Financial Frictions and the Risk-Premium Channel of Monetary Policy

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Abstract

Interest rate surprises measured around the Federal Open Market Committee announcements capture both surprises due to the central bank deviating from its usual stance and surprises due to the non-monetary central bank communication about the economic outlook. Looking at the response of financial markets in the Fed announcement window, I show that when stock prices fall in response to a positive interest rate surprise, firms reduce their investments, and financial frictions amplify this effect. Conversely, if stock prices increase in response to a positive interest rate surprise, firms accumulate more capital and financial frictions dampen investment. I show that a positive response of the financial markets to a tightening interest rate surprise is empirically consistent with an unexpected decrease in the risk premium in the capital markets, which in turn increases the price of debt and reduces the cost of financing capital investment. I develop a dynamic general equilibrium model with firm idiosyncratic productivity and real and financial frictions to explain the empirical findings and quantify the distributional effects of monetary policy on investment. The theoretical model also helps to explain recent findings in the literature.

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1 Introduction

It is widely acknowledged that differences in financial frictions between firms are of primary importance for understanding the effectiveness of monetary policy interventions. In light of the significant role that financial frictions played during the Global Financial Crisis, there has been considerable effort devoted to the understanding of how financial frictions influence firm investment decisions and monetary policy transmission. However, at this date, there is no agreement in either the theoretical or the empirical literature.

The theoretical literature suggests that there is no clear answer to this question due to differences in capital costs across firms experiencing different levels of financial frictions and the impact of changes in monetary policy on firms' net worth. On the one hand, a firm with a high level of friction may find borrowing an additional unit of funds to be more costly or practically unfeasible. Therefore, financial frictions may dampen the effectiveness of a monetary stimulus. On the other hand, an easing monetary policy may alleviate financial frictions by improving firms' net worth and borrowing capacity. As a result, financial frictions may enhance the effectiveness of central bank interventions, a result implied by the theory of seminal works of Bernanke et al. (1999b), Kiyotaki and Moore (1997). Which one of these effects prevails and when is an empirical question.

Several empirical studies have examined the heterogeneous effect of interest rate surprises on firms' investment, reaching conflicting conclusions.[1] In a recent study, Ottonello and Winberry (2018) shows that firms with a high level of financial frictions, proxied by leverage and distance to default, accumulate relatively less capital in response to an expansionary interest rate surprise. As a result, the presence of financial friction reduces the effectiveness of monetary policy in the economy. However, Jeenas (2018b), Cloyne et al. (2018) and Ferrando et al. (2020) come to the opposite conclusion, using different methodologies. They find that when monetary policy is eased, firms with high levels of financial friction increase their capital stock by a greater amount after two years. Consequently, financial friction serves as an amplification mechanism for monetary policy. In light of these contrasting findings, it is not entirely clear whether financial frictions may have a significant impact on enhancing the effects of monetary policy on aggregate investment.

In this paper, I show that financial frictions play a different role in the transmission of interest rate surprises depending upon the nature of the underlined structural shocks.[2] Interest

[1] High-frequency changes in interest rates around FOMC announcements (i.e., interest rate surprises) are a standard method of measuring monetary policy shocks (or surprises) in the literature.

[2] Interest rate surprise, measured as changes in the federal funds rate future within a 20-minute window surrounding an announcement by the Federal Open Market Committee, are used as proxy to measure

rate surprises measured around the Federal Open Market Committee (FOMC) announcements capture both surprises due to the central bank deviating from its usual stance and surprises due to the non-monetary central bank's communication about the economic outlook. Looking at the response of financial markets in the Fed announcement window, I show that when stock prices fall in response to a positive interest rate surprise, firms reduce their investments, and financial frictions amplify this effect. Conversely, if stock prices increase in response to a positive interest rate surprise, firms accumulate more capital and financial frictions dampen the effect on investment growth. To the best of my knowledge, this is the first paper that examines the role of financial friction in determining the heterogeneous transmission of monetary policy to firms, depending upon the stock market response and accounting for both monetary and non-monetary shocks.

I organize the paper into three parts. In the first part, I show that the dynamics of investment and the role that financial frictions play in the transmission of monetary policy depends on how interest rate surprises co-move with stock market prices. Following the approach of Jarociński and Karadi (2020), I decompose interest rate surprises into two aggregate components: surprises that correlate negatively with stock market prices, the *pure monetary policy shock*, and surprises that correlate positively with stock market prices, the *non-pure monetary policy shock*. With this separation at hand, I use an instrumental variable strategy to estimate the average and dynamic heterogeneous effect of monetary policy on firms' capital accumulation using firm-level data from Compustat. I show that the stock market's response to an interest rate surprise completely changes literature-based predictions. In response to a positive interest rate surprise that results in an increase in interest rates by 25 basis points and a decline in stock prices (i.e., a pure monetary policy shock), firms reduce their capital stock by approximately 1.25 percent ten quarters after the shock. Leveraged firms suffer the most and reduce their investment by approximately 0.4 percent more for every 10 percent increase in leverage.[3] Hence, financial friction is a source of amplification for monetary policy. Instead, in response to a positive interest rate surprise that leads to an increase in interest rates by the same amount and an increase in stock prices (i.e., a non-pure monetary policy shock), firms increase their investment in physical capital by approximately 1.6 percent two years after the shock occurred. In this case, leveraged firms receive less benefit from the shock and invest approximately 0.3 percent less for every 10 percent increase in leverage. Therefore, financial friction is a source of dampening for monetary policy.

monetary policy shocks.

[3]These estimates are in in line with the findings of Jeenas (2018b) and Cloyne et al. (2018) that studied one type of monetary policy shock on firms' investment.

In the second part of the paper, I show that positive stock price responses to interest rate surprise are empirically consistent with a risk premium hypothesis. Two explanations have been proposed to explain the positive comovement between stock prices and interest rate surprises: a news hypothesis and a risk premium hypothesis. According to the news hypothesis, stock market may respond positively to an apparent tightening of monetary policy if the Federal Reserve simultaneusly provides enough private information about the future economic conditions to the market, Romer and Romer (2000), Nakamura and Steinsson (2018). Stock prices suddenly increase due to investors revising their expectations about firms' future profits upwards. According to the risk premium hypothesis instead, a Fed tightening might have a positive effect on stock prices if agents become more confident about the future and lower the compensation they require to invest in risky assets. Stock market prices increase as a result of a lower risk premium in the economy, Pinchetti and Szczepaniak (2021), Lunsford (2020).[4]. I propose a test based on firm market value to discriminate between the two hypotheses and find evidence in favor of risk premium hypothesis.

In the third part of the paper, I use a model to rationalize my findings in light of the results in the second part. I develop a New-Keynesian dynamic general equilibrium heterogeneous firm model with idiosyncratic productivity and financial frictions and fixed investment adjustment costs. The model features a well-defined distribution of investment firms that are heterogeneous by idiosyncratic productivity. These firms produce a homogeneous wholesale good using a decreasing returns to scale technology, hire labor in a competitive labor market at the equilibrium wage and invest in new capital facing adjustment costs. Firms finance investment with internal and external funding, corporate bonds, and equity. Corporate bonds are issued at discount and are cheaper than equity because of tax advantage and the absence of underwriting fees. I introduce financial frictions by assuming the presence of quadratic equity issuance costs consistently with previous work of Altınkılıç and Hansen (2000). To introduce a role for monetary policy, I assume that the monetary authority sets the nominal interest rate according to a Taylor rule. In the model, an orthogonal deviation from the systematic policy rule proxies the pure monetary policy shock; and a shock to the risk premium in the bond market, proxies the non-pure monetary policy shock.

The model helps to rationalize the empirical findings in the paper. A pure monetary policy shock increases the nominal interest rate and reduces the marginal benefit of capital through the stochastic discount factor (i.e., *interest rate channel*). Because the return on future investment falls, firms find it optimal to reduce their capital stock over time. Firms

[4] In this case, Fed does not reveal any new information about the state of the economy to the agents but it only affect how optimistic or pessimist agents are about the future.

with high levels of leverage are the most adversely affected by a pure monetary policy shock, as it increases their reliance on more expensive external financing sources. Consequently, highly leveraged firms are induced to invest relatively less as a result of an increase in their marginal cost of capital. Instead, a non-pure monetary policy shock does not only increases the nominal interest rate, it also raises the price of corporate bonds via a lowering the risk premium (i.e., *risk-premium channel*). Eventually, as the price of debt rises, the marginal cost of capital falls, outweighing the negative effects of an increase in real interest rates. High-leverage firms take fewer advantage of an increase in the price of debt because they face a downward sloping debt pricing schedule in future leverage and higher marginal cost of capital.

I use the model to revisit the distributional effects of monetary policy depending on a market response to a Fed communication. Previous literature focuses on studying the effect of monetary policy in a recession compared to normal times. In my model, an market reaction to a Fed announcement increases the cost of debt making external financing more expensive. This in turn, reduces the effectiveness of conventional monetary policy interventions in a period of recession. Because of real and financial frictions, monetary policy interventions are state-dependent in the model. A TFP-induced recession produces two effects on the economy that may affect the potency of monetary policy. First, it increases the share of financially constrained firms that are more sensitive to Taylor rule shocks. Second, it increases the relative cost of capital financing due to the presence of fixed adjustment costs on investment. This, in turn, discourages firms from investing in response to a positive monetary shock. Based on my calibration, an expansionary Taylor rule shock without a negative market reaction is 12% more effective than in normal times. A negative market reaction to the same shock dampens the effectiveness of monetary policy by more than 20 percent compared to the case where there is no market response.

