# Financial Heterogeneity and the Investment Channel of Monetary Policy

Preliminary Draft *


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**Abstract**

We study the role of heterogeneity in firms' financial positions in determining the investment channel of monetary policy. In the data, firms with low leverage or high credit ratings invest significantly more following an expansionary monetary policy shock; for example, the 50% least leveraged firms account for nearly all of the total response to monetary policy in our sample. We develop a heterogeneous firm New Keynesian model with financial frictions to interpret this fact and study its aggregate implications. In our model, low-leverage are more likely to be free of default risk and respond to monetary policy through a strong intertemporal channel; high-leverage firms are instead more likely to be risky and respond to monetary policy by paying down their debt in order to reduce default risk. The aggregate effect of monetary policy therefore depends on the distribution of default risk, which varies over time.



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# 1 Introduction

Our goal in this paper is to understand the role of financial frictions in shaping the 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, and why? The answer is theoretically ambiguous. On the one hand, because financial frictions make investment costly, they may dampen the response of investment to monetary policy. On the other hand, because monetary policy can potentially alleviate financial frictions, they may amplify the response to monetary policy. This latter view underlies the financial accelerator mechanism that has formed the backbone of many quantitative DSGE models in monetary economics.

We revisit this question using new cross-sectional evidence and a heterogeneous firm New Keynesian model. Our main empirical result is that firms with low leverage ratios or high credit ratings are significantly more responsive to monetary policy shocks; in our sample, the 50% least-leveraged firms account for nearly all the total response to monetary policy. To speak to this evidence, our model embeds heterogeneous firms subject to default risk into a benchmark New Keynesian environment. The model is consistent with our empirical results because low-leverage firms are more likely to be financially unconstrained in the sense that they have zero probability of default; unconstrained firms respond to monetary policy through the strong neoclassical intertemporal channel. High-leverage firms are instead more likely to be financially constrained and use monetary stimulus as an opportunity to pay down their debt rather than do capital investment. The aggregate effect of a monetary policy shock is therefore primarily driven by unconstrained firms; when more firms are financially unconstrained, monetary policy is more powerful. Taken together, our results suggest that financial frictions dampen the response of aggregate investment to monetary policy rather than amplify it.

Our empirical work combines monetary policy shocks, measured using high-frequency changes in Fed Funds futures as in Cook and Hahn (1989) and Gurkaynak, Sack and Swanson (2005), with firm-level outcomes in quarterly Compustat data. We estimate how the semi-elasticity of firms' investment to monetary policy shocks depends on firms' financial positions, conditioning on both firm fixed effects – to capture permanent differences across firms – and sector-by-quarter fixed effects – to capture differences in how sectors respond to aggregate conditions. Our estimates imply that firms with leverage one standard deviation higher than the average firm are about half as responsive to monetary policy as the average firm.

Although we do not exploit exogenous variation in financial position, we argue that our empirical results reflect the role of financial heterogeneity rather than the host of other characteristics that could potentially drive both finances and investment. First, the heterogeneous responses that we find are not driven by differences in size, sales growth, or future sales growth. Second, our baseline estimates are stable if we instrument leverage with past leverage, suggesting that unobservable differences do not drive our results either. Taken together, we view our results as providing strong descriptive evidence that the response to monetary policy depends crucially on firms' financial positions.[1]

In order to interpret these empirical findings, our model embeds a benchmark corporate finance-style model of investment in the dynamic New Keynesian framework. There is a group of heterogeneous production firms who finance their investment through either internal funds or external borrowing. However, these firms cannot commit to repaying their debt, leading to an external finance premium based on the firms' default risk. There is also a group of retailer firms with sticky prices, generating a New Keynesian Phillips Curve. We calibrate the model to match key features of firms' investment and financing behavior in the micro data.

We first use the model to decompose the channels through which monetary policy affects firms' investment decisions. A subset of firms in the model are financially unconstrained in the sense that they have accumulated enough internal resources to face zero probability of default going forward. Monetary policy affects these firms through the *intertemporal channel*: changes in the real interest rate affect firms' discounting and therefore incentive to invest. The remaining firms in the model are financially constrained and finance their investment through a combination of internal resources and new borrowing. Monetary policy affects therefore

[1] Another concern is that our monetary policy shocks are in fact correlated with other economic conditions which themselves are driving the differences across firms. Although our shock identification was designed to correct for this bias, we also show that there are not significant differences in how firms respond to changes in other cyclical variables like GDP growth, the unemployment rate, the inflation rate, or the VIX index.

affects these firms through a *cash flow channel* and a *borrowing cost channel*. However, the analysis of constrained firms is complicated by the fact that they must also decide how much of their resources to put into capital investment or into financial investment by paying down their debt.

The quantitative magnitudes of these channels are broadly consistent with our empirical results. Low-leverage firms are more responsive to monetary policy shocks because they are more likely to be financially unconstrained and respond through the strong intertemporal channel. High-leverage firms are less responsive because they are more likely to be financially constrained; while monetary policy does increases the cash flows of these firms, they primarily use the extra cash to pay down their debt rather than invest in capital.

The presence of financially constrained firms in our model dampens the aggregate response to monetary policy. Starting from steady state, the impulse response of aggregate investment to a monetary shock is somewhat smaller than in the version of the model without financial constraints. However, outside of steady state, this aggregate response varies over time according to the distribution of net worth; when there are fewer unconstrained firms in the economy, monetary policy is less effective. We illustrate this state dependence by showing that monetary policy is less powerful if it recently attempted to stimulate the economy. More generally, we conclude that in times when the distribution of net worth is weak, the effect of monetary policy on the economy will be dampened.

**Related Literature** Our paper contributes to four key strands of literature. First, we contribute to the literature studying the transmission of monetary policy to the aggregate economy. Bernanke, Gertler and Gilchrist (1999) embed the financial accelerator mechanism in a New Keynesian model and argue that financial constraints amplify, not dampen, the effect of monetary policy on aggregate investment. However, Bernanke, Gertler and Gilchrist (1999) assume firms face a constant returns to scale technology, which implies that financial constraints are the key factor limiting the scale of the firm and hence that all firms are financially constrained. In contrast, firms in our model face decreasing returns and therefore have an optimal scale of production. This assumption allows for the co-existence of constrained and unconstrained firms, which is central to our analysis.

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 or presumably more credit constrained firms are more responsive to monetary policy changes. We prefer to focus on leverage and credit rating as the key measure of financial heterogeneity across firms; these are only weakly 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.

Third, we contribute to the literature that studies how micro-level heterogeneity affects our understanding of monetary policy relative to traditional representative agent models. To date, this literature has focused on how household-level heterogeneity affects the consumption channel of monetary policy; see, for example, Auclert (2015); McKay, Nakamura and Steinsson (2015); Wong (2016); or Kaplan, Moll and Violante (2016). In contrast, we explore the role of firm-level heterogeneity in determining the investment channel of monetary policy.[2]

Finally, we contribute to the literature studying the role of financial heterogeneity in determining the dynamics of aggregate investment more broadly. Our model of firm-level investment is most closely related to 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 monetary policy shocks. Khan and Thomas (2013) and Gilchrist, Sim and Zakrajsek (2014) also present related flexible-price models of investment under financial constraints.

**Road Map** Our paper is organized as follows. Section 2 provides the descriptive empirical evidence that the firm-level response to monetary policy varies with financial position. Section 3 develops our heterogeneous firm New Keynesian model to interpret this evidence. Section 4 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 5 uses the model to study the monetary transmission mechanism. Section 6 concludes.

[2] Although not explicitly about monetary policy, Gilchrist et al. (2016) show that financially constrained firms raised prices in the recent financial crisis while unconstrained firms cut prices, which they interpret as constrained firms being less willing to invest in a customer base. We view this work as complementary to our own, which argues that constrained firms are less willing to invest in capital as well.

# 2 Heterogeneous Responses to Monetary Policy

This section provides descriptive empirical evidence on how the response of investment to monetary policy shocks varies across firms in the micro data.

## 2.1 Data Description

We combine monetary policy shocks with firm-level outcomes from quarterly Compustat.

**Monetary Policy Shocks** A key challenge in measuring changes in monetary policy is that most of the variation in the Fed Funds Rate is driven by the Fed's endogenous response to aggregate economic conditions. We identify shocks to monetary policy, not driven by aggregate economic conditions, using the high-frequency event-study approach pioneered by Cook and Hahn (1989).[3] This high-frequency identification imposes less assumptions to identify shocks than the VAR approach as in Christiano, Eichenbaum and Evans (2005) or the narrative approach as in Romer and Romer (2004).[4]

Following Gurkaynak, Sack and Swanson (2005) and Gorodnichenko and Weber (2016), we construct our monetary policy shocks $\varepsilon_t^{\mathrm{m}}$ as

$$\varepsilon_t^{\mathrm{m}} = \tau(t) \times (\mathtt{ffr}_{t+\Delta_+} - \mathtt{ffr}_{t-\Delta_-}), \tag{1}$$

where $t$ is the time of the monetary announcement, $\mathtt{ffr}_t$ 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.[5] We focus on a window of $\Delta_-$ = fifteen minutes before the announcement and $\Delta_+$ = forty five minutes after the announcement. Our shock series

[3]In our theoretical 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. In Section 2.3 we argue that the information component of Fed announcements does not drive our results.

[4]For example, we find that firms respond to monetary policy shocks in the quarter they are announced, which violates the typical timing assumption in the VAR literature.

[5]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 $\tau(t) \equiv \frac{\tau_m^n(t)}{\tau_m^n(t) - \tau_m^d(t)}$, where $\tau_m^d(t)$ denotes the day of the meeting in the month and $\tau_m^n(t)$ the number of days in the month.

begins in January 1990, when the Fed Funds futures market opened, and ends in December 2007, before the financial crisis. During this time there were 183 shocks with a mean of approximately zero and a standard deviation of 9 basis points.

TABLE 1
MONETARY POLICY SHOCKS: SUMMARY STATISTICS

| | high frequency | smoothed | sum |
|---|---|---|---|
| mean | -0.0209 | -0.0481 | -0.0477 |
| median | 0 | -0.0124 | -0.00536 |
| std | 0.0906 | 0.111 | 0.132 |
| min | -0.463 | -0.480 | -0.479 |
| max | 0.152 | 0.235 | 0.261 |
| num | 183 | 79 | 80 |

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

We time aggregate the high-frequency shocks to the quarterly frequency in order to merge them with our firm-level outcome variables. We construct a moving average of the raw shocks weighted by the number of days in the quarter after the shock occurs.[6] Our time aggregation strategy ensures that we weight shocks by the amount of time firms have had to react to the shocks. Table 1 indicates that these smoothed shocks have similar features as the original high-frequency shocks.[7]

**Firm-Level Outcomes** We draw firm-level outcome variables from quarterly Compustat data, a panel of publicly listed U.S. firms. We use this dataset because it satisfies three key requirements for our study: it is quarterly, a high enough frequency to study monetary policy;

[6]Formally, the monetary-policy shock in quarter $q$ is defined as

$$\varepsilon_q^{\mathrm{m}} = \sum_{t \in J(q)} \omega^a(t)\varepsilon_t^{\mathrm{m}} + \sum_{t \in J(q-1)} \omega^b(t)\varepsilon_t^{\mathrm{m}} \tag{2}$$

where $\omega^a(t) \equiv \frac{\tau_q^n(t) - \tau_q^d(t)}{\tau_q^n(t)}$, $\omega^b(t) \equiv \frac{\tau_q^d(t)}{\tau_q^n(t)}$, $\tau_q^d(t)$ denotes the day of the monetary-policy announcement in the quarter, $\tau_q^n(t)$ denotes the number of days in the monetary-policy announcement's quarter, and $J(q)$ denote the set periods $t$ contained in quarter $q$.

[7]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 differ significantly from the moments of the smoothed shocks.

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. The main disadvantage of Compustat is that it excludes private firms which are likely subject to more severe financial frictions.[8] In Section 4, we calibrate our model to match an economy-wide sample of firms, not just those in Compustat.

We focus on two measures of investment in our empirical analysis. The first measure is $\Delta \log k_{jt}$, where $k_{jt}$ denotes the capital stock of firm $j$ at the end of period $t$. We use the log-difference specification because investment is highly skewed, suggesting a log-linear rather than level-linear model. We use net change in capital rather than gross investment because gross investment often takes negative values. The second measure we consider is an indicator for whether the firm $j$ has a gross investment rate greater than 1%, $\mathbb{1}\left\{\frac{i_{jt}}{k_{jt}} > 1\%\right\}$. This measure is motivated by the fact that the extensive margin is the dominant source of changes in micro-level investment (see, for example, Cooper and Haltiwanger (2006)). Additionally, by focusing on large investment episodes, this measure is less subject to small measurement error in the capital stock.

Our main measure of financial position is the firms' debt-to-asset ratio, which we refer to as the leverage ratio. We measure debt as the sum of short term and long term debt, and measure assets as the book value of assets. In some specifications we also measure financial position with the firm's credit rating provided by S&P.

Appendix A.1 provides details of our data construction, which follows standard practice in the investment literature. Table 2 presents simple summary statistics of the final sample used in our analysis. The mean capital growth rate is roughly 0.4% quarterly with a standard deviation of 9.3%. The mean leverage ratio is approximately 27% with a cross-sectional standard deviation of 36%, indicating substantial variation across firms.

[8]The Census Longitudinal Research database includes many small firms with the required information, but only at an annual frequency.

TABLE 2
FIRM-LEVEL VARIABLES: SUMMARY STATISTICS

| Statistic | $\Delta \log K$ | $\frac{i_{j,s,t}}{k_{j,s,t}}$ | $\mathbb{I}\{\frac{i_{j,s,t}}{k_{j,s,t}} > \iota\}$ | $\texttt{leverage}_{jt}$ |
|---|---|---|---|---|
| Average | 0.004 | 0.040 | 0.732 | 0.267 |
| Median | -0.004 | 0.027 | 1.000 | 0.204 |
| Std | 0.093 | 0.102 | 0.443 | 0.364 |
| Bottom 5% | -0.089 | -0.053 | 0.000 | 0.000 |
| Top 5% | 0.130 | 0.171 | 1.000 | 0.726 |

Notes: Summary statistics of firm-level outcome variables. $\Delta \log(k)$ is the net change in the capital stock, constructed using perpetual inventory. $\mathbb{1}\left\{\frac{i_{jt}}{k_{jt}} > 1\%\right\}$ is an indicator variable for whether a firm's investment rate is greater than 1%. $\texttt{leverage}_{jt}$ is the ratio of debt to assets.

## 2.2 Main Results

Our baseline empirical specification is

$$\Delta \log k_{jt} = \alpha_j + \alpha_{st} + \beta \ell_{jt-1} \varepsilon_t^{\text{m}} + \mathbf{\Gamma}' Z_{jt-1} + \varepsilon_{jt}, \tag{3}$$

where $\alpha_j$ is a firm $j$ fixed effect, $\alpha_{st}$ is a one-digit sector $s$ by quarter $t$ fixed effect, $\varepsilon_t^{\text{m}}$ is the monetary policy shock, $\ell_{jt}$ is the firm's leverage ratio, $Z_{jt}$ is a vector of firm-level controls, and $\varepsilon_{jt}$ is a residual. We lag both leverage $\ell_{jt-1}$ and the controls $Z_{jt-1}$ to ensure they are predetermined at the time of the monetary shock.

Our coefficient of interest is $\beta$, which measures how the semi-elasticity of investment with respect to monetary shocks depends on the firm's leverage $\ell_{jt-1}$. This coefficient is conditional on a number of factors that may also affect investment and leverage. First, firm fixed effects $\alpha_j$ capture permanent differences in investment behavior across firms.[9] Second, sector-by-quarter fixed effects $\alpha_{st}$ capture differences in how broad sectors are exposed to aggregate economic conditions. Finally, the firm-level controls $Z_{jt}$ include the leverage ratio $\ell_{jt}$, total assets, sales growth, current assets as a share of total assets, and a fiscal quarter dummy.

Table 3 reports the results from estimating the baseline specification (3). To make the

[9] Our main results are robust to not including firm fixed effects.

