign of the monetary shock $\varepsilon^m_t$ so that a positive shock is expansionary (corresponding to a decrease in interest rates). We have standardized within-firm leverage ($\ell_{jt} - E[\ell_{jt}]$) and within-firm distance to default ($dd_{jt} - E[dd_{jt}]$) over the entire sample, so their units are in standard deviations relative to the mean.
Figure 8: Dynamics Without Controlling for Differences in Cyclical Sensitivities

(a) Leverage

(b) Distance to Default

Notes: dynamics of the interaction coefficient between leverage and monetary shocks over time. Reports the coefficient $\beta_h$ over quarters $h$ from

$$\log k_{jt+h} - \log k_{jt} = \alpha_{jh} + \alpha_{sth} + \beta_h(y_{jt-1} - E[y_{jt}])\varepsilon_t^m + \Gamma'_{jh}Z_{jt-1} + e_{jt},$$

where $\alpha_{jh}$ is a firm fixed effect, $\alpha_{sth}$ is a sector-by-quarter fixed effect, $y_{jt} \in \{\ell_{jt}, dd_{jt}\}$ is either the firm's leverage ratio or distance to default, $E[y_{jt}]$ is the average of $y_{jt}$ for firm $j$ in the sample, $\varepsilon_t^m$ is the monetary shock, $Z_{jt-1}$ is a vector of firm-level controls containing leverage, sales growth, size, current assets as a share of total assets, and an indicator for fiscal quarter. Standard errors are two-way clustered by firms and time. Dashed lines report 90% error bands. We have normalized the sign of the monetary shocks $\varepsilon_t^m$ so that a positive shock is expansionary (corresponding to a decrease in interest rates). We have standardized within-firm leverage ($\ell_{jt} - E[\ell_{jt}]$) and within-firm distance to default ($dd_{jt} - E[dd_{jt}]$) over the entire sample, so their units are in standard deviations relative to the mean.

A.4 Comparison to Jeenas (2018)

In this appendix, we relate our findings to recent work by Jeenas (2018) along three dimensions. First, Appendix A.4.1 shows that the differences between our estimated dynamics are accounted for by permanent heterogeneity in responsiveness across firms. Second, Appendix A.4.2 shows that our results are not driven by differences in liquidity across firms. Third, Appendix A.4.3 shows that our results are not driven by outliers or non-standard choices about data trimming.
A.4.1 Dynamics

We begin by replicating Jeenas (2018)’s results in our sample. For reference, Panel (a) of Figure 9 plots the dynamics of the interaction of within-firm leverage and the monetary shock \((\ell_{jt-1} - \mathbb{E}_j[\ell_{jt-1}])\varepsilon_t^m\) from the local projection

\[
\log k_{jt+h} - \log k_j = \alpha_{jh} + \alpha_{sth} + \beta_h (\ell_{jt-1} - \mathbb{E}_j[\ell_{jt}])\varepsilon_t^m + \Gamma'_{1h} Z_{jt-1} + \Gamma'_{2h} (\ell_{jt-1} - \mathbb{E}_j[\ell_{jt}])Y_{t-1} + \varepsilon_{jth}, \tag{17}
\]

which simply extends Figure 1 from the main text out to twenty quarters. Jeenas (2018)’s specification differs from our’s in two key ways. First, Jeenas (2018) drops observations in the top 1% of the leverage distribution while we winsorize the top 0.5%.\(^{36}\) Second, Jeenas (2018) computes the interaction between the monetary shock and the firm’s average leverage over the past four quarters, \(\hat{\ell}_{jt-1}\), rather than the within-firm variation in the stock of leverage in the past quarter, \(\ell_{jt} - \mathbb{E}_j[\ell_{jt}]\). Panel (d) applies these two operations and recovers the spirit of Jeenas (2018)’s result: high-leverage firms become substantially more responsive to the shock after approximately four quarters. Quantitatively, this point estimate implies that four years after a one percentage point expansionary shock, a firm with one standard deviation more leverage than the average firm increases their capital stock by over ten percentage points more than the average firm.

The remaining panels of Figure 9 decompose the effect of these two differences between our specifications on the estimated dynamics. Panel (b) shows that Jeenas (2018)’s more aggressive trimming of high-leverage observations has an insignificant effect on the estimated dynamics. In this panel, we estimate our baseline specification (17) after dropping observations in the top 1% of the leverage distribution and find that high-leverage firms are not statistically significantly more responsive to monetary policy. Appendix A.4.3 shows that the heterogeneity upon impact, which is the focus of our economic model, is extremely robust to the trimming cutoff.