Literature. This paper contributes to several strands of the literature. First, it contributes to the literature that studies how the effect of monetary policy varies across firms with different balance sheet characteristics. This literature has investigated the excess sensitivity to a interest rate surprise by looking at different metrics of the firms' performance and proxies for financial frictions. An earlier paper by Gertler and Gilchrist (1994) finds evidence that small firms are more sensitive than large firms to an interest rate tightening with respect to sales and inventories. Bahaj et al. (2019) study the role of financial frictions in the transmission of monetary policy to employment and found that younger, more-levered firms are most sensitive. Others instead study more generally the implication of heterogeneity in firm or industry behavior in response to monetary policy shocks Gaiotti and Generale (2002), Ehrmann and Fratzscher (2004), Peersman and Smets (2005). Closer to my paper, two recent papers, Ottonello and Winberry (2018) and Jeenas (2018a), study the role of leverage in the transmission of monetary policy with respect to investment using Compustat data with contrasting results. Ottonello and Winberry (2018) find that firms with low default risk or low leverage accumulate relatively more capital after an interest rate cut. Jeenas (2018a) instead, find the opposite. High leverage firms display excess sensitivity to monetary policy interventions, but the result disappears once one controls for cash holdings. In light of this debate Cloyne et al. (2018) suggest measuring financial frictions by looking at dividend policy over the firm's life cycle and find that younger corporations paying no dividends are more responsive to monetary policy with respect to investment and borrowing decisions. I discuss the differences between the results of those papers in the robustness check. My paper contributes significantly to this literature by showing that stock prices reactions to monetary policy interventions can lead to contradictory conclusions. In particular, in the absence of a positive reaction by the stock market to a positive interest rate surprise, high leverage firms are more susceptible to a monetary policy shock, whereas if the stock market reacts positively, they are less susceptible to a hike.

Second, it contributes to the growing literature that studies the effect of the stock market prices and monetary policy on the economy. The idea that Fed announcements can convey information about the future path of output and inflation beyond current and future monetary policy stance was put forth by Romer and Romer (2000) and formally developed in a model by Ellingsen and Söderström (2001). Gürkaynak et al. (2005), Campbell et al. (2012) and Nakamura and Steinsson (2018) argue that the presence of information effects can contaminate traditional estimates of monetary policy shocks that rely oh high-frequency identification and, it can change our conclusions of the effectiveness of monetary policy interventions. I use the identification strategy to disentangle interest rate surprises due to monetary surprise and macroeconomic expectations revision as proposed by Jarociński and Karadi (2020) and Andrade and Ferroni (2021).[5] My contribution to this literature is twofold. Second, I show that pure monetary policy surprises have a significant effects on firm-level decisions and that, financial frictions, proxied by leverage amplifies the investment response. Second, I show that

[5]Jarociński and Karadi (2020), Andrade and Ferroni (2021) and Miranda-Agrippino and Ricco (2018) use market-based measures of interest rate expectations and economic fundamentals, combined with a sign-restriction approach to separate interest rate surprises. Other papers have proposed different identification strategies. Doh et al. (2020), Handlan (2020) and Acosta (2021) use machine-learning and text-based techniques applied to the Fed's alternative policy statements to identify interest rate surprises due to Fed information. Cai et al. (2021) and Lakdawala (2019) remove information effects from the Fed statement by controlling for the difference between the Fed's and the public's information.

non-pure monetary policy shocks are dampened by financial frictions and this occurs through a risk-premium channel. To the best of my knowledge, this paper is the first to study at the micro and macro level the role of financial frictions on the two shocks separately.

Finally, it contributes to the theoretical literature that studies the role of credit market frictions in amplifying monetary policy disturbances. In a seminal paper, Bernanke et al. (1999a) embed the financial accelerator in a representative firm New Keynesian model with financial frictions and show that pro-cyclical firms' net worth amplifies monetary policy interventions. Ottonello and Winberry (2018) confirm the exact mechanism in a model with firms' heterogeneity and default risk. I contribute to this literature quantifying the distributional effects of monetary policy intervention allowing for the presence of a non-pure monetary policy shock in an addition to a standard Taylor rule shock.

2 Empirical analysis

In this section, I present the results of the empirical analysis. I divide the empirical research into two parts. In the first part, I replicate Jarociński and Karadi (2020) and separates interest rate surprises in two parts, a pure monetary policy shock and a non-pure monetary policy shock based on how they affect stock prices. Then, I describe the data used for the empirical analysis. In the second part, I study the response of investment to two types of policy shocks (section 2.3) and the role of financial friction in the transmission of monetary policy (section 2.4 and 2.5) following the recent works of Jeenas (2018a) and Ottonello and Winberry (2018) among others.

2.1 Disentangling monetary policy shocks

The literature that studies monetary policy and firm heterogeneity identifies monetary policy shocks following the standard high-frequency identification approach pioneered by Kuttner (2001).[6] The high-frequency identification literature relies on the assumption that variations in the financial market variables that arise in a short window of time around the Federal Open Market Committee (FOMC) policy announcements are attributable only to the central bank actions and are completely exogenous (i.e., uncorrelated with the other structural shocks in the economy). Under this assumption, variations in the market-based measure of the interest rate expectations (hereafter, interest rate surprises) around the FOMC

[6] The high-frequency identification approach is used in Ottonello and Winberry (2018), Jeenas (2018a), Cloyne et al. (2018) among others to identify monetary policy shocks.

announcements window are a valid proxy for monetary policy shocks.[7]

However, a large part of the literature highlights that interest rate surprises around FOMC announcements may be contaminated with an additional component that may reflect the possibility that during the FOMC announcements, together and independent of the actual policy actions, the Fed engages in non-monetary policy communication about the state of the economy.[8] It follows that because market-based measures of the interest rate expectations can respond to both, an observed interest rate surprise, confounds a shock driven by the action of changing the policy rate, a *pure monetary policy shock* $\varepsilon_t^{\mathrm{p}}$, and a shock driven by the Fed non-monetary communication, a *non-pure monetary policy shock* $\varepsilon_t^{\mathrm{nop}}$. As both components are contemporaneously present in interest rate surprises, separating them requires imposing additional assumptions.

To disentagle the two components, I follow the approach proposed in Jarociński and Karadi (2020) which uses a combination of high-frequency identification and sign restrictions between changes in federal funds rates future and stock market prices to decompose interest rate surprises into two structural shocks. Their empirical separation comes from identifying a shock that increases stock market prices p_t and the interest rates expectations Δi_t^e simultaneously versus a shock that decreases p_t while increasing Δi_t^e in a narrow window around an FOMC statement. A shock that leads interest rates and stock market surprises to move in the opposite direction is a pure monetary policy shock ε_t^p. A shock that leads to a response of interest rate surprise and stock market surprise that is positive is a non-pure monetary policy shock $\varepsilon_t^{\mathrm{nop}}$.[9]

$$\begin{pmatrix} \Delta i_t^e \\ \Delta p_t \end{pmatrix} = \begin{pmatrix} + & + \\ - & + \end{pmatrix} \times \begin{pmatrix} \varepsilon_t^{\mathrm{p}} \\ \varepsilon_t^{\mathrm{nop}} \end{pmatrix}$$

Those sign restrictions are justified by economic theory. Standard economic textbooks predict that a pure tightening of monetary policy will result in an unexpected increase in interest rates, as well as a decline in the discounted factor at which dividends are capitalized. Thus, the econometrician would observe stock prices falling in response to a positive interest rate surprise.[10] It follows that when stock prices rise concurrently with a positive interest

[7] A standard variable used in the literature to measure interest rate expectations is the 3-month federal funds rate future. The idea is that if agents are risk-neutral, federal funds rate futures perfectly reflect the conditional expectations about future interest rates.

[8] A part of the literature suggest that it may reflect the possibility that during the FOMC announcements, together and independent of the actual policy actions, the Fed engages in communication policy about the state of the economy, Romer and Romer (2000), Nakamura and Steinsson (2018) and Campbell et al. (2012).

[9] Other approaches used in the literature to identify the two shocks and that are based on similar identifying assumptions are Miranda-Agrippino and Ricco (2018), and Acosta (2021).

[10] In this case, there is no need to impose additional assumptions since interest rate surprises would not be contaminated by a non-monetary component.

rate surprise, this must indicate another effect, perhaps induced by the Fed's statement, that triggered the positive comovement. Figure (11) in the Appendix plots the impulse response function of macro aggregates to a pure and non-pure monetary policy shock identified using a Bayesian structural VAR model.

2.2 Firm-level data

To study the dynamics of investment and role of financial frictions in the transmission of monetary policy, I extract firm-level data from the quarterly Compustat database from 1990-Q1 to 2016-Q4. Compustat is a reliable source of information about firms' financial statements, which has been used extensively in studies exploring the effects of monetary policy on firms' investment.[11] I combine firm level data with the aggregate series of the pure and non-pure monetary policy shocks identified in the previous section.[12]

Following the literature, I estimate the response of the two shocks on capital accumulation rather than on capital expenditure. I use the perpetual inventory method to calculate the capital value $k_{i,t}$ for each firm i at the end of the quarter t as in Jeenas (2018a), and Ottonello and Winberry (2018). The literature agrees to look at the dynamics of firms' capital stocks rather than the variable investment expenditure because of measurement errors issues which make difficult to precisely detect systematic responses in investment rates in the cross-section at quarterly level, Doms and Dunne (1998).

I use leverage $\text{lev}_{i,t}$ to measure the level of indebtness of a firm in a given quarter. I construct the variable leverage as the ratio between total debt and total assets as in Jeenas (2018a). I choose this variable to measure the level of firms' financial frictions in the data because of two reasons. First, in a standard theoretical model with financial frictions, leverage can be interpreted as an inverse measure of firms' net worth.[13] Second, Ottonello and Winberry (2018) show that firms' leverage is 60% correlated with measures of default risk, and leads to the same conclusions when studying the dynamic heterogeneous responsiveness to a monetary policy shock. The appendix shows that the empirical results do not change if I use other measures of financial frictions such as cash liquidity, size, age, or credit ratings as alternatives.

[11] Firm-level investment data from Compustat accounts for around 50% of aggregate business investment in the universal of U.S. firms.

[12] In order to merge the two structural shocks with firm-level data, I sum the high-frequency shocks at a quarterly level as in Ottonello and Winberry (2018) and Jeenas (2018a).

[13] In a firm investment model with firm heterogeneity and financial frictions, conditional to firms' size, higher level of debt predicts an higher marginal cost of capital.

2.3 Average response of investment

I estimate the investment response to the two identified shocks separately using Jordà (2005)'s LP-IV for panel regression as in Cloyne et al. (2018). I prefer to use LP-IV instead of standard local projection for two reasons. First, it imposes a unit effect of normalization of the shocks in terms of a 1 unit change in the endogenous variable as explained in Stock and Watson (2018). Second, it is more efficient than the standard LP-OLS regression as it does not soffer of the generated regressor problem, Pagan (1984).