Table 3
Heterogeneity in the Response to Monetary Policy Shocks

A) Dependent variable: $\Delta \log k$

| | (1) | (2) | (3) |
|---|---|---|---|
| leverage × ffr shock | -0.92*** | -0.71** | -0.73** |
| | (0.34) | (0.29) | (0.31) |
| ffr shock | | | 1.37 |
| | | | (0.99) |
| Observations | 233182 | 233182 | 233182 |
| $R^2$ | 0.107 | 0.118 | 0.104 |
| Firm controls | no | yes | yes |
| Time sector FE | yes | yes | no |
| Time clustering | yes | yes | yes |

B) Dependent variable: $\mathbb{1}\{\frac{i}{k} > 1\%\}$

| | (1) | (2) | (3) |
|---|---|---|---|
| leverage × ffr shock | -5.22*** | -4.81*** | -4.57*** |
| | (1.41) | (1.28) | (1.34) |
| ffr shock | | | 4.00 |
| | | | (4.40) |
| Observations | 233182 | 233182 | 233182 |
| $R^2$ | 0.212 | 0.217 | 0.204 |
| Firm controls | no | yes | yes |
| Time sector FE | yes | yes | no |
| Time clustering | yes | yes | yes |

Notes: Results from estimating variants of the baseline specification

$$\Delta \log k_{jt} = \alpha_j + \alpha_{st} + \beta \ell_{jt-1} \varepsilon_t^{\mathrm{m}} + \mathbf{\Gamma}' Z_{jt-1} + \varepsilon_{jt},$$

where $\alpha_j$ is a firm fixed effect, $\alpha_{st}$ is a sector-by-quarter fixed effect, $\ell_{jt-1}$ is leverage, $\varepsilon_t^{\mathrm{m}}$ 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. Panel (A) uses the intensive margin measure of investment $\Delta \log k_{jt}$ as the outcome variable and Panel (B) uses the extensive margin measure $\mathbb{1}\left\{\frac{i_{jt}}{k_{jt}} > 1\%\right\}$ as the outcome variable. Standard errors are two-way clustered by firms and time. We have normalized the sign of the monetary shocks $\varepsilon_t^{\mathrm{m}}$ 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.

estimated coefficient $\beta$ interpretable, we standardize the leverage ratio $\ell_{jt}$ over the entire sample, so that the units of leverage are in standard deviations around its mean. We also normalize the sign of the monetary shock $\varepsilon_t^{\mathrm{m}}$ so that a positive value corresponds to an expansionary monetary policy shock. Standard errors are clustered two-way to account for correlation within firms and within quarters. This clustering strategy is conservative, leaving less than 80 time-series observations.

Panel (A) shows that firms with higher leverage are less responsive to monetary policy shocks. Column (1) reports the interaction coefficient $\beta$ without the firm-level controls $Z_{jt-1}$, and implies that firms with one standard deviation higher leverage than the average firms have a nearly one unit lower semi-elasticity of investment than the average firm. Adding firm-level controls $Z_{jt-1}$ in Column (2) does not significantly change this point estimate.

A natural way to assess the economic significance of our estimated interaction coefficient

$\beta$ is to compare it to the average effect of a monetary policy shock. However, in our baseline specification (3), the average effect is absorbed into the sector-by-quarter fixed effect $\alpha_{st}$. Column (3) relaxes this restriction by estimating

$$\Delta \log k_{jt} = \alpha_j + \gamma \varepsilon_t^{\mathrm{m}} + \beta \ell_{jt-1} \varepsilon_t^{\mathrm{m}} + \mathbf{\Gamma}_1' Z_{jt-1} + \mathbf{\Gamma}_2' Y_t + \varepsilon_{jt}, \tag{4}$$

where $Y_t$ is a vector of controls for GDP growth, the inflation rate, the unemployment rate, and the VIX index. The average investment semi-elasticity is roughly 1.4. Hence, our point estimate in Column (2) indicates that a firm with leverage one standard deviation higher than the average firm has an investment semi-elasticity roughly half as large as the average firm. However, this point estimate is not statistically significant because the time-series variation in the monetary shocks $\varepsilon_t^{\mathrm{m}}$ is small and we cluster our standard errors at the quarterly level.

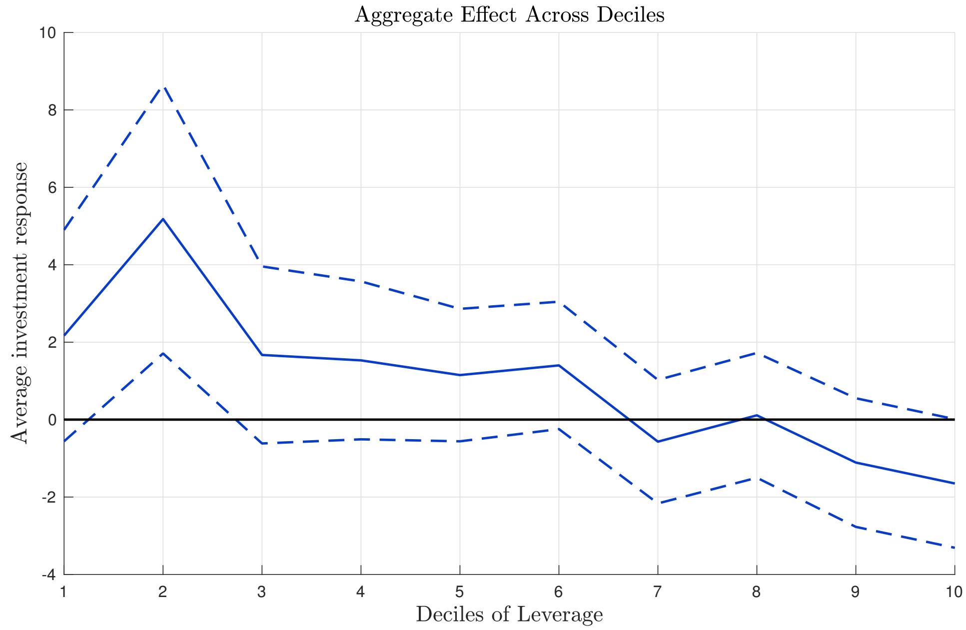
Panel (B) shows that all of these results holds for the extensive margin measure of investment $\mathbb{1}\left\{\frac{i_{jt}}{k_{jt}} > 1\%\right\}$ as well. Quantitatively, firms with one cross-sectional standard deviation higher leverage are nearly 5% less likely to invest following a monetary policy shocks.

**Aggregate Implications** As another way to assess the economic significance of the heterogeneity we found above, as well as assess whether the heterogeneity survives aggregation, we estimate the equation

$$\Delta \log K_{jt} = \mathbf{\Gamma}' Y_t + \beta_j \varepsilon_t^{\mathrm{m}} + \varepsilon_{jt}, \tag{5}$$

where the outcome $\Delta \log K_{jt}$ is the total investment done by firms in the $j^{th}$ decile of the leverage distribution in quarter $t$, and again $Y_t$ contains controls for aggregate GDP growth, the inflation rate, the unemployment rate, and the VIX index. Figure 1 plots the aggregated semi-elasticities $\beta_j$ against decile $j$. Although this specification is far less structured than (3), the aggregated semi-elasticity declines fairly steadily with leverage. Furthermore, the aggregated semi-elasticity is essentially zero past the $6^{th}$ decile of the leverage distribution, indicating that the total effect of monetary policy is driven entirely by low-leverage firms.

Figure 1: Aggregated Effect of Monetary Policy Shocks




Notes: Semi-elasticity of aggregated investment to monetary policy shocks for deciles of leverage distribution. Reports estimated semi-elasticities $\beta_j$ from specification

$$\Delta \log K_{jt} = \mathbf{\Gamma}' Y_t + \beta_j \varepsilon_t^{\mathrm{m}} + \varepsilon_{jt}$$

where $\Delta \log K_{jt}$ is the aggregated investment of firms with leverage in the $j$th decile of the leverage distribution, $Y_t$ is a vector containing GDP growth, the inflation rate, the unemployment rate, and the VIX index. Dotted lines provide 90% standard error bands. We have normalized the sign of the monetary shocks $\varepsilon_t^{\mathrm{m}}$ so that a positive shock is expansionary (corresponding to a decrease in interest rates).

**Dynamics** Since estimated aggregate investment equations typically indicate strong inertia, we estimate the Jorda (2005)-style projection

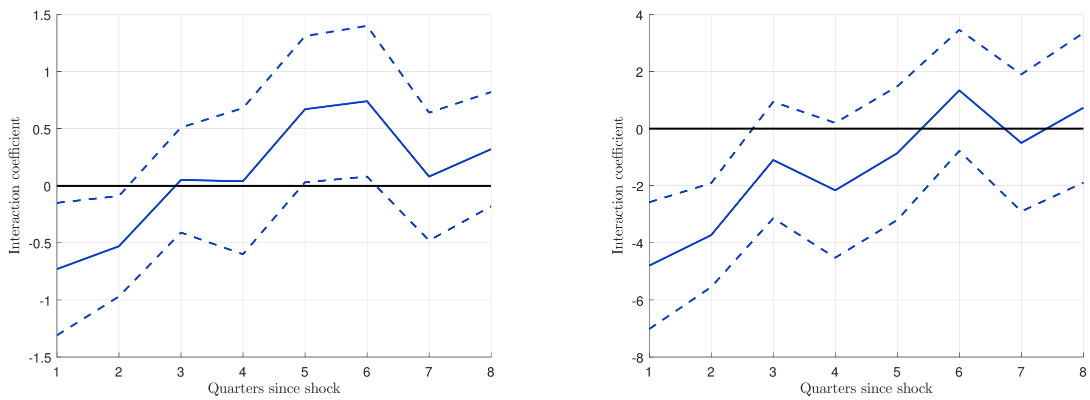
$$\Delta \log k_{jt+h} = \alpha_{jh} + \alpha_{sth} + \beta_h \ell_{jt-1} \varepsilon_t^{\mathrm{m}} + \mathbf{\Gamma}'_h Z_{jt-1} + \varepsilon_{jt}, \tag{6}$$

where $h$ indexes quarters in the future. The coefficient $\beta_h$ measures how the response of investment in quarter $t+h$ to a monetary policy shock in quarter $t$ depends on the firm's leverage in quarter $t-1$.[10] Panel (a) of Figure 2 plots the dynamics of the coefficient $\beta_h$ estimated in (6); the interaction coefficient returns to zero three quarters after the initial

[10]This specification abstracts from how the dynamics of leverage itself drive differences over time. We are currently addressing this by estimating a joint dynamic system between investment and leverage.

FIGURE 2: Dynamics of Differential Response to Monetary Shocks

(a) Intensive Margin | (b) Extensive Margin




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

$$\Delta \log k_{jt+h} = \alpha_{jh} + \alpha_{sth} + \beta_h \ell_{jt-1} \varepsilon_t^{\mathrm{m}} + \mathbf{\Gamma}_h' Z_{jt-1} + \varepsilon_{jt},$$

where $\alpha_{jh}$ is a firm fixed effect, $\alpha_{sth}$ is a sector-by-quarter fixed effect, $\ell_{jt-1}$ is leverage, $\varepsilon_t^{\mathrm{m}}$ 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 time. Dashed lines report 90% error bands. We have normalized the sign of the monetary shocks $\varepsilon_t^{\mathrm{m}}$ 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.

shock, although the dynamics are somewhat hump-shaped after that. Panel (b) estimates (6) using the extensive margin measure of investment and finds that differences across firms disappear after six quarters. Taken together, we conclude that the differential response to monetary shocks across firms is fairly short-lived and therefore mainly focus on the impact period.

It is important to note that the short-lived dynamics of the cross-sectional differences that we find are not necessarily in conflict with the long-lived dynamics of the aggregate response typically found in identified VARs. The cross-sectional differences are simply a distinct object from aggregate investment; the long-lived aggregate responses may reflect aggregate capital supply frictions or general equilibrium linkages which are absorbed by the sector-by-quarter fixed effects $\alpha_{st}$.[11]

[11] Gertler and Karadi (2015) show that the high-frequency monetary shocks generate aggregate impulse responses that are similar to the VAR literature using an instrumental variable VAR strategy.

Table 4
Stock Prices

| | (1) | (2) | (3) |
|---|---|---|---|
| leverage × ffr shock | -0.87*** | -0.82** | -0.61 |
| | (0.29) | (0.35) | (0.41) |
| ffr shock | | | 2.49** |
| | | | (1.13) |
| Observations | 39232 | 36915 | 36915 |
| $R^2$ | 0.114 | 0.112 | 0.029 |
| Firm controls | no | yes | yes |
| Time sector FE | yes | yes | no |
| Time clustering | yes | yes | yes |

Notes: Results from estimating the regression $R_{jt} = \alpha_j + \alpha_{st} + \beta \ell_{jt-1} \varepsilon_t^{\mathrm{m}} + \mathbf{\Gamma}' Z_{jt-1} + \varepsilon_{jt}$ where $R_{jt} = \frac{p_{jt+1} - p_{jt}}{p_{jt}}$ is the percentage change in the firm's stock price, $\alpha_j$ is a firm fixed effect, $\alpha_{st}$ is a sector-by-quarter fixed effect, $\ell_{jt-1}$ is leverage, $\varepsilon_t^{\mathrm{m}}$ 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 time. We have normalized the sign of the monetary shocks $\varepsilon_t^{\mathrm{m}}$ 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.

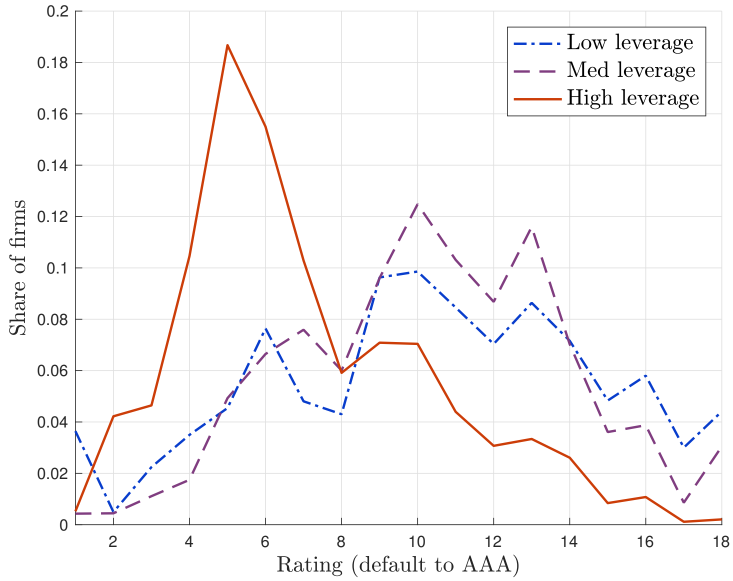
**Supporting Evidence From Stock Prices** Stock prices provide a natural reality check on our findings because they are highly correlated with investment and encode the extent to which monetary policy shocks are good news for firms. Additionally, stock prices are available at high frequency, so they are not subject to time-aggregation bias. We therefore estimate the equation

$$R_{jt} = \alpha_j + \alpha_{st} + \beta \ell_{jt-1} \varepsilon_t^{\mathrm{m}} + \mathbf{\Gamma}' Z_{jt-1} + \varepsilon_{jt}, \tag{7}$$

where $R_{jt} = \frac{p_{jt+1} - p_{jt}}{p_{jt}}$ is the percentage change in the firm's stock price between the beginning and end of the trading day in which a monetary policy announcement occurs. Accordingly, the time period in $t$ is a day and the monetary policy shock $\varepsilon_t^{\mathrm{m}}$.

Table 4 shows that stock prices of low-leverage firms are significantly more responsive to monetary policy shocks. Quantitatively, increasing leverage by one standard deviation decreases the exposure of stock returns to monetary policy shocks by nearly one percentage point. The average response of stock returns to the monetary policy shock is about 2.5 percentage points.

Figure 3: Distribution of Credit Ratings, Conditional on Leverage




Notes: Conditional distribution of credit ratings by leverage. "Low leverage" refers to observations in the bottom tercile of leverage. "Medium leverage" refers to observations in the middle tercile of leverage. "High leverage" refers to observations in the top tercile of leverage.

**Heterogeneity by Credit Rating** We now briefly explore heterogeneity by credit rating as an alternative to leverage as a measure of the firm's financial position. Figure 3 plots the distribution of firm-level credit ratings for conditional on having low, medium, and high leverage. Most of the mass of the high-leverage distributions in concentrated in the left tail, below credit rating category 8 (BB). In contrast, most of the mass of medium- and particularly high-leverage firms is in the right tail of the distribution.

Table 5 shows that highly-rated firms are more responsive to monetary policy shocks. Column (2) indicates that firms with a credit rating above AA have a 2.5 unit higher investment semi-elasticity than the average firm; recall from Table 3 that the average semi-elasticity is 1.4. Column (3) shows that this relationship continues to hold even conditional on leverage.

