Financial Heterogeneity and the Investment Channel of Monetary Policy

Preliminary and Incomplete[*]

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Abstract

We study the role of heterogeneity in firms' financial positions in determining the investment channel of monetary policy. We first show empirically that firms with low debt invest significantly more following a monetary policy shock than firms with high debt; quantitatively, the 50% least indebted firms account for nearly all of the total response to monetary policy in our sample. We then develop a heterogeneous firm New Keynesian model with financial frictions that is consistent with this fact and use the model to draw two lessons for policy design. First, monetary policy stimulates investment mainly by increasing investment done by financially unconstrained firms; financially constrained firms use the stimulus as an opportunity to pay down their debt. Second, the aggregate effect of monetary policy depends on the distribution of net worth across firms, which varies endogenously over time.

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1 Introduction

Aggregate investment is one of the most responsive components of GDP to monetary policy shocks.[1] At the micro level, firms' investment decisions are shaped by their available financing, which is unequally distributed across firms.[2] Our goal in this paper is to understand the role of this financial heterogeneity in determining the investment channel of monetary policy.

We make two main contributions in this paper. First, we study the interaction between firms' financial position and their investment response to monetary policy shocks in the micro data. Our main finding is that firms with low debt invest significantly more following a monetary shock than firms with high debt; quantitatively, the 50% least indebted firms in our sample account for nearly all of the aggregate response to monetary policy. Second, we develop a heterogeneous firm New Keynesian model with financial frictions that explains this fact, and use the model to study the aggregate transmission mechanism. In our model, monetary policy stimulates investment mainly by increasing the investment of financially unconstrained firms; financially constrained firms use the additional cash to pay down their debt. The aggregate effect of a given change in monetary policy depends on the distribution of net worth across firms; when this distribution is weak, such as in recessions or after previous monetary stimulus, monetary policy is less powerful.

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. In these data, the semi-elasticity of firms' investment with respect to monetary shocks declines sharply with their debt-to-asset ratio. This estimate is conditional on a number of controls and compares firms within sector and quarter.

In our model, low-debt firms are more responsive to monetary shocks because they have cheaper funds available to finance investment; before building this model, we first rule out other obvious explanations in the data. One concern is that firms with higher

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[1] See, for example, the VAR evidence presented in Christiano, Eichenbaum and Evans (2005).

[2] See, for example, Rauh (2006), Hennessy and Whited (2007), or Almeida et al. (2012).

leverage are also different along other dimensions which affect the response to monetary shocks. However, our most stringent specification includes sector-by-quarter fixed effects, which control for sectoral differences in the exposure to monetary shocks. In addition, there are not significant differences according to other observable firm characteristics like size or growth rates. Another concern is that our monetary shocks are in fact responding to other changes in the economy which drive investment decisions. 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. Taken together, we view our results as providing strong descriptive evidence that the firm-level response to monetary policy depends crucially on the firm's financial position.

The model has two key features in order to explain our empirical findings. First, prices are sticky as in Calvo (1983), so changes in the nominal interest rate affects real investment. Second, there are heterogeneous firms which borrow to finance their investment. However, firms cannot commit to repaying their debt, leading to an external finance premium based on default risk.[3] This financial friction generates heterogeneity in the responsiveness of firms' investment to monetary shocks according to leverage. We calibrate the model to match features of firms' investment and financing behavior.

To understand the heterogeneity we find in the micro data, we decompose the key channels through which monetary policy affects firms' investment decisions. A portion of firms in our model are financially unconstrained in the sense that they have accumulated enough internal resources to borrow permanently at the risk-free rate. Quantitatively, monetary policy primarily affects these firms through the *intertemporal* channel: changing the real interest rate affects the return, and therefore incentive, to invest. On the other hand, the majority of firms in our model are financially constrained and finance their investment either through internal cash or new borrowing. Quantitatively, monetary policy primarily affects these firms by changing their internal

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[3] Our model of firm behavior closely follows the formulation in Khan, Senga and Thomas (2016), who study a flexible-price economy.

cash flow. However, financially constrained firms use most of this increased cash flow to pay down their debt rather than finance new investment.

Quantitatively, most of the aggregate effect of monetary policy is driven by unconstrained firms responding to interest rate changes through the intertemporal channel. Starting from steady state, the impulse response of aggregate investment in our heterogeneous firm model closely resembles that of the representative firm version of the model without financial constraints, despite the fact that only 15% of firms are financially unconstrained in our model. Due to the strength of the intertemporal channel, small differences in the real interest rate paths in the two models move their aggregate investment series in line with the desires of the representative household, which is the same in both models.

Outside of steady state, the response of aggregate investment to a given monetary shock depends on the distribution of net worth, which varies over time. We illustrate this state dependence by showing that monetary policy is less powerful if it recently attempted to stimulate the economy; in response to previous stimulus, firms' optimal scale increased, making it harder to become unconstrained. Hence, policymakers in our model have a natural incentive to keep their powder dry until it is really needed.

Related Literature Our paper contributes to three key strands of literature. First, 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, McKay, Nakamura and Steinsson (2015); Auclert (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.[4]

Second, we contribute to the literature that studies how the effect of monetary

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[4] 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.

policy varies across firms. A number of papers, including Bernanke and Gertler (1995); Kashyap, Lamont and Stein (1994); and Kashyap and Stein (1995) argue that smaller or presumably more credit constrained firms are more responsive to monetary policy changes. We instead focus directly on leverage as the key driver of heterogeneity across firms without taking a stand on the specific mapping from observables to financial constraints. In addition, we use a different empirical specification, identification of monetary policy shocks, sample of firms, and sample of time.

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.

2 Descriptive Evidence on Heterogeneous Investment Responses to Monetary Policy

2.1 Data Description

Our empirical analysis combines monetary policy shocks with firm-level outcomes from Compustat.

Monetary Policy Shocks The key challenge to measuring the firm-level response to monetary policy is that most of the variation in the Fed Funds Rate is driven by the Fed's endogenous response to economic conditions. Simply regressing firm-level investment on changes in the Fed Funds Rate would mainly capture the effect of the economic conditions to which the Fed is responding. Therefore, we focus our analysis on how firms respond to monetary policy shocks $\varepsilon_t^{\mathrm{m}}$ that are not driven by economic conditions.

We identify monetary policy shocks $\varepsilon_t^{\mathrm{m}}$ using the high-frequency event-study approach pioneered by Cook and Hahn (1989) and subsequently used by Gurkaynak, Sack and Swanson (2005), Gorodnichenko and Weber (2016), and Nakamura and Steinsson (2013) among others. The strategy exploits the fact that Fed policy announcements occur at discrete intervals. We use Fed Funds Futures markets to construct a market-based measure of the expected FFR in a tight window around the policy announcement. Assuming no fundamentals of the economy change in this tight window, the change in the expected FFR in this tight window identifies the change in the Fed Funds Rate orthogonal to economic conditions. The key advantage of this strategy compared to a VAR-based approach as in Christiano, Eichenbaum and Evans (2005) or a narrative approach as in Romer and Romer (2004) is that it imposes less structure on the economic environment to identify shocks.[5]

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 FFR from a current-month Federal Funds Future contract at time t, Δ_+ and Δ_- 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.[6] We focus on a window of $\Delta_- =$ fifteen minutes before the announcement and $\Delta_+ =$ forty five minutes after the announcement. Our shock series is available January 1990 to December 2007, during which time there were 183 shocks with a mean of approximately zero and a standard deviation of 9 basis points (bps).

We time aggregate the high-frequency shocks to the quarterly frequency in order to merge with our firm-level outcome variables. We construct a moving average of the

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[5] For example, we find that aggregate investment responds to monetary policy shocks in the quarter they are announced, which violates the typical timing assumption in the VAR literature.

[6] This adjustment accounts for the fact that Fed Funds Futures pay out based on the average effective rate over the month, 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.

Table I
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.

raw shocks weighted by the number of days in the quarter after the shock occurs.[7] Our time aggregation strategy ensures that we weight shocks by the amount of time firms have had to react to the shocks. Table I indicates that these smoothed shocks have similar features as the original high-frequency shocks. For robustness we will also use the alternative time aggregation of simply summing all the shocks that occur within the quarter, as in Wong (2016). Table I shows that the moments of these alternative shocks do not differ significantly from the moments of the smoothed shocks.

Firm-Level Outcomes We draw firm-level outcome variables from quarterly Compustat data, a panel of U.S. publicly listed firms. The key advantage of this dataset is that it contains rich balance sheet information concerning the main variables of interest – investment and leverage – at a quarterly frequency. Furthermore, since these are the largest firms in the economy, Compustat covers nearly half of the total investment in the U.S. The main disadvantage of our data is that it excludes small firms who may be subject to more severe financial frictions. These small firms may be found in the

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[7] 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.

Census Longitudinal Research database, but only at an annual frequency. In Section 5.1, we will calibrate our model to match an economy-wide sample of firms, not just those in Compustat.

We study two measures of investment in our empirical analysis. First, we consider $\Delta \log k_{jt}$, where k_{jt} denotes the capital stock of firm j at the end of period t. We use the log-difference specification because investment in Compustat 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 of investment 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, this measure of investment is less subject to small measurement error in the capital stock.

Our main measure of leverage is the firms' debt-to-asset ratio. We measure debt as the sum of current short term debt and long term debt and measure assets as the book value of the firm's current assets. Since much of our analysis exploits variation in leverage across firms, Table X in Appendix A.1 provides descriptive evidence of the source in variation in leverage across firms. The table shows that leverage is highly persistent and most highly correlated with past sales growth. We do not claim that this variation in leverage is exogenous to the firm; we simply provide descriptive evidence of how the response of firms' investment varies with the firm's leverage.

Appendix A.1 provides details of our data construction, which follows standard practice in the investment literature. Table II presents simple summary statistics of the final sample used in our analysis. The mean capital growth rate is roughly 0.9% quarterly with a standard deviation of 6.5%. The mean leverage ratio is approximately 23% with a cross-sectional standard deviation of 32%, indicating substantial variation across firms.

Table II

Firm-Level Variables: Summary Statistics

	$\Delta\log(k)$	$\mathbb{I}\{\frac{i_{jt}}{k_{jt}} > 1\%\}$	$\texttt{leverage}_{jt}$
mean	0.00868	0.270	0.228
median	-0.00132	0.264	0.183
std	0.0649	0.497	0.320
bottom 5%	-0.0690	-0.0548	0
top 5%	0.120	0.702	0.620

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 current assets.