I estimate the average response of investment regressing the capital change h-period ahead $\Delta_h \log(k_{i,t+h}) = \log(k_{i,t+h}) - \log(k_{i,t-1})$ on the change in 1-year Treasury rate, $\Delta \mathrm{i}_t$, that I use as my preferred endogenous policy variable following Gertler and Karadi (2015). My baseline specification is as follows:

$$\Delta_h \log(k_{i,t+h}) = \alpha_{i,h} + \gamma_h^s \Delta \mathrm{i}_t + \Gamma_h' \left(W_{i,t-1} + \sum_{k=1}^{4} Z_{t-k} \right) + u_{i,h,t+h} \tag{1}$$

where I instrument the endogenous variable $\Delta \mathrm{i}_t$ with the two monetary shocks ε_t^p and $\varepsilon_t^{\mathrm{nop}}$ separately. I add additional controls to improve the efficiency and robustness of the estimates as standard in the literature. I control for firm fixed effects to capture time-invariant unobserved heterogeneity at firm level $\alpha_{i,h}$, a set macro-aggregates Z_{t-k} to control for the state of business cycle: four lags of GDP growth, inflation, changes in stock market prices, 1-year Treasury rate, excess bond premium, and a firm-specific time trend. Finally, I add a set of predetermined firm-level variables $W_{i,t-1}$ to control for firms' idiosyncratic characteristics: size, cash over assets, and past quarter sales growth. I cluster the errors at the firm-quarter level as standard in the literature.

Regression (1) returns two vectors of coefficients $\gamma_h^s = \{\gamma_h^{\mathrm{p}}, \gamma_h^{\mathrm{nop}}\}$ which are the point estimates of the firm-level impulse response respectively to a pure and a non-pure monetary policy shock. To be consistent with previous literature, I re-scale the estimated coefficients γ_h^s in terms of a 25bp change in the policy variable. γ_h^s provides an estimate of the average response of firm-level capital to the two identified interest surprises, normalized to increase the 1-year Treasury rate by 0.25 percent. The coefficients γ_h^s should be interpreted as the micro-level equivalent of the aggregate impulse response function in figure (11) in the Appendix.[14] If γ_h^{s} is positive, on average, firms increase investment by γ_h^s percentage points h periods after the shock. Instead, if γ_h^{s} is negative, on average, firms decrease investment

[14]These estimates also serve as a benchmark to understand the sensitivity across firms to different kinds of monetary policy shocks in the next section.

by γ_h^s percentage points h periods after the shock occurred. I report the estimates for γ_h^s in figure (1).

Figure (1) illustrates that the response of investment to interest rate surprises depends on the nature of the underlined structural shocks. In response a pure monetary policy shock that increase interest rates by 0.25%, firms reduce their capital stock by approximately 1.25% ten quarters after the shock. Instead, a non-pure monetary policy shock that increases interest rates by the same amounts leads to firms increasing their investment in physical capital by 1.6% two years later. In the following section, I use average responses to examine the excess sensitivity of investment to the two shocks.

2.4 Heterogeneity of investment response

In this section, I examine the role of financial friction in response to the two decomposed interest surprises. I estimate the dynamic heterogeneous response for capital accumulation $\Delta \log \mathrm{k}_{i,t+h}$ using LP-IV with an interaction term following Cloyne et al. (2018) among others.[15] In the baseline specification, I treat the variable leverage as a continuous variable when interacting with the two shocks and run the following specification:

$$\Delta_h \log\left(k_{i,t+h}\right) = \alpha_{i,h} + \alpha_{t\times j,h} + \left(\beta_h^s \Delta \mathrm{i}_t + \delta_h\right) \mathrm{lev}_{i,t-4} + \Gamma_h' W_{i,t-1} + u_{i,h,t+h} \tag{2}$$

where I instrument the endogenous variable $\Delta \mathrm{i}_t \cdot \mathrm{lev}_{i,t-4}$ with the interaction between $\mathrm{lev}_{i,t-4}$ and the exogenous disturbances ε_t^p and $\varepsilon_t^{\mathrm{nop}}$ separately. I control for firm fixed effects α_i to capture time invariant differences in investment behavior across firms, the sector-by-quarter fixed effects at SIC-1 digit level $\alpha_{j\times t}$ to capture differences in how sectors respond to aggregate business cycle fluctuations. I also control for cash over total assets, two measures of firms size, the logarithm of past total assets and the past real sales growth, and the interaction between size and the two shocks to capture heterogeneous responsiveness in investment due to size or collateralizable assets.

The coefficients of interest are $\beta_h^s = \{\beta_h^{\mathrm{p}}, \beta_h^{\mathrm{nop}}\}$ which capture respectively the differential effect of a pure and a non-pure monetary policy shock on capital accumulation h period ahead. Since the partial derivative $\frac{\partial \Delta \log k_{t+h}}{\partial \Delta i_t}$ in equation (2) captures the firm-level impulse response function to a policy shock, the cross derivative with respect to Δi_t and lev_{t-4}, $\frac{\partial \Delta log k_{t+h}}{\partial \Delta i_t \partial lev_{t-1}} = \beta_h^s$ can be interpreted as an estimate of the average difference in the impulse responses of capital

[15] Others papers, Ottonello and Winberry (2018), Ferrando et al. (2020), Jeenas (2018a) directly estimate the effect of the interact between the exogenous series of the shocks with the firm-level variable leverage on capital accumulation in a 1-stage regression. I checked that the results do not change qualitatively.

expenditure between two firms with 1pp difference in past leverage.[16]

The signs of γ_h^s and β_h^s provide information about the sensitivity to the two shocks and the role financial frictions play in the transmission of monetary policy. Suppose γ_h^s is positive, which means that firms increase investment on average for h periods after the shock. This suggests that the sensitivity to a shock is dependent upon the sign of β_h^s. When β_h^s has the same sign as γ_h^s, high-leverage firms accumulate relatively more capital than low-leverage firms. As a consequence, financial frictions contribute to the amplitude of a monetary policy shock. Alternatively, if β_h^s is the opposite of γ_h^s, high-leverage firms accumulate relatively less capital than low-leverage firms. In this case, firm leverage dampens the effects of a monetary policy shock. I plot the impulse response function for the average and heterogeneous response in figure (1).

Figure (1) suggests that the role of financial frictions depends on the type of monetary shock. On the one hand, in response to a pure monetary policy shock that increases the interest rate by 0.25%, high leverage firms are more sensitive to it. On average, firms with 10pp more leverage before the shock accumulate around 0.4% less capital after two years. On the other hand, in response to a non-pure monetary policy shock that equally increases the interest rate by 0.25%, firms increase their capital stock over time but firms with high leverage tend to accumulate less capital. Based on my estimates, on average firms with 10% more leverage accumulate around 0.3pp less capital around ten quarters after the shock occurred.

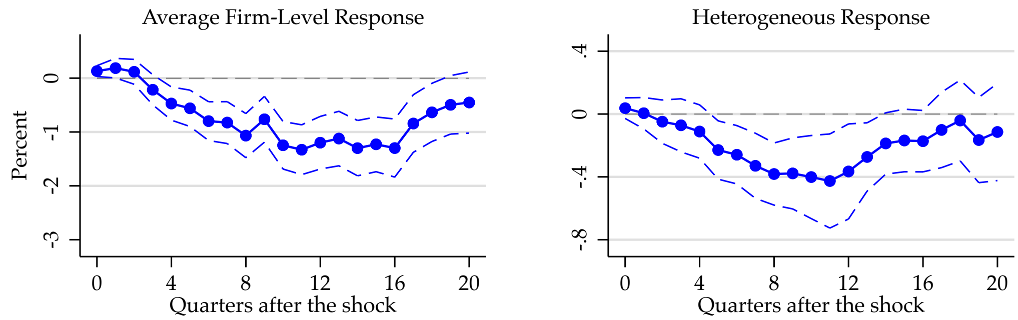
Previous results in the literature have studied the heterogeneous effects of an interest rate surprise on investment without separating the two components,Jeenas (2018a), Ottonello and Winberry (2018), Cloyne et al. (2018) among the others. My study complements the existing literature by suggesting that empirically the response to firms' investments and the role of financial frictions on monetary transmission depends on the underlined structural disturbance.[17] In the event of a tightening monetary policy accompanied by a decrease in the stock market price, firms are more likely to contact investments, and firms with higher frictions suffer the most, in line with Jeenas (2018a). Predictions completely flip if stock market prices spike at the time of intervention. A tightening monetary policy which leads to an increase in stock market prices results in firms increasing their investment, which benefits firms with lower levels of friction the most. This result is novel in the literature. I provide an explanation of these results in the next section.

[16] Because of the linearity assumption in the interaction term, the heterogeneous effect of the shocks is independent on the level of past leverage.

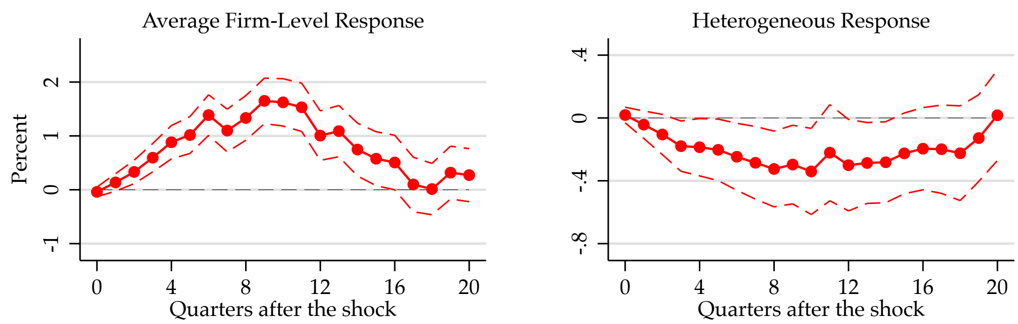
[17] In the Appendix figure (12), I show that an econometrician would draw to an incomplete conclusion if he did not separate interest surprises as I do here.