Panel (c) shows that sorting firms by the average of their past four quarters of leverage \(\hat{\ell}_{jt-1}\) accounts for the difference between our results. In this panel, we re-estimate our dynamic specification (17) after dropping the top 1% of leverage observations and replacing

\(^{36}\)We winsorize the top 0.5% rather than drop the top 1% because the most highly indebted firms are the most likely to have substantial default risk, which is our object of interest.
Figure 9: Comparison of Our Dynamic Results to Jeenas (2018)

(a) Baseline Model (Winsorizing 0.5 percent)

(b) Model (a) + Trimming top 1 percent

(c) Model (b) using 1-year Average Leverage

(d) Model (c) + Demeaning Leverage within Firm

Notes: dynamics of the interaction coefficient between leverage and monetary shocks over time. Reports the coefficient $\beta_h$ over quarters $h$ from

$$\log k_{jt+h} - \log k_{jt} = \alpha_{jh} + \alpha_{sth} + \beta_h (\ell_{jt} - \mathbb{E}_j[\ell_{jt}]) e_t^m + \Gamma_{1h}^1 Z_{jt-1} + \Gamma_{2h}^1 (\ell_{jt} - \mathbb{E}_j[\ell_{jt}]) Y_{t-1} + e_{jt},$$

where $\alpha_{jh}$ is a firm fixed effect, $\alpha_{sth}$ is a sector-by-quarter fixed effect, $\ell_{jt-1}$ is leverage, $\mathbb{E}_j[\ell_{jt}]$ is the average leverage of firm $j$ in our sample, $e_t^m$ is the monetary shock, $Y_{t-1}$ is lagged GDP growth, and $Z_{jt-1}$ is a vector of firm-level controls containing leverage, sales growth, size, current assets as a share of total assets, and an indicator for fiscal quarter. Standard errors are two-way clustered by firms and time. Dashed lines report 90% error bands. Panel (b) drops the top 1% of the observations in the leverage variable used in the particular forecasting horizons. Panel (c) applies this operation and replaces demeaned leverage $\ell_{jt-1} - \mathbb{E}_j[\ell_{jt}]$ with the firm’s average leverage over the last four quarters, $\hat{\ell}_{jt-1}$. Panel (d) estimates this specification using only within-firm variation in averaged leverage $\hat{\ell}_{jt-1} - \mathbb{E}[\hat{\ell}_{jt}]$. We have normalized the sign of the monetary shocks $e_t^m$ so that a positive shock is expansionary (corresponding to a decrease in interest rates). We have standardized leverage $\ell_{jt}$, averaged leverage $\hat{\ell}_{jt}$, and demeaned average leverage $\hat{\ell}_{jt} - \mathbb{E}[\hat{\ell}_{jt}]$ over the entire sample, so their units are in standard deviations relative to the mean.
the within-firm variation in last quarter’s stock of leverage \( \ell_{jt} - \mathbb{E}_j[\ell_{jt}] \) with Jeenas (2018)’s moving average \( \hat{\ell}_{jt-1} \). The moving average eliminates high-frequency variation in leverage within a firm, implying that the estimated dynamics are more strongly driven by permanent heterogeneity across firms. Consistent with this idea, Panel (d) shows that using only within-firm variation in averaged leverage \( \hat{\ell}_{jt-1} - \mathbb{E}_j[\hat{\ell}_{jt}] \) renders the long-horizon dynamics smaller and significantly insignificant, largely consistent with our baseline specification. We prefer our specification because it maps more directly into our economic model in which heterogeneity in leverage is driven by ex-post realizations of idiosyncratic shocks and lifecycle dynamics across firms. We focus our analysis of the model on the heterogeneous responses upon impact, which are robustly estimated in both our specification and Jeenas (2018) and survive the litany of robustness checks in Appendices A.2 and A.3.\(^{37}\)

A.4.2 Heterogeneous Responses Not Driven by Liquidity

Jeenas (2018) argues that the dynamics of heterogeneous responses by leverage documented in Appendix A.4.1 are driven by differences in liquidity across firms. Table 17 above shows that the heterogeneous responses upon impact are not driven by liquidity once we use within-firm variation in our main specification (5). Figure 10 shows that our dynamics results are not driven by differences in liquidity either. We estimate the local projection

\[
\log k_{j,t+h} - \log k_{j,t} = \alpha_{j,t} + \alpha_{st,t} + \beta_{1h}(y_{j,t-1} - \mathbb{E}_j[y_{j,t}])\varepsilon_{t}^m + \beta_{2h}(x_{j,t-1} - \mathbb{E}_j[x_{j,t}])\varepsilon_{t}^m + \Gamma_{1h}Z_{jt-1} + \Gamma_{2h}(y_{j,t-1} - \mathbb{E}_j[y_{j,t}])Y_{t-1} + \Gamma_{3h}(x_{j,t-1} - \mathbb{E}_j[x_{j,t}])Y_{t-1} + e_{j,t,h},
\]

(18)

where \( x_{j,t} - \mathbb{E}_j[x_{j,t}] \) is the within-firm variation in liquidity. Panel (a) shows that the point estimate of the leverage dynamics are similar to those presented in the main text, although