2.2 Main Results

Empirical Specification The goal of our empirical analysis is to measure how the response of firm-level investment to monetary policy shocks varies with the firm's leverage ratio. Our baseline specification is

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

where α_j is firm fixed effect, α_{st} is a sector-quarter specific fixed effect by one-digit sector, $\varepsilon_t^{\mathrm{m}}$ is the monetary policy shock, x_{jt} is the firm's $\texttt{leverage}_{jt}$ ratio, Z_{jt} is a vector of firm-level controls, and ε_{jt} is a residual. Both the controls Z_{jt-1} and the firm's $\texttt{leverage}_{jt-1}$ ratio x_{jt-1} are lagged to ensure that they are predetermined at the time of the monetary shock $\varepsilon_t^{\mathrm{m}}$. The coefficient of interest is β, which measures how the semi-elasticity of net investment with respect to monetary shocks, $\frac{\partial\Delta\log k_{jt}}{\partial\varepsilon_t^{\mathrm{m}}}$, depends on the firm's leverage ratio x_{jt-1}. We standardize x_{jt-1} across the whole sample, so the units of the interaction are in terms of cross-sectional standard deviation of leverage. We also normalize the sign of $\varepsilon_t^{\mathrm{m}}$ so that a positive value corresponds to an expansionary monetary policy shock.

We control for a number of factors which simultaneously effect leverage and investment. In particular, we include firm fixed effects α_j to control for permanent differences across firms.[8] We also include for sector-quarter fixed effects α_{st} to control for differential exposure of various sectors to monetary policy shocks. Finally, the firm-level controls Z_{jt} include the $\texttt{leverage}_{jt}$ ratio, total assets, sales, size, and a fiscal quarter dummy.

We use two-way clustering to account for correlation within firms and within quarters when computing standard errors. This clustering strategy is conservative, leaving less than 80 time-series observations.

Regression Analysis Table III reports the main result from estimating specification (3): firms with high leverage are significantly less responsive to monetary policy shocks. Panel (A) reports different versions of the baseline specification. Column (1) reports the interaction coefficient without any firm-quarter level controls Z_{jt}; quantitatively, the estimated coefficient implies that increasing leverage by one cross-sectional standard deviation decreases the semi-elasticity of investment with respect to monetary shocks by nearly one. Adding firm-quarter controls Z_{jt} in column (2) does not significantly change the point estimate, indicating that our interaction is not simply driven by other factors simultaneously affecting leverage and investment.[9]

Since our baseline specification (3) includes sector-by-quarter fixed effects α_{st}, we cannot estimate the average effect of monetary policy shocks $\varepsilon_t^{\mathrm{m}}$ across all firms. Columns (3) and (4) relax this restriction by estimating

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

where Y_t controls for GDP growth, the inflation rate, the unemployment rate, and the VIX index. Column (3) shows that the average investment semi-elasticity is roughly 1.4; therefore, firms with leverage two cross-sectional standard deviations above the mean do not respond to monetary policy at all. However, the point estimate of the average semi-elasticity is not statistically significant because the monetary policy shocks $\varepsilon_t^{\mathrm{m}}$

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

[9] In Section 2.4 we also show that the interaction coefficient between the monetary policy shock and these controls is not significantly different from zero.

TABLE III
HETEROGENEITY IN THE RESPONSE TO MONETARY POLICY SHOCKS

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

	(1)	(2)	(3)	(4)
leverage × ffr shock	-0.93***	-0.73**	-0.74**	-0.74***
	(0.34)	(0.29)	(0.31)	(0.20)
ffr shock			1.38	1.38***
			(0.99)	(0.20)
Observations	233182	233182	233182	233182
R^2	0.107	0.119	0.104	0.104
Firm controls	no	yes	yes	yes
Time sector FE	yes	yes	no	no
Time clustering	yes	yes	yes	no

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

	(1)	(2)	(3)	(4)
leverage × ffr shock	-5.22***	-4.80***	-4.59***	-4.59***
	(1.42)	(1.29)	(1.35)	(0.87)
ffr shock			4.01	4.01***
			(4.39)	(0.87)
Observations	233182	233182	233182	233182
R^2	0.212	0.217	0.204	0.204
Firm controls	no	yes	yes	yes
Time sector FE	yes	yes	no	no
Time clustering	yes	yes	yes	no

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 α_j is a firm fixed effect, α_{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).

are small relative to the total variation in the incentive to invest. Consistent with this interpretation, column (4) shows that the standard error falls enormously when we do not cluster our standard errors within quarter.

Panel (B) shows that these results also hold for the extensive margin measure of investment $\mathbb{1}\left\{\frac{i_{jt}}{k_{jt}} > 1\%\right\}$. Quantitatively, firms with one cross-sectional standard deviation higher leverage are nearly 5% less likely to invest following a monetary policy shocks. The interaction coefficient is in fact larger than the average response.

Aggregate Implications To quantify the impact of this heterogeneity for aggregate investment, 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. This specification (5) allows us to assess whether the heterogeneity we find across firms survives aggregation.

Figure 1 plots the responsiveness of these aggregated investment groups to monetary shocks. As in our firm-level regression analysis (3), investment done by firms with lower leverage is more responsive to monetary policy shocks. Although we do not constrain this specification to be linear, the estimated semi-elasticities decline fairly steadily with leverage. The semi-elasticity is essentially zero past the 60^{th} percentile of the leverage distribution, indicating that the entire aggregate effect of monetary policy is driven by relatively low-leverage firms in our sample.

Dynamics Since estimated aggregate investment equations typically indicate strong inertia, it is natural to ask how the differences across firms we document evolve over time. We investigate this question by estimating the Jorda (2005)-style projection

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

where h indexes the quarter being forecasted. The coefficient β_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]

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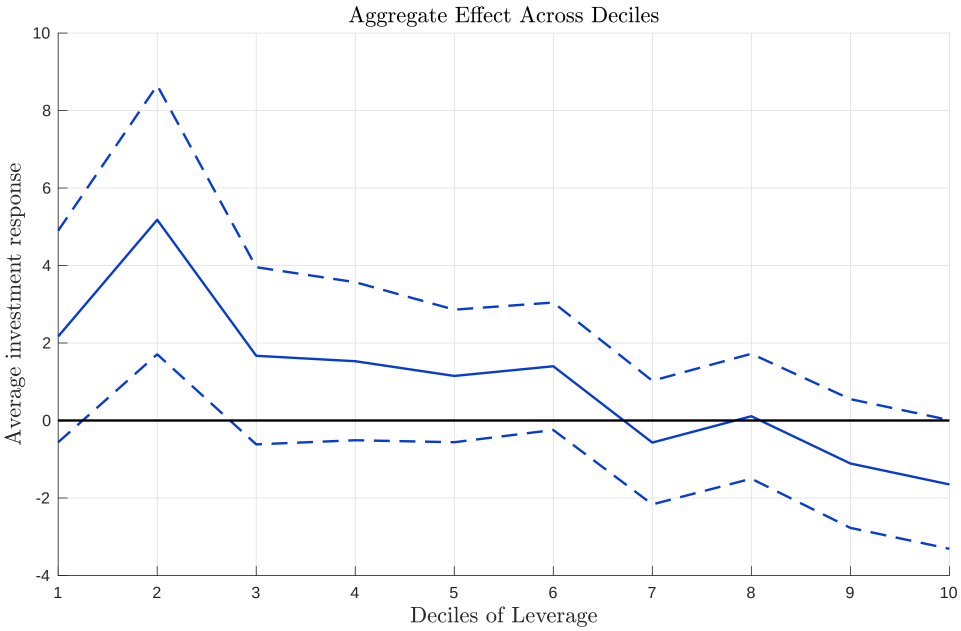
[10] This specification abstracts from how the dynamics of leverage itself drive differences over time. We are currently addressing this by estimating a joint dynamic system between investment and leverage.

Figure 1: Aggregated Effect of Monetary Policy Shocks



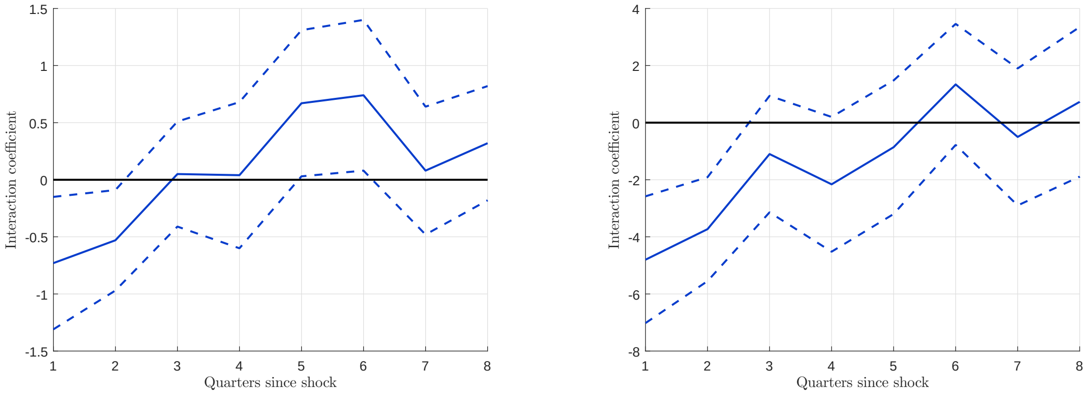
Notes: semi-elasticity of aggregated investment across firms within deciles of leverage distribution. Reports estimated semi-elasticities β_j from specification

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

where $\Delta \log K_{jt}$ is the aggregated investment of firms with leverage in the jth 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% 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).

Figure 2 shows that the estimated differences across firms are relatively short lived. Panel (a) plots the dynamics of the coefficient β_h estimated in (6); the interaction coefficient returns to zero three quarters after the initial shock, although the dynamics are slightly hump-shaped after that. Panel (b) estimates (6) using our extensive margin measure of investment $\mathbb{1}\left\{\frac{i_{jt}}{k_{jt}} > 1\%\right\}$. The differences across firms by this measure are longer-lived than for the intensive margin, but nonetheless revert to zero six quarters after the shock.

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 β_h over quarters h from

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

where α_{jh} is a firm fixed effect, α_{sth} 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. 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).

2.3 Supporting Evidence From Stock Returns

Section 2.2 shows that low-leverage firms invest significantly more following a monetary policy shock than high-leverage firms. In this subsection, we show that low-leverage firms are also more responsive in terms of their stock returns. Stock returns are 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 returns are available at high frequency, so they are not subject to any bias from time aggregation as with capital investment.