Figure 1: Heterogeneous response of investment

(a) Pure Monetary Policy Shock



(b) Non-Pure Monetary Policy Shock

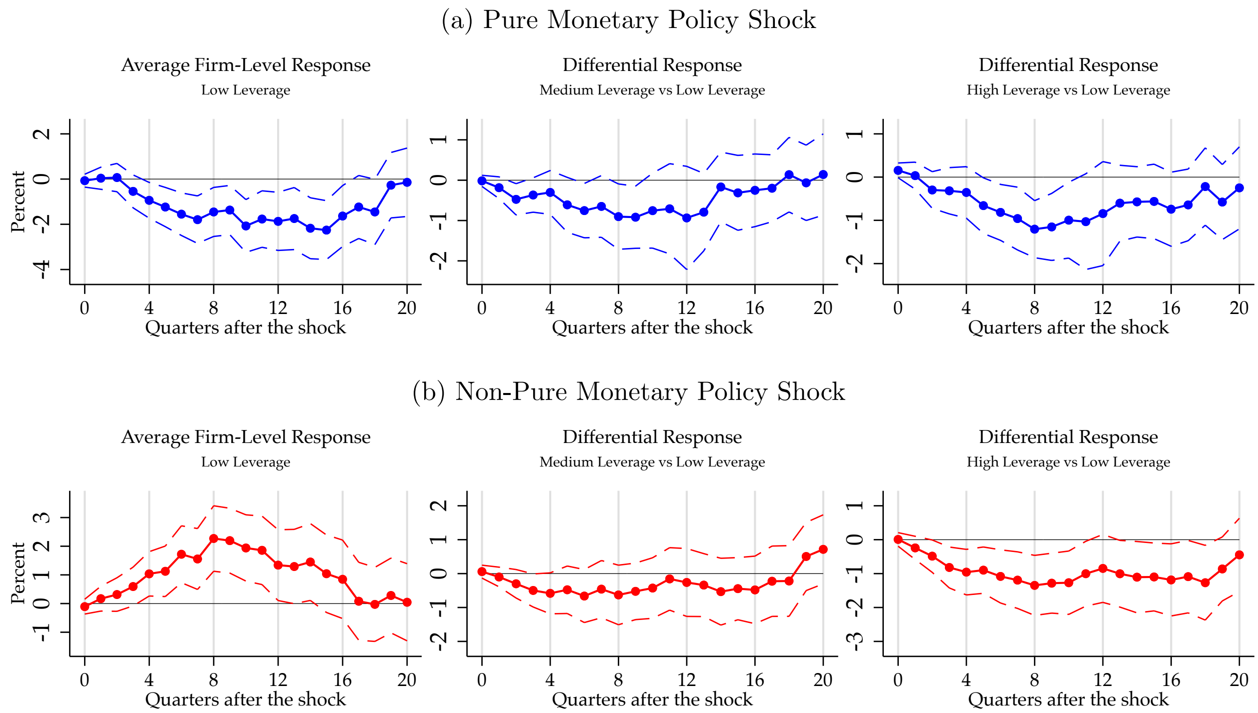


Note: Plot the impulse response function of capital accumulation to one standard deviation shock to a pure monetary policy shock (first row) and to a non-pure monetary policy shock (second row). In the first column, the average firm-level response to the exogenous shock; in the second column, the heterogeneous effect of the shocks across firms with different levels of leverage. I report the 90% confidence intervals constructed based on two-way clustered standard errors at firm and quarter levels.

2.5 Non-linear heterogeneous effect of monetary policy

In the baseline specification, equation (2), I assume the heterogeneous effect of the two shocks is linear over past leverage, i.e., shocks interact linearly with firms' debt position. However, firms with higher leverage can behave sensibly differently depending on the level of debt. To investigate the presence of non-linearity heterogeneous effects, I follow Cloyne et al. (2018). I split the firm-level observations i into three percentiles bins $\{g_j\}_{j=1}^{3}$ of leverage. For a given quarter-year, I define a firm observation i as low leverage if it is in the 20th percentile of the distribution of past year leverage, medium if it is between the $20th$ and $60th$ percentile of the distribution, and high if it is above the $60th$ percentile. I estimate the average firm-level response to the two shocks for a firm within a reference bin (i.e., firms in the $[0, 20]$ percentile of leverage) as in equation (1). I then estimate the differential response

Figure 2: Heterogeneous response of investment by leverage group



Note: Plot the impulse response function of capital accumulation to one standard deviation shock to a pure monetary policy shock (first row) and to a non-pure monetay policy shock (second row). In the first column, the average firm-level response to a policy shock for a firm within the 20th percentile of the distribution of leverage (reference response); in the second column, the average differential effect between a medium leverage firm (between the 20th the 60th percentile) and low leverage; in the third column, the average differential effect between a high leverage firm (above the 60th percentile) and low leverage. I report the 90% confidence intervals constructed based on two-way clustered standard errors at firm and quarter levels.

by groups relative to the low leverage firm as follows:

$$\Delta_h \log\left(k_{i,t+h}\right) = \alpha_{i,h} + \alpha_{t\times j,h} + \sum_{j=1}^{3} \beta^s_{h,g} \cdot \mathbb{1}\left[i \in g_j\right] \Delta \mathrm{i}_t + \sum_{j=1}^{3} \alpha^s_{h,g} \cdot \mathbb{1}\left[i \in g_j\right] + \Gamma'_h W_{i,t-1} + u_{i,h,t+h}$$

Compared to the previous section, the interaction term is a set of dummies that take value 1 if a firm is in the group g_j for all j and 0 otherwise. As in the previous specification, I instrument the interaction term between the dummies and the endogenous variable Δi_t with the interaction between the group and the shocks. I control from the firm and time-sector fix effects and a set of firms' specific controls as in the baseline specification. The vector of coefficients $\beta^s_{h,g} = \{\beta^{\mathrm{p}}_{h,g}, \beta^{\mathrm{nop}}_{h,g}\}^3_{g=2}$ captures the average differential response of investment to a shock for a firm within the group g relative to a low-leverage firms. Figure (2) show the results of this exercise. First, it confirms the presence of heterogeneous effects on the two shocks, as suggested in the previous section. Second, the sensitivity to the two shocks appears to be non-linear. In particular, in response to a pure monetary policy shock (first row), low leverage firms reduce capital by around 2pp after ten quarters. Relative to low leverage firms, medium and high leverage firms reduce their capital stock by 0.9 pp more after the same quarters. The effect is statistically significant for the high leverage firms while only weakly statistically significant for the medium leverage ones.

The results are similar in response to a non-pure monetary policy shock (second row). In response to a non-pure monetary policy shock, low leverage firms accumulate around 2.2pp more capital after the shock. Relative to low leverage, medium leverage firms do not display a statistically significant differential response, while high leverage firms increase capital significantly by around 1pp less. These results are consistent with previous literature highlighting that firms within the first 40th percentile of the distribution and between the 40th and 80th percentile do not display significantly different riskiness profiles and balance sheet characteristics and thus, they respond similarly to aggregate shocks.

2.6 Robustness checks

This section contains a set of robustness checks for my main specification. As a comprehensive measure of the level of financial frictions is not available, earlier studies on firms' heterogeneity have found contrasting results on the role that firms' financial frictions play in the transmission of monetary policy shock when using different proxies for financial frictions and specifications. Therefore, I verify that my results are robust to varying measures of financial friction. As mentioned hereabove, the two closest papers to mine are Ottonello and Winberry (2018) and Jeenas (2018a). Ottonello and Winberry (2018) find that firms with high default risk or high leverage are less responsive to monetary shocks attributable to changes in the policy rates. They argue that when financial variables, such as leverage or any other proxy for financial frictions, are demeaned at the firm level, the predictions regarding heterogeneous sensitivity can change. The argument is that demeaning the right-hand side of the specification in equation (2) would allow controlling for permanent differences across firms that would otherwise be left in the error term and potentially bias the results. In the Appendix figure (16), I show that my results are robust to demeaning leverage at the firm level and are statistically significant at 90% confidence interval.

My results are also closely linked with the results of Jeenas (2018a). His results are twofold. First, he finds that cash holding is a better proxy for financial frictions than leverage, i,e., after controlling for cash liquidity, past leverage loses significance in explaining the different sensitivity to the monetary policy shock.[18] Second, he suggests using cash liquidity as a proxy for financial frictions. In the Appendix figure (13), I show that my results are robust to this specification, and the conclusion in terms of the heterogeneity does not change. My paper can be read as a potential explanation for the contrasting findings between Ottonello and Winberry (2018) and Jeenas (2018b). This is because different shocks, predicting the same variation in the interest rate surprises, produce opposite conclusions when studying the firms' average and the heterogeneous investment response.[19]

A large amount of literature has proposed other alternative proxies for measuring financial frictions. In a seminal paper, Gertler and Gilchrist (1994) and more recently Crouzet and Mehrotra (2020), have investigated the heterogeneous response of investment to monetary policy based on past sales growth. Gertler and Gilchrist (1994) find that small firms are more sensitive to monetary policy shocks because they may experience a higher level of financial frictions. I construct the variable size following Gertler and Gilchrist (1994) using Compustat data, and I interact it with the two shocks as in equation (2). Similar to their results, I found that small firms are more responsive to pure monetary policy shocks and less sensitive to non-pure monetary policy shocks, figure (15). In another work, Whited (1992) suggests using credit ratings as a measure of the level of financial frictions that firms face. Compared to leverage, credit ratings reflect the likelihood of a firm defaulting closely and do not fluctuate as frequently as debt ratings over time. To check for this, I divide the firms' sample into three groups based on the Standard & Poor's credit rating assigned in Compustat and interact this variable with the two exogenous shocks. In the Appendix figure (14), I show that my results are robust to this specification as well.

Finally, my results are robust to different periods. I estimate the main regression as in figure (1) from 1990 to 2010 to exclude the period of zero-lower bound, and from 1994 to 2016 to avoid a potential identification issue. Figure (18) and (19) shows the results of these exercises.[20]

[18] In this sense, cash liquidity is a sufficient statistic to measure the level of financial frictions.

[19] In other words, without separating the two shocks the effect of an increase in the policy rate has an ambiguous effect on the sign of the average investment response which can lead to the wrong conclusion when looking at the heterogeneous response.

[20] From 1990 to 1994, the Fed did not use to release a statement during the FOMC meeting. This poses a potential problem in the identification from the high-frequency variables.