\(^{37}\)An additional difference between our specification and Jeenas (2018)’s is that we control for differences in cyclical sensitivities while Jeenas (2018) does not. We include these controls because we have found that there are significant differences in long-run cyclical sensitivities and that GDP growth is correlated with monetary shocks over these horizons in our sample. Appendix A.3 shows that excluding these controls does not affect the point estimates in our specification but does increase the standard errors. We have also found that excluding these controls does not strongly affect the point estimates or standard errors in Jeenas (2018)’s baseline specification with averaged leverage \( \hat{\ell}_{jt} \). Excluding these controls slightly increases the responsiveness of high demeaned average leverage firms \( \hat{\ell}_{jt} - \mathbb{E}_j[\hat{\ell}_{jt}] \), but the difference from Panel (d) in Figure 9 is small and not statistically significant.
the standard errors are wider given the correlation between leverage and liquidity. Panel (b) shows that the dynamics of distance to default are strongly and significantly positive, as in the main text. In that case, the dynamics of liquidity are always statistically insignificant, suggesting that default risk the primary source of heterogeneous responses across firms when using within-firm variation.

A.4.3 Outliers

As we discussed in Appendix A.4.1, one difference between our specification and Jeenas (2018)’s is that we winsorize the top 0.5% of observations while Jeenas (2018) trims the top 1%. Our discussion in A.4.1 shows that this difference does not have a significant effect on the dynamics of the heterogeneous responses by leverage. Figure 11 shows that our estimated impact effects by leverage and distance to default – which are the main focus of our analysis – are extremely robust to different choices about outliers. The left column of Panel (a) plots the interaction coefficient on demeaned leverage in our baseline specification (5) as a function of the cutoff when winsorizing and the right column plots the coefficient as a function of the cutoff when trimming. Panel (b) plots the same objects for the coefficient on demeaned distance to default. The estimated coefficients are stable across all these different samples.
Figure 10: Joint Dynamics of Financial Position and Liquidity

(a) Leverage and Liquidity

Notes: estimated coefficients $\beta_{1h}$ and $\beta_{2h}$ over quarters $h$ from

$$
\log k_{jt+h} - \log k_{jt} = \alpha_{jh} + \alpha_{sth} + \beta_{1h}(y_{jt-1} - \mathbb{E}_j[y_{jt}])\varepsilon_t^m + \beta_{2h}(x_{jt-1} - \mathbb{E}_j[x_{jt}])\varepsilon_t^m \\
+ \Gamma_{1h}Z_{jt-1} + \Gamma_{2h}(y_{jt-1} - \mathbb{E}_j[y_{jt}])Y_{t-1} + \Gamma_{3h}(x_{jt-1} - \mathbb{E}_j[x_{jt}])Y_{t-1} + \epsilon_{jt},
$$

where $\alpha_{jh}$ is a firm fixed effect, $\alpha_{sth}$ is a sector-by-quarter fixed effect, $y_{jt} \in \{\ell_{jt}, dd_{jt}\}$ is leverage or distance to default, $x_{jt}$ is liquidity, $\varepsilon_t^m$ is the monetary shock, $Y_{t-1}$ is lagged GDP growth and $Z_{jt-1}$ is a vector of firm-level controls containing leverage, sales growth, size, current assets as a share of total assets, and an indicator for fiscal quarter. Standard errors are two-way clustered by firms and time. Dashed lines report 90% error bands. Panel (a) runs our baseline specification with leverage $y_{jt} = \ell_{jt}$. Panel (b) runs our preferred specification with distance to default $y_{jt} = dd_{jt}$. We have normalized the sign of the monetary shocks $\varepsilon_t^m$ so that a positive shock is expansionary (corresponding to a decrease in interest rates). We have standardized the demeaned financial position variables $y_{jt} - \mathbb{E}_j[y_{jt}]$ and demeaned liquidity $x_{jt} - \mathbb{E}_j[x_{jt}]$ over the entire sample, so their units are in standard deviations relative to the mean.
Figure 11: Heterogeneous Responses Not Driven by Outliers

(a) Leverage

(b) Distance to Default

Notes: plots of the coefficients $\beta$ estimated from the specification

$$\Delta \log k_{jt+1} = \alpha_j + \alpha_{st} + \beta (y_{jt} - E_j[y_{jt}]) \varepsilon_t + \Gamma_1 Z_{jt-1} + \Gamma_2 (y_{jt-1} - E_j[y_{jt}]) Y_{t-1} + \varepsilon_{jt},$$