The heterogeneity by these two dimensions of financial heterogeneity is consistent with the key mechanisms in the economic model in Section 3. In our model, financially unconstrained firms are the most responsive to monetary policy. These firms have low default risk – high credit rating– and low leverage. Hence, through the lens of our model, the two measures

Table 5
Heterogeneous Responses by Credit Rating

| | (1) | (2) | (3) |
|---|---|---|---|
| leverage $\times$ ffr shock | -0.73** | | -0.71** |
| | (0.29) | | (0.29) |
| $\mathbb{1}\{\texttt{rating}_{it} \geq AA\} \times$ ffr shock | | 2.50** | 2.37** |
| | | (1.14) | (1.16) |
| Observations | 233232 | 233182 | 233182 |
| $R^2$ | 0.119 | 0.119 | 0.119 |
| Firm controls | yes | yes | yes |
| Time sector FE | yes | yes | yes |
| Time clustering | yes | yes | yes |

Notes: Results from estimating variants of the baseline specification $\Delta \log k_{jt} = \alpha_j + \alpha_{st} + \beta y_{jt-1}\varepsilon_t^{\mathrm{m}} + \mathbf{\Gamma}' Z_{jt-1} + \varepsilon_{jt}$, where $\alpha_j$ is a firm fixed effect, $\alpha_{st}$ is a sector-by-quarter fixed effect, $y_{jt-1}$ is the firm's leverage or an indicator for having a credit rating above AA, $\varepsilon_t^{\mathrm{m}}$ 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 time. We have normalized the sign of the monetary shocks $\varepsilon_t^{\mathrm{m}}$ 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.

of financial position presented here provide independent information about the degree of financial constraints faced by firms.

## 2.3 What Drives Our Results?

Before moving to the economic model, we further investigate the source of variation in the data which identifies our key findings in Section 2.2 above, and argue that it is consistent with the model.

**Endogeneity of Leverage** A key limitation of our analysis is that we do not have exogenous variation in leverage in order to identify the causal effect of leverage on how firms respond to monetary policy. Although our baseline specification controls for a number of other factors which may drive our results, one still may concerned that the differential responses that we have found simply reflect other factors which happen to be correlated with leverage.

Table 6
Interaction With Other Firm-Level Covariates

| | (1) | (2) | (3) | (4) | (5) | | |
|---|---|---|---|---|---|---|---|
| leverage × ffr shock | -0.73** | | -0.78** | | -0.72** | | -0.70** |
| | (0.29) | | (0.31) | | (0.29) | | (0.29) |
| sales growth × ffr shock | | -0.06 | -0.07 | | | | |
| | | (0.26) | (0.26) | | | | |
| future sales growth × ffr shock | | | | -0.51 | -0.48 | | |
| | | | | (0.39) | (6.97) | | |
| size × ffr shock | | | | | | 0.35 | 0.38 |
| | | | | | | (0.29) | (0.28) |
| Observations | 233182 | 221451 | 233182 | 233182 | 221451 | 233182 | 233182 |
| $R^2$ | 0.119 | 0.120 | 0.116 | 0.118 | 0.122 | 0.116 | 0.119 |
| 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 $\Delta \log k_{jt} = \alpha_j + \alpha_{st} + \beta y_{jt} \varepsilon_t^{\text{m}} + \mathbf{\Gamma}' Z_{jt-1} + \varepsilon_{jt}$, where $\alpha_j$ is a firm fixed effect, $\alpha_{st}$ is a sector-by-quarter fixed effect, $y_{jt}$ is the firm's lagged sales growth, future sales growth, or lagged size (measured by current assets), $\varepsilon_t^{\text{m}}$ 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. Columns (2) and (4) additionally include an interaction between leverage $\ell_{jt-1}$ and the monetary policy shock $\varepsilon_t^{\text{m}}$. Standard errors are two-way clustered by firms and time. We have normalized the sign of the monetary shocks $\varepsilon_t^{\text{m}}$ so that a positive shock is expansionary (corresponding to a decrease in interest rates). We have standardized leverage $x_{jt}$ over the entire sample, so its units are in standard deviations relative to the mean.

Table 6 shows that our main results are not driven by the interaction between monetary policy shocks and key observable variables, potentially correlated with leverage. The table interacts the monetary policy shocks in our baseline specification with the firm's lagged size, lagged sales growth, or future sales growth in:

$$\Delta \log k_{jt} = \alpha_j + \alpha_{st} + \beta_\ell \ell_{jt-1} \varepsilon_t^{\text{m}} + \beta_y y_{jt} \varepsilon_t^{\text{m}} + \mathbf{\Gamma}' Z_{jt-1} + \varepsilon_{jt},$$

where $y_{jt}$ is the variable of interest. Results indicate that our baseline estimates remain similar when we include these additional controls.

Table 7 presents evidence that unobservable factors are not driving our main results either. We instrument leverage $\ell_{jt-1}$ in our baseline specification (3) with past leverage ($\ell_{jt-4}$ or $\ell_{jt-8}$). To the extent that unobserved factors drive both leverage and the response to monetary policy, we expect these factors to be more weakly correlated with lagged leverage,

Table 7
Instrumenting Leverage with Past Leverage

| | (1) | (2) |
|---|---|---|
| leverage × ffr shock | -0.65** | -2.29** |
| | (0.32) | (0.95) |
| Observations | 225753 | 216928 |
| $R^2$ | | |
| Firm controls, Time-Sector FE | yes | yes |
| Instrument | 4q lag | 8q lag |

Notes: Results from estimating and IV strategy for the baseline specification $\Delta \log k_{jt} = \alpha_j + \alpha_{st} + \beta x_{jt-1}\varepsilon_t^{\mathrm{m}} + \mathbf{\Gamma}' Z_{jt-1} + \varepsilon_{jt}$, where $\alpha_j$ is a firm fixed effect, $\alpha_{st}$ is a sector-by-quarter fixed effect, $x_{jt-1}$ is leverage, $\varepsilon_t^{\mathrm{m}}$ 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. Leverage in $t-4$ and $t-8$ are used as instruments for leverage in $t-1$. Standard errors are two-way clustered by firms and time. We have normalized the sign of the monetary shocks $\varepsilon_t^{\mathrm{m}}$ so that a positive shock is expansionary (corresponding to a decrease in interest rates). We have standardized leverage $x_{jt}$ over the entire sample, so its units are in standard deviations relative to the mean.

and therefore that these instrumental variables coefficients to be smaller than our baseline results. Instead, Table 7 shows that the estimated coefficients increase in this instrumental variables specification. This result is consistent with measurement error creating attenuation bias in our baseline specification (3).

**Heterogeneity in Collateralizability of Assets** In our model, low-leverage firms are more responsive to monetary policy shocks because they are more likely to financially unconstrained. However, if heterogeneity in leverage were driven by heterogeneity in the collateralizability of assets – so that low-leverage firms have poor collateral, which limits their ability to borrow – then low leverage firms would instead be financially constrained.

We argue that heterogeneity in collateralizability does not drive our empirical results for two main reasons. First, our sector-by-quarter fixed effects $\alpha_{st}$ absorb the effect of differences in collateralizability at the sectoral level, due to, for example, the mix of capital goods that firms use. Second, Table 8 shows that our benchmark results are stronger if we first demean leverage at the firm level. This specification differences out any heterogeneity in collateralizability that is fixed at the firm level.

Table 8

Within-Firm Variation in Leverage

| | (1) | (2) | (3) |
|---|---|---|---|
| leverage × shock | -1.06** | -0.85** | -0.84** |
| | (0.41) | (0.36) | (0.35) |
| ffr shock | | | 1.37 |
| | | | (0.98) |
| Observations | 233182 | 233182 | 233182 |
| $R^2$ | 0.107 | 0.118 | 0.104 |
| Firm controls | no | yes | yes |
| Time sector FE | yes | yes | no |
| Time clustering | yes | yes | yes |

Results from estimating

$$\Delta \log k_{jt} = \alpha_j + \alpha_{st} + \beta(\ell_{jt-1} - \mathbb{E}_j[\ell_{jt}])\varepsilon_t^{\mathrm{m}} + \mathbf{\Gamma}' Z_{jt-1} + \varepsilon_{jt},$$

where $\alpha_j$ is a firm fixed effect, $\alpha_{st}$ 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 the sample, $\varepsilon_t^{\mathrm{m}}$ 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. Panel (A) uses the intensive margin measure of investment $\Delta \log k_{jt}$ as the outcome variable and Panel (B) uses the extensive margin measure $\mathbb{1}\left\{\frac{i_{jt}}{k_{jt}} > 1\%\right\}$ as the outcome variable. Standard errors are two-way clustered by firms and time. We have normalized the sign of the monetary shocks $\varepsilon_t^{\mathrm{m}}$ 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..

**Variation in Monetary Policy Shocks** Another concern is that our monetary policy shocks may be correlated with other business cycle conditions that themselves drive differences across firms. Although our high-frequency shock identification is designed to address this concern, as a further check we interact leverage with various business cycle proxies in

$$\Delta \log k_{jt} = \alpha_j + \alpha_{st} + \beta x_{jt-1} Y_t + \mathbf{\Gamma}' Z_{jt-1} + \varepsilon_{jt},$$

where $Y_t$ is GDP growth, the inflation rate, the unemployment rate, or the VIX index. Table 9 shows that the estimated coefficients $\beta$ in this regression are not significantly different from zero or economically meaningful.

**Additional Results** Appendix A.1 reports a number of additional empirical results. The first set of additional results concerns the variation in monetary shocks is driving our results. First, following Gurkaynak, Sack and Swanson (2005) we decompose monetary policy

Table 9
Monetry Shocks vs. Business Cycle Conditions

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| leverage × ffr shock | -0.79*** | -0.70** | -0.72** | -0.86*** | -0.93*** |
| | (0.29) | (0.28) | (0.28) | (0.29) | (0.30) |
| leverage × dlog gdp | -0.05 | | | | -0.06 |
| | (0.08) | | | | (0.07) |
| leverage × dlog cpi | | -0.08 | | | -0.07 |
| | | (0.09) | | | (0.09) |
| leverage × ur | | | 0.00 | | 0.00 |
| | | | (0.00) | | (0.00) |
| leverage × vix | | | | 0.00* | 0.00* |
| | | | | (0.00) | (0.00) |
| Observations | 233232 | 233232 | 233232 | 233232 | 233232 |
| $R^2$ | 0.119 | 0.119 | 0.118 | 0.119 | 0.119 |
| Firm controls | yes | yes | yes | yes | yes |

Notes: Results from estimating variants of the baseline specification $\Delta \log k_{jt} = \alpha_j + \alpha_{st} + \beta x_{jt-1} Y_t + \mathbf{\Gamma}' Z_{jt-1} + \varepsilon_{jt}$, where $\alpha_j$ is a firm fixed effect, $\alpha_{st}$ is a sector-by-quarter fixed effect, $\ell_{jt-1}$ is leverage, $\varepsilon_t^{\mathrm{m}}$ 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 $Y_t$ is GDP growth, the inflation rate, the unemployment rate, or the VIX index. Standard errors are two-way clustered by firms and time. We have normalized the sign of the monetary shocks $\varepsilon_t^{\mathrm{m}}$ 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.

announcements into a "target" component that affects short-term rates and a "path" component affecting long-term rates. We find that all of the differences across firms are driven by the target component. This result indicates that our results are driven primarily by the effect of Fed policy announcements on interest rates rather than on expectations of future growth, which would show up primarily in long-term interest rates. Second, we restrict our sample to post-1994 observations, after which time monetary policy announcements became more transparent. We find similar results, though with less statistical power given the smaller sample. Third, instead of using the monetary shock directly, we instrument the BAA spread with the shock and find similar results. Fourth, we decompose the shocks into expansionary and contractionary shocks, and find that almost all the differential responses across firms are driven by expansionary monetary policy announcements.

The second set of additional results concerns the variation in leverage that is driving our results. First, we run our benchmark specification measuring leverage using debt net of liquid assets, and find similar results. Second, we decompose leverage into components driven by short-term debt, long-term debt, and other liabilities, and find consistent differential responses for all three subcomponents.[12]

# 3 Model

We develop a heterogeneous firm New Keynesian model in order to interpret the cross-sectional evidence in Section 2 and draw aggregate implications. Our model embeds a benchmark corporate finance-style model of investment into the dynamic New Keynesian framework.

## 3.1 Environment

Time is discrete and infinite. We describe in the model in three blocks: an investment block, which captures heterogeneous investment responses to monetary policy; a New Keynesian block, which generates a New Keynesian Phillips Curve, and a representative household.

### 3.1.1 Investment Block

Our investment block contains a time-varying 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).

**Production Firms** Each period, there is a mass $N_t$ of these heterogeneous production firms. Each firm $j \in [0, N_t]$ produces an undifferentiated good $y_{jt}$ using the production function

$$y_{jt} = z_{jt} k_{jt}^{\theta} n_{jt}^{\nu}, \tag{8}$$

[12]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.

where $z_{jt}$ is an idiosyncratic productivity shock, $k_{jt}$ is the firm's capital stock, $n_{jt}$ is the firm's labor input, and $\theta + \nu < 1$. The idiosyncratic productivity shock follows an log-AR(1) process[13]

$$\log z_{jt+1} = \rho z_{jt} + \varepsilon_{jt+1}, \text{ where } \varepsilon_{jt+1} \sim N(0, \sigma^2). \tag{9}$$

Each period, each firm $j$ makes a series of decisions in order to maximize its market value. First, with probability $\pi_d$ the firm receives an i.i.d. exit shock and must exit the economy at the end of the period; firms that do not receive the exit shock will be allowed to continue into the next period.

Second, conditional on the realization of the exit shock, the firm decides whether or not to default. If the firm defaults it permanently and immediately exits the economy. In order to continue, the firm must pay back the face value of its outstanding debt, $B_{jt}$, as well as a fixed operating cost $\xi$ in units of the final good (described below). We assume that in the event of default the firm's owners do not directly recover any resources from the firm, so that the firm's market value upon default is zero. However, lenders recover a fraction of the capital stock and the remaining capital is rebated lump-sum to the representative household, so no capital is destroyed by default.

Third, firms that do not default produce output using the production function (8). These firms are perfectly competitive and sell their undifferentiated output at price $P_t$. In order to produce, firms hire labor $n_{jt}$ from a competitive labor market at wage $W_t$.

Finally, firms that did not receive the idiosyncratic exit shock make investment and financing decisions for the next period. Capital in period $t$ has price $Q_t$. Firms have two sources of investment finance, each of which is subject to a friction. First, firms can use external finance by issuing debt with face value $B_{jt+1}$. However, because firms may default on this debt, lenders offer price $\mathcal{Q}_t(z_{jt}, k_{jt+1}, B_{jt+1})$ which is decreasing in the amount of borrowing $B_{jt+1}$. Second, firms can use internal finance by lowering dividend payments $D_{jt}$. However, firms cannot issue new equity, which bounds dividend payments $D_{jt} \geq 0$. Dividend

[13] We additionally assume that the idiosyncratic shock process is bounded in the interval $\left[-\frac{2.5\sigma}{\sqrt{1-\rho^2}}, \frac{2.5\sigma}{\sqrt{1-\rho^2}}\right]$. This assumption is important in our definition of unconstrained firms below.

payments in period $t$ are given by[14]

$$D_{jt} = \max_{n} P_t z_{jt} k_{jt}^{\theta} n_{jt}^{\nu} - W_t n_{jt} - B_{jt} - \xi + Q_t(1-\delta)k_{jt} - Q_t k_{jt+1} + \mathcal{Q}_t(z, k_{jt+1}, B_{jt+1})B_{jt+1}.$$

**Lenders** There is a representative financial intermediary that lends resources from the household to the production firms at the firm-specific price schedule $\mathcal{Q}_t(z_{jt}, k_{jt+1}, B_{jt+1})$. These lenders are competitive, so the schedule $\mathcal{Q}_t(z_{jt}, k_{jt+1}, B_{jt+1})$ prices the firm's default risk in period $t+1$. In the event of default the lender recovers a fraction $\alpha$ of the market value of the firm's undepreciated capital stock $Q_{t+1}(1-\delta)k_{jt+1}$.