3 The risk-premium origins of Fed communication

What are the explanations for the micro-level findings presented in the previous section? What are the implications of my results for monetary policy? Previous literature argue that positive response of stock market prices (and many other variables) to unexpected increases in interest rates is usually considered evidence of the effectiveness of non-monetary central bank communication. However, It is still unclear in the literature how non-monetary communication, as represented by non-pure monetary policy shocks, affects the economy. One part of the literature argue that the observed aggregate response to non-pure monetary policy shock are consistent with the central bank revealing private information about current and future demand conditions and tightening its policy to counteract their impact on the macroeconomy, Romer and Romer (2000), Nakamura and Steinsson (2018) among the others. For example, the Fed may have better information about the future level of aggregate productivity or labor market conditions, and agents learn this new information from the announcements made by the Fed.[21]

In contrast, another part of the literature argues that the positive response of stock prices to an unexpected interest rate surprise is consistent with a decline in the aggregate risk premium in the financial market as a consequence of an FOMC announcement, Pinchetti and Szczepaniak (2021), Lunsford (2020). For example, if the Federal Reserve announces that it is tightening monetary policy because the future is bright, agents may become more optimistic about the future, thereby lowering the compensation they require to invest in risky assets. Stock market prices increase as a result of a lower risk premium in the economy.[22]

In this section I propose a test to distinguish between the two views using micro-level data and then, I demonstrate that this channel is responsible for the investment response.

3.1 A test for the risk-premium hypothesis

I propose a test based on firm market valuation (or average Q) to identify the main driver of the positive co-movement between interest rate surprises and stock market prices. In asset pricing theory, the market value of a firm is determined by its ability to generate dividends for its shareholders, as well as an aggregate risk premium. The non-pure monetary policy shock $\varepsilon_t^{\text{nop}}$ is expected to positively correlate with the market value of a firm $Q_{i,t}$ regardless

[21] In this case, stock prices suddenly increase due to investors revising their expectations about future dividends upwards.

[22] In the risk hypothesis, a non-pure monetary policy shock can be represented as a shock to the aggregate risk-premium.

of the narrative.[23]

The idea of the test is to study the covariance between the non-pure monetary policy shock $\varepsilon_t^{\text{nop}}$ and the firm market value Q conditional to a measure of aggregate risk-premium. If $\varepsilon_t^{\text{nop}}$ affects firm market value primarily through future dividends, conditioning to a measure of aggregate risk premium results in a $\text{cov}\left(\varepsilon_t^{\text{nop}}, Q_{j,t}\right)$ still different from zero (and positive). If $\varepsilon_t^{\text{nop}}$ affects firms market value primary through the risk premium, the covariance between the firm market value Q and $\varepsilon_t^{\text{nop}}$ conditional to a measure of risk-premium is statistically zero or negative.

To implement the test, I regress the firm-level average Q on $\varepsilon_t^{\text{nop}}$ and control for a set of proxies for the aggregate risk-premium, λ_t:

$$\log Q_{i,t} = \alpha_i + \beta_0 \varepsilon_t^{nop} + \beta_1 \lambda_t + \Gamma \sum_{k=1}^{4} X_{i,t-k} + u_{i,t} \tag{3}$$

where α_i controls for firm-fixed effects, X_{t-k} controls for a set of past macro aggreagates, as in the previous regressions, and a set of predetermined firm-specific variables: cash liquidity, leverage to control the presence of financial frictions; log of total assets as a measure of size; past average Q and past sales growth to capture expected future profitability at firm-level.[24] I use several measures of aggregate risk-premium: the Gilchrist and Zakrajšek (2012) excess bond premium (EBP) that captures the risk-premium in the bond market; the Jurado et al. (2015) 1-year horizon macro uncertainty index, and the global risk-aversion index from Bekaert et al. (2022) as a proxy for price of risk on the household.[25]

I report the result of this test in the table (1). Column (1) confirms the intuition that non-pure monetary policy shocks positively correlates with firms' value if I do not control for risk premium.[26] Column (2) tests the hypothesis that the positive response of stock market prices to a monetary tightening is driven primarily by risk-premium. After controlling for risk-premium, $\varepsilon_t^{\text{nop}}$ does not contain any information left to predict an increase in the firm value, i.e., the $\text{cov}(\varepsilon_t^{\text{nop}}, Q_{i,t}|\lambda_t)$ is statistically zero.

Columns (3)-(5) examine the hypothesis that the change in external financing cost is the primary channel for investment. In columns (3), I control only for the Jurado et al. (2015)

[23]In the example of a news, the positive correlation between $\varepsilon_t^{\text{nop}}$ and firm market valuation $Q_{i,t}$ is primarily due to higher dividends in the future; in the example of the risk-premium instead, this correlation is primary due to a fall in the aggregate risk premium.

[24]The results do not change in micro level controls are removed from the regression.

[25]I prefer to use the excess bond premium rather than the credit spread as the latter may confound variation due to the aggregate firms probability of default and risk bearing capacity.

[26]In contrast, pure monetary policy hikes negatively affect firms' profitability, in line with the standard monetary policy theory.

Table 1: Regression of average Q on monetary and non-pure monetary policy shocks

	Firm-level Q (log)				
	(1)	(2)	(3)	(4)	(5)
Non-Pure MP Shock	0.658***	-0.050	0.292***	0.384***	0.067
	(0.071)	(0.072)	(0.072)	(0.071)	(0.071)
Pure MP Shock	-1.580***	-0.810***	-0.715***	-1.332***	-0.967***
	(0.072)	(0.077)	(0.077)	(0.072)	(0.072)
Excess Bond Premium		-5.289***			-6.479***
		(0.189)			(0.162)
Uncertainty Index		-1.154***	-9.375***		
		(0.415)	(0.362)		
Global Risk Aversion		-2.837***		-4.302***	
		(0.144)		(0.137)	
Firm Effects	Yes	Yes	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes	Yes	Yes
Macro Controls	Yes	Yes	Yes	Yes	Yes
Obs	138378	138378	138378	138378	138378

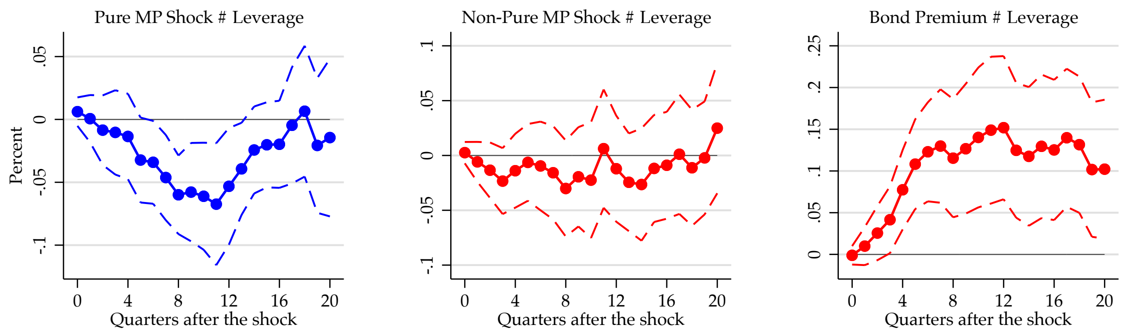
Notes: The table reports panel OLS estimates of the coefficients of a regression of the log average Q on the indicated variable. The standard errors are clustered at the firm level. Average Tobin's Q is the ratio of total assets, the market value of equity from CRSP, minus the book value of equity and deferred taxes to total assets. All control variables are standardized in the regression. $*=10\%$ level, $**=5\%$ level, and $***=1\%$ level. The standard deviations of the coefficients for each variable are in parentheses.

macro uncertainty index and find that the effect of $\varepsilon_t^{\text{nop}}$ on the firm Q is halved, but it is still statistically significant. I get the same result if I only control for the Bekaert et al. (2022) global risk aversion index, column (4). In column (5), I control only for the Gilchrist and Zakrajšek (2012) excess bond premium, which is a proxy for risk premium in bond market, and find that the $\text{cov}(\varepsilon_t^{\text{nop}}, Q_{i,t})$ is statistically insignificant.

Reassessing heterogeneity controlling for risk premium. If variations in the risk premium in the bond market is the key driver of non-monetary central bank communication, then it should also explain the results in figure (1). In order to test this hypothesis, I re-estimate the dynamic heterogeneous response for capital accumulation $\Delta \log \text{k}_{i,t+h}$ h period ahead using LP-OLS as in (2) adding a interaction term between past leverage $\text{lev}_{i,t-4}$ and the excess bond premium EBP_t to cleans out the risk-premium component of $\varepsilon_t^{\text{nop}}$ in the regression:

$$\Delta_h \log\left(k_{i,t+h}\right) = \alpha_{i,h} + \alpha_{t,j,h} + \left(\beta_h^1 \varepsilon_t^{\text{p}} + \beta_h^2 \varepsilon_t^{\text{nop}} + \gamma_h \text{EBP}_t + \delta_h\right) \text{lev}_{i,t-4} + \Gamma_h' W_{i,t-1} + u_{i,h,t+h}$$

Figure 3: Heterogeneous response controlling for risk premium



Note: Plot the heterogeneous response of interest surprise shock after controlling for the interaction between the excess bond premium and past leverage. On the left-hand side, I report the estimated coefficients of the interaction between $\varepsilon_t^{\mathrm{p}}$ and past leverage; in the center, I report the estimated coefficients of the interaction between $\varepsilon_t^{\mathrm{nop}}$ and past leverage; on the right-hand side, the the estimated coefficients of the interaction between EBP_t and past leverage; I report the 90% confidence intervals constructed based on two-way clustered standard errors at firm and quarter levels.

I add the same controls that I added in equation (2). The coefficients of interest are β_h^1, β_h^2, γ_h which capture respectively the differential effect of a pure and a non-pure monetary policy shock on capital accumulation h period ahead controlling specifically for risk premium variations. If the results are driven primarily by risk premium, the coefficients for β_h^2 are expected to be not statistically significant while γ_h is expected to be positive. Instead, if risk-premium is not the main channel of transmission for Fed communication, β_h^1 should not be significantly influenced by the interaction between past leverage and bond premium.

Figure (3) presents the estimates for β_h^1, β_h^2, γ_h from the joint regression. When simultaneously controlling for the risk premium, the relevance of leverage in explaining differences in firms' capital accumulation responses over the medium run disappears, thereby confirming the results in table (1).