where $\alpha_j$ is a firm fixed effect, $\alpha_{st}$ is a sector-by-quarter fixed effect, $y_{jt}$ is leverage, distance to default, size (measured by log of current assets), cash flows, an indicator for whether the firm pays dividends, or liquidity, $E_j[y_{jt}]$ is the average financial position $y_{jt}$ of firm $j$ in our sample, $\varepsilon_t$ is the monetary shock, $Y_{t-1}$ is lagged GDP growth, and $Z_{jt-1}$ is a vector of firm-level controls containing leverage, sales growth, size, current assets as a share of total assets, and an indicator for fiscal quarter. The left column winsorizes the top and bottom of the financial position $y_{jt}$ distribution. The right column trims the top of the financial position $y_{jt}$ distribution. Standard errors are two-way clustered by firms and quarters. We have normalized the sign of the monetary shock $\varepsilon_t$ so that a positive shock is expansionary (corresponding to a decrease in interest rates). We have standardized within-firm leverage ($\ell_{jt} - E[\ell_{jt}]$) and within-firm distance to default ($dd_{jt} - E[dd_{jt}]$) over the entire sample, so their units are in standard deviations relative to the mean.
B Model Appendix

B.1 Proof of Proposition 1

We prove Proposition 1 in steady state; extending the proof to include transition dynamics is straightforward. To clarify the economic mechanisms, we work with a simple version of the model that abstracts from capital-quality shocks ($\sigma_\omega = 0$), has zero recovery value of debt ($\alpha = 0$), and has no exogenous exit shocks ($\pi_d = 0$). The proof in the full model follows the same steps with more complicated notation.

Default Threshold  As discussed in the main text, firms only default when they have no feasible choice which satisfies the non-negativity constraint on dividends, i.e., there is no $(k', b')$ such that $x - k' + Q(z, k', b')b' \geq 0$. Define the default threshold $x(z) = \min_{k', b'} k' - Q(z, k', b')b'$. Note that the largest feasible dividend payment of a firm is $x = x(z)$. If $x \geq x(z)$, then $\arg \min_{k', b'} k' - Q(z, k', b')b'$ is a feasible choice and the firm will not default. On the other hand, if $x < x(z)$, then $d \leq 0$ for all $(k', b')$, violating feasibility.

With this notation in hand, the Bellman equation of a continuing firm in this simple case is

$$v(z, x) = \max_{k', b'} x - k' + Q(z, k', b')b' + \beta \mathbb{E} \left[ v(z', x') I \{ x' > x(z') \} | z, k', b' \right] \quad \text{s.t. } d \geq 0,$$

(19)

where $x(z')$ is the default threshold.

Although the continuation value is kinked at the default point, it is never optimal for a firm to choose this point (see Clausen and Strub (2017) and the discussion in Arellano et al. (2016)). Hence, the first order conditions are necessary at the optimum.

Unconstrained Firms  Define the unconstrained capital accumulation rule $k^*(z)$ as

$$k^*(z) = \arg \max_{k'} -k' + \beta \mathbb{E} [\iota(z', k') + (1 - \delta)k' | z],$$

where $\iota(z, k) = \max_{n} zk^{\theta}n - wn$. After some algebra, one can show that the expression in the main text solves this maximization problem (extending the expression to the full model).
We will now fully characterize the decision rules for firms that can afford the unconstrained capital accumulation rule while have zero probability of default in all future states. We first claim that such a firm is indifferent over any choice of debt $b'$ which leaves the firm unconstrained. To show this, note that since the firm has no default risk it borrows at the risk-free rate $\beta$. In this case, the first order condition for borrowing $b'$ is $\beta = \beta$, which is obviously true for any value of $b'$.

Following Khan, Senga and Thomas (2016), we resolve this indeterminacy by defining the maximum borrowing policy $b^*(z)$ as the maximal borrowing $b'$ the firm can do while having zero probability of default in all future states. To derive the maximum borrowing policy $b^*(z)$, first note that if the firm invests $k^*(z)$ and borrows $b^*(z)$ in the current period, its dividends in the next period are

$$\nu(z', k^*(z)) + (1 - \delta)k^*(z) - b^*(z) - \xi - k^*(z') + \beta b^*(z'),$$

for a given realization of $z'$. The requirement that the firm has zero probability of default in all future states then implies that

$$b^*(z) = \min_{z'} \nu(z', k^*(z)) + (1 - \delta)k^*(z) - k^*(z') + \beta b^*(z').$$

Hence, $b^*(z)$ is the largest amount of borrowing the firm can do and be guaranteed to satisfy the non-negativity constraint on dividends.\(^{39}\)

By construction, if a firm can follow the unconstrained capital accumulation policy $k^*(z)$ and the maximum borrowing policy $b^*(z)$ while satisfying the non-negativity constraint on dividends in the current period, it will also satisfy the non-negativity constraint in all future periods. Moreover, following $k^*(z)$ is indeed optimal for such firms because it solves the associated first-order condition of these firms. Hence, a firm is unconstrained and follows

\(^{38}\)Khan, Senga and Thomas (2016) refer to this object as the “minimum savings policy.”