**Entry** Each period, a mass $\overline{\mu}$ of new firms enters the economy. Each of these new entrants $j \in [0, \overline{\mu}]$ draws an idiosyncratic productivity shock $z_{jt}$ from a time-invariant distribution $\mu^{\text{ent}}(z)$. This distribution has the same standard deviation as the ergodic distribution of productivity shocks, $\frac{\sigma}{\sqrt{(1-\rho^2)}}$, but has a lower mean, $m\frac{\sigma}{\sqrt{(1-\rho^2)}}$. The parameter $m \geq 0$ controls the mean level of productivity of new entrants. We calibrate $m$ below to match the average size and growth rate of new entrants, motived by the evidence in Foster, Haltiwanger and Syverson (2016) that young firms have persistently low levels of measured productivity.[15] In additional to the draw of initial productivity $z_{jt}$, new entrants are endowed with $k_0$ units of capital and no debt. They then proceed as incumbent firms given the initial state $(z_{jt}, k_0, 0)$.

### 3.1.2 New Keynesian Block

The New Keynesian block of the model is designed to 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 economy for simplicity.

[14] We are implicitly assuming that firms value their undepreciated capital stock at its market, rather than book value, in order to simplify the analysis.

[15] Foster, Haltiwanger and Syverson (2016) argue that these low levels of measured productivity reflect differences in demand across firms rather than differences in physical productivity. We remain agnostic about this interpretation.

**Retailers** There is a fixed unit mass of retailers $i \in [0,1]$. Each retailer producers a differentiated good $\widetilde{y}_{it}$ according to the production function

$$\widetilde{y}_{it} = y_{it},$$

where $y_{it}$ is the amount of the undifferentiated good from the production firms that is demanded by retailer $i$. Retailers are monopolistic competitors who set their prices $\widetilde{P}_{it}$ subject to the demand curve generated by the final good producer (described below). We introduce Rotemberg (1982)-style nominal rigidities by assuming that retailers pay a quadratic adjustment cost $\frac{\varphi}{2}\left(\frac{\widetilde{P}_{it}}{\widetilde{P}_{it-1}} - 1\right)^2 Y_t$ to adjust their price, where $Y_t$ is units of the final good.

**Final Good Producer** There is a representative final good producer who produces aggregate output $Y_t$ using the production function

$$Y_t = \left(\int \widetilde{y}_{it}^{\frac{\gamma-1}{\gamma}} \mathrm{d}i\right)^{\frac{\gamma}{\gamma-1}},$$

where $\gamma$ is the elasticity of substitution over intermediate goods.

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

$$K_{t+1} = \Phi(\frac{I_t}{K_t})K_t + (1-\delta)K_t, \tag{10}$$

where $\Phi(\frac{I_t}{K_t}) = \frac{\delta^{1/\phi}}{1-1/\phi}\left(\frac{I_t}{K_t}\right)^{1-1/\phi} - \frac{\delta}{\phi-1}$ and $I_t$ are units of the final good used to produce capital.[16] The capital good has price $Q_t$.

**Monetary Authority** The monetary authority sets the nominal risk-free interest rate $R_t^{\mathrm{nom}}$ according to the Taylor rule

$$\log R_t^{\mathrm{nom}} = \log\frac{1}{\beta} + \varphi_\pi \log \Pi_t + \varepsilon_t^m, \text{ where } \varepsilon_t^m \sim N(0,\sigma_m^2),$$

[16] We implicitly assume that production firms resell their undepreciated capital to the capital good producer each period.

where $\Pi_t$ is gross inflation of the final good price, $\varphi_\pi$ is the weight on inflation in the reaction function, and $\varepsilon_t^{\mathrm{m}}$ is the monetary policy shock. $\varepsilon_t^{\mathrm{m}}$ is the only source of aggregate uncertainty in the model.

### 3.1.3 Household

There is a representative household with preferences over consumption $C_t$ and hours worked $H_t$ represented by the expected utility function

$$\mathbb{E}_0 \sum_t^{\infty} \beta^t \left( \log C_t - \Psi N_t \right),$$

where $\Psi$ controls the disutility of labor supply. The household owns all firms in the economy.

## 3.2 Equilibrium

We now characterize and define the model's equilibrium.

### 3.2.1 New Keynesian Block

We begin with the New Keynesian block of the model. As usual, the final good producer's profit maximization problem gives the demand curve $\left(\frac{\widetilde{P}_{it}}{\widetilde{P}_t}\right)^{-\gamma} Y_t$ where $\widetilde{P}_t = \left(\int \widetilde{P}_{it}^{1-\gamma} \mathrm{d}i\right)^{\frac{1}{1-\gamma}}$ is the price index. We take the final good as the numeraire.

Retailers are symmetric and face real marginal cost $p_t = \frac{P_t}{\widetilde{P}_t}$ in their price-setting decision. After aggregation, this yields the familiar New Keynesian Phillips Curve:[17]

$$\log \Pi_t = \frac{\gamma - 1}{\varphi} \log \frac{p_t}{p^*} + \beta \mathbb{E}_t \log \Pi_{t+1}, \tag{11}$$

where $\Pi_t = \frac{\widetilde{P}_t}{\widetilde{P}_{t-1}}$ is gross inflation and $p^* = \frac{\gamma-1}{\gamma}$ is the steady state relative price of the heterogeneous production firm's good. The relative price $p_t$ links to the New Keynesian block of the model to the investment block; when demand for the final good $Y_t$ increases, retailers must increase their demand for the production firms' good $y_{it}$ due to sticky prices; higher demand then increases the relative price $p_t$.

[17] We focus directly on the linearized formulation for computational simplicity.

Aggregate output is given by the total output of production firms::

$$Y_t = \int_0^{N_t} z_{jt} k_{jt}^{\theta} n_{jt}^{\nu} \mathrm{d}j. \tag{12}$$

From the capital good producer's profit maximization problem, the real price of capital is given by

$$q_t = \frac{1}{\Phi'(\frac{I_t}{K_t})} = \left(\frac{I_t}{\delta K_t}\right)^{1/\phi}. \tag{13}$$

### 3.2.2 Investment Block

We now characterize the decisions of the heterogeneous production firms.

**Firms' Decision Rules** We characterize the production firms' decisions recursively. The individual state variable of a production firm is $z$, its draw of the idiosyncratic productivity shock, $k$, its pre-existing stock of capital inherited from past investment, and $B$, the face value of outstanding debt. We denote the aggregate state $\mathbf{s}$ and remain agnostic about its contents until defining equilibrium.

If the firm receives the idiosyncratic exit shock, its value is

$$V_t^{\text{exit}}(z,k,B) = \max\{0, \max_n P_t z k^{\theta} n^{\nu} - W_t n + Q_t(1-\delta)k - B - \widetilde{P}_t \xi\}.$$

The firm first decides whether to default, corresponding to the binary max operator. If the firm does not default, it chooses its labor input $n$ to maximize its current revenue net of labor costs, sells its undepreciated capital, pays back the face value of its debt, pays its fixed operating cost, and exits the economy.

If the firm does not receive the idiosyncratic exit shock, its value is

$$\begin{aligned} V_t^{\text{cont}}(z,k,B) = \max\{0, \max_{n,k',B'} & P_t z k^{\theta} n^{\nu} - W_t n + Q_t(1-\delta)k - B - \widetilde{P}_t \xi - Q_t k' + \mathcal{Q}_t(z,k',B')B' \\ & + \mathbb{E}_t\left[\hat{\Lambda}_{t,t+1} V_{t+1}^0(z',k',B')\right]\} \qquad \text{such that} \qquad (14) \\ & P_t z k^{\theta} n^{\nu} - W_t n + Q_t(1-\delta)k - B - \widetilde{P}_t \xi - Q_t k' + \mathcal{Q}_t(z,k',B')B' \geq 0, \end{aligned}$$

where $\hat{\Lambda}_{t,t+1} = \beta \frac{C_{t+1}^{-\sigma}}{C_t^{-\sigma}} \frac{\widetilde{P}_t}{\widetilde{P}_{t+1}}$ is the nominal stochastic discount factor. The firm chooses labor input, investment, and borrowing to maximize the value of its current dividends plus the continuation value. In making this investment, it faces the debt price schedule $\mathcal{Q}_t(z, k', B')$ and cannot pay negative dividends.

It is convenient to make three simplifications to the firm's decision problem. First we write the problem in real terms relative to the price level $\widetilde{P}_t$. To that end, let $b = \frac{B}{\widetilde{P}_t}$, $b' = \frac{B'}{\widetilde{P}_t}$, $\Lambda_{t,t+1} = \beta \frac{C_{t+1}^{-\sigma}}{C_t^{-\sigma}}$, and $v_t(z, k, b) = \frac{V_t^{\text{cont}}(z,k,B)}{\widetilde{P}_t}$. Second, we combine capital $k$ and debt $b$ into a composite state variable $x = \max_n p_t z k^\theta n^\nu - w_t n + q_t(1-\delta)k - b - \xi$. The composite state variable $x$ is sufficient because capital is a liquid asset. Third, we define the value function $v_t(z, x)$ as the normalized value function conditional on not defaulting in the current period. It is easy to verify that $v_t(z, x)$ satisfies the transformed Bellman equation.

$$
\begin{aligned}
v_t(z,x) = \max_{k',b'} x - q_t k' + \mathcal{Q}_t(z,k',b')b' + \mathbb{E}_t\left[\Lambda_{t,t+1}\left(\pi_d \max\{0,x'\} + (1-\pi_d)\max\{0, v_{t+1}(z',x')\}\right)\right] \\
\text{such that } x - q_t k' + \mathcal{Q}_t(z,k',b')b' \geq 0 \qquad (15) \\
x' = \max_{n'} p_{t+1} z'(k')^\theta (n')^\nu - w_{t+1} n' + q_{t+1}(1-\delta)k' - \frac{b'}{\Pi_{t+1}} - \xi.
\end{aligned}
$$

Proposition 1 characterizes the decision rules which solve this Bellman equation.

***Proposition* 1.** *Consider a firm at time $t$ that is eligible to continue into the next period and has idiosyncratic productivity $z$ and internal resources $x$. The firm's optimal decision is characterized by one of the following three cases.*

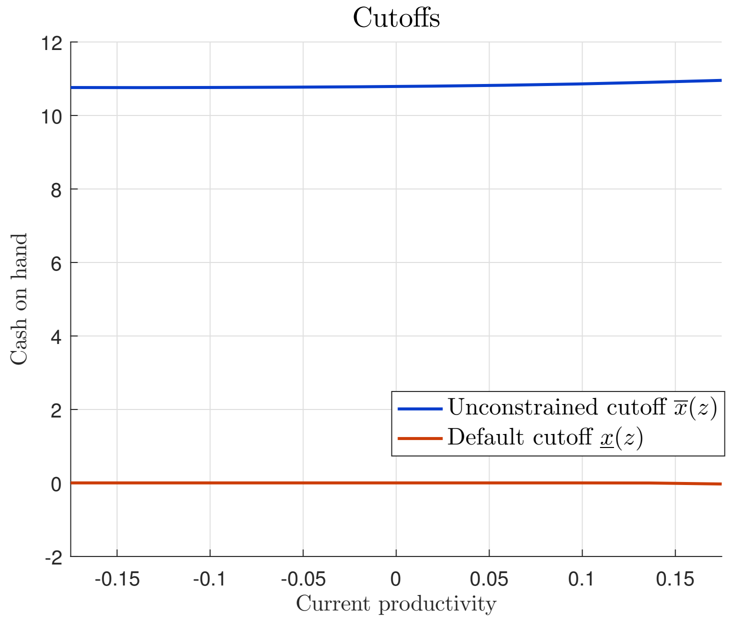
*(i)* ***Default****: there exists a threshold $\underline{x}_t(z)$ such that the firm defaults if $x < \underline{x}_t(z)$.*

*(ii)* ***Unconstrained****: there exists a threshold $\overline{x}_t(z)$ such that the firm is unconstrained if $x > \overline{x}_t(z)$. Unconstrained firms follow the capital accumulation policy*

$$
k_t'(z,x) = k_t^*(z) = \left( \frac{1}{q_t} \frac{\mathbb{E}_t\left[\Lambda_{t+1} A \hat{\theta} p_{t+1}^{\frac{1}{1-\nu}} w_{t+1}^{-\frac{\nu}{1-\nu}} z'^{\frac{1}{1-\nu}}\right]}{1 - (1-\delta)\mathbb{E}_t\left[\Lambda_{t+1} \frac{q_{t+1}}{q_t}\right]} \right)^{\frac{1}{1-\hat{\theta}}}, \qquad (16)
$$

*where $A = \nu^{\frac{\nu}{1-\nu}} - \nu^{\frac{1}{1-\nu}}$ and $\hat{\theta} = \frac{\theta}{1-\nu}$, for period $t$ and every period in the future.*

Figure 4: Partition of Individual State Space




Notes: Partition of individual state space for the calibrated parameters from Section 4 in steady state. Firms in the red shaded area have $x < \underline{x}_t(z)$ and default. Firms in the light blue shaded area have $x > \overline{x}_t(z)$ and are unconstrained. Firms in the grey shaded area have $x \in [\underline{x}_t(z), \overline{x}_t(z)]$ and are constrained according to the definition in Proposition 1.

*Unconstrained firms are indifferent over any combinations of $b'$ and $d$ such that they remain unconstrained for every period with probability one. We assume that they choose borrowing $b' = b_t^*(z)$ defined by*

$$b_t^*(z) = \Pi_{t+1} \min_{z'} \{ \max_{n'} \{ p_{t+1} z' k_t^*(z)^\theta (n')^\nu - w_{t+1} n' \} + q_{t+1} k_t^*(z) - \xi$$
$$+ \min\{ \mathbb{E}_t [\Lambda_{t+1}] \, b_{t+1}^*(z') / \Pi_{t+1} - q_{t+1} k_{t+1}^*(z'), 0 \} \}. \tag{17}$$

*(iii)* ***Constrained****: firms with $x \in [\underline{x}_t(z), \overline{x}_t(z)]$ are constrained. Constrained firms' optimal investment $k_t'(z,x)$ and borrowing $b_t'(z,x)$ decisions solve the Bellman equation (15) and pay zero dividends.*

*Proof.* See Appendix A.2. ■

Proposition 1 partitions the individual state space $(z, x)$ into three distinct regions, which Figure 4 plots for the calibrated parameter values from Section 4 in steady state. Firms with low internal resources $x < \underline{x}_t(z)$ default and permanently exit the economy. In our model, firms only default if there is no feasible choice of capital investment $k'$ and financial investment $b'$ that satisfies the non-negativity constraint on dividends,

$$x - q_t k' + \mathcal{Q}_t(z, k', b')b' \geq 0.$$

The minimum amount of cash-on-hand that a firm can have and still satisfy this constraint is

$$\underline{x}_t(z) = \xi - \max_{k', b'} \left( \mathcal{Q}_t(z, k', b')b' - q_t k' \right).$$

The threshold $\underline{x}_t(z)$ is decreasing in productivity $z$ because firms with high productivity face more favorable borrowing rates.

Firms with high internal resources $x > \overline{x}_t(z)$ are unconstrained in the sense that they can follow the first-best capital accumulation policy (16) for their entire lifetime and not default with probability one. Any combination of external financing $b'$ and internal financing $d$ that leaves these firms unconstrained is an optimal decision; in this sense, the Modigliani-Miller theorem holds for unconstrained firms. Following Khan, Senga and Thomas (2016), we resolve this indeterminacy by imposing the "minimum savings policy" $b_t^*(z)$ defined in (17). $b_t^*(z)$ is the highest level of debt which firms can incur and be guaranteed to, with probability one, not default.[18]

Firms with intermediate cash on hand $x \in [\underline{x}_t(z), \overline{x}_t(z)]$ do not default but are not financially unconstrained. Constrained firms set $d = 0$ because the value of resources inside the firm, used to loosen the financial constraint, is higher than the value of resources outside the firm. Setting $d = 0$ implies

$$q_t k' = x + \mathcal{Q}_t(z, k', b')b'. \tag{18}$$

Constrained firms' investment expenditures are therefore financed by either their internal resources $x$ or new borrowing $\mathcal{Q}_t(z, k', b')b'$.[19]

[18]The "with probability one" statement does not take into account the monetary policy shock, which is completely unexpected by firms. However, since we only analyze expansionary shocks, monetary policy in our model does not induce any firm to default.