We estimate the equation

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

where $\Delta R_{jt} = \frac{p_{jt+1} - p_{jt}}{p_{jt}}$ 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 $\varepsilon_t^{\mathrm{m}}$ is the original high-frequency version. We merge this high frequency data with quarterly balance sheet information from Compustat to construct leverage x_{jt-1} and the firm-level controls Z_{jt-1}; see Appendix A.1 for details.

TABLE IV
STOCK RETURNS

A) Dependent variable: ΔR

	(1)	(2)	(3)	(4)
leverage × ffr shock	-0.87***	-0.82**	-0.61	-0.61***
	(0.29)	(0.35)	(0.41)	(0.16)
ffr shock			2.49**	2.49***
			(1.13)	(0.18)
Observations	39232	36915	36915	36915
R^2	0.114	0.112	0.029	0.029
Firm controls	no	yes	yes	yes
Time sector FE	yes	yes	no	no
Time clustering	yes	yes	yes	no

Notes: Panel (A) shows results from estimating the regression $\Delta R_{jt} = \alpha_j + \alpha_{st} + \beta x_{jt-1}\varepsilon_t^{\mathrm{m}} + \mathbf{\Gamma}' Z_{jt-1} + \varepsilon_{jt}$ where $\Delta R_{jt} = \frac{p_{jt+1} - p_{jt}}{p_{jt}}$ is the percentage change in the firm's stock price, α_j is a firm fixed effect, α_{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. 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 IV 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. Comparing columns (1) and (2), this result is robust to adding firm-level controls Z_{jt}. The average response of stock returns to the monetary policy shock is about 2.5 percentage points.

2.4 Robustness

In our model, we interpret the results of this section as evidence of financial frictions; low-leverage firms have access to cheaper investment financing and are able to respond more strongly to monetary policy shocks. In this subsection, we rule out other possible explanations in the data.

Monetary Shocks A potential concern about our results so far is that monetary policy shocks may be correlated with other business cycle conditions that themselves drive differences across firms. Our high-frequency shock identification is designed to address this. However, 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. If the differential response of firms to monetary policy shocks were driven by the shocks' correlation with these variables, the estimated coefficients β in this regression would be nonzero. Table V shows this is not the case; none of the variables in Y_t are significant or economically meaningful.

Appendix A.1 reports a number of additional robustness checks on our measure of monetary policy shocks. First, we estimate our baseline specification (3) using only post-1994 data, after which the Fed began making explicit policy announcements, and find simlar results. Second, following Gurkaynak, Sack and Swanson (2005) we decompose monetary policy announcements into a "target" component that affects current rates and a "path" component affecting future rates. We find that all of the differences across firms are driven by the target component. Third, we use an alternative procedure to aggregate the high-frequency shocks to the quarterly level, and find similar results.

Leverage Another potential concern about our results is that differences in leverage across firms are driven by other factors that themselves drive the differential response to monetary policy shocks. We have attempted to control for these other factors in our baseline specification and showed that our coefficient estimates do not materially change when the controls are included. We now further address this concern in two additional ways. First, we interact the monetary policy shocks with firm-level sales

TABLE V
MONETRY SHOCKS VS. BUSINESS CYCLE CONDITIONS

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

	(1)	(2)	(3)	(4)	(5)
leverage × ffr shock	-0.81***	-0.72**	-0.73**	-0.87***	-0.95***
	(0.29)	(0.28)	(0.29)	(0.29)	(0.30)
leverage × dlog gdp	-0.05				-0.06
	(0.08)				(0.07)
leverage × dlog cpi		-0.07			-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	0.119	0.119	0.119
Firm controls	yes	yes	yes	yes	yes

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

	(1)	(2)	(3)	(4)	(5)
leverage × ffr shock	-4.86***	-4.73***	-4.77***	-5.26***	-5.17***
	(1.19)	(1.08)	(1.11)	(1.10)	(1.15)
leverage × dlog gdp	-0.04				-0.11
	(0.29)				(0.28)
leverage × dlog cpi		-0.54			-0.56
		(0.41)			(0.43)
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	0.217	0.217	0.217	0.217	0.217
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 α_j is a firm fixed effect, α_{st} is a sector-by-quarter fixed effect, x_{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. 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).

growth rather than leverage in

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

where Δy_{jt-1} is the firm's past sales growth. To the extent that the factors driving leverage also drive sales growth, the estimated coefficients β would be non-zero. Table VI shows that this is not the case.

TABLE VI
INTERACTION WITH SALES GROWTH

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

	(1)	(2)	(3)	(4)
sales growth × ffr shock	1.10***	-0.05	0.12	0.12
	(0.32)	(0.27)	(0.29)	(0.17)
ffr shock			1.36	1.36***
			(0.98)	(0.20)
Observations	233182	233182	233182	233182
R^2	0.107	0.118	0.104	0.104
Firm controls	no	yes	yes	yes
Time sector FE	yes	yes	no	no
Time clustering	yes	yes	yes	no

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

	(1)	(2)	(3)	(4)
sales growth × ffr shock	4.10***	0.70	1.58	1.58**
	(1.54)	(1.24)	(1.30)	(0.75)
ffr shock			3.97	3.97***
			(4.35)	(0.87)
Observations	233182	233182	233182	233182
R^2	0.212	0.217	0.204	0.204
Firm controls	no	yes	yes	yes
Time sector FE	yes	yes	no	no
Time clustering	yes	yes	yes	no

Notes: Results from estimating variants of the baseline specification $\Delta \log k_{jt} = \alpha_j + \alpha_{st} + \beta \Delta y_{jt-1} \varepsilon_t^{\mathrm{m}} + \mathbf{\Gamma}' Z_{jt-1} + \varepsilon_{jt}$, where α_j is a firm fixed effect, α_{st} is a sector-by-quarter fixed effect, Δy_{jt-1} is the firm's past sales growth, $\varepsilon_t^{\mathrm{m}}$ 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).

Appendix A.1 presents three further robustness checks on our measure of leverage. First, we intrument leverage x_{jt-1} in (3) with past leverage x_{jt-4}. This allows us to assess the extent of endogeneity bias if past leverage is uncorrelated with confounding factors affecting the current investment decision. Results show that we find similar results in this instrumental variables specification. Second, we estimate our baseline specification (3) with leverage net of current assets, and find similar results. Third, we decompose leverage into short term and long term debt and find similar magnitudes for both components.[11]

3 Model

Section 2 shows that the response of firm-level investment to a monetary shock depends strongly on the firm's financial position. To explain these results, we now develop a heterogeneous firm New Keynesian model in which firms face financial frictions to their investment. Our model builds heavily on Khan, Senga and Thomas (2016), who study financial frictions in a flexible price model.

3.1 Environment

Time is discrete and infinite. We describe the agents in our model in three blocks: heterogeneous production firms, who invest in capital subject to financial frictions; the New Keynesian block, which generates a Phillips curve; and a representative household, who owns all firms and supplies labor.

3.1.1 Heterogeneous Producers

Production Firms Each period, there is a mass N_t of heterogeneous production firms. Each firm $j \in [0, N_t]$ produces a homogeneous output good y_{jt} using the pro-

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[11] 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.

duction function

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

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 AR(1) process in logs

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

Production firms enter each period with three individual state variables: z_{jt}, its idiosyncratic productivity, k_{jt}, its capital stock, and B_{jt}, the face value of debt inherited from past borrowing. The firm then makes a series of decisions to maximize its market value.

First, the firm decides whether to default. If the firm defaults, it permanently exits the economy and loses all value. If the firm does not default, it must pay back its debt B_{jt} and pay a fixed operating cost ξ in units of the final good, described below.

Second, the firm produces using the production function (8). To produce, the firm hires labor n_{jt} from a competitive labor market at wage W_t. The firm sells its output competitively at price P_t.

Third, with probability π_d the firm is forced to exit the economy. In this case, the firm takes on no new debt and sells its undepreciated capital $(1-\delta)k_{jt}$ at price Q_t. The realization of this exogeneous exit shock is i.i.d. across firms and time.

Fourth, firms that are not forced to exit make investment k_{jt+1} which has price Q_t. There are two sources of investment finance, both of which are subject to financial frictions. First, the firm can borrow new debt with face value B_{jt+1} in return for $\frac{1}{R_{jt}} B_{jt+1}$ resources, where R_{jt} is the firm-specific borrowing rate. R_{jt} contains an external finance premium due to the fact that the firm may default in the next period. Second, the firm can reduce its dividend payment to shareholders D_{jt}, which we loosely refer to as equity finance. Firms cannot raise new equity, implying that $D_{jt} \geq 0$.

Financial Intermediary There is a financial intermediary that lends resources from the household to production firms at firm-specific interest rate R_{jt}. In the event of default, intermediaries recover a fraction α of the firm's capital stock k_{jt+1}, which has value Q_{t+1}. Therefore, the recovered value of a defaulted loan is $\alpha Q_{t+1} k_{jt+1}$. Financial intermediaries price this default risk competitively.

New Entrants Each period a fixed mass $\overline{\mu}$ of new entrants enter the economy. Each entrant $j \in [0, \overline{\mu}]$ draws an idiosyncratic productivity shock z_{jt} from the invariant distribution of (9) and is endowed with initial capital k_0 and debt b_0. Entrants then proceed as incumbent firms given this initial condition.

3.1.2 New Keynesian Block

Retailers There is a fixed unit mass of retailers $j \in [0, 1]$. Each retailer producers a differentiated good q_{jt} according to the production function

$$q_{jt} = y_{jt},$$

where y_{jt} is the amount of the homogeneous production good demanded by retailer j. Retailers are monopolistic competitors who set prices P_{jt} subject to the demand curve generated by the final good producer, described below. However, each period retailers can change their price only with probability $1 - \varphi$ each period, which is i.i.d. across retailers and time.

Final Good Producers There is a final good producer who produces aggregate output Y_t using the production function

$$Y_t = \left(\int q_{jt}^{\frac{\gamma-1}{\gamma}} \, \mathrm{d}j \right)^{\frac{\gamma}{\gamma-1}},$$

where γ 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.[12] The capital good has price Q_t.

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

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

Π_t is gross inflation of the final good, ϕ_{pi} is the weight on inflation in the reaction function, and ε_t^m is the monetary policy shock. ε_t^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

$$\mathbb{E}_0 \sum_t^\infty \beta^t \left(\frac{C_t^{1-\sigma}-1}{1-\sigma} - \Psi\frac{N_t^{1-1/\eta}}{1-1/\eta}\right),$$

where $1/\sigma$ is the elasticity of intertemporal substitution and η is the Frisch elasticity of labor supply. The household owns all firms in the economy and markets are complete.