\(^{39}\)To derive this expression, first re-arrange the non-negativity constraint on dividends conditional on a realization of the future shocks as an inequality with $b'$ on the left-hand side. This results in a set of inequalities for each possible realization of the future shocks. The min operator ensures that all of these inequalities are satisfied.
these decision rules if and only if \( d = x - k^*(z) + \beta b^*(z) \), i.e.,

\[
x > \underline{x}(z) \equiv k^*(z) - \beta b^*(z).
\]

**Constrained Firms**  Consider again the constrained Bellman equation (19). We will show that firms with \( x \in [\underline{x}(z), \overline{x}(z)] \) pay zero dividends. Invert the default threshold \( \underline{x}(z) \) so that the firm defaults if \( z' < \underline{x}(k', b') \). The Bellman equation (19) can then be written as

\[
v(z, x) = \max_{k', b'} x - k' + Q(z, k', b')b' + \beta \int_{\underline{x}(k', b')}^{\overline{x}} v(z', x')g(z'|z)dz' \text{ s.t. } d \geq 0,
\]

where \( g(z'|z) \) is the density of \( z' \) conditional on \( z \), \( \overline{x} \) is the upper bound of the support of \( z \), and \( Q_3(z, k', b') \) is the derivative of the debt price schedule with respect to \( b' \).

Letting \( \lambda(z, x) \) be the Lagrange multiplier on the \( d \geq 0 \) constraint, the first order condition for \( b' \) is

\[
(1 + \lambda(z, x))(Q(z, k', b') + Q_3(z, k', b')b') = \\
\beta \left[ \int_{\underline{x}(k', b')}^{\overline{x}} (1 + \lambda(z', k', b')g(z'|z)dz' + g(\underline{x}(k', b')|z)v(\underline{x}(k', b'), \overline{x}(k', b'))\frac{\partial \underline{x}(k', b')}{\partial b'} \right],
\]

where \( \overline{x}(k', b') = \max_{n'} \underline{x}(k', b')(k')^{\eta} - wn' + (1 - \delta)k' - b' - \xi \) and \( \lambda(z', k', b') = \lambda(z', x') \) for the \( x' \) implied by \( (z', k', b') \). The left hand side of this expression measures the marginal benefit of borrowing. The marginal resources the firm receives on borrowing is the debt price, adjusting for the fact that the marginal cost of borrowing changes on existing debt. The firm values those marginal resources using the Lagrange multiplier. The right hand side of this expression measures the discounted marginal cost of borrowing. In states of the world in which the firm does not default, it must give up one unit of resources, which it values using the next period’s Lagrange multiplier. In addition, marginal borrowing implies that the firm defaults in additional future states.

Note that the debt price schedule is \( Q(z, k', b') = \beta \int_{\underline{x}(k', b')}^{\overline{x}} g(z'|z)dz' \), which implies that
Q_3(z, k', b') = -\beta g(\bar{z}(k', b')|z) \frac{\partial \bar{z}(k', b')}{\partial b'}. \text{ Plugging this into the first order condition gives}

\beta(1 + \lambda(z, x))(\int_{z(k', b')}^{\bar{z}} g(z'|z)dz' - \beta g(\bar{z}(k', b')|z) \frac{\partial \bar{z}(k', b')}{\partial b'}) = 

\beta \left[ \int_{z(k', b')}^{\bar{z}} (1 + \lambda(z', k', b')g(z'|z)dz' + g(\bar{z}(k', b')|z)v(\bar{z}(k', b'), \bar{x}(k', b')) \frac{\partial \bar{z}(k', b')}{\partial b'} \right]. \quad (21)

We will now show that constrained firms set \( d = 0 \). We do so by contradiction: suppose that a constrained firm sets \( d > 0 \), implying that \( (z, x) = 0 \).

First consider a firm that has zero probability of default in the next period, i.e., \( z(k', b') = \bar{z} \) and \( \frac{\partial z(k', b')}{\partial b'} = 0 \). In this case, the first order condition (21) can be simplified to

\[ 0 = \int_{\bar{z}}^{\bar{z}} \lambda(z', k', b')g(z'|z)dz'. \]

Since the firm is constrained, \( \lambda(z', k', b') > 0 \) for some positive mass of realizations of \( z' \), leading to a contradiction.

Now consider a firm that has some positive probability of default, implying that \( z(k', b') > \bar{z} \) and \( \frac{\partial z(k', b')}{\partial b'} > 0 \). In this case, the first order condition (21) can be rearranged to

\[ 0 = \int_{\bar{z}(k', b')}^{\bar{z}} \lambda(z', k', b')g(z'|z)dz' + \frac{\partial \bar{z}(k', b')}{\partial b'} g(\bar{z}(k', b')|z)(b' + v(z', k', b')), \]

where \( v(z', k', b') = v(z', x') \) for the \( x' \) implied by \( (z', k', b') \). By construction, risky constrained firms engage in strictly positive borrowing \( b' > 0 \). This implies that the right hand side is strictly greater than zero, leading to a contradiction.