[19]It is important to note that a firm that can currently borrow at the risk-free rate can still be constrained

**Lenders** In real terms, a loan to a firm is an asset that pays $\frac{1}{\Pi_{t+1}}$ units of the final good if the firm does not default and pays $\min\{\frac{\alpha q_{t+1}k'}{b'/\Pi_{t+1}},1\}$ if the firm does default. Therefore, its price is

$$\mathcal{Q}_t(z,k',b') = \mathbb{E}_t\left[\Lambda_{t+1}\frac{1}{\Pi_{t+1}}\left(1-\left(\pi_d(1-\chi^1(x'))+(1-\pi_d)(1-\chi_t^2(x'))\right)\left(1-\min\{\frac{\alpha q_{t+1}(1-\delta)k'}{b'/\Pi_{t+1}},1\}\right)\right)\right], \tag{19}$$

where $x' = \max_{n'} p_{t+1}z(k')^\theta(n')^\nu - w_t n' + q_{t+1}(1-\delta)k' - b' - \xi$ is the implied cash-on-hand, $\chi^1(x) = \mathbb{1}\{x \geq 0\}$ and $\chi_t^2(z,x) = \mathbb{1}\{x \geq \underline{x}_t(z)\}$.

**Distribution of Firms** The aggregate state of the economy contains the distribution of heterogeneous firms. Let $\mu_t(z,k,b)$ denote the distribution of incumbent firms at the beginning of the period before new entry and default decisions are made.

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

$$\begin{aligned}\hat{\mu}_t(z,x) = &\int \left(\pi_d\chi^1(x_t(z,k,b)) + (1-\pi_d)\chi_t^2(z,x_t(z,k,b))\right)\mathrm{d}\mu_t(z,k,b) \\ &+ \overline{\mu}\int\left(\pi_d\chi^1(x_t(z,k_0,0)) + (1-\pi_d)\chi_t^2(z,x_t(z,k_0,0))\right)\mathrm{d}\mu^{\text{ent}}(z),\end{aligned} \tag{20}$$

where $x_t(z,k,b) = \max_n p_t z k^\theta n^\nu - w_t n + q_t(1-\delta)k - b - \xi$ is the implied cash-on-hand $x$ of a firm with state $(z,k,b)$.

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

$$\begin{aligned}\mu_{t+1}(z',k',b') = &\int (1-\pi_d)\chi_t^2(z,x_t(z,k,b))1\{k_t'(z,x_t(z,k,b)) = k'\} \\ &\times \mathbb{1}\{\frac{b_t'(z,x_t(z,k,b))}{\Pi_{t+1}} = b'\}p(\varepsilon|e^{\rho\log z+\varepsilon} = z')\mathrm{d}\varepsilon\mathrm{d}\mu_t(z,k,b) \\ &+ \overline{\mu}\int(1-\pi_d)\chi_t^2(z,x_t(z,k_0,0))1\{k_t'(z,x_t(z,k_0,0)) = k'\} \\ &\times \mathbb{1}\{\frac{b_t'(z,x_t(z,k_0,0))}{\Pi_{t+1}} = b'\}p(\varepsilon|e^{\rho\log z+\varepsilon} = z')\mathrm{d}\varepsilon\mathrm{d}\mu^{\text{ent}}(z),\end{aligned} \tag{21}$$

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

---

if it has some positive probability of default in any future period.

### 3.2.3 Equilibrium Definition

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

(i) Production firms optimzation: $v_t(z,x)$ solves the Bellman equation (15) 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 (19).

(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 (20) and the distribution $\mu_t(z,k,b)$ evolves according to (21).

(v) Household block: the stochastic discount factor is given by $\Lambda_{t,t+1} = \beta \frac{C_{t+1}^{-\sigma}}{C_t^{-\sigma}}$. The wage must satisfy $w_t C_t^{-\sigma} = \Psi N_t^{1/\eta}$. The stochastic discount factor and nominal interest rate are linked by the Euler equation for bonds, $1 = \mathbb{E}_t \left[ \Lambda_{t,t+1} \frac{R_t^{\text{nom}}}{\Pi_{t+1}} \right]$.

(vi) Market clearing: aggregate investment is defined implicitly by $K_{t+1} = \Phi(\frac{I_t}{K_t})K_t + (1-\delta)K_t$, where $K_t = \int k \mathrm{d}\mu_t(z,k,b)$. Aggregate consumption is defined by $C_t = Y_t - I_t - \xi \mu_t$, where $\mu_t = \int \mathrm{d}\hat{\mu}_t(z,x)$ is the mass of firms in operation.

# 4 Calibration and Steady State Analysis

Before analyzing the effect of a monetary policy shock $\varepsilon_t^{\text{m}}$, we calibrate the model and verify that its steady state behavior is consistent with the micro data.

## 4.1 Calibration

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

Table 10
Fixed Parameters

| Parameter | Description | Value |
|---|---|---|
| **Household** | | |
| $\beta$ | Discount factor | 0.99 |
| **Firms** | | |
| $\nu$ | Labor coefficient | 0.64 |
| $\theta$ | Capital coefficient | 0.21 |
| $\delta$ | Depreciation | 0.026 |
| **New Keynesian Block** | | |
| $\phi$ | Aggregate capital AC | 2 |
| $\gamma$ | Demand elasticity | 10 |
| $\varphi_\pi$ | Taylor rule coefficient | 1.25 |
| $\varphi$ | Price adjustment cost | 90 |

Notes: Parameters exogenously fixed in the calibration.

**Fixed Parameters** Table 10 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 quarterly investment to capital ratio in 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 $\frac{\gamma-1}{\gamma}\nu \approx$ 58%, close to the 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 (2016).

**Fitted Parameters** We choose the parameters listed in Table 11 in order to match the empirical moments reported in Table 12. The first two parameters, $\rho$ and $\sigma$, govern the idiosyncratic productivity shock process faced by firms. The next two parameters, $\xi$ and $\alpha$, control the frictions to external finance; the fixed operating cost $\xi$ governs how often firms default and the recovery rate $\alpha$ governs how costly default is to lenders. The remaining

TABLE 11
FITTED PARAMETERS

| Parameter | Description | Value |
|---|---|---|
| **Productivity process** | | |
| $\rho$ | Persistence | 0.87 |
| $\sigma$ | SD of innovations | 0.034 |
| **Financial frictions** | | |
| $\xi$ | Operating cost | 0.15 |
| $\alpha$ | Loan recovery rate | 0.24 |
| **Firm lifecycle** | | |
| $m$ | Mean shift of entrants' prod. | 2.60 |
| $k_0$ | Initial capital | 1.43 |
| $\pi_d$ | Exogeneous exit rate | 0.015 |

Notes: Parameters chosen to match the moments in Table 12.

three parameters, $m$, $k_0$, and $\pi_d$, govern the firm lifecycle. The factor $m$ controls average productivity of new entrants, which impacts both the average size of new entrants and, together with the persistence $\rho$, how quickly firms grow. The initial capital stock $k_0$ controls the mean level of initial cash on hand. The exogenous exit probability $\pi_d$ controls the average exit rate of firms in the economy.

We target four key sets of moments in our calibration. First, we target the dispersion of plant-level investment rates in Census microdata as reported by Cooper and Haltiwanger (2006).[20] Their sample is a balanced panel of plants that have survived at least sixteen years; to generate this moment in the model, we condition on firms that have survived for twenty years.[21] Most of these remaining firms are financially unconstrained, so productivity shocks are the key force driving the dispersion in investment rates.

The second set of moments we target are related to the use of external finance. Following Bernanke, Gertler and Gilchrist (1999), we target a mean default rate of 3% as estimated by Dun and Bradstreet. We target an average annual credit spread implied by BAA rated corporate bond yields relative to the ten-year Treasury yield. Finally, we target the average aggregate debt to capital ratio of 50%, also reported in Bernanke, Gertler and Gilchrist

[20]Our model is arguably a model of the firm rather than the plant. However, we prefer to use the plant-level data of Cooper and Haltiwanger (2006) because it carefully constructs measures of retirement and sales of capital, which is important given that capital is liquid in our model.

[21]Our calibration results are robust to different choices of this cutoff.

TABLE 12
MODEL FIT

| Moment | Description | Data | Model |
|---|---|---|---|
| **Investment behavior (annual)** | | | |
| $\sigma\left(\frac{i}{k}\right)$ | SD investment rate | 33.7% | 37.8% |
| **Financial behavior (annual)** | | | |
| $\mathbb{E}\left[\text{default rate}\right]$ | Mean default rate | 3% | 2.78% |
| $\mathbb{E}\left[\text{credit spread}\right]$ | Mean credit spread | 2.35% | 2.86% |
| $B/K$ | Agg debt-to-capital | 50% | 48.5% |
| **Firm Exit (annual)** | | | |
| $\mathbb{E}\left[\text{exit rate}\right]$ | Mean exit rate | 8.7% | 8.65% |
| **Firm Growth (annual)** | | | |
| $\mathbb{E}[n_1]/\mathbb{E}[n]$ | Size of age 1 firms (relative to mean) | 28% | 44% |
| $\mathbb{E}[n_2]/\mathbb{E}[n]$ | Size of age 2 firms (relative to mean) | 36% | 68% |

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 and aggregate debt to capital ratio are drawn from Bernanke, Gertler and Gilchrist (1999). 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.

(1999).

The final two sets of moments are informative about the lifecycle of firms. We target the average annual exit rate of firms reported in the Business Dynamics Statistics (BDS), the public-release sample drawn from the Census' Longitudinal Business Database (LBD). We also target the average size of firms for ages one and two, which is informative about how quickly young firms grow.

At each step of this moment-matching process, we choose the mass of new entrants to ensure the steady state mass of firms in production is one, and choose the disutility of labor supply $\Psi$ to generate a steady state employment rate of 60%.

Table 12 shows that our model matches the targeted moments reasonably well.[22] It roughly matches the dispersion of investment rates, which captures the degree of idiosyncratic risk faced by firms. The model also matches the mean default rate and credit spread,

[22]Because the model is overidentified and nonlinear, we do not match the moments exactly. We use simulated annealing to minimize the weighted sum of squared errors implied by these moments.

which control the financial frictions associated with external finance. However, firms in our model grow too quickly relative to the data, which is not surprising because we do not include adjustment costs or other frictions which also slow down the growth process.

The calibrated parameters in Table 11 are broadly comparable to the existing literature. Idiosyncratic productivity shocks are less persistent and more volatile than aggregate productivity shocks, consistent with direct measurements of plant- or firm-level productivity. Although the calibrated loan recovery rate is somewhat lower than direct estimates, it should be interpreted more broadly as capturing other direct or indirect costs from default in our model.

## 4.2 Financial Heterogeneity in the Model and the Data

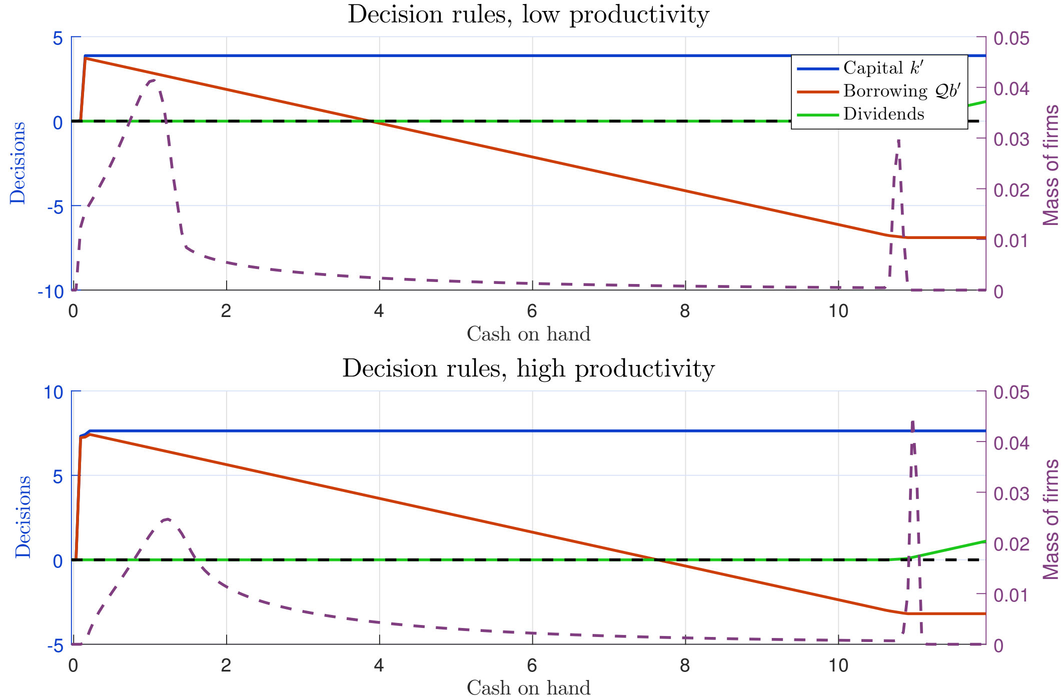
We now analyze firms' decision rules in our calibrated steady state and argue that the financial heterogeneity in the model is comparable to that in the data.

**Firms' Decision Rules** The left axis of Figure 5 plots the investment, borrowing, and dividend payment decisions of firms in the steady state of our calibrated model. Firms with cash-on-hand below the default threshold $\underline{x}_t(z)$ default and make no decisions. Once they clear this default threshold, firms lever up to increase their capital to its optimal scale $k_t^*(z)$. Once capital is at its optimal level $k_t^*(z)$, firms then use additional resources to pay down their debt until their resources are above the unconstrained threshold $\overline{x}_t(z)$. Unconstrained firms set $k' = k_t^*(z)$ and $b' = b_t^*(z)$, which do not depend on internal resources $x$. Only unconstrained firms pay positive dividends.

The right axis of Figure 5 plots the stationary distribution of firms. Approximately 1% of firms are close to their default threshold and accumulating capital below their optimal scale. Roughly 93% of firms achieve the optimal scale of capital but are still constrained in the sense that they do not pay positive dividends (and thus have a positive probability of default in some future state). The remaining 6% of firms are unconstrained according to the definition in Proposition 1. Since unconstrained firms pay out additional cash-on-hand as dividends, they are bunched at the unconstrained threshold $\overline{x}_t(z)$.

Figure 5 makes clear that there are two key sources of financial heterogeneity in the

FIGURE 5: Steady State Decision Rules

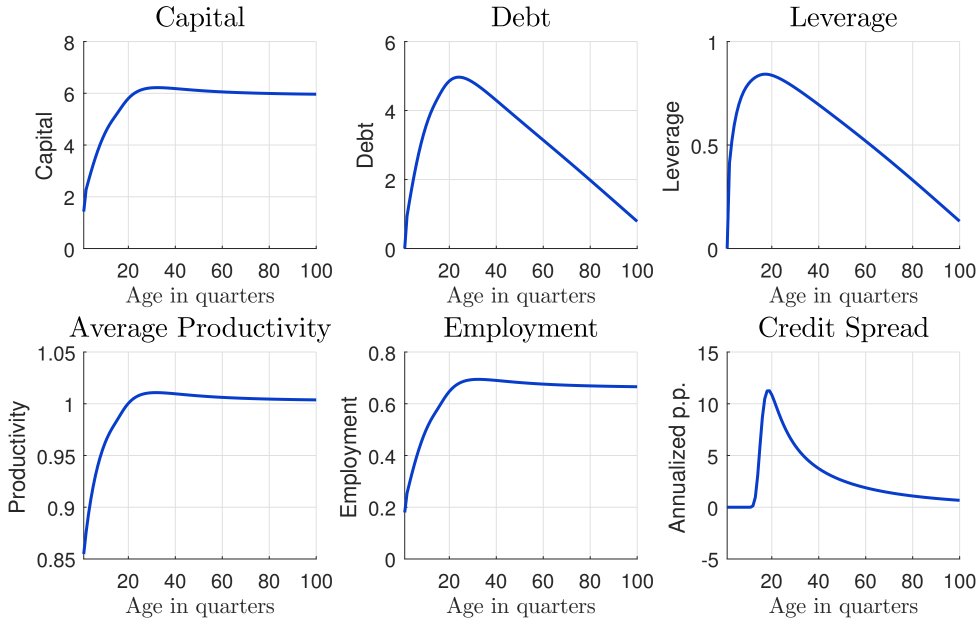



Notes: Top panel plots decision rules and stationary distribution of firms conditional on idiosyncratic productivity one standard deviation below the mean. The bottom panel plots the same objects conditional on one standard deviation above the mean. The left y-axis measures the decision rules (capital accumulation, borrowing, and dividend payments) as a function of cash-on-hand x. The right y-axis measures the stationary distribution of firms.

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 as they generate revenue and increase their cash-on-hand. Second, reading the graphs from top to bottom 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.