3.2 Equilibrium

We now characterize the model's equilibrium. We begin with the New Keynesian block, which aggregates to a standard New Keynesian Phillips curve. We then move onto the

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

producer's investment and financing decision.

3.2.1 New Keynesian Block

As usual, the final good producer's profit maximization problem gives the demand curve $\left(\frac{p_{it}}{\hat{P}_t}\right)^{-\gamma} Y_t$ where $\hat{P}_t = \left(\int p_{it}^{1-\gamma} \mathrm{d}j\right)^{\frac{1}{1-\gamma}}$ is the price index. We take the final good as the numeraire.

Retailers follow the typical Calvo solution with real marginal cost given by $p_t = \frac{P_t}{\hat{P}_t}$, the real price of production firms' output. After aggregation, this yields the typical expressions for the evolution of prices:

$$\begin{aligned}
1 &= (1-\varphi)(\Pi_t^*)^{1-\gamma} + \varphi \Pi_t^{\gamma-1} \qquad (11)\\
\Pi_t^* &= \left(\frac{\gamma}{\gamma-1}\right)\frac{x_{1t}}{x_{2t}}\\
x_{1t} &= \lambda_t p_t Y_t + \beta\varphi \mathbb{E}_t \Pi_{t+1}^{\gamma} x_{1t+1}\\
x_{2t} &= \lambda_t Y_t + \beta\varphi \mathbb{E}_t \Pi_{t+1}^{\gamma-1} x_{2t+1}\\
\Delta_t &= (1-\varphi)(\Pi_t^*)^{-\gamma} + \varphi \Pi_t^{\gamma}\Delta_{t-1},
\end{aligned}$$

where Π_t^* is reset price inflation and Δ_t is price dispersion. Aggregate output is given by the total output of production firms, adjusted for price dispersion:

$$Y_t = \frac{1}{\Delta_t}\int_0^{N_t} z_{jt} k_{jt}^{\theta} n_{jt}^{\nu} \mathrm{d}j. \qquad (12)$$

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

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

3.2.2 Production Firms

Incumbents We characterize production firms' decisions recursively. Let $V_t^0(z,k,B)$ be the value function of an incumbent firm with individual state (z,k,B) and an aggregate state $\mathbf{s}_t$, which we embed in the time subscript t. The firm first decides whether or not to default:

$$V_t^0(z,k,B) = \max\{0, \pi_d V_t^{\text{exit}}(z,k,B) + (1-\pi_d)V_t^{\text{cont}}(z,k,B)\},$$

where the continuation value is the expectation of the value of producing but being forced to exit, $V_t^{\text{exit}}(z,k,B)$, and the value of not being forced to exit, $V_t^{\text{cont}}(z,k,B)$.

If the firm is forced to exit at the end of the period, its value is

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

The firm chooses its labor input n to maximize current revenue net of labor costs, sells its undepredicated capital, pays back its debt, pays its fixed operating cost, and exits the economy. Denote $\Pi_t(z,k) = \max_n P_t z k^\theta n^\nu - W_t n$ as the maximized value of revenue net of labor costs.

If the firm continues on to the next period, its value is

$$\begin{aligned} V_t^{\text{cont}}(z,k,B) = \max_{k',B'} & \Pi_t(z,k) + Q_t(1-\delta)k - B - \hat{P}_t\xi - Q_t k' + \frac{1}{R_t(z,k',B')}B' \\ & + \mathbb{E}_t\left[\hat{\Lambda}_{t,t+1}V_{t+1}^0(z',k',B')\right] \qquad \text{such that} \\ & \Pi_t(z,k) + Q_t(1-\delta) - B_t - \hat{P}_t\xi - Q_t k' + \frac{1}{R_t(z,k',B')}B' \geq 0, \end{aligned} \tag{14}$$

where $\hat{\Lambda}_{t,t+1} = \beta \frac{C_{t+1}^{-\sigma}}{C_t^{-\sigma}} \frac{P_t}{P_{t+1}}$ is the stochastic discount factor. The firm chooses investment and borrowing to maximize the value of its current dividends plus the continuation value. In making this investment, it faces the upward-sloping interest rate schedule $R_t(z,k',B')$ and cannot pay negative dividends.

It is convenient to write the firm's decision problem in real terms relative to the price level $\hat{P}_t$. To that end, let $b = \frac{B}{\hat{P}_t}$, $b' = \frac{B'}{\hat{P}_t}$, $\pi_t(z,k) = \frac{\Pi_t(z,k)}{\hat{P}_t}$, $q_t = \frac{Q_t}{\hat{P}_t}$, $\Lambda_{t,t+1} = \beta \frac{C_{t+1}^{-\sigma}}{C_t^{-\sigma}}$, and $v_t(z,k,b) = \frac{V_t^{\text{cont}}(z,k,B)}{\hat{P}_t}$. The normalized value function $v_t(z,k,b)$ satisfies the Bellman equation

$$\begin{aligned} v_t(z,k,b) = \max_{k',b'} \pi_t(z,k) + q_t(1-\delta)k - b - \xi - q_t k' + \frac{1}{R_t(z,k',b')} b' \\ + \mathbb{E}_t \left[\Lambda_{t,t+1} v^0_{t+1}\left(z', k', \frac{b'}{\Pi_{t+1}}\right)\right] \qquad \text{such that} \\ \pi_t(z,k) + q_t(1-\delta)k - b - \xi - q_t k' + \frac{1}{R_t(z,k',b')} b' \geq 0 \end{aligned} \tag{15}$$

where $\Lambda_{t,t+1} = \beta \frac{C_{t+1}^{-\sigma}}{C_t^{-\sigma}}$ is the real stochastic discount factor, $v^0_{t+1}(z,k,b) = \frac{V^0_{t+1}(z,k,B)}{\hat{P}_{t+1}}$, and $R_t(z,k',b')$ is the real interest rate on loans.

Finally, it is also convenient to combine two of the firm's state variables, k and b, into a composite state variable x which measures the total amount of resources the firm has for investment before any new borrowing. In particular, $x = \pi_t(z,k) + q_t(1-\delta)k - b - \xi$. Then it is easy to verify that the firms' Bellman equation (15) can be equivalently represented as

$$v_t(z,x) = \max_{k',b'} x - q_t k' + \frac{1}{R_t(z,k',b')} b' + \mathbb{E}_t \left[\Lambda_{t,t+1} \max\{0, \pi_d x' + (1-\pi_d) v_{t+1}(z',x')\}\right] \tag{16}$$

$$\begin{aligned} \text{such that } x - q_t k' + \frac{1}{R_t(z,k',b')} b' \geq 0 \\ x' = \pi_{t+1}(z',k') + q_{t+1}(1-\delta)k' - \frac{b'}{\Pi_{t+1}} - \xi \end{aligned}$$

Financial Intermediaries 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 $\min\{\frac{\alpha q_{t+1} k'}{b'/\Pi_{t+1}}, 1\}$ units of the final good if the firm defaults. Therefore, its price is

$$\frac{1}{R_t(z,k',b')} = \mathbb{E}_t \left[\Lambda_{t+1} \frac{1}{\Pi_{t+1}} \left(1 - \Pr(v_{t+1}(z',k',b'/\Pi_{t+1}) = 0) \left(1 - \min\{\frac{\alpha q_{t+1} k'}{b'/\Pi_{t+1}}, 1\}\right)\right)\right]. \tag{17}$$

Distribution of Firms The aggregate state of the economy contains the distribution of production firms. Let $\mu_t(z,k,b)$ denote the distribution of incumbents firms at the beginning of the period before new entry and default decisions are made. Also let $\mu(z)$ denote the ergodic distribution of productivity in the population.

The distribution of firms in production will be composed of incumbents who do not default and new entrants who do not default. Denoting this distribution $\hat{\mu}_t(z,x)$, mathematically this is

$$\begin{aligned}\hat{\mu}_t(z,x) = &\int \mathbb{1}\{v_t^0(z,k,b) > 0\}\mathbb{1}\{\pi_t(z,k) + q_t(1-\delta)k - b - \xi = x\}\mathrm{d}\mu_t(z,k,b) \\ &+ \overline{\mu}\int \mathbb{1}\{v_t^0(z,k_0,b_0) > 0\}\mathbb{1}\{\pi_t(z,k_0) + q_t(1-\delta)k_0 - b_0 - \xi = x\}\mathrm{d}\mu(z).\end{aligned} \tag{18}$$

The evolution of the distribution is then given by

$$\mu_{t+1}(z',k',b') = (1-\pi_d)\int \mathbb{1}\{k'(z,x) = k'\}\mathbb{1}\{\frac{b'(z,x)}{\Pi_{t+1}} = b'\}p(\varepsilon|e^{\rho\log z + \varepsilon = z'})\mathrm{d}\varepsilon\mathrm{d}\hat{\mu}_t(z,x). \tag{19}$$

3.2.3 Equilibrium Definition

An **equilibrium** of this model is a set of $v_t(z,x)$, $k_t'(z,x)$, $b_t'(z,x)$, $n_t(z,x)$, $R_t(z,k',b')$, Π_t, Δ_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 (16) 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 (17).

(iii) New Keynesian block: Π_t, Δ_t, Y_t, and q_t satisfy (11), (12), and(13).

(iv) The distribution of firms in production $\hat{\mu}_t(z,x)$ satisfies (18) and the distribution $\mu_t(z,k,b)$ evolves according to (19).

(v) Household block: the stochastic discount factor is given by $\Lambda_{t,t+1} = \beta\frac{C_{t+1}^{-\sigma}}{C_t^{-\sigma}}$ and the wage must satisfy $w_tC_t^{-\sigma} = \Psi N_t^{1/\eta}$.

(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 $K_t = \int k\mathrm{d}\mu_t(z,k,b)$ and $K_{t+1} = \int k_t'(z,x)\mathrm{d}\hat{\mu}_t(z,x)$. 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 Theoretical Decomposition of Investment Response to Monetary Policy

We now study the channels through which monetary policy changes individual firms' investment and financing behavior in the model. In this section, we provide a theoretical decomposition of these channels. In Section 5, we calibrate the model to assess the quantitative significance of each channel, and show that the model is consistent with the empirical evidence presented in Section 2.