**B.2 Equilibrium Definition**

**Distribution of Firms** We need to derive the evolution of the distribution of firms in order to precisely define an equilibrium. The distribution of firms in production is composed of incumbents who do not default and new entrants who do not default. Mathematically,
this distribution $\hat{\mu}_t(z, x)$ is given by

$$\hat{\mu}_t(z, x) = \int (\pi_d x^1(x_t(z, \omega, k, b)) + (1 - \pi_d) \chi_t^2(z, x_t(z, \omega, k, b))) \, d\mu_t(z, \omega, k, b)$$

$$+ \bar{\mu} \int (\pi_d x^1(x_t(z, \omega, k_0, 0)) + (1 - \pi_d) \chi_t^2(z, x_t(z, \omega, k_0, 0))) \, g(\omega) \, d\omega \, d\mu^{ent}(z),$$

where $x_t(z, \omega, k, b) = \max_n p_t(z(\omega k)^n - w_t n + q_t (1 - \delta) \omega k - b - \xi$ is the implied cash-on-hand $x$ of a firm with state $(z, \omega, k, b)$ and $g(\omega)$ is the PDF of capital quality shocks.

The evolution of the distribution of firms $\mu_t(z, \omega, k, b)$ is given by

$$\mu_{t+1}(z', \omega', k', b') = \int (1 - \pi_d) \chi_t^2(z, x_t(z, \omega, k, b)) \, 1\{k'_t(z, x_t(z, \omega, k, b)) = k'\}$$

$$\times \mathbb{I}\{\frac{b'_t(z, x_t(z, \omega, k, b))}{\Pi_{t+1}} = b'\} \, p(\varepsilon|\varepsilon^{\log z + \varepsilon} = z') \, g(\omega') \, d\varepsilon \, d\mu_t(z, \omega, k, b)$$

$$+ \bar{\mu} \int (1 - \pi_d) \chi_t^2(z, x_t(z, \omega, k_0, 0)) \, 1\{k'_t(z, x_t(z, \omega, k_0, 0)) = k'\}$$

$$\times \mathbb{I}\{\frac{b'_t(z, x_t(z, \omega, k_0, 0))}{\Pi_{t+1}} = b'\} \, p(\varepsilon|\varepsilon^{\log z + \varepsilon} = z') \, g(\omega') \, d\varepsilon \, d\mu^{ent}(z),$$

where $p(\varepsilon|\varepsilon^{\log z + \varepsilon} = z')$ denotes the density of draws $\varepsilon$ such that $e^{\varepsilon^{\log z + \varepsilon}} = z'$.

**Equilibrium Definition** An equilibrium of this model is a set of $v_t(z, x), k'_t(z, x), b'_t(z, x), n_t(z, x), Q_t(z, k', b'), \Pi_t, \Delta_t, Y_t, q_t, \mu_t(z, \omega, k, b), \hat{\mu}_t(z, x), \Lambda_{t,t+1}, w_t, C_t,$ and $I_t$ such that

(i) Production firms optimization: $v_t(z, x)$ solves the Bellman equation (9) with associated decision rules $k'_t(z, x), b'_t(z, x)$, and $n_t(z, x)$.

(ii) Financial intermediaries price default risk according to (10).

(iii) New Keynesian block: $\Pi_t, p_t$, and $q_t$ satisfy (11) and (13).

(iv) The distribution of firms in production $\hat{\mu}_t(z, x)$ satisfies (22) and the distribution $\mu_t(z, \omega, k, b)$ evolves according to (23).

(v) Household block: the stochastic discount factor is given by $\Lambda_{t,t+1} = \beta \frac{C_{t+1}}{C_t}$. The wage must satisfy $w_t = \Psi C_t$. The stochastic discount factor and nominal interest rate are
Figure 12: Steady State Decision Rules

Notes: Left column plots decision rules and stationary distribution of firms conditional on idiosyncratic productivity one standard deviation below the mean. Right column plots the same objects conditional on productivity one standard deviation above the mean. The left y-axis measures the decision rules (capital accumulation, borrowing, and dividend payments) as a function of cash-on-hand $x$. The right y-axis measures the stationary distribution of firms. Top row plots these functions over the entire space of cash on hand. Bottom row plots these functions for low levels of cash on hand only.

linked through the Euler equation for bonds, $1 = \mathbb{E}_t \left[ \Lambda_{t,t+1} \frac{R_{t+1}^{\text{nom}}}{R_{t+1}} \right]$.

(vi) Market clearing: aggregate investment is implicitly defined by $K_{t+1} = \Phi(\frac{I_{t}}{K_{t}})K_{t} + (1 - \delta)K_{t}$, where $K_{t} = \int k d\mu_{t}(z, \omega, k, b)$. Aggregate consumption is defined by $C_{t} = Y_{t} - I_{t} - \xi$.\textsuperscript{40}

B.3 Analysis of Calibrated Model

In this appendix, we analyze firms’ decision rules in our calibrated steady state and show that the financial heterogeneity in our model is broadly comparable to that in the data.