**Lifecycle Dynamics** Figure 6 plots the lifecycle dynamics of key variables for the average firm in the steady state of our model. New entrants are smaller than average because they have low initial capital $k_0$ and low productivity. Over time, as productivity reverts to its mean, the optimal scale of capital $k_t^*(z)$ increases and firms increase their capital. In order

Figure 6: Lifecycle Dynamics in Model



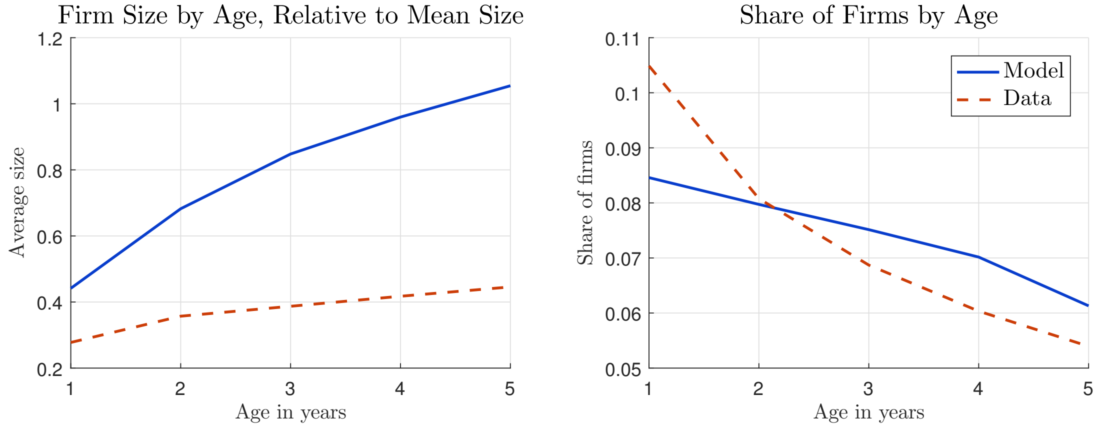

Notes: Average capital, debt, leverage, productivity, employment, and credit spread conditional on age in steady state.

to finance this investment, firms take on debt, increasing default risk and therefore credit spreads. Once productivity has returned to its mean and firms have built up their desired capital stock $k_t^*(z)$, firms then pay down their accumulated debt and deleverage.

The assumption that new entrants have lower productivity than average is crucial to generating these prolonged lifecycle dynamics. In a version of the model in which new entrants drew productivity from its ergodic distribution, we found that the vast majority of firm growth counterfactually occurred in the first year of life. In this alternative model, constrained firms were disproportionately young rather than being more evenly distributed across the population. We prefer the current calibration because the assumption that new entrants have persistently lower productivity than average is consistent with the findings of Foster, Haltiwanger and Syverson (2016) among others.

Figure 7 compares the lifecycle dynamics of our model relative to the data. The left plan plots the average size of firms by age relative to the average firm the economy. In the data, young firms are substantially smaller than average, and take many years to catch up.

FIGURE 7: Comparison of Lifecycle Dynamics to the Data



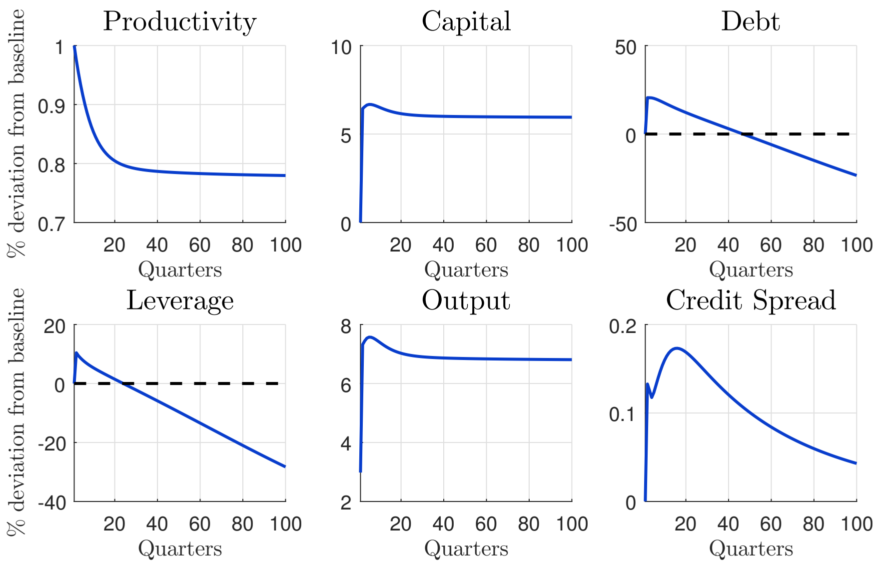

Notes: Left panel plots the average employment of firms by age, relative to the average employment in the population. Right panel plots the share of firms by age. Model: steady state of the calibrated model; Data: BDS.

Qualitatively, our model captures this prolonged growth process; however, quantitatively, growth in our model is still too rapid compared to the data. As discussed above, this result is due to the fact that we do not include other frictions to firm growth such as capital adjustment costs that are also quantitatively relevant.

The right panel of Figure 7 plots the share of firms in the economy at different ages. 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. The model under-predicts exit by young firms and over-predicts exit by old firms. This occurs because, as can be seen in Figure 6, firms do not become sufficiently leveraged to run the risk of default until year four or five of the lifecycle.

**Idiosyncratic Productivity Shocks** Figure 8 plots the impulse response of firms to an idiosyncratic productivity shock. Higher productivity increases the optimal scale of capital $k_t^*(z)$. In order to reach that level, firms initially take on debt and invest; once they have reached it, firms then pay back their debt. Hence, these dynamics qualitatively resemble the lifecycle dynamics in Figure 6; however, quantitatively they are much faster.

FIGURE 8: Response to Idiosyncratic Productivity Shock




Notes: Impulse response to positive idiosyncratic productivity shock. Because our model is nonlinear, these impulse responses depend on both the size of the shock and firms' initial state. We compute the average response for firms in the stationary distribution starting at productivity level 0.95 and moving to productivity 1.02. We rescale the units of the responses so that the impact effect on productivity is 1%.

**Investment and Leverage Heterogeneity** Table 13 compares the model-implied distribution of investment rates and leverage ratios to the data. The top panel analyzes the distribution of investment rates in the annual Census data drawn from Cooper and Haltiwanger (2006) used to calibrated the model. We present the corresponding statistics in a selected sample of our model – in which we condition on firms that survive at least twenty years to mirror the selection into the LRD – and in the full sample of firms in our model. 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 is also reasonable. The mean investment rate in the full sample is much higher because it includes young, growing firms.

The middle and bottom panels of Table 13 compare the model-implied distribution of investment rates and leverage ratios in quarterly Compustat data. We mirror the sample selection into Compustat by conditioning on firms that survive for at least seven years, which is the near the median time to IPO in 2015 according to ?. Our model provides a close match of the peristence of leverage and its correlation with investment in this sample.

Table 13
Investment and Leverage Heterogeneity

| Moment | Description | Data | Model (selected) | Model (full) |
|---|---|---|---|---|
| **Investment heterogeneity (annual LRD)** | | | | |
| $\mathbb{E}\left[\frac{i}{k}\right]$ | Mean investment rate | 12.2% | 6.7% | 13.3% |
| $\sigma\left(\frac{i}{k}\right)$ | SD investment rate (calibrated) | 33.7% | 38.8% | 43.1% |
| $\rho\left(\frac{i}{k}, \frac{i}{k}_{-1}\right)$ | Autocorr investment rate | 0.058 | -0.20 | -0.20 |
| **Leverage heterogeneity (quarterly Compustat)** | | | | |
| $\mathbb{E}\left[\frac{b}{k}\right]$ | Mean leverage ratio | 26.7% | 31.2% | 55.2% |
| $\sigma\left(\frac{b}{k}\right)$ | SD leverage ratio | 36.4% | 55.7% | 38.0% |
| $\rho\left(\frac{b}{k}, \frac{b}{k}_{-1}\right)$ | Autocorr leverage ratio | 0.944 | 0.971 | 0.909 |
| **Joint investment and leverage (quarterly Compustat)** | | | | |
| $\rho\left(\frac{i}{k}, \frac{b}{k}\right)$ | Corr. of leverage and investment | -0.080 | -0.104 | -0.210 |

Notes: Statistics about the cross-sectional distribution of investment rates and leverage ratios in steady state. Data for investment heterogeneity are moments 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 eleven years in a panel simulation. Model (full) correpsonds to the full sample of firms in a panel simulation.

However, the mean leverage ratio is somewhat lower than the data and the dispersion of leverage ratios is somewhat higher. The mean leverage ratio is even higher in the full sample because it includes young firms who have accumulated debt in order to grow.

**Measured Investment-Cash Flow Sensitivity** We close this subsection by showing that the model generates a positive investment-cash flow sensitivity consistent with the data. Following Gomes (2001), we measure investment-cash flow sensitivity using the regression

$$\frac{i_{jt}}{k_{jt}} = \alpha_j + \alpha_t + a_1 \frac{\mathtt{CF}_{jt-1}}{k_{jt}} + a_2 \mathtt{q}_{jt-1} + \varepsilon_{jt}, \tag{22}$$

where $\mathtt{CF}_{jt}$ is cash flow and $\mathtt{q}_{jt}$ is Tobin's q. The coefficient $a_1$ captures the statistical co-movement of investment with cash flow, conditional on 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 the data, we identify cash flow as earnings

Table 14
Measured Investment-Cash Flow Sensitivity

| | **Without q** | | **With q** | |
|---|---|---|---|---|
| | *Data* | *Model* | *Data* | *Model* |
| Tobin's q | 0.01*** | 0.09 | 0.01*** | -0.05 |
| cash flow | | | 0.02*** | 0.17 |
| $R^2$ | 0.097 | 0.03 | 0.104 | 0.05 |

Notes: Results from estimating the regression (22). Data refers to quarterly Compustat data. We measure cash flow as earnings before interest and taxes (EBIT) and Tobin's q as the market to book value of the firm, both in quarterly Compustat. Model refers to simulating a panel of firms from the calibrated model, conditional on surviving at least eleven 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, $k$.

before interest and taxes (EBIT) and Tobin's q as the market to book value of the firm, both in quarterly Compustat.

Table 14 shows that the model's implications for regression (22) 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 (22) significantly increases the $R^2$ of the regression, indicating that it has predictive power for investment. However, the quantitative magnitude of the cash flow coefficient is larger in the model than the data.

# 5 Monetary Policy Analysis

We now analyze the effect of a monetary policy shock $\varepsilon_t^{\mathrm{m}}$. Section 5.1 theoretically characterizes the channels through monetary policy affects firms' investment decisions. Section 5.2 computes the aggregate impulse responses in our calibrated model. Section 5.3 decomposes the aggregate responses and shows that the majority of the investment response is driven by financially unconstrained firms. Section 5.4 shows that the aggregate impulse response functions depend on the amount of unconstrained firms in the economy.

## 5.1 Channels of Monetary Transmission

We model the monetary shock as a one-time, unexpected innovation to the Taylor rule $\varepsilon_t^{\mathrm{m}}$ followed by a perfect foresight transition back to steady state. This "MIT shock" approach allows for clean analytical results because there is no distinction between ex-ante expected and ex-post realized real interest rates.

**Unconstrained Firms** Totally differentiating the unconstrained capital decision (16), the monetary shock $\varepsilon_t^{\mathrm{m}}$ perturbs unconstrained firms' investment decisions by

$$\frac{\mathrm{d}\log k'}{\mathrm{d}\varepsilon_t^{\mathrm{m}}} = \frac{1-\nu}{1-\nu-\theta}\left[\underbrace{-\frac{R_t}{R_t-(1-\delta)\frac{q_{t+1}}{q_t}}\frac{\partial \log R_t}{\partial \varepsilon_t^{\mathrm{m}}}}_{\text{discounting}} - \underbrace{\frac{\partial \log q_t}{\partial \varepsilon_t^{\mathrm{m}}}}_{\text{capital price}} + \underbrace{\frac{(1-\delta)\frac{q_{t+1}}{q_t}}{R_t-(1-\delta)\frac{q_{t+1}}{q_t}}\frac{\partial \log \frac{q_{t+1}}{q_t}}{\partial \varepsilon_t^{\mathrm{m}}}}_{\text{capital gains}}\right] + \frac{1}{1-\nu-\theta}\left[\underbrace{\frac{\partial \log p_{t+1}}{\partial \varepsilon_t^{\mathrm{m}}} - \nu\frac{\partial \log w_{t+1}}{\partial \varepsilon_t^{\mathrm{m}}}}_{\text{capital revenue}}\right], \tag{23}$$

where $R_t = \frac{R_t^{\mathrm{nom}}}{\Pi_{t+1}}$ is the real interest rate between periods $t$ and $t+1$.

The expression (23) decomposes the effect of monetary policy on unconstrained firms' investment into four distinct channels. The *discounting* channel isolates the direct effect of changing the real interest rate on investment decisions through discounting future revenues. The *capital price* channel isolates the effect of monetary policy on the relative price of capital. The *capital gains* channel isolates the effect of monetary policy on the change in the value of the firms' capital between periods $t$ and $t+1$. Finally, the *capital revenue* channel isolates the effect of monetary policy on the marginal revenue product of capital. Monetary policy changes the marginal revenue product by affecting the relative price of the firms' output, $p_{t+1}$, and the relative price of labor, $w_{t+1}$. The capital revenue channel measures the net effect of both of these terms.

We refer to the sum of all these channels as the *intertemporal channel* because it reflects the fact that unconstrained firms' investment decisions are purely forward-looking. Note that there is no heterogeneity among unconstrained firms' responses because monetary policy only impacts their decision rules through aggregate prices.

**Constrained Firms** Since constrained firms set $d = 0$, it in instructive to totally differentiate (18) to get the decomposition

$$\frac{\mathrm{d}\log k'}{\mathrm{d}\varepsilon_t^{\mathrm{m}}} = \underbrace{-\frac{\partial \log q_t}{\partial \varepsilon_t^{\mathrm{m}}}}_{\text{capital price}} + \underbrace{\frac{\partial \log x}{\partial \varepsilon_t^{\mathrm{m}}}\frac{x}{q_t k'}}_{\text{cash flow}} + \underbrace{\frac{\partial \log(\mathcal{Q}_t(z,k',b')b')}{\partial \varepsilon_t^{\mathrm{m}}}\frac{\mathcal{Q}_t(z,k',b')b'}{q_t k'}}_{\text{borrowing cost}}. \tag{24}$$

This expression should be interpreted with caution because it involves derivatives of the endogenous variables on both sides of the equality and does not fully characterize the firms' portfolio choice problem between $k'$ and $b'$. It is nonetheless instructive in isolating three channels through which monetary policy can affect constrained firms' investment decisions. As with unconstrained firms, the *capital price* channel isolates how monetary policy affects the price of capital.

The *cash flow* channel isolates how monetary policy affects firms' internal resources for financing investment. Differentiating the definition of internal resources $x$ allows us to further characterize how monetary policy affects firms' cash flows:

$$\frac{\partial \log x}{\partial \varepsilon_t^{\mathrm{m}}} = \frac{1}{1-\nu-\theta}\left(\frac{\partial \log p_t}{\partial \varepsilon_t^{\mathrm{m}}} - \nu\frac{\partial \log w_t}{\partial \varepsilon_t^{\mathrm{m}}}\right)\frac{\chi_t(z,k)}{x} + \frac{\partial \log q_t}{\partial \varepsilon_t^{\mathrm{m}}}\frac{q_t(1-\delta)k}{x} + \frac{\partial \log \Pi_t}{\partial \varepsilon_t^{\mathrm{m}}}\frac{b/\Pi_t}{x}, \tag{25}$$

where $\chi_t(z,k) = \max_n p_t z k^\theta n^\nu - w_t n$. The expression (25) makes clear that monetary policy affects firms' cash in three ways. First, monetary policy affects current revenues by changing the relative price of firms' output $p_t$ and the relative price of their labor input $w_t$. Second, monetary policy affects the value of firms' capital stock by changing the relative price of capital $q_t$. Finally, monetary policy revalues the real value of outstanding debt by changing inflation $\Pi_t$.