4.1 Individual Investment Decisions

Before analyzing the effect of monetary policy on investment and financing, we must first characterize firms' decisions.

***Proposition* 1.** *Consider a firm at time t with idiosyncratic productivity z and cash-on-hand x. Then 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 $x < \underline{x}_t(z)$.*

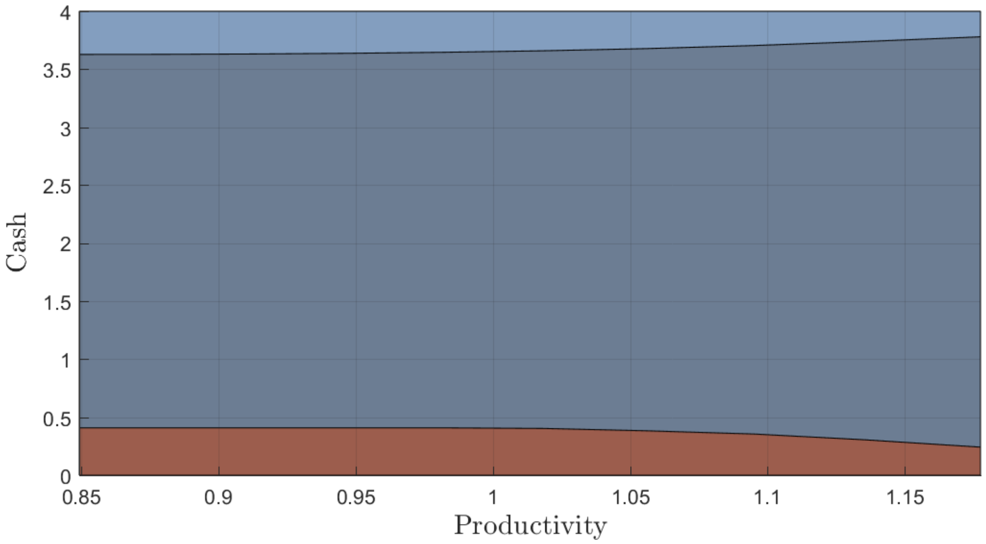
(ii) ***Unconstrained****: there exists a threshold $\overline{x}_t(z)$ such that the firm is unconstrained if $x > \overline{x}_t(z)$. Unconstrained firms follow the capital accumulation policy*

$$k_t'(z,x) = k_t^*(z) = \left(\frac{1}{q_t} \frac{\mathbb{E}_t \left[\Lambda_{t+1} A \hat{\theta} p_{t+1}^{\frac{1}{1-\nu}} w_{t+1}^{-\frac{\nu}{1-\nu}} z'^{\frac{1}{1-\nu}} \right]}{1-(1-\delta)\mathbb{E}_t\left[\Lambda_{t+1}\frac{q_{t+1}}{q_t}\right]} \right)^{\frac{1}{1-\hat{\theta}}}, \tag{20}$$

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. 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

$$b_t^*(z) = \min_{z'}\{\pi_t(z', k_t^*(z)) + q_{t+1}k_t^*(z) - \xi + \min\{\mathbb{E}_t\left[\Lambda_{t+1}\right] b_{t+1}^*(z')/\Pi_{t+1} - q_{t+1}k_{t+1}^*(z'), 0\}\}. \tag{21}$$

Figure 3: Partition of Individual State Space



Notes: Partition of individual state space in the steady state of our calibrated model. 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.

(iii) **`Constrained:`** *firms with $x \in [\underline{x}_t(z), \overline{x}_t(z)]$ are constrained. Constrained firms set $d = 0$ and their optimal investment $k'_t(z,x)$ and borrowing $b'_t(z,x)$ decisions solve the Bellman equation (16) with $d = 0$. Therefore, their optimal choices satisfy*

$$k'_t(z,x) = \frac{1}{q_t}\left(x - \xi + \frac{1}{R_t(z, k'_t(z,x), b'_t(z,x))} b'_t(z,x)\right) \tag{22}$$

Proof. See Appendix A.2. ■

Proposition 1 partitions the individual state space (z, x) into three distinct regions, which Figure 3 plots in our calibrated model. Firms with low cash on hand $x < \underline{x}_t(z)$ default and permanently exit the economy. Firms only default if there is no feasible choice k' and b' that satisfies the non-negativity constraint on dividends,

$$x - \xi - q_t k' + \frac{1}{R_t(z, k', b')} b' \geq 0.$$

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

$$\underline{x}_t(z) = \xi - \max_{k',b'} \left(\frac{1}{R_t(z,k',b')} b' - q_t k' \right).$$

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

Firms with high cash on hand $x > \overline{x}_t(z)$ are unconstrained. We define unconstrained firms as those which can follow the optimal capital accumulation policy (20) for their entire lifetime with probability one and default with probability zero. The Modigliani-Miller theorem holds for these firms because the marginal cost of debt financing b' and equity financing d are both equal to the risk-free rate. Therefore, any combination of b' and d which leaves these firms unconstrained is an optimum. Following Khan, Senga and Thomas (2016), we resolve this indeterminacy by imposing that unconstrained firms follow the "minimum savings policy" $b_t^*(z)$ defined in (21). $b_t^*(z)$ is the highest level of debt which firms can incur and be guaranteed to not default with probability one.

Firms with intermediate cash on hand $x \in [\underline{x}_t(z), \overline{x}_t(z)]$ are constrained. Constrained firms strictly prefer to exhaust equity finance by setting $d = 0$ because the shadow value of resources inside the firm, used to loosen the financial constraint, is higher than the shadow value of dividends. Constrained firms' investment is therefore financed either by internal resources or new borrowing, as shown in (22).[13]

Figure 4 plots the investment, borrowing, and dividend policy rules of firms in the steady state of our calibrated model, which provides an alternative way to visualize the results from Proposition 1. Firms with cash on hand below $\underline{x}_t(z)$ default and make no decisions. Firms with cash on hand above $\overline{x}_t(z)$ are unconstrained and choose $k' = k_t^*(z)$ and $b' = b_t^*(z)$, which do not depend on cash on hand x. Finally, firms with intermediate cash on hand are constrained and their decisions depend on x. Firms with low levels of x currently pay a risk premium and cannot achieve their optimal level of capital $k_t^*(z)$. Firms with higher levels of x can achieve their optimal level of capital $k_t^*(z)$, but spend resources to decrease their borrowing and build up internal net worth.

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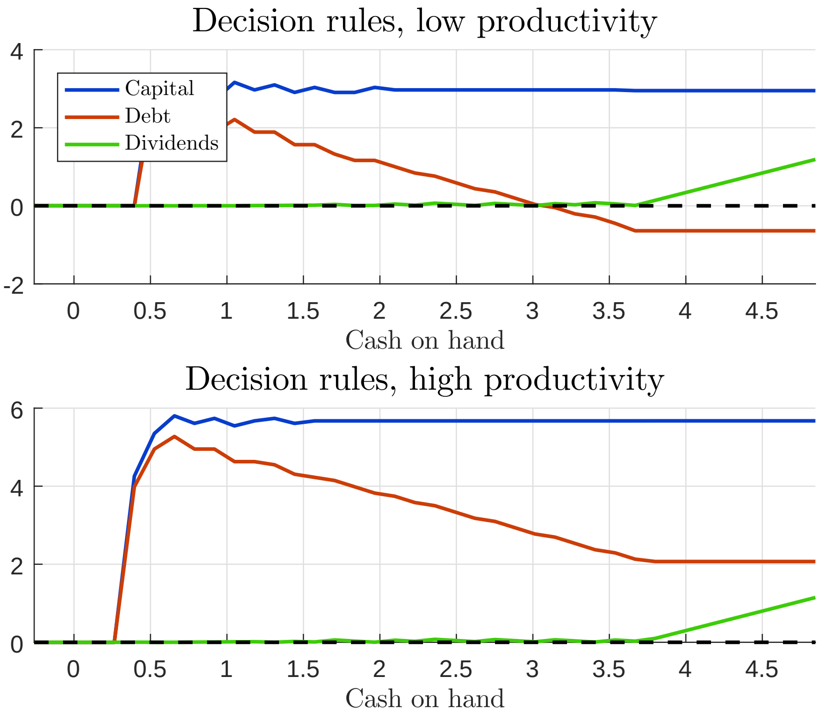
[13] It is important to note that a firm that can currently borrow at the risk-free rate can still be constrained if it has some positive probability of default in any future period.

Figure 4: Policy Rules



Notes: Policy rules for calibrated firm in the steady state of our model.

4.2 Decomposing the Effect of Monetary Policy on Individual Decisions

We now use this characterization of individual decisions to decompose the effect of a monetary policy shock. We model the monetary policy 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 is similar to the impulse response function of the full rational expectations equilibrium, but allows for cleaner analytical results because there is no difference between ex-ante and ex-post expected real interest rates.

4.2.1 Unconstrained Firms

It is convenient to separately analyze the responses of unconstrained and constrained firms because the two behave quite differently. The monetary shock $\varepsilon_t^{\mathrm{m}}$ perturbs unconstrained firms' decision rules by

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

$$+\frac{1}{1-\nu-\theta}\left[\underbrace{\frac{\partial \log p_{t+1}}{\partial \varepsilon_t^{\mathrm{m}}} - \nu\frac{\partial \log w_{t+1}}{\partial \varepsilon_t^{\mathrm{m}}}}_{\text{capital revenue}}\right], \tag{23}$$

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 `intertemporal substitution` channel isolates the direct effect of changing the real interest rate investment decisions; decreasing the real interest rate increases investment through this channel. The `capital price` channel isolates the effect of monetary policy on the relative price of capital; increasing the price of capital decreases investment through this channel. The `capital gains` channel isolates the effect of monetary policy on the change in the value of capital the firm holds between periods t and $t+1$; increasing capital gains increases investment through this channel. 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 of capital by changing the relative price of output p_{t+1}, which increases investment, or by changing the relative price of labor w_{t+1}, which decreases investment. The `capital revenue` channel measures the net effect of these two terms.

4.2.2 Constrained Firms

Totally differentiating (22), the monetary policy shock perturbs constrained firms' decision rules according to the decomposition

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

The decomposition (24) isolates three channels through which monetary policy can affect constrained firms' investment. This expression should be interpreted with care because it involves derivatives of the endogenous variables k' and b' on both sides. However, it is nonetheless a useful pedagogical tool for understanding how monetary policy affects the decisions of constrained firms.