Firms’ Decision Rules Figure 12 plots the investment, borrowing, and dividend payment decisions of firms. The top row of the figure plots the decision rules over the entire state space.

\textsuperscript{40}We normalize the mass of firms in production to 1, so $\xi$ is the total resources lost from the fixed operating costs.
Firms with cash-on-hand $x$ below the default threshold $\underline{x}_t(z)$ do not operate. Once firms clear this default threshold, they lever up to increase their capital to its optimal scale $k_t^*(z)$. Once capital is at its optimal level $k_t^*(z)$, firms use additional cash-on-hand to pay down their debt until they reach the unconstrained threshold $\bar{x}_t(z)$. Unconstrained firms set $k' = k_t^*(z)$ and $b' = b_t^*(z)$, which do not depend on cash on hand $x$. Only unconstrained firms pay positive dividends.

The curvature in the policy functions over the region with low cash on hand $x$ reflects the role of financial frictions in firms’ decisions. Without frictions, all non-defaulting firms would borrow the amount necessary to reach the optimal scale of capital $k_t^*(z)$. However, firms with low cash-on-hand $x$ would need to borrow a substantial amount, increasing their risk of default and therefore borrowing costs. Anticipating these higher borrowing costs, low cash on hand $x$ firms accumulate capital below its optimal scale.

The right axis of Figure 12 plots the stationary distribution of firms. 53.1% of firms pay a risk premium, i.e., are “risky constrained.” These firms are in the region with curved policy functions described above. 43% of firms are constrained but do not currently pay a risk premium, i.e., are “risk-free constrained.” These firms have achieved their optimal scale of capital $k_t^*(z)$ and have linear borrowing policies. The remaining 3.9% of firms are unconstrained. Due to our assumed debt accumulation policy, unconstrained firms pay out any cash on hand $x > \underline{x}_t(z)$ as dividends.

Figure 12 makes clear that there are two key sources of financial heterogeneity in the model. First, reading the graphs from left to right captures heterogeneity due to lifecycle dynamics; young firms accumulate debt in order to reach their optimal level of capital $k_t^*(z)$ and then pay down that debt over time. Second, moving from the left to the right column captures heterogeneity due to idiosyncratic productivity shocks; a positive shock increases the optimal scale of capital $k_t^*(z)$, again leading firms to first accumulate and then decumulate debt.\footnote{A third source of financial heterogeneity are the capital quality shocks, which simply generate variation in firms’ cash on hand $x$.} \footnote{Buera and Karmakar (2017) study how the aggregate effect of an interest rate shock depends on these two sources of heterogeneity in a simple two-period model.}
Comparing Lifecycle Dynamics to the Data  Figure 13 plots the dynamics of key variables over the firm lifecycle. New entrants begin with a low initial capital stock $k_0$ and, on average, a low draw of idiosyncratic productivity $z$. As described above, young firms take on new debt in order to finance investment, which increases their default risk and credit spreads. Over time, as firms accumulate capital and productivity reverts to its mean, they reach their optimal capital stock $k^*_t(z)$ and begin paying down their debt.

Figure 14 shows that these lifecycle dynamics are in line with key features of the data. The left panel plots the average size of firms by age. In the data, young firms are substantially smaller than average and take many years to catch up. Qualitatively, our model captures this prolonged growth process; however, quantitatively, growth in our model is too rapid because we do not include other frictions to firm growth such as capital adjustment costs or customer accumulation. The right panel of Figure 14 plots the share of firms in the economy in different age groups. The curve is downward-sloping because firms exit over time. In the model, the only source of curvature is state-dependent exit due to default. Although the
model underpredicts the overall level of the curve, it provides a good match of the slope.

**Investment and Leverage Heterogeneity in the Data**  Table 20 shows that our model is broadly consistent with key features of the distributions of investment and leverage not targeted in the calibration. The top panel analyzes the distribution of investment rates in the annual Census data reported by Cooper and Haltiwanger (2006). We present the corresponding statistics in our model for a selected sample – conditioning on firms that survive at least twenty years to mirror the selection into the LRD – and in the full sample. Although we have calibrated the selected sample to match the dispersion of investment rates, the mean and autocorrelation of investment rates in the selected sample are also reasonable. The mean investment rate in the full sample is higher than the selected sample because the full sample includes young, growing firms.