The *borrowing cost* channel in (24) isolates how monetary policy affects firms' external resources from new borrowing. Monetary policy can change either how much debt the firm takes on, $b'$, or the price of that debt $\mathcal{Q}_t(z,k',b')$. It is convenient to instead characterize the effect of monetary policy on the borrowing rate $\widehat{R}_t(z,k',b') = \frac{1}{\mathcal{Q}_t(z,k',b')}$. The effect of monetary policy on the borrowing rate is given by

$$\frac{\partial \log \widehat{R}_t(z,k',b')}{\partial \varepsilon_t^{\mathrm{m}}} = \frac{\partial \log R_t}{\partial \varepsilon_t^{\mathrm{m}}} - (\widehat{R}_t(z,k',b') - R_t)\frac{\partial \log \Theta_t(z,k',b')}{\partial \varepsilon_t^{\mathrm{m}}}, \tag{26}$$

where $\Theta_t(z,k',b') = \Pr(v_{t+1}(z',k',b'/\Pi_{t+1}) = 0)\left(1 - \min\{\frac{\alpha q_{t+1}k'}{b'/\Pi_{t+1}}, 1\}\right)$ is the expected cost of default to the lender. Monetary policy affects borrowing costs through two channels. First, it affects the real risk-free rate $R_t$, which shifts the level of the interest rate schedule $\widehat{R}_t(z,k',b')$. Second, if the firm incurs a positive external finance premium $\widehat{R}_t(z,k',b') - R_t$, then monetary policy can additionally affect the credit spread of the firm by changing either default probabilities or loan recovery rates.

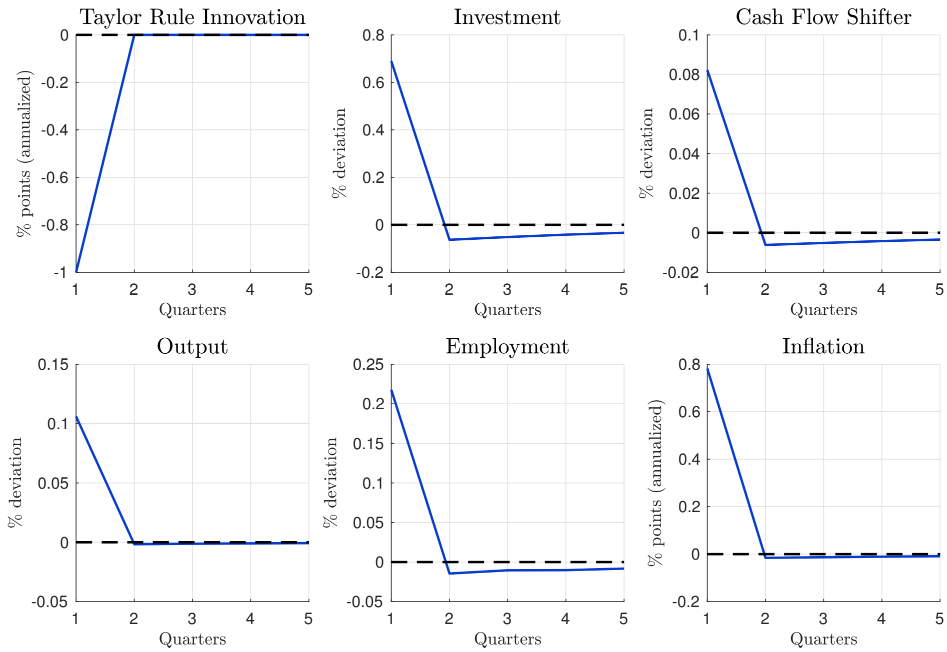
It is important to emphasize that the analysis of only (24) above is incomplete because the firm additionally faces the endogenous portfolio choice problem between $k'$ and $b'$. We have not been able to analytically characterize how monetary policy affects the optimal solution to this problem, so we leave it to the quantitative analysis below.

## 5.2 Aggregate Impulse Responses

Figure 9 plots the response of key aggregate variables to a one-time, unexpected $\varepsilon_0^{\mathrm{m}} = -.0025$ expansionary innovation to the Taylor rule.[23] The immediate effect of the shock is to decrease the nominal interest rate; because prices are sticky, this also decreases the real interest rate. The lower real interest rate directly stimulates investment demand by unconstrained firms through the discounting channel. Higher investment demand, as well as higher consumption

[23]The results presented in this section are for an older calibration of the model which we do not expected to produce significantly different results from the current calibration presented in Section 4. The key difference between the old and new calibrations is that the old calibration abstracts from aggregate capital adjustment costs, i.e., implicitly sets $\phi \to \infty$, which implies that the price of capital $q_t$ is constant. This raises two potential concerns. First, we may overstate the response of unconstrained firms because there is no offsetting increase in the capital price $q_t$. However, in order to generate a reasonably-sized aggregate response, the older calibration dampens the pass-through of the monetary shock to the real interest rate by lowering price rigidities; adding capital adjustment costs in the new calibration will also allow us to increase price rigidities, the pass-through to real interest rates, and therefore ultimately strengthen the discounting channel. The second concern is that abstracting from capital adjustment costs may understate the response of constrained firms because increases in the price of capital will increase the recovery value of debt in default and, therefore, lead to more favorable borrowing rates. However, the higher price of capital will also make investment more expensive for constrained firms, so the net effect is unclear. We are currently working on producing aggregate results with these channels included. Overall, we view the older calibration as providing a parsimonious quantification of the strength of the intertemporal channel for constrained firms.

FIGURE 9: Aggregate Impulse Response to Expansionary Monetary Shock




Notes: Aggregate impulse responses to a $\varepsilon_0^{\mathrm{m}} = -0.0025$ innovation to the Taylor rule, starting from steady state. Computed as the perfect foresight transition path following a one-time expected shock. Aggregate results come from an old calibration of the model that abstracts from capital adjustment costs.

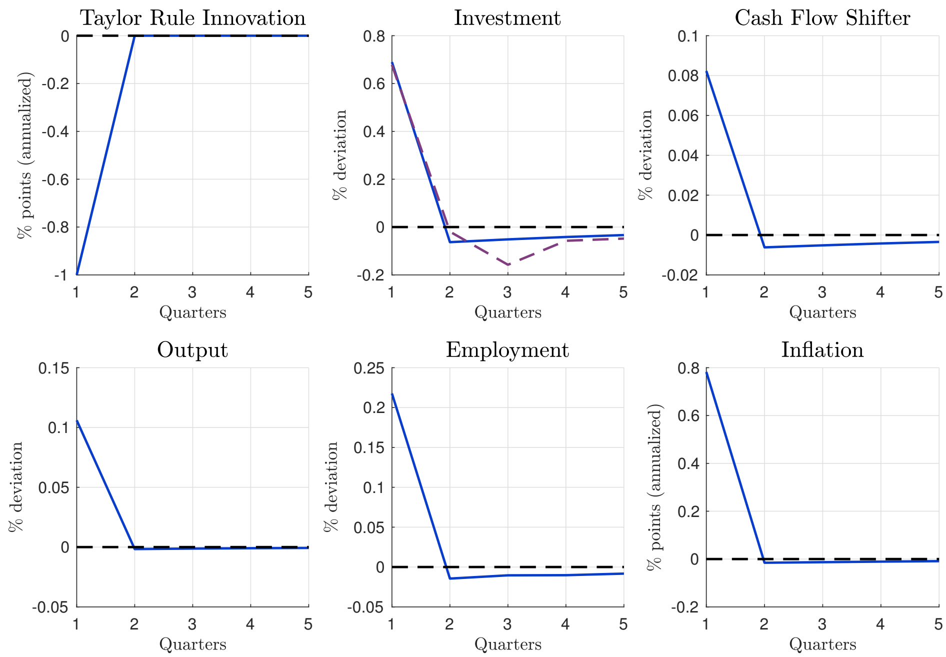
demand from the household, raises demand for aggregate output, which increases profits and therefore cash flows to firms. Constrained firms then adjust their capital and financial investment decisions through the cash flow and borrowing cost channels. The sum of these direct and indirect effects on aggregate demand thus increase output, employment, and inflation.[24]

## 5.3 Decomposition of Monetary Transmission Mechanism

Figure 10 shows that unconstrained firms account for nearly all of the aggregate response to monetary policy. This result reflects the well-known strength of the discounting channel in the neoclassical model of investment. In fact, the decomposition (23) shows that as the

[24]Our model does not generate the hump-shaped aggregate responses emphasized by Christiano, Eichenbaum and Evans (2005). We could do so by incorporating investment adjustment costs; however, for simplicity, we focus on how financial heterogeneity shapes monetary transmission in an otherwise benchmark environment.

FIGURE 10: Decomposition of Aggregate Investment Response




Notes: Aggregate impulse responses to a $\varepsilon_0^{\mathrm{m}} = -0.0025$ innovation to the Taylor rule, starting from steady state. Computed as the perfect foresight transition path following a one-time expected shock. Purple dashed line represents the contribution of unconstrained firms to the response of aggregate investment. Aggregate results come from an old calibration of the model that abstracts from capital adjustment costs.

model approaches constant returns to scale, the elasticity of investment with respect to the real interest rate is infinite; intuitively, constant returns to scale firms are indifferent over the scale of operation and are therefore infinitely sensitivity to price changes. Although our calibration features decreasing returns to scale, our unconstrained firms are sufficiently close to the constant returns case for the discounting channel to dominate.

Figure 10 also shows that cash flows increase following the monetary shock; given that constrained firms are not investing in capital, they must be using these resources to pay down their debt. As discussed in Figure 5, constrained firms quickly build up to their optimal scale of capital, after which point they prefer to use additional resources to pay down their debt rather than increasing capital. Although the monetary shock increases the optimal scale of capital, the effect is short-lived relative to the lifetime benefit of deleveraging.

TABLE 15

HETEROGENEITY IN THE RESPONSE TO MONETARY POLICY SHOCKS

A) Dependent variable: $\Delta b_{it+1}/a_{it}$

| | (1) | (2) |
|---|---|---|
| leverage × ffr shock | -2.66 | -1.76 |
| | (4.06) | (4.22) |
| Observations | 230659 | 230659 |
| $R^2$ | 0.040 | 0.041 |
| Firm controls | no | yes |

Dependent variable: $\mathbb{1}\{\Delta b_{i,t+1} > 0\}$

| | (1) | (2) |
|---|---|---|
| leverage × ffr shock | -2.54 | -1.78 |
| | (1.93) | (1.70) |
| Observations | 230659 | 230659 |
| $R^2$ | 0.151 | 0.156 |
| Firm controls | no | yes |

Notes: Results from estimating variants of the baseline specification

$$\frac{\Delta b_{jt+1}}{a_{jt}} = \alpha_j + \alpha_{st} + \beta \ell_{jt-1}\varepsilon_t^{\mathrm{m}} + \mathbf{\Gamma}' Z_{jt-1} + \varepsilon_{jt},$$

where $\alpha_j$ is a firm fixed effect, $\alpha_{st}$ is a sector-by-quarter fixed effect, $\ell_{jt-1}$ is leverage, $\varepsilon_t^{\mathrm{m}}$ 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 time. We have normalized the sign of the monetary shocks $\varepsilon_t^{\mathrm{m}}$ 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.

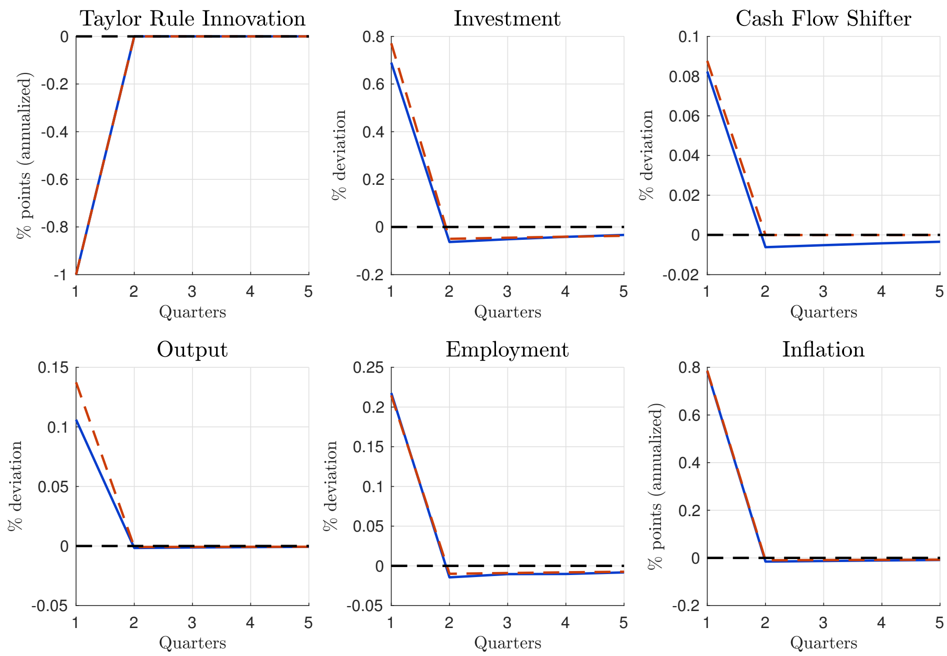
**Comparison to the Micro Data** The fact that unconstrained firms are the most responsive to monetary policy in our model is consistent with three key empirical results from Section 2. First, following the discussion in Section 4, low-leverage firms are more likely to be unconstrained and therefore more responsive to monetary policy shocks. Second, low-leverage firms also have lower risk of default as measured by their credit ratings. Third, nearly all of the aggregate response of monetary policy is driven by the relatively small set of low-leverage, unconstrained firms. Note that, due to the presence of idiosyncratic shocks, there is not a one-to-one mapping from leverage to unconstrained status, generating additional heterogeneity.

Table 15 provides empirical support for the prediction that high leverage firms delever following a monetary policy shock, although the estimates are not statistically significant.

The next step in our analysis is to quantitatively compare the regressions we estimated in Section 2 to data generated from our model. The results in this section indicate that the model is qualitatively consistent with these empirical estimates.[25]

[25]For this exercise we must move past the MIT shock specification in order to generate the variation in interest rates we exploited in our empirical work.

Figure 11: Aggregate Impulse Response in Heterogeneous Firm vs. Representative Firm Model




Notes: Aggregate impulse responses to a $\varepsilon_0^{\mathrm{m}} = -0.0025$ innovation to the Taylor rule, starting from steady state. Computed as the perfect foresight transition path following a one-time expected shock. The blue line is our full model. The red line is the version of our model in which no firms are financially constrained. In this case, the production side aggregates to a representative firm. Aggregate results come from an old calibration of the model that abstracts from capital adjustment costs.

**Comparison to Representative Firm Model** Figure 11 shows that the aggregate response to monetary policy is somewhat dampened compared to the representative firm version of our model without financial frictions.[26] This dampening is due to the fact that only a fraction of firms are unconstrained.

In contrast, in Bernanke, Gertler and Gilchrist (1999)'s model, financial frictions strongly amplify the response to monetary policy. Explicit consideration of financial heterogeneity is crucial in accounting for the difference between our results and Bernanke, Gertler and Gilchrist (1999). In order to generate a well-defined distribution of firms in our model, we assumed that the production technology is decreasing returns to scale. This assumption implies that firms have an optimal scale of capital and allows for the existence of financially unconstrained

[26]Without frictions, the firm side of our model aggregates to a representative firm.

firms. In Bernanke, Gertler and Gilchrist (1999), on the other hand, firms have a constant returns to scale production technology. This assumption implies that productive firms always want to increase their capital stock and hence that all firms are financially constrained. The fact that financial constraints are the only factor limiting the size of the firm is crucial to the financial accelerator mechanism.

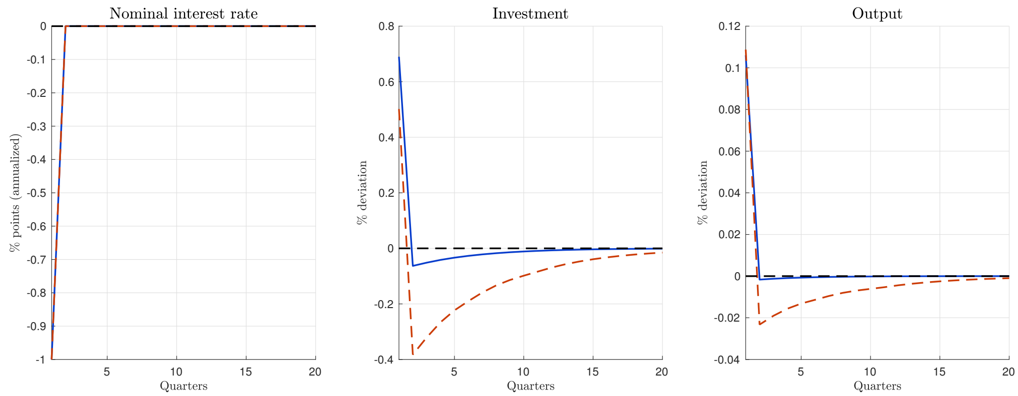
Nevertheless, despite the differences between our heterogeneous firm model and the frictionless model, the aggregate responses are broadly similar across the two models. This result may seem surprising in light of the fact that only 15% of firms are unconstrained in our calibration (and only 30% of the capital stock is held by unconstrained firms). Similar to the results of Khan and Thomas (2008), small general equilibrium price differences across the two models bring the aggregate series close in line with each other. In both the heterogeneous and representative firm models, the degree of decreasing returns is rather modest, so unconstrained firms have a close to linear production technology. Hence, in both models, the representative household faces the same utility maximization problem constrained by a nearly linear technology. The solution of this problem will therefore generate similar consumption paths, and force the real interest rate to adjust in order to signal the production sector to generate these paths.