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 the firms' cash flows and therefore resources for financing investment. Firms with higher values for $\frac{x}{q_t k'}$ finance more of their investment expenditure out of their cash flows and are therefore more exposed to the cash flow channel:

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

Expression (25) makes clear that monetary policy affects cash flows in three distinct ways. First, monetary policy affects current revenues by changing the relative price of firms' output p_t or of their labor input w_t, similar to unconstrained firms. Second, monetary policy affects the value of the firms capital stock by changing the price of capital q_t. Finally, monetary policy affects the real value of the firm's outstanding debt by changing the inflation rate Π_t.

Finally, the `borrowing cost` channel in (24) isolates how monetary policy affects firms' resources from new borrowing. Monetary policy can either change the real face value of new debt b', or the interest rate associated with that debt. The effect of monetary policy on the interest rate is given by

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

where $r(z,k',b') = \Pr(v_{t+1}(z',k',b'/\Pi_{t+1}) = 0)\left(1 - \min\{\frac{\alpha q_{t+1}k'}{b'/\Pi_{t+1}}, 1\}\right)$ is the cost to the lender in the event of default. The expression (26) makes clear that monetary policy affects borrowing costs through two channels. First, it affects the real interest rate R_t, which shifts the level of the interest rate schedule $R_t(z,k',b')$. Second, if the firm incurs a positive external finance premium $R_t(z,k',b') - R_t$, then additionally monetary policy can affect the credit spread of the firm by changing either default probabilities or loan recovery rates.

It is important to emphasize that the expression in (24) includes an endogenous "portfolio choice" problem: constrained firms can use the stimulus provided by monetary policy to either invest in capital or pay down their debt. In Section 5 below, we evaluate these channels quantitatively and find that in fact constrained firms primarily pay down their debt.

5 Quantitative Analysis

We now quantitatively evaluate the strength of the individual channels through which monetary policy affects firms' investment decisions. In Section 5.1, we calibrate the steady state of the model to match firms' investment and financing behavior. In Section 5.2 we briefly describe the aggregate impulse responses to a monetary policy shock starting from steady state. In Section 5.3 we decompose the quantitative channels of individual firms' responses and relate them to the empirical evidence presented in Section 2.

5.1 Calibration

We make two key simplifying assumptions for the quantitative analysis. First, we set the aggregate capital adjustment cost $\phi = 0$ so that $q_t = 1$ for all t, eliminating the

Table VII
Fixed Parameters

Parameter	**Description**	**Value**
Household		
β	Discount rate	0.99
Firms		
ν	Labor coefficient	0.64
θ	Capital coefficient	0.21
δ	Depreciation	0.03
b_0	Initial debt	0
ϕ	Aggregate capital AC	0
New Keynesian Block		
γ	Demand elasticity	10
φ_π	Taylor rule coefficient	1.25
φ	Prob keep price	0.25

Notes: Parameters fixed exogenously in the calibration.

`capital price` and `capital gains` channels of monetary policy. Second, we assume that firms' borrowing is in real, not nominal debt. These assumptions are made to simplify the exposition and will be relaxed in future work.[14]

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

Fixed Parameters Table VII lists the parameters that we exogenously fix. A model period is one quarter, so we set the discount factor $\beta = 0.99$. We set the coefficient on labor in production $\nu = 0.64$; given this value, we choose the capital coefficient $\theta = 0.21$ to imply total returns to scale 85%. Capital depreciates at rate $\delta = 0.03$. We assume that new entrants start with $b_0 = 0$ debt. The initial net worth of new entrants is $k_0 - b_0$; given that we choose k_0 to match initial net worth, our choice of b_0 is a normalization.

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[14] We believe that both these assumptions are not central to our analysis. The capital price channel will dampen the overall effect of monetary policy but does not directly generate heterogeneity across firms. The assumption of real debt eliminates any revaluation effects of monetary policy, but because all debt in our model is short term these effects are likely small.

TABLE VIII
FITTED PARAMETERS

Parameter	Description	Value
Productivity process		
ρ_z	Persistence	0.9
σ_z	SD of innovations	0.029
Financial frictions		
ξ	Operating cost	0.075
α	Loan recovery rate	0.16
Firm lifecycle		
k_0	Initial capital	0.412
π_d	Exogeneous exit rate	0.022

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

We choose elasticity of demand faced by retailers $\gamma = 10$, implying the steady state markup is 11%. 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 assume that retailers keep their price with probability $\varphi = 0.25$.[15]

Fitted Parameters We choose the parameters listed in Table VIII – governing idiosyncratic shocks, default risk, and firm lifecycles – to match three sets of moments, reported in Table IX. First, we target the mean and standard deviation of the distribution of plant-level investment rates in Census microdata reported by Cooper and Haltiwanger (2006).[16] Second, we target the average default rate and aggregate debt to capital ratio, both taken from Bernanke, Gertler and Gilchrist (1999). Finally, we target the initial size of new entrants and the overall exit rate in the economy, reported in Khan, Senga and Thomas (2016).

This set of moments provides an intuitive identification of our parameters. First, the investment rate moments pin down the parameters governing idiosyncratic productivity

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[15] Our calibration implies that prices are relatively flexible; even with flexible prices monetary policy has a strong effect on aggregate investment because the price of capital is constant. We will later allow for the price of capital to increase, which will allow us to calibrate a more reasonable degree of price flexibility.

[16] Our model makes no distinction between plant and firm, and we use the two interchangeably in the calibration.

shocks. These moments are drawn from a balanced sample of firms who have survived at least sixteen years; when we apply this sample selection to our data, the resulting firms have accumulated enough assets to be relatively unaffected by financial constraints. Therefore, productivity shocks are the only force driving dispersion in these firms investment rates. Second, given the values of idiosyncratic shocks, the default rate pins down the size of the operating cost and, given this, the loan recovery rate determines the total amount of resources the financial intermediary lends to firms. Finally, the initial size of new entrants pins down their initial capital stock, and the overall exit rate pins down the exogenous exit probability.

Table IX shows that our model matches these moments reasonably well.[17] In particular, it matches the dispersion of investment rates, which captures the degree of idiosyncratic risk faced by firms. The model also matches the default rate and aggregate debt to capital ratio, which capture the strength of financial frictions. However, the model underpredicts the average size of new entrants.

Table VIII shows that the calibrated parameters are broadly comparable to the existing literature. Our calibrated idiosyncratic shocks are less persistent and more volatile than aggregate shocks, consistent with estimates based on direct measurement of productivity. The calibrated loan recovery rate is considerably lower than direct estimates, but plays a broader role in determining financial intermediation in our model.

5.2 Aggregate Impulse Responses

We compute the impulse response to a monetary policy shock as the perfect foresight transition path of the economy to a one-time, unexpected $\varepsilon_0^{\mathrm{m}} = -0.0025$ expansionary innovation to the Taylor rule starting from the steady state.

Figure 5 plots the impulse response of key aggregate variables this expansionary monetary shock. The immediate effect of the shock is to decrease the nominal interest rate; because prices are sticky, this decreases the real interest rate. This stimulates investment of unconstrained firms through the `intertemporal substitution` channel

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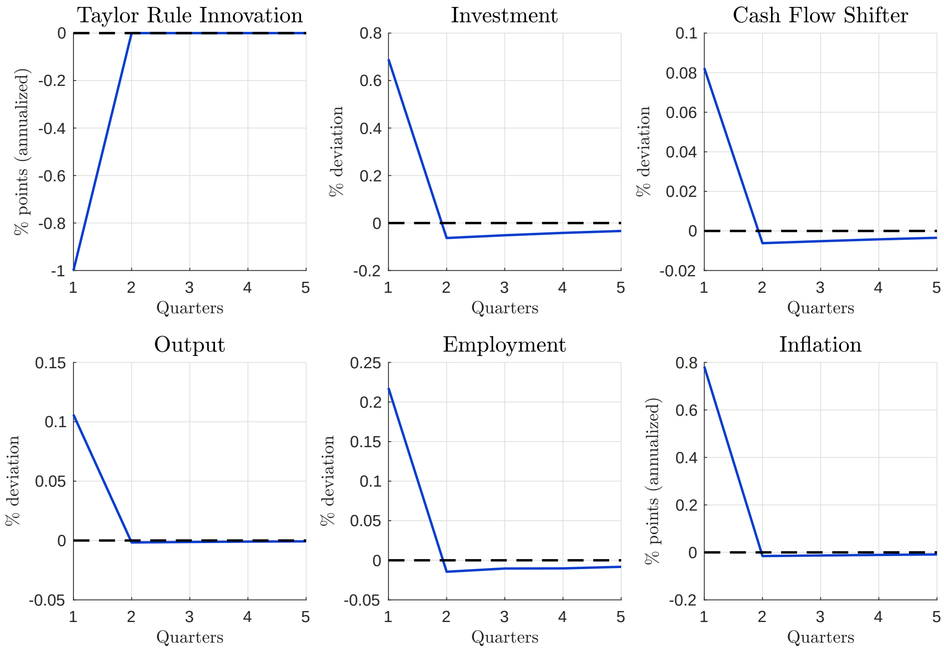
[17] The distance between data and model has not been fully optimized; instead, we are simply exploring a quantitatively relevant parameterization of the model.

TABLE IX
MODEL FIT

Moment	Description	Data	Model
Investment behavior (annual)			
$\mathbb{E}\left[\frac{i}{k}\right]$	Mean investment rate	12.2%	9.8%
$\sigma\left(\frac{i}{k}\right)$	SD investment rate	33.7%	32.0%
Financial behavior (annual)			
$\mathbb{E}\left[\text{default rate}\right]$	Mean default rate	3%	3.01%
B/K	Agg debt-to-capital	50%	52%
Entry and exit (annual)			
$\mathbb{E}\left[\text{exit rate}\right]$	Mean exit rate	10%	10.1%
$k_0/\mathbb{E}\left[k-b\right]$	Avg size of new entrants	28.5%	20.7%

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 of firms; we mirror this sample selection in the model by computing investment moments for firms who have survived at least twenty six years. Financial behavior targets drawn from Bernanke, Gertler and Gilchrist (1999). Entry and exit statistics drawn from Khan, Senga and Thomas (2016).