4 Model

To explain the mechanism behind the micro-level results and quantify the aggregate implication of monetary policy, I develop a general equilibrium New-Keynesian model with heterogeneous firms, idiosyncratic productivity, and real and financial frictions. The presence of idiosyncratic productivity allows me to study the distributional effects of firms' characteristics more precisely by capturing the rich heterogeneity we observe in the firm-level data. Because those effects tend to be highly non-linear, standard macroeconomic models that do not incorporate this heterogeneity would fail to capture the distributional effects of leverage.

However, modeling firms' heterogeneity increases computational complexity. That entails the disadvantage of modeling non-pure monetary policy shocks in a reduced form to keep the model computationally tractable.

The theoretical part of this paper is organized into three sections. In section 4, I describe the main elements of the model and the estimation of the parameters. The model is close to the previous works of Gomes (2001), Koby and Wolf (2020) among the others. The key actors are set firms that make investments and are heterogeneous because of idiosyncratic productivity. These firms produce a homogeneous wholesale good using a decreasing return to scale technology, hire labor in a competitive labor market at the equilibrium wage and invest in new capital. They finance investment with internal and external source of funds, corporate bond, and equity issuance.[27] I also assume that firms face real and financial frictions. Real frictions arise because of adjustment costs in capital accumulation, while I introduce financial frictions with a premium on firms' equity financing and an interest rate on bonds that depends upon on leverage. Both frictions are important for matching data.

In section 5 and 6, I study the predictions of the model and compare them with the data. Given the calibration of the model, I show that on simulated data, the average and heterogeneous dynamic response of investment to the represented policy shocks in the model are consistent with the empirical findings and provide an intuition of the mechanism looking at the first order condition for capital. Finally, I focus on the aggregate implications for monetary policy. My micro-level results suggest that the aggregate effects of monetary policy may depend on the distribution of leverage, which varies over time, and the effect that Fed communication has on market risk premium. I show that the presence of non-pure monetary policy component in Fed communication reduces the effect of an expansionary pure monetary policy shock on investment.

4.1 Heterogeneous firms

Time is discrete and the horizon is infinite. In each period there is a unit mass of firms indexed by j with a well-defined distribution $\Gamma_t = \Gamma(\varepsilon_{j,t}, \mathrm{K}_{j,t}, \mathrm{B}_{j,t})$ over idiosyncratic productivity $\varepsilon_{j,t}$, capital $\mathrm{K}_{j,t}$ and debt $\mathrm{B}_{j,t}$. Firms are owned by a representative household. Firms produce an homogeneous wholesale good $\mathrm{Y}_{j,t}$ in the economy which is purchased by retailers at the equilibrium price p_t^w. After producing, paying taxes and investing in new capital, firms decide either to distribute dividends to the household or to issue equity paying a premium.

[27]This is different from Ottonello and Winberry (2018), who assume that firms can endogenously default in equilibrium and exit from the market.

Production and investment. Firms produce an homogeneous wholesale good $\mathrm{Y}_{j,t}$ using capital $\mathrm{K}_{j,t}$ and labor $\mathrm{N}_{j,t}$ with a decreasing return to scale technology: $\mathrm{Y}_{j,t} = \mathrm{Z}_t \varepsilon_{j,t} \mathrm{K}_{j,t}^{\alpha} \mathrm{N}_{j,t}^{\nu}$ where $\alpha + \nu \leq 1$ is the degree of return to scale. The decreasing return to scale assumption guarantees the existence of an optimal firm size. Firms' technology is subject to an aggregate shock Z_t common to all firms, and a firm specific shock $\varepsilon_{j,t} \in \mathcal{E} \equiv \{\varepsilon_1, \varepsilon_2, ..., \varepsilon_N\}$ which follows a discrete time first-order stationary Markov chain with $P(\varepsilon_{j,t+1} = \varepsilon_s | \varepsilon_{j,t} = \varepsilon_i) \equiv \pi_{is} \geq 0,$ and $\sum_s^N \pi_{is} = 1, \forall i.$[28]

Each period, firms hire labor in a competitive labor market at the equilibrium wage w_t, invest in new capital $\mathrm{K}_{j,t+1}$ and issue one period debt $\mathrm{B}_{j,t+1}$. Because firms do not face any frictions in adjusting labor, the optimal labor policy $\mathrm{N}^*_{j,t}$ solves the static problem:

$$\mathrm{N}^*_{j,t} = \underset{N_{j,t} \geq 0}{\arg\max} \left\{ p^w_t \mathrm{Z}_t \varepsilon_{j,t} \mathrm{K}^{\alpha}_{j,t} \mathrm{N}^{\nu}_{j,t} - w_t \mathrm{N}_{j,t} \right\} = \left(\frac{\nu p^w_t \mathrm{Z}_t \varepsilon_{j,t}}{w_t} \right)^{\frac{1}{1-\nu}} \mathrm{K}_{j,t}^{\frac{\alpha}{1-\nu}}$$

After hiring labor and producing, firms decide the investment policy in physical capital, given that the existing capital stock depreciates at the rate δ. In equilibrium, capital accumulation follows the standard law motion for capital $\mathrm{K}_{j,t+1} = (1-\delta)\mathrm{K}_{j,t} + \mathrm{I}_{j,t}$, where $\mathrm{I}_{j,t}$ is the amount of new investment in capital stock. I assume that the price of investment p^I_t is fixed and it is normalized to 1. To generate a more realistic firm size distribution I assume that firms face adjustment costs whenever they invest or divest in new capital:

$$\mathcal{G}\left(\mathrm{K}_{j,t+1}, \mathrm{K}_{j,t}\right) = c_0 \left(\frac{\mathrm{K}_{j,t+1} - (1-\delta)\mathrm{K}_{j,t}}{\mathrm{K}_{j,t}} \right)^2 \mathrm{K}_{j,t} + c_1 \mathbb{1}_{\mathrm{I}_{j,t} \neq 0}, \tag{4}$$

where $\mathbb{1}_{\mathrm{I}_{j,t} \neq 0}$ is an indicator that equals one if firm investment is different from zero and c_0 and c_1 are two parameters controlling the strength of the adjustment costs. The functional form $\mathcal{G}$ is made up of two terms. The first term is a quadratic adjustment cost which generates slow convergence to the optimal firm size implied by the decreasing returns to scale assumption and idiosyncratic productivity. The second term adds a non-convex adjustment cost component which introduces periods of inaction in the firms' investment choices, Doms and Dunne (1998). The presence of adjustment costs brings two advantages to the model. First, allow imperfect correlation between firm size and idiosyncratic shocks by introducing the desire to smooth firms' investment in the model. In a world without adjustment cost, the optimal choice of capital would only depend on the conditional expectations of firms' future productivity, making firms continuously adjust capital every period, at odds with the

[28] The aggregate productivity shock follows an auto-regressive process in logs and it is used to generate a TFP-induced recession in the model.

firms' behavior in the data. Second, it introduces a forward-looking component in investment choice by creating a positive correlation between investment and expected marginal-Q, which is missing in the absence of real frictions.

Financial frictions. Each firm jointly decides the capital to buy for the next period and its financing policy. As a means of financing investment, firms rely on both internal and external funds, which are represented by corporate bonds $\mathrm{B}_{j,t}$ offered at a discount and new equity issuance. Firms prefer debt over equity financing because of a tax advantage[29]. The corporate tax rate is denoted by τ. Internal financing is represented by the cash flows generated from production net of debt repayment and tax saving and, it is the preferred source of firms' financing in the model because of the absence of transaction costs. The total source of internal financing available to a firm after production, debt repayment and taxes at the beginning of every period is:

$$\Pi = (1-\tau)\max_{\mathrm{N}_{j,t}\geq 0}\left\{p_t^w \mathrm{Z}_t \varepsilon_{j,t}\mathrm{K}_{j,t}^{\alpha}\mathrm{N}_{j,t}^{\nu} - w_t \mathrm{N}_{j,t}\right\} - \eta - \mathrm{B}_{j,t} + \tau\left(\delta \mathrm{K}_{j,t} + i_t \mathrm{B}_{j,t}\right) \tag{5}$$

The first term is the after taxes operating profits gross of the cost of debt; the second term is the amount that firms have to repay to the bondholders at the beginning of every period t; the last term is the tax rebate from issuing debt and depreciating capital. The parameter η is a fixed cost of production introduced in the model to match the cross-sectional moments in the data.

Beyond internal funds, firms have access to the bond market. Firms can finance investments by issuing one-period corporate bonds at discount. The price of debt is $\mathcal{Q}$ and it is firm-specific and determined in equilibrium by a financial intermediary.[30] Because debt is risk-free, bondholders require firms to be able to repay their debt in every state of the world, Hennessy and Whited (2007). This is guaranteed by introducing a ceiling on the maximum amount of resources that firms can collect on the bond market for financing investment. I follow Jeenas (2018b) and Buera and Moll (2015), I assume that debt is constrained to be less than a fixed

[29]Because of tax advantage, Modigliani-Miller's theorem does not hold and firms choose to finance investment by issuing debt over equity.

[30]Since I do not restrict debt to be positive, $\mathrm{B}_{j,t}$ can take both positive or negative values, with a positive value denoting debt and a negative value denoting cash.

fraction of the future capital stock.[31]

$$\mathrm{B}_{j,t+1} \leq \theta_k \mathrm{K}_{j,t+1} \tag{6}$$

This linearity in the ceiling on debt introduces two elements. First, it directly limits the maximum leverage that a firm can achieve next period at value θ_k. Second, as explained in DeAngelo et al. (2011), the presence of a forward-looking variable in the ceiling constraint adds value to the financial flexibility in the future. This effect will affect the firms' optimal decision for capital and debt in the model.