## 5.4 Time-Varying Monetary Transmission Transmission

Since the aggregate effect of monetary policy is driven by unconstrained firms, the magnitude of the response depends on the amount of unconstrained firms in the economy. The amount of unconstrained firms in turn depends on the distribution of net worth $x$, which varies over time in response to aggregate shocks. Since we only have monetary policy shock in the model, we illustrate this general state dependence with a particular exercise. Specifically, we compare the effect of a $\varepsilon_0^{\mathrm{m}} = -0.0025$ innovation to the Taylor rule starting from two different distributions: the steady state distribution and the distribution following a $\varepsilon_{-1}^{\mathrm{m}} = -0.0075$ expansionary shock.

Figure 12 shows that, upon impact, investment responds significantly less following the previous monetary stimulus than starting from steady state. Quantitatively, the initial impact is 30% lower and the following dynamics feature strong disinvestment. This occurs because,

FIGURE 12: Aggregate Impulse Response Following Previous Stimulus




Notes: Aggregate impulse responses to a $\varepsilon_0^{\mathrm{m}} = -0.0025$ innovation to the Taylor rule. Blue line is starting from steady state and the dashed red line is starting from a previous stimulative shock $\varepsilon_0^{\mathrm{m}} = -0.0075$. Computed as the perfect foresight transition path following unexpected shocks. Aggregate results come from an old calibration of the model that abstracts from capital adjustment costs.

in response to previous stimulus, the optimal capital stock $k_t^*(z)$ increases for all firms, which also increases the unconstrained cutoff $\overline{x}_t(z)$. The inflow of unconstrained firms falls, leaving the economy less willing to respond to additional monetary stimulus. This logic also suggests that monetary policy will be less powerful in recessions, when the distribution of net worth across firms weakens. However, since our MIT shock approach does feature other aggregate shocks driving business cycles, we do not pursue that logic yet.

# 6 Conclusion

In this paper, we have argued that financially unconstrained firms are the most responsive firms in the economy to monetary policy shocks. Our argument had two main components. First, in the micro data, we showed that low-leverage and highly-rated firms invest significantly more following an expansionary monetary policy shock than high-leverage firms; the 50% least leveraged firms in our sample account for nearly all of the aggregate response. Second, we built a heterogeneous firm New Keynesian model consistent with these empirical results. In the model, low-leverage firms are likely to be financially unconstrained and respond to monetary policy through a strong intertemporal substitution channel; high-leverage firms are likely to be financially constrained and instead primarily pay down their debt. The aggregate effect of monetary policy thus depends on the fraction of unconstrained firms in the economy, which varies over time according to the distribution of net worth.

Our results may be of independent interest to policymakers who are concerned about the distributional implications of monetary policy. An often-discussed goal of monetary policy is to provide resources to viable but credit constrained firms; for example, in a 2010 speech then-chairman Ben Bernanke said that "over the past two years, the Federal Reserve and other agencies have made a concerted effort to stabilize our financial system and our economy. These efforts, importantly, have included working to facilitate the flow of credit to viable small businesses (Bernanke (2010))." Many policymakers' conventional wisdom, built on the financial accelerator mechanism, suggests that these constrained firms will significantly increase their capital investment in response to expansionary monetary policy. Our results imply that, instead, expansionary policy will stimulate the least constrained firms in the economy.

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# A Appendix

## A.1 Empirical Work

### A.1.1 Data Construction

We construct firms' capital stocks following the perpetual inventory method. The initial value of the capital stock for each firm is obtained from the variable `PPEGTQ` (property, plant, and equipment, gross value), and its evolution is computed with net investment, obtained from the variable `PPENTQ` (property, plant, and equipment, net value). The reason for this method is that `PPENTQ` is available for a substantial number of firm-quarters.[27] The capital stock is deflated by the implicit price deflator of the nonfarm business sector, constructed by the BLS. We exclude financial firms and utilities and, following Clementi and Palazzo (2015), we also exclude observations with acquisitions larger than 5 percent of assets of observations in the top and bottom 0.5 percent of the distribution.

### A.1.2 Robustness

This appendix contains various results referenced in Section 2 of the main text. See Tables 16 through Table 21.

## A.2 Proof of Proposition 1

To be completed.

[27]Formally, let $t_{i0}$ be the first period for which firm $i$ has an observation of the variable `PPEGTQ`. We set the initial value of capital from firm $i$ as $k_{i,t_{i0}+1} = \texttt{PPEGTQ}_{i,t_{i0}}$, and for all periods $t > t_{i0}$ for which the variable `PPENTQ` is available for firm $i$, compute $k_{i,t+1} = k_{i,t} + \Delta\texttt{PPENTQ}_{i,t}$.

## Table 16
## Leverage: Sources of Variation

A) Dependent variable: `leverage`

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| leverage ($t-1$) | 1.01*** | 1.01*** | 1.01*** | 1.01*** |
| | (0.06) | (0.07) | (0.06) | (0.07) |
| sales growth ($t-1$) | -0.01** | -0.02*** | -0.01* | -0.02*** |
| | (0.00) | (0.00) | (0.00) | (0.00) |
| size ($t-1$) | -0.01* | -0.01** | -0.01* | -0.01** |
| | (0.01) | (0.00) | (0.01) | (0.00) |
| share current assets ($t-1$) | 0.00 | 0.00 | 0.00 | 0.00 |
| | (0.04) | (0.04) | (0.04) | (0.04) |
| investment ($t-1$) | 0.00 | 0.01 | 0.00 | 0.01 |
| | (0.01) | (0.01) | (0.01) | (0.01) |
| sales growth ($t$) | | -0.04** | | -0.04** |
| | | (0.02) | | (0.02) |
| investment ($t$) | | | -0.03* | -0.02* |
| | | | (0.02) | (0.01) |
| Observations | 290854 | 289961 | 290854 | 289961 |
| $R^2$ | 0.504 | 0.512 | 0.504 | 0.512 |
| Firm controls | yes | yes | yes | yes |
| Time sector FE | yes | yes | yes | yes |
| Time clustering | yes | yes | yes | yes |

All specifications include firm and sector-quarter fixed effects. Firm controls are previous period leverage, current and previous period sales growth, period period size, share of current assets, investment, and fiscal quarter.

Table 17

Monetary Shocks: Target vs. Path

A) Dependent variable: $\Delta \log k$

| | (1) | (2) |
|---|---|---|
| leverage $\times$ ffr shock | -0.71** | |
| | (0.29) | |
| leverage $\times$ target shock | | -1.18*** |
| | | (0.44) |
| leverage $\times$ path shock | | 1.86 |
| | | (1.67) |
| Observations | 233182 | 227595 |
| $R^2$ | 0.118 | 0.120 |

B) Dependent variable: $\mathbb{I}\{\frac{i}{k} > \iota\}$

| | (1) | (2) |
|---|---|---|
| leverage $\times$ ffr shock | -4.81*** | |
| | (1.28) | |
| leverage $\times$ target shock | | -7.98*** |
| | | (1.96) |
| leverage $\times$ path shock | | 2.79 |
| | | (5.80) |
| Observations | 233182 | 227595 |
| $R^2$ | 0.217 | 0.218 |

Notes: Results from estimating the model (3) with "target" and "path" components of interest rate shocks. Panel (A) uses $\Delta \log k_{jt}$ as the dependent variable and Panel (B) uses $\mathbb{I}\left\{\frac{i}{k} > \iota\right\}$ with $\iota = 1\%$. All specifications include firm and sector-quarter fixed effects. Firm controls are sales growth, size, share of current assets, and fiscal quarter.

## Table 18
## Post 1994 Estimates

A) Dependent variable: $\Delta \log k$

| | (1) | (2) | (3) |
|---|---|---|---|
| leverage × ffr shock | -0.51 | -0.55 | -0.64 |
| | (0.50) | (0.44) | (0.45) |
| leverage | -0.01*** | -0.01*** | -0.01*** |
| | (0.00) | (0.00) | (0.00) |
| ffr shock | | | -0.05 |
| | | | (1.54) |
| Observations | 185752 | 185752 | 185752 |
| $R^2$ | 0.120 | 0.131 | 0.116 |
| Firm controls | no | yes | yes |
| Time sector FE | yes | yes | no |
| Time clustering | yes | yes | yes |

B) Dependent variable: $\mathbb{I}\{\frac{i}{k} > \iota\}$

| | (1) | (2) | (3) |
|---|---|---|---|
| leverage × ffr shock | -2.60 | -2.52 | -2.60 |
| | (2.07) | (1.92) | (2.07) |
| leverage | -0.02*** | -0.02*** | -0.02*** |
| | (0.00) | (0.00) | (0.00) |
| ffr shock | | | -2.81 |
| | | | (6.34) |
| Observations | 185752 | 185752 | 185752 |
| $R^2$ | 0.228 | 0.233 | 0.219 |
| Firm controls | no | yes | yes |
| Time sector FE | yes | yes | no |
| Time clustering | yes | yes | yes |

Notes: Results from estimating the model (3) after 1994. Panel (A) uses $\Delta \log k_{jt}$ as the dependent variable and Panel (B) uses $\mathbb{I}\left\{\frac{i}{k} > \iota\right\}$ with $\iota = 1\%$. All specifications include firm and sector-quarter fixed effects. Firm controls are sales growth, size, share of current assets, and fiscal quarter.

## Table 19
## Alternative Time Aggregation

A) Dependent variable: $\Delta \log k$

| | (1) | (2) | (3) |
|---|---|---|---|
| leverage × ffr shock (sum) | -0.89*** | -0.79*** | -0.79*** |
| | (0.33) | (0.28) | (0.29) |
| ffr shock (sum) | | | 1.02 |
| | | | (0.82) |
| Observations | 236296 | 236296 | 236296 |
| $R^2$ | 0.106 | 0.118 | 0.103 |
| Firm controls | no | yes | yes |
| Time sector FE | yes | yes | no |
| Time clustering | yes | yes | yes |

B) Dependent variable: $\mathbb{I}\{\frac{i}{k} > 1\%\}$

| | (1) | (2) | (3) |
|---|---|---|---|
| leverage × ffr shock (sum) | -3.75*** | -3.56*** | -3.43*** |
| | (1.19) | (1.10) | (1.14) |
| leverage | -0.03*** | -0.02*** | -0.03*** |
| | (0.00) | (0.00) | (0.00) |
| ffr shock (sum) | | | 2.09 |
| | | | (3.55) |
| Observations | 236296 | 236296 | 236296 |
| $R^2$ | 0.211 | 0.216 | 0.203 |
| Firm controls | no | yes | yes |
| Time sector FE | yes | yes | no |
| Time clustering | yes | yes | yes |

Notes: Results from estimating variants of the baseline specification $\Delta \log k_{jt} = \alpha_j + \alpha_{st} + \beta x_{jt-1}\varepsilon_t^{\mathrm{m}} + \mathbf{\Gamma}' Z_{jt-1} + \varepsilon_{jt}$, where $\alpha_j$ is a firm fixed effect, $\alpha_{st}$ is a sector-by-quarter fixed effect, $x_{jt-1}$ is leverage, $\varepsilon_t^{\mathrm{m}}$ 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. Panel (A) uses the intensive margin measure of investment $\Delta \log k_{jt}$ as the outcome variable and Panel (B) uses the extensive margin measure $\mathbb{1}\left\{\frac{i_{jt}}{k_{jt}} > 1\%\right\}$ as the outcome variable. Standard errors are two-way clustered by firms and time. We have normalized the sign of the monetary shocks $\varepsilon_t^{\mathrm{m}}$ so that a positive shock is expansionary (corresponding to a decrease in interest rates).

Table 20
Net Leverage

A) Dependent variable: $\Delta \log k$

| | (1) | (2) | (3) |
|---|---|---|---|
| net leverage $\times$ ffr shock | -1.01** | -0.81** | -0.74* |
| | (0.43) | (0.36) | (0.37) |
| net leverage | -0.01*** | -0.01*** | -0.01*** |
| | (0.00) | (0.00) | (0.00) |
| ffr shock | | | 1.25 |
| | | | (0.94) |
| Observations | 233182 | 233182 | 233182 |
| $R^2$ | 0.110 | 0.119 | 0.106 |
| Firm controls | no | yes | yes |
| Time sector FE | yes | yes | no |
| Time clustering | yes | yes | yes |

B) Dependent variable: $\mathbb{I}\{\frac{i}{k} > \iota\}$

| | (1) | (2) | (3) |
|---|---|---|---|
| net leverage $\times$ ffr shock | -5.34*** | -4.87*** | -4.14** |
| | (1.76) | (1.54) | (1.63) |
| net leverage | -0.04*** | -0.02*** | -0.03*** |
| | (0.00) | (0.00) | (0.00) |
| ffr shock | | | 3.56 |
| | | | (4.26) |
| Observations | 233182 | 233182 | 233182 |
| $R^2$ | 0.213 | 0.217 | 0.204 |
| Firm controls | no | yes | yes |
| Time sector FE | yes | yes | no |
| Time clustering | yes | yes | yes |

Notes: Results from estimating the model (3) with leverage net of current assets. Panel (A) uses $\Delta \log k_{jt}$ as the dependent variable and Panel (B) uses $\mathbb{I}\left\{\frac{i}{k} > \iota\right\}$ with $\iota = 1\%$. All specifications include firm and sector-quarter fixed effects. Firm controls are sales growth, size, share of current assets, and fiscal quarter.

TABLE 21
ALTERNATIVE BALANCE-SHEET ITEMS

A) Dependent variable: $\Delta \log k$

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| ST debt × ffr shock | -0.53$^{**}$ | | -0.57$^{**}$ | | |
| | (0.23) | | (0.24) | | |
| LT debt × ffr shock | | -0.38 | -0.42 | | |
| | | (0.28) | (0.29) | | |
| leverage × ffr shock | | | | -0.69$^{**}$ | |
| | | | | (0.29) | |
| other liab × ffr shock | | | | -1.21 | |
| | | | | (1.18) | |
| liabilities × ffr shock | | | | | -3.49 |
| | | | | | (2.99) |
| Observations | 233182 | 233182 | 233182 | 233161 | 233161 |
| $R^2$ | 0.118 | 0.117 | 0.118 | 0.118 | 0.116 |
| Firm controls | yes | yes | yes | yes | yes |

B) Dependent variable: $\mathbb{I}\{\frac{i}{k} > \iota\}$

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| ST debt × ffr shock | -5.01$^{***}$ | | -5.13$^{***}$ | | |
| | (1.32) | | (1.35) | | |
| LT debt × ffr shock | | -1.44 | -1.66 | | |
| | | (1.23) | (1.23) | | |
| leverage × ffr shock | | | | -4.76$^{***}$ | |
| | | | | (1.30) | |
| other liab × ffr shock | | | | -3.05 | |
| | | | | (3.50) | |
| liabilities × ffr shock | | | | | -11.83 |
| | | | | | (10.55) |
| Observations | 233182 | 233182 | 233182 | 233161 | 233161 |
| $R^2$ | 0.217 | 0.216 | 0.217 | 0.217 | 0.216 |
| Firm controls | yes | yes | yes | yes | yes |

Notes: Results from estimating the model (3) with different balance-sheet items. Panel (A) uses $\Delta \log k_{jt}$ as the dependent variable and Panel (B) uses $\mathbb{I}\left\{\frac{i}{k} > \iota\right\}$ with $\iota = 1\%$. All specifications include firm and sector-quarter fixed effects. Firm controls are sales growth, size, share of current assets, and fiscal quarter.