FIGURE 5: Aggregate Impulse Response in Our Model 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.

and of constrained firms through the `borrowing cost` channel. This raises demand for aggregate output, which increases cash flows. Constrained firms then further increase their investment through the `cash flow` channel, to the extent that they use the extra cash to invest rather than pay down debt. The sum of these direct and indirect effects on aggregate demand increase output, employment, and inflation.[18]

5.3 Lesson 1: Unconstrained Firms Drive Aggregate Response

We now use the quantitative model to draw two key implications for the aggregate transmission mechanism. First, in this subsection, we show that most of the aggregate effect of monetary policy is driven by unconstrained firms and the intertemporal substitution channel. Second, in the next subsection, we show that the effect of a given change in monetary policy depends on the distribution of net worth across firms, which varies over time.

Figure 6 shows that unconstrained firms account for nearly all of the investment response to monetary policy; the intertemporal substitution channel quantitatively dominates the other channels active for constrained firms. However, the top right panel shows that monetary policy does increase cash flows, so it must be that constrained firms use the extra cash to pay down existing debt rather than invest in capital. Consistent with this, the policy functions plotted in Figure 4 show that constrained firms build up to their optimal capital scale relatively quickly, and afterward use additional cash to decrease their leverage.

Comparison to Empirical Results In our model, firms with low leverage are likely to financially unconstrained. Hence, the fact that the intertemporal substitution channel is quantitatively dominant is consistent with the empirical evidence presented in Section 2. The next step in our analysis is to quantitatively compare regression specification we estimated in the data to the same specification estimated in our model.

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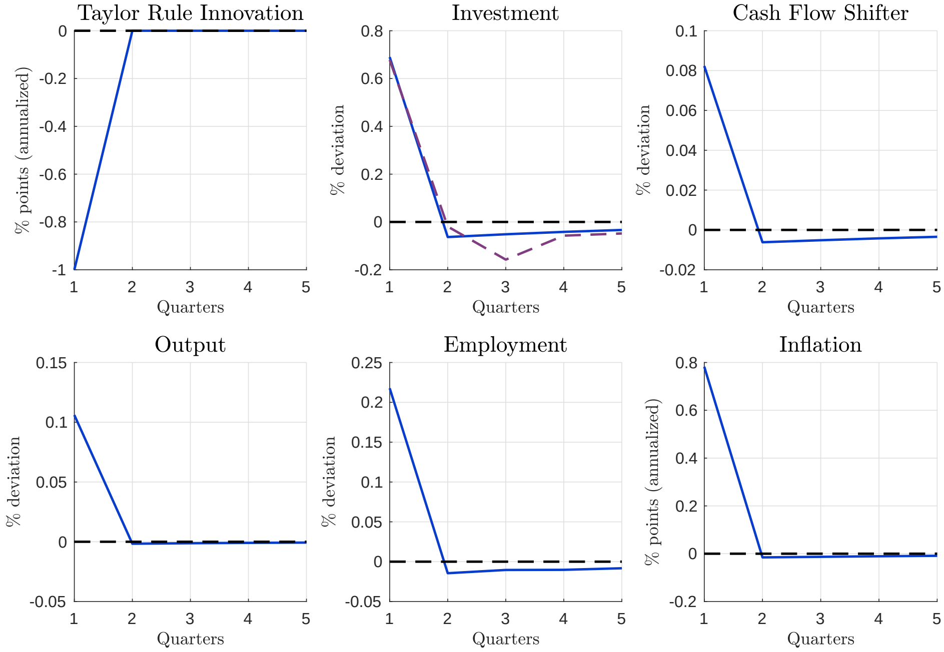
[18] Our model does not capture the hump-shaped responses of investment to monetary policy shocks emphasized by Christiano, Eichenbaum and Evans (2005) because we do not include the investment adjustment costs designed to generate them. In this paper, we are interested in how financial heterogeneity shapes the response to monetary policy in an otherwise benchmark environment.

Figure 6: Decomposition of Aggregate Investment Response



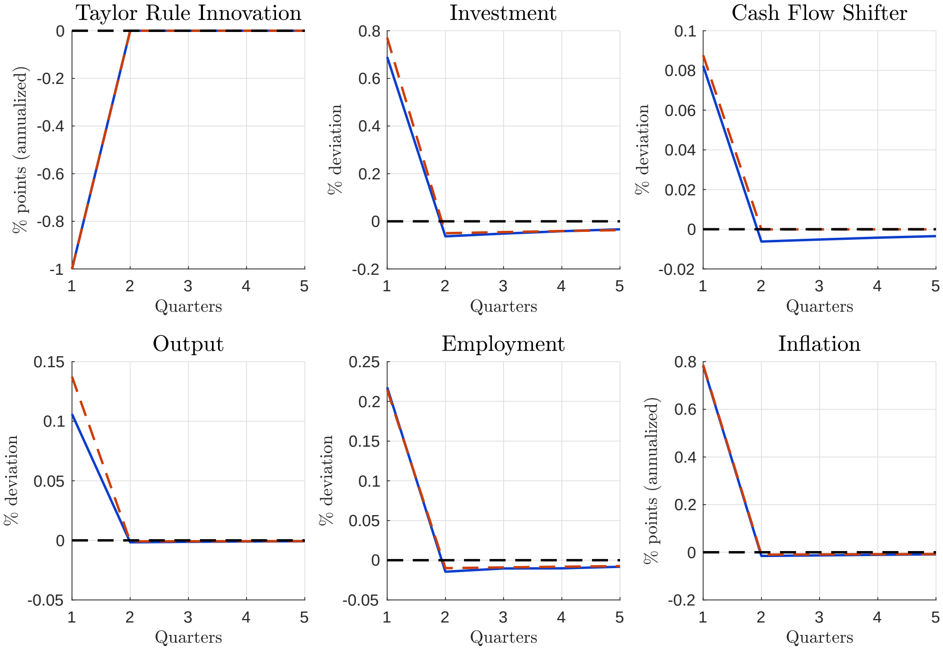
Notes: Aggregate impulse responses to a $\varepsilon_0^{\mathrm{m}} = -0.0025$ innovation to the Taylor rule, starting from steady state. Computed as the perfect foresight transition path following a one-time expected shock. Purple dashed line represents the contribution of unconstrained firms to the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

However, the results in this section indicate that the model is qualitatively consistent with the empirical estimates.

Comparison to Representative Firm Model Figure 7 shows that the aggregate impulse responses in our model are quantitative similar to those in the representative firm version of the model. The representative firm is financially unconstrained; in the aggregate, investment is less than retained earnings. Therefore, the representative firm is unconstrained according to our definition in Section 4.2 and responds to monetary policy purely through the `intertemporal substitution` channel.

The fact that the aggregate responses are similar in our model is due to the fact that almost all of the aggregate investment response in our model is due to the response of unconstrained firms. This result obtains despite the fact that only 15% of firms are financially unconstrained in our model; small general equilibrium changes in the real

Figure 7: Aggregate Impulse Response in Our Model vs. Representative Firm Model



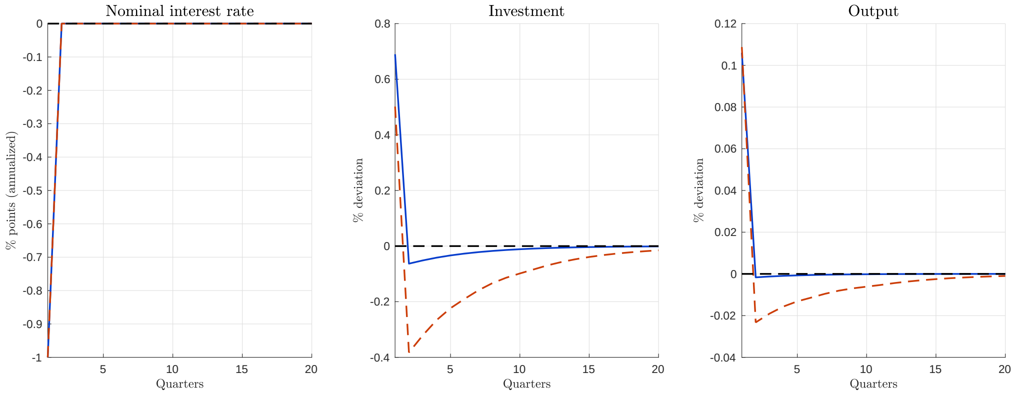
Notes: Aggregate impulse responses to a $\varepsilon_0^{\mathrm{m}} = -0.0025$ innovation to the Taylor rule, starting from steady state. Computed as the perfect foresight transition path following a one-time expected shock. The blue line is our full model. The red line is the representative firm version of our model in which the representative firm is financially unconstrained according to the definition in Section 4.2.

interest rate have strong effects on these firms, and push their investment paths close to the representative firm benchmark.

5.4 Lesson 2: Monetary Transmission Depends on Distribution

At the individual level, the effect of monetary policy depends on financial position; therefore, the aggregate effect depends on the distribution of financial positions across firms. We illustrate this general state dependence with a particular quantitative exercise. 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

Figure 8: 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.

following a $\varepsilon_{-1}^{\mathrm{m}} = -0.0075$ expansionary shock.[19]

Figure 8 shows that investment responds significantly less following previous monetary stimulus than starting from steady state. Quantitatively, the initial impact is 30% lower, and the following dynamics feature strong disinvestment. In response to the previous stimulus, firms either spend their internal resources or borrow further to finance investment, leaving them with less resources to respond to the current stimulus. Once the real interest rate returns to steady state, firms disinvest these additional resources. Hence, the monetary authority in our model provides a natural rationale for the monetary authority to “keep its powder dry ” until it needs to stimulate the economy.

6 Conclusion

In this paper, we have argued that financial heterogeneity across firms is crucial to understanding the investment channel of monetary policy. Our argument had two main

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[19] This logic also suggests that monetary policy will be less powerful in recessions, when the distribution of net worth across firms weakens. However, our model does not feature other aggregate shocks driving business cycles.

components. First, at the micro level, we showed that there is a strong interaction between firms' financial position and their investment response to monetary policy shocks; low-leverage firms invest significantly more following a monetary policy shocks, and the 50% least leveraged firms in our sample account for nearly all of the total response of aggregate investment to shocks.

These empirical results may also be of independent interest to policymakers who care 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))." Conventional wisdom, built on previous empirical work showing that monetary policy stimulates small and presumably credit constraint firms, suggested that conventional monetary policy would accomplish this goal. Our results call into question whether this conventional wisdom is still valid, and suggests that in contrast conventional monetary policy stimulates the least indebted firms in the economy.

The second component of our argument was a heterogeneous firm New Keynesian model consistent with the firm-level interaction in the micro data. We used this model to extract two lessons for the design of monetary policy. First, monetary policy stimulates investment primarily by stimulating financially unconstrained firms. Second, the effect of a given change in monetary policy on aggregate investment depends on the distribution of net worth across firms, which varies endogenously over time.