Finally, firms can raise funds by issuing new equity shares. Equity issuance is more expensive than debt financing and arises just when current investment opportunities justify the additional cost. To introduce that, I first define dividends in the model. The amount of dividends paid to the shareholders after issuing debt and investing in new capital is:

$$\mathcal{D} = \Pi(\varepsilon_{j,t}, \mathrm{K}_{j,t}, \mathrm{B}_{j,t}) - \mathcal{G}\left(\mathrm{K}_{j,t+1}, \mathrm{K}_{j,t}\right) - \mathrm{I}_{j,t} + \mathcal{Q} \cdot \mathrm{B}_{j,t+1} \tag{7}$$

If $\mathcal{D}$ is positive it means that firm distributes positive dividends to the shareholders while if it is negative, it means that firm is collecting external resources from the household by issuing new equity. However, to ensure that equity issuance is infrequent in the model, I assume firms incur additional costs when raising new equity funds. I assume that the firm pays a quadratic cost to raise external equity funds, which is as follows:

$$\mathcal{H}\left(\mathcal{D}\right) = \left(a_0 + a_1 \mathcal{D}_{j,t}^2\right) \mathbb{1}_{\mathcal{D}_{j,t}<0} \tag{8}$$

The cost of external finance is zero if a firm decides to distribute dividends. At the same time, it is positive, and it marginally increases in the amount of new issuance if a firm is receiving injections of funds from the shareholders, consistent with the empirical findings in Altınkılıç and Hansen (2000). The parameters a_0 and a_1 control the degree of financial friction[32]. The equity payout left to the shareholders is equal to the dividends net of equity issuance cost.

[31] In Hennessy and Whited (2007) debt is collateralized by the following period operating profits to guarantee that firms always can repay their debt. In contrast, in Khan and Thomas (2013) the maximum debt is constrained to a fraction of the value of current capital, which resembles the idea that smaller firms can borrow less today.

[32] In the literature, it is common to introduce also a fixed cost of equity issuance as in Hennessy and Whited (2007). In the calibration, I set the fixed cost of equity issuance to zero to avoid a jump in the value function.

4.2 Financial intermediary

The household owns a representative, perfectly competitive financial intermediary. The financial intermediary transfers household deposits to firms in the form of zero-coupon bonds. To introduce a premium on the corporate bond, I assume that the intermediary charges a premium Φ above the safe-interest rate on the cost of borrowing $\mathcal{R}_t^b$ which is $\mathcal{R}_t^b = (1 + i_t)\,\Phi$. The premium Φ depends on the riskiness of the firm, as proxies by leverage, and the attitude towards riskier firms of the financial intermediary. The premium Φ is subject to an exogenous shock $\varepsilon_t^{\text{risk}}$ that captures an exogenous change in the premium due to a change in the financial intermediary attitude towards risk. A positive shock to $\varepsilon_t^{\text{risk}}$ thus, decreases the premium on holding bond assents regardless of the firms' characteristics hence $\partial\Phi/\partial\varepsilon_t^{\text{risk}} < 0$.

In addition, I allow the shock to produce heterogeneous effects on the price of debt across firms. If a positive shock $\varepsilon_t^{\text{risk}}$ occurs, the premium charged by intermediaries may increase in the amount of firms' leverage hence $\partial\Phi/\partial\varepsilon^{\text{risk}}\partial\text{lev}' \geq 0$. This assumption wants to capture the idea that as the risk-premium falls in the market, financial intermediaries may prefer less risky assets, resulting in a higher benefit for those firms with low levels of leverage.[33] I specify a functional form for Φ in the calibration section and estimate its' parameters to match the heterogeneous response of investment observed in the data. I show that the heterogeneous response of bond market prices to a risk-premium shock is important to explain the empirical findings in the paper.

4.3 The New-Keynesian block

Retailers. There is a unit continuum of retailers indexed by i. Retailers purchase the homogeneous good $\mathrm{Y}_{j,t}$ produced by the wholesale heterogeneous firms at price p_t^w and transform it into a differentiated good $\tilde{\mathrm{Y}}_{i,t}$ using a linear technology $\tilde{\mathrm{Y}}_{i,t} = \mathrm{Y}_{j,t}$. Retailers are subject to Rotemberg quadratic adjustment costs and set the prices $p_{i,t}$ for the differentiated good $\tilde{\mathrm{Y}}_{i,t}$ in a monopolistic competitive market.

Final good producers. There is a unit mass of perfectly competitive final good producers. Final good producers buy a basket of differentiated goods $\tilde{\mathrm{Y}}_{i,t}$ from the retailers at price $p_{i,t}$ and aggregate into a final consumption good using a standard CES aggregator production function. The retailers and the final good producers aggregate to derive the standard New

[33]This is a reduced form to introduce firms' specific excess bond premium in the model without explicitly modeling risk-bearing capacity in the financial system. Also, note that because there is no probability of default, a change in the credit spread in the model is equivalent to a change in the excess bond premium.

Keynesian Phillips curve

$$\log \Pi_t = \frac{\theta - 1}{\phi_p} \log \frac{p_t^w}{p} + \beta \mathbb{E}_t \log \Pi_{t+1} \tag{9}$$

which links gross inflation today Π_t to the expected future path of the retailer marginal cost p_t^w. A complete derivation of the equation (9) is in the Appendix.

4.4 Monetary authority

To introduce a role for the monetary authority, I assume that the central bank sets the nominal interest rate i_t following a standard Taylor rule, that is:

$$\log(1 + i_t) = \log(1 + \bar{i}) + \phi_\pi \log\left(\frac{1 + \pi_t}{1 + \bar{\pi}}\right) + \varepsilon_t^{\text{mps}} \tag{10}$$

where, $\bar{i}$ is the stationary value for the interest rate, and $\bar{\pi}$ is the inflation target. The parameter ϕ_π measures the response of monetary policy to deviations in inflation from its targeted values. Under this assumption, a change in the nominal rate can occur endogenously, if the central bank sees inflation increasing, or exogenously if the central bank deviates temporarily from the systematic Taylor rule.

To map the model to the data I assume that a shock to the Taylor rule $\varepsilon_t^{\text{mps}}$ proxies a pure monetary policy shock while, a shock to the risk-premium $\varepsilon_t^{\text{risk}}$ proxies a non-pure monetary policy shock. This captures the idea that, as the monetary authority engages in non-monetary communication, it affects firms' investment primary through the willingness to take risks and the price of debt in the bond market.

4.5 Household and government

Household. There is a representative household that owns all the firms in the economy. The representative household supplies labor in the market N_t, consumes the output produced C_t, and saves in one-period deposits D_t. Household maximizes the discounted sum of the future utility, taking the wage w_t and the interest rate i_t as given. The household utility function is additive and separable in consumption and labor. The household problem is as follows:

$$\max_{\{\mathrm{C}_t, \mathrm{N}_t, \mathrm{B}_t\}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{\mathrm{C}_t^{1-\gamma} - 1}{1 - \gamma} - \kappa \mathrm{N}_t \right\} \tag{11}$$

such that

$$\mathrm{C}_t + \mathrm{D}_t = w_t \mathrm{N}_t + \frac{1 + i_{t-1}}{1 + \pi_t} \mathrm{D}_{t-1} + \mathcal{D}_t + \mathcal{D}_t^R + \mathcal{D}_t^F + \mathrm{G}_t \tag{12}$$

where $\mathcal{D}_t$, $\mathcal{D}_t^R$ and $\mathcal{D}_t^F$ are respectively the dividends payed by the wholesale heterogeneous firms, retailers and final good producers and G_t is the government transfer from firms taxes. The first order conditions of the household problem pin down the Euler equation for consumption, the labor supply and the stochastic discount factor $\Lambda_{t,t+1} = \beta \mathbb{E}_t \left[\frac{\mathrm{C}_t}{\mathrm{C}_{t+1}} \right]$.

Government. I close the model by assuming that there is a government that run a balanced budget constraint every period. For simplicity, I assume that the collected taxes from the firms are rebated to the household in a lump-sum fashion

$$\mathrm{G}_t = \int \tau \left(p_t^w \mathrm{Y}_{j,t} - w_t \mathrm{N}_{j,t} \right) - \tau \left(\delta \mathrm{K}_{j,t} + i_t \mathrm{B}_{j,t} \right) d\Gamma \tag{13}$$

Ricardian equivalence holds in the model, so the precise financing path of the given stream of government expenditure is irrelevant.

4.6 Calibration and estimation

I calibrate the model parameters following the literature. A set of parameters are calibrated based on previous works. In contrast, I estimate the parameters governing real and financial frictions to match the cross-sectional moments of the model's stationary equilibrium to the averages observed in the data. I calculate the average moments to target in the data at the quarterly level as in Jeenas (2018a).

Calibrated parameters. I set the household discount factor $\beta = 0.98$ which implies a roughly 2% nominal interest rate in the stationary equilibrium consistent with the long-term average of the 1-year Treasury yield used in the empirical analysis. I set the depreciation rate $\delta = 0.01$ to match the cross-sectional average of the firms' investment rate in the data at quarterly frequency.[34] I calibrate the firms' production function and the idiosyncratic technological process parameters following Gilchrist et al. (2014) and Jeenas (2018b). I set the capital share $\alpha = 0.255$ and the labor share $\nu = 0.595$ which imply a decreasing returns to scale of 0.85 as commonly used in the literature. I assume that the idiosyncratic productivity ε follows an AR(1) log-normal process $\log \varepsilon_{i,t} = \rho_\varepsilon \log \varepsilon_{i,t-1} + u_{i,t}$, with $u_{i,t} \sim N\left(0, \sigma_\varepsilon^2\right)$. I

[34]Other papers calibrate $\delta = 0.025$ based on the quarterly measure of capital depreciation from the U.S national income and product accounts (NIPA).

discretize the stochastic process for the logarithm of idiosyncratic productivity using the Tauchen (1986) method. I set the auto-correlation parameter $\rho_\varepsilon = 0.785$ and the standard deviation $\sigma_\varepsilon = 0.125$ which are close to the parameters estimates in Gilchrist et al. (2014) on Compustat firms. I follow Bordalo et al. (2021) to calibrate the corporate tax rate $\tau = 0.2$.[35] The maximum leverage parameter θ_k instead is set to guarantee that the next period cash on hand is sufficient to repay the financial intermediaries given the amount of debt chosen. I also use the parameter θ_k as the upper bound of the variable leverage when discretizing the leverage choice. I set the CRRA parameter σ in the representative household utility function to 1 to have a logarithm in consumption. I calibrate the parameters governing the New-Keynesian block following Ottonello and Winberry (2018) instead. I calibrate the elasticity of goods θ to 10, and the price adjustment coefficient cost $\phi_p = 90$, which implies a mark-up in the steady-state equal to 11%. I set ϕ_π, the coefficient on the inflation gap, at 1.25, values in line with those used in the New Keynesian literature. I fix the disutility of labor parameter k to 1.5 to have a value of hours worked in the steady-state close to 0.6. For the quantitative exercise, I set the function $\Phi^{-1} = 1 + \varepsilon_t^{\text{risk}} e^{-\theta_l \frac{B'}{K'}}$ so that in the steady state the price of debt is the same across firms. I estimate the parameter θ_l to 1.5 to produce a differential response of firm-level investment to a non-pure monetary policy shock of approximately 1% consistent with figure (3.b).[36] Finally, I calibrate the parameters of the aggregate shocks to match the persistence and the effect of the dynamic response observed in the data. A summary of the calibrated parameters used in the model is in the table (2.A).