The middle and bottom panels of Table 20 compare the model-implied distribution of investment rates and leverage to quarterly Compustat data. We mirror the sample selection into Compustat by conditioning on firms that survive for at least ten years. According to Wilmer et al. (2017), the median time to IPO has ranged from roughly six to eight years.
Table 20
INVESTMENT AND LEVERAGE HETEROGENEITY

<table>
<thead>
<tr>
<th>Moment Description</th>
<th>Data</th>
<th>Model (selected)</th>
<th>Model (full)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Investment heterogeneity (annual LRD)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \mathbb{E} \left[ \frac{\hat{i}_k}{k} \right] )</td>
<td>Mean investment rate</td>
<td>12.2%</td>
<td>8.83%</td>
</tr>
<tr>
<td>( \sigma \left( \frac{\hat{i}_k}{k} \right) )</td>
<td>SD investment rate (calibrated)</td>
<td>33.7%</td>
<td>31.8%</td>
</tr>
<tr>
<td>( \rho \left( \frac{\hat{i}<em>k}{k}, \frac{\hat{i}</em>{k-1}}{k_{k-1}} \right) )</td>
<td>Autocorr investment rate</td>
<td>0.058</td>
<td>-0.26</td>
</tr>
<tr>
<td><strong>Leverage heterogeneity (quarterly Compustat)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \sigma \left( \frac{\hat{b}_k}{b} \right) )</td>
<td>SD leverage ratio</td>
<td>36.4%</td>
<td>76.4%</td>
</tr>
<tr>
<td>( \rho \left( \frac{\hat{b}<em>k}{b}, \frac{\hat{b}</em>{k-1}}{b_{k-1}} \right) )</td>
<td>Autocorr leverage ratio</td>
<td>0.94</td>
<td>0.92</td>
</tr>
<tr>
<td><strong>Joint investment and leverage (quarterly Compustat)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \rho \left( \frac{\hat{i}_k}{k}, \frac{\hat{b}_k}{b} \right) )</td>
<td>Corr. of leverage and investment</td>
<td>-0.08</td>
<td>-0.16</td>
</tr>
</tbody>
</table>

Notes: Statistics about the cross-sectional distribution of investment rates and leverage ratios in steady state. Data for investment heterogeneity are drawn from Cooper and Haltiwanger (2006). Model (selected) for investment heterogeneity corresponds to firms alive for longer than twenty years in a panel simulation, time aggregated to the annual frequency. Model (full) corresponds to the full sample of firms in a panel simulation, time aggregated to the annual frequency. Data for leverage heterogeneity drawn from quarterly Compustat data. Model (selected) for leverage heterogeneity corresponds to firms alive for longer than ten years in a panel simulation. Model (full) corresponds to the full sample of firms in a panel simulation.

over the last decade.\textsuperscript{43} Our model provides a close match of the persistence of leverage and its correlation with investment in the selected sample. However, the standard deviation of leverage ratios is about twice as large as in the data.

Table 21 shows that the model generates a positive measured investment-cash flow sensitivity, consistent with the data. Following Gomes (2001), we compute investment-cash flow sensitivity using the regression

\[
\frac{\dot{i}_{jt}}{k_{jt}} = \alpha_j + \alpha_t + a_1 \frac{\text{CF}_{jt-1}}{k_{jt}} + a_2 q_{jt-1} + \varepsilon_{jt},
\]  \hspace{1cm} (24)

where \( \text{CF}_{jt} \) is cash flow and \( q_{jt} \) is Tobin’s q. The coefficient \( a_1 \) captures the statistical co-movement of investment with cash flow, conditional on the fixed effects and Tobin’s q. In the model, we identify cash flow as the firm’s cash on hand \( x \) and Tobin’s q as the ratio of the market value of the firm to the book value of its capital stock, \( k \). In quarterly Compustat, we identify cash flow as earnings before tax, depreciation, and amortization (EBITDA) and

\textsuperscript{43}Our results are robustness to sensitivity analysis around this cutoff.
Table 21

MEASURED INVESTMENT-CASH FLOW SENSITIVITY

<table>
<thead>
<tr>
<th></th>
<th>Without cash flow</th>
<th>With cash flow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Data</td>
<td>Model</td>
</tr>
<tr>
<td>Tobin’s q</td>
<td>0.01***</td>
<td>0.06</td>
</tr>
<tr>
<td>cash flow</td>
<td>0.02***</td>
<td>0.08</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.097</td>
<td>0.065</td>
</tr>
</tbody>
</table>

Notes: Results from estimating the regression (24). Data refers to quarterly Compustat data. We measure cash flow as earnings before tax, depreciation, and amortization (EBITDA) and Tobin’s q as the market to book value of the firm. Model refers to simulating a panel of firms from the calibrated model, conditional on surviving at least ten years. We measure cash flow as the firm’s cash-on-hand $x$ and Tobin’s q as the ratio of market value to the book value of capital, $k$.

Tobin’s q as the market to book value of the firm.

The model’s implications for regression (24) are consistent with two key features of the data. First, the coefficient on cash flow $a_1$ is positive, indicating that increases in cash flows are associated with increases in investment. Second, the inclusion of cash flow as a regressor in (24) significantly increases the $R^2$ of the regression, indicating that cash flow has predictive power for investment. However, the quantitative magnitude of the cash flow coefficient is larger in the model than the data.