References

Almeida, H., M. Campello, B. Laranjeria, and S. Weisbenner (2012): "Corporate Debt Maturity and the Real Effects of the 2007 Credit Crisis," *Critical Finance Review*, 1, 3–58.

Auclert, A. (2015): "Monetary policy and the redistribution channel," working paper.

Bernanke, B. (2010): "Restoring the Flow of Credit to Small Businesses," Speech.

Bernanke, B. S., and M. Gertler (1995): "Inside the black box: the credit channel of monetary policy transmission," *The Journal of Economic Perspectives*, (4), 27–48.

Bernanke, B. S., M. Gertler, and S. Gilchrist (1999): "The financial accelerator in a quantitative business cycle framework," *Handbook of macroeconomics*, pp. 1341–1393.

Calvo, G. (1983): "Staggered Prices in a Utility-Maximizing Framework," *Journal of Monetary Economics*, 12, 383–398.

Christiano, L. J., M. Eichenbaum, and C. L. Evans (2005): "Nominal rigidities and the dynamic effects of a shock to monetary policy," *Journal of Political Economy*, 113, 1–45.

Clementi, G. L., and B. Palazzo (2015): "Investment and the Cross-Section of Equity Returns," Working paper.

Cook, T., and T. Hahn (1989): "The effect of changes in the federal funds rate target on market interest rates in the 1970s.," *Journal of Monetary Economics*, 24, 331–351.

Cooper, R. W., and J. C. Haltiwanger (2006): "On the nature of capital adjustment costs," *The Review of Economic Studies*, 73, 611–633.

Gertler, M., and S. Gilchrist (1994): "Monetary Policy, Business Cycles, and the Behavior of Small Manufacturing Firms," *The Quarterly Journal of Economics*, pp. 309–340.

Gilchrist, S., R. Schoenle, J. Sim, and E. Zakrajsek (2016): "Inflation Dynamics During the Financial Crisis," *The American Economic Review (Forthcoming).*

Gilchrist, S., J. Sim, and E. Zakrajsek (2014): "Uncertainty, Financial Frictions, and Investment Dynamics," Working paper.

Gorodnichenko, Y., and M. Weber (2016): "Are sticky prices costly? Evidence from the stock market," *The American Economic Review*, 106, 165–199.

Gurkaynak, R. S., B. Sack, and E. T. Swanson (2005): "Do Actions Speak Louder Than Words? The Response of Asset Prices to Monetary Policy Actions and Statements," *International Journal of Central Banking.*

Hennessy, C., and T. Whited (2007): "How Costly is External Finance? Evidence from a Structural Estimation," *The Journal of Finance*, 62, 1705.

Jorda, O. (2005): "Estimation and Inference of Impulse Responses by Local Projections," *The American Economic Review*, pp. 161–182.

Kaplan, G., B. Moll, and G. L. Violante (2016): "Monetary policy according to HANK," No. w21897. National Bureau of Economic Research.

Kashyap, A. K., O. A. Lamont, and J. C. Stein (1994): "Credit Conditions and the Cyclical Behavior of Inventories," *The Quarterly Journal of Economics*, 109, 565–592.

Kashyap, A. K., and J. C. Stein (1995): "The impact of monetary policy on bank balance sheets," *Carnegie-Rochester Conference Series on Public Policy*, 42.

Khan, A., T. Senga, and J. Thomas (2016): "Default Risk and Aggregate Fluctuations in an Economy with Production Heterogeneity," Working paper.

Khan, A., and J. Thomas (2013): "Credit Shocks and Aggregate Fluctuations in an Economy with Production Heterogeneity," *Journal of Political Economy*, 121, 1055–1107.

McKay, A., E. Nakamura, and J. Steinsson (2015): "The power of forward guidance revisited," No. w20882. National Bureau of Economic Research.

Nakamura, E., and J. Steinsson (2013): "High frequency identification of monetary non-neutrality," No. w19260. National Bureau of Economic Research.

Rauh, J. (2006): "Investment and Financing Constraints: Evidence from the Funding of Corporate Pension Plans," *The Journal of Finance*, 61, 33–71.

Romer, C. D., and D. H. Romer (2004): "A new measure of monetary shocks: Derivation and implications," *The American Economic Review*, 94, 1055–1084.

Wong, A. (2016): "Transmission of Monetary Policy to Consumption and Population Aging," working paper.

A Appendix

A.1 Empirical Work

A.1.1 Data Construction

To construct the series of capital stock for each firm in Compustat, we follow the standard practice in the investment literature and apply a 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.[20]

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

See Tables X - XVI below.

A.2 Proofs

To be completed.

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[20] 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 $k_{i,t+1} = k_{i,t} + \texttt{PPENTQ}_{i,t}$.

Table X
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 XI
Monetary Shocks: Target vs. Path

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

	(1)	(2)
leverage × ffr shock	-0.73**	
	(0.29)	
leverage × target shock		-1.01***
		(0.38)
leverage × path shock		1.35
		(1.22)
Observations	233182	227595
R^2	0.119	0.120

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

	(1)	(2)
leverage × ffr shock	-4.80***	
	(1.29)	
leverage × target shock		-6.73***
		(1.65)
leverage × path shock		2.09
		(4.25)
Observations	233182	227595
R^2	0.217	0.219

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 XII
POST 1994 ESTIMATES

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

	(1)	(2)	(3)	(4)
leverage × ffr shock	-0.52	-0.56	-0.66	-0.66**
	(0.49)	(0.44)	(0.45)	(0.26)
leverage	-0.01	-0.01	-0.01***	-0.01***
	(0.02)	(7.28)	(0.00)	(0.00)
ffr shock			-0.05	-0.05
			(1.52)	(0.29)
Observations	185752	185752	185752	185752
R^2	0.120	0.131	0.116	0.116
Firm controls	no	yes	yes	yes
Time sector FE	yes	yes	no	no
Time clustering	yes	yes	yes	no

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

	(1)	(2)	(3)	(4)
leverage × ffr shock	-2.59	-2.51	-2.63	-2.63**
	(2.07)	(1.91)	(2.07)	(1.12)
leverage	-0.02	-0.02	-0.02***	-0.02***
	(0.02)	(0.01)	(0.00)	(0.00)
ffr shock			-2.85	-2.85**
			(6.25)	(1.26)
Observations	185752	185752	185752	185752
R^2	0.228	0.233	0.219	0.219
Firm controls	no	yes	yes	yes
Time sector FE	yes	yes	no	no
Time clustering	yes	yes	yes	no

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 XIII
ALTERNATIVE TIME AGGREGATION

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

	(1)	(2)	(3)	(4)
leverage × ffr shock (sum)	-0.89***	-0.79***	-0.79***	-0.79***
	(0.33)	(0.28)	(0.29)	(0.17)
ffr shock (sum)			1.02	1.02***
			(0.82)	(0.18)
Observations	236296	236296	236296	236296
R^2	0.106	0.118	0.103	0.103
Firm controls	no	yes	yes	yes
Time sector FE	yes	yes	no	no
Time clustering	yes	yes	yes	no

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

	(1)	(2)	(3)	(4)
leverage × ffr shock (sum)	-3.74***	-3.56***	-3.43***	-3.43***
	(1.19)	(1.10)	(1.14)	(0.75)
leverage	-0.03***	-0.02***	-0.03***	-0.03***
	(0.00)	(0.00)	(0.00)	(0.00)
ffr shock (sum)			2.09	2.09***
			(3.55)	(0.77)
Observations	236296	236296	236296	236296
R^2	0.212	0.216	0.203	0.203
Firm controls	no	yes	yes	yes
Time sector FE	yes	yes	no	no
Time clustering	yes	yes	yes	no

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 α_j is a firm fixed effect, α_{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 XIV
INSTRUMENTING LEVERAGE

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

	(1)	(2)
leverage × ffr shock	-1.02***	-0.61*
	(0.24)	(0.32)
Observations	230654	225753
Instrument	1q lag	4q lag
Firm controls, Time-Sector FE	yes	yes

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

	(1)	(2)
leverage × ffr shock	-3.57**	-5.27
	(1.42)	(4.22)
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 α_j is a firm fixed effect, α_{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 $t-2$ and $t-4$ are used as instruments for leverage in $t-1$. 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 XV
NET LEVERAGE

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

	(1)	(2)	(3)	(4)
net leverage × ffr shock	-0.89**	-0.68*	-0.61*	-0.61*
	(0.41)	(0.34)	(0.34)	(0.34)
net leverage	-0.02***	-0.01***	-0.01***	-0.01***
	(0.00)	(0.00)	(0.00)	(0.00)
ffr shock			1.37	1.37
			(0.98)	(0.98)
Observations	233182	233182	233182	233182
R^2	0.112	0.119	0.104	0.104
Firm controls	no	yes	yes	yes
Time sector FE	yes	yes	no	no
Time clustering	yes	yes	yes	no

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

	(1)	(2)	(3)	(4)
net leverage × ffr shock	-4.53***	-4.05***	-3.21**	-3.21**
	(1.67)	(1.52)	(1.57)	(1.57)
net leverage	-0.05***	-0.03***	-0.03***	-0.03***
	(0.00)	(0.00)	(0.00)	(0.00)
ffr shock			3.94	3.94
			(4.38)	(4.38)
Observations	233182	233182	233182	233182
R^2	0.215	0.217	0.204	0.204
Firm controls	no	yes	yes	yes
Time sector FE	yes	yes	no	no
Time clustering	yes	yes	yes	no

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 XVI
ALTERNATIVE BALANCE-SHEET ITEMS

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

	(1)	(2)	(3)	(4)	(5)
ST debt × ffr shock	-0.54**		-0.58**		
	(0.24)		(0.24)		
LT debt × ffr shock		-0.38	-0.43		
		(0.28)	(0.29)		
leverage × ffr shock				-0.70**	
				(0.30)	
other liab × ffr shock				-1.39	
				(1.34)	
liabilities × ffr shock					-3.96
					(3.30)
Observations	233182	233182	233182	233161	233161
R^2	0.118	0.117	0.119	0.119	0.117
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	-4.98***		-5.10***		
	(1.33)		(1.35)		
LT debt × ffr shock		-1.45	-1.67		
		(1.23)	(1.23)		
leverage × ffr shock				-4.74***	
				(1.31)	
other liab × ffr shock				-3.54	
				(3.99)	
liabilities × ffr shock					-13.44
					(11.67)
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.