Estimated parameters. The parameters $(\eta, c_0, c_1, a_0, a_1)$ governing the fixed cost of production, the real and the degree of financial frictions are estimated using simulated method of moments to match a set of empirical moments drawn from Compustat. I choose the moments to target based on the previous works in the literature and perform a sensitivity analysis before estimation to ensure that the target moments are informative about the structural parameters.

I target the average leverage, as defined earlier in the empirical analysis, the average return on capital[37] at the quarterly frequency as in Hennessy and Whited (2007) which are informative about the fixed cost of production and the degree of quadratic adjustment cost. I also target the inaction rate of investment, defined as the percentage of the firms with an

[35] They estimate the corporate tax rate based on the (CBO) (2017) data. Other papers in the literatue have calibrated τ in an interval between 0.15 and 0.35, Graham (2000), Begenau and Salomao (2019).

[36] Alternatively, one could estimate θ_l in the model to match the heterogeneous response observed in the data after simulation. I avoid this procedure as it is intensive computationally.

[37] I calculate the average return on capital in Compustat as the ratio of total dividends, cash dividends plus equity repurchases, and total assets.

Table 2: Summary of the parameters in the model

Parameters	Description	Value	Target
A. Calibrated			
β	Discount factor	0.98	2% risk-free rate
δ	Depreciation rate	0.01	Average investment rate
α	Capital share	0.255	Jeenas (2018)
ν	Labor share	0.595	Jeenas (2018)
τ	Corporate tax	0.2	Bordalo et al. (2021)
κ	Labor disutility	1.5	SS Labor ≈ 0.6
σ	CRRA coefficient	1	Log Utility Consumption
ρ_ε	Productivity persistence	0.785	Gilchrist et al. (2014)
σ_ε	Productivity dispersion	0.125	Gilchrist et al. (2014)
θ	Goods substitutability	10	Ottonello, Winberry (2018)
ϕ_p	Price adjustment cost	90	Ottonello, Winberry (2018)
ϕ_π	Taylor rule inflation coefficient	1.25	Ottonello, Winberry (2018)
B. Estimated			
η	Fix cost of production	0.054	Average leverage
c_0	Non-convex adjustment cost	0.125	Average dividends/total assets
c_1	Quadratic adjustment cost	4.9	Inaction rate
a_0	Fix issuance cost	0	
a_1	Quadratic issuance cost	12.54	Frequency equity issuance
θ_k	Max leverage	0.988	Maximum leverage

Note: I report the calibrated and the estimated parameters of the model in panel A and panel B. The values of the targeted moments are calculated at quarterly frequency from Compustat data.

investment rate lower, in absolute value, than one-tenth of the average investment rate in the data as in Khan and Thomas (2013). The rate of inaction is informative about the real friction parameters and, in particular, about the fixed cost component of investment, and it is a common target in the investment literature. Finally, I target the percentage of firms that issue equity in the data which is the share of firms that report having raised funds from the issuance of common and preferred stock in Compustat as in Hennessy and Whited (2007) and Begenau and Salomao (2019). This moment is informative to pin down the structural parameters governing the degree of financial frictions in the model. Intuitively, an increase in the equity issuance component a_1 raises the firms' cost of equity financing, and therefore, it reduces the share of financially constrained firms in the model[38].

The estimation procedure returns the following estimated parameters: the quadratic adjustment cost parameter $c_0 = 4.9$, the non-convex adjustment cost parameter $c_1 = 0.125$,

[38]Hennessy and Whited (2007) target this moment along with the first and second moments of the ratio of equity issuance to assets, the frequency of negative debt, and the co-variance between equity issuance and investment to pin down the level, the slope and the curvature of equity issuance costs in a similar model to mine.

the fix cost of production $\eta = 0.054$ and the quadratic issuance cost $a_1 = 12.54$. These estimates are in line with other papers in the literature. The table (2.B) reports a summary of the parameters that are estimated and the target moments.

5 Financial frictions in the model

The presence of equity issuance cost is the main source of financial frictions in the model. To see this, I write the firms' problem using the Bellman equation. I denote with $\{\varepsilon, \mathrm{S}\}$ the set of state variables $\{\varepsilon, \mathrm{K}, \mathrm{B}\}$ for a firm j and with a $'$ a variable tomorrow. At the beginning of every period t, each firm solves the following dynamic profit maximization problem subject to a set of constraints:

$$V(\varepsilon, \mathrm{S}) = \max_{\mathrm{K}', \mathrm{B}'} \left\{ \mathcal{D}(\varepsilon, \mathrm{S}, \mathrm{S}') - (a_0 + \frac{a_1}{2}\mathcal{D}^2)\mathbb{1}_{\mathcal{D}<0} + \Lambda_{t,t+1} \sum_{\varepsilon'} \pi\left(\varepsilon'|\varepsilon\right) V'\left(\varepsilon', \mathrm{S}'|\varepsilon\right) \right\} \tag{14}$$

subject to:

$$\mathcal{D}(\varepsilon, \mathrm{S}, \mathrm{S}') = \Pi(\varepsilon, \mathrm{S}) - c_0 \left(\frac{\mathrm{K}'}{\mathrm{K}} - 1 + \delta\right)^2 \mathrm{K} + c_1 \mathbb{1}_{\mathrm{I}\neq 0} - \mathrm{K}' + (1-\delta)\mathrm{K} + \mathcal{Q}\mathrm{B}' \tag{15}$$

$$\Pi(\varepsilon, \mathrm{S}) = \max_{\mathrm{N}\geq 0} (1-\tau)(p_t^w \mathrm{Y} - w_t \mathrm{N} - \eta) - \mathrm{B} + \tau\left(\delta \mathrm{K} + i_t \mathrm{B}\right) \tag{16}$$

$$\mathcal{Q}\left(\mathrm{S}'\right) = \frac{1 + \varepsilon_t^{\text{risk}} e^{-\theta_l \frac{\mathrm{B}'}{\mathrm{K}'}}}{1 + i_t} \tag{17}$$

$$\mathrm{B}' \leq \theta_k \mathrm{K}' \qquad (\lambda') \tag{18}$$

where $V(\varepsilon, \mathrm{S})$ is the value of a firm at the beginning of the period, $\Pi(\varepsilon, \mathrm{S})$ is the cash on hand available to finance investment, $\mathcal{D}(\varepsilon, \mathrm{S}, \mathrm{S}')$ are the dividends to the shareholders, and λ' is the multiplier associate to the non-binding constraint on debt.

The introduction of equity issuance cost implies a natural way to define the level of financial friction faced by a firm in the model.[39] At the beginning of every period, firms are distinct by the internal funds available to finance investment. I define a firm as *financially unconstrained* (or, with low level of financial friction) if it has accumulated enough internal resources to finance new investment through only cash on hand and new debt issuance. Unconstrained firms never issue equity since it is costly and find it optimal to pay dividends to the shareholders by raising debt, $\mathcal{H} = 0$. I define a firm as *financially constrained* (or,

[39]This distinction is the same as in Rojas (2018) which defines the financing gap of a firm as the difference between resources needed to operate and invest minus the resources available to do so.

with high level of financial friction) instead if at the optimum it does not have accumulated enough resources to buy capital K' through debt and cash, and they find optimal to issue equity to forego investment. Constrained firms never distribute dividends to the shareholders and pay an external premium to raise funds through equity, $\mathcal{H} > 0$.[40]

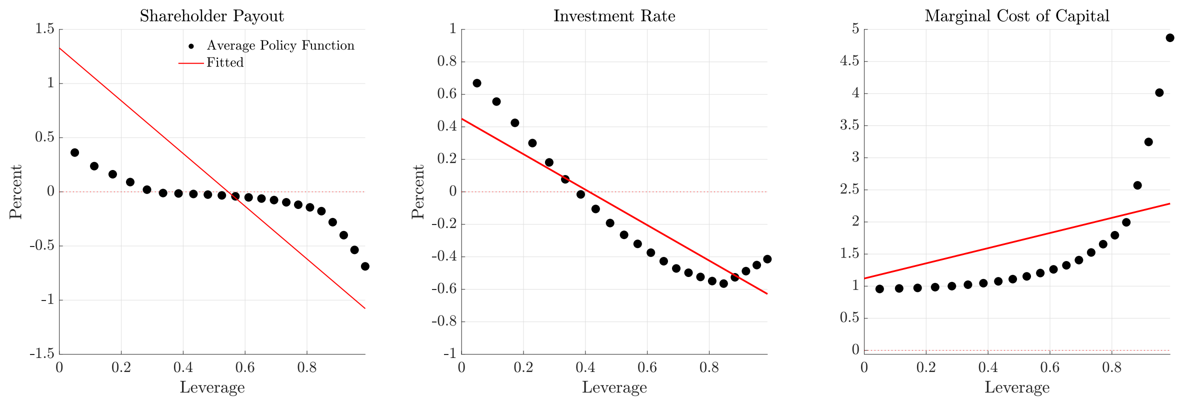
The steady-state policy functions for capital and equity issuance along the leverage dimension shows a linkage between firms' leverage, and financial frictions that is important to understand the results in the empirical part of the paper. I report that in figure (4). Figure (4) shows two main facts. First, given a fixed amount of capital, high leverage firms are more likely to be financially constrained (first column). In the stationary equilibrium, low leverage firms are more likely to pay dividends to the shareholders while high leverage firms are more likely to issue equity to finance investment. The intuition is that firms with a high level of debt are not generating enough resources via debt and internal resources, and so they find optimal financing investment by issuing equity. Whereas firms with a low level of debt can sustain their optimal investment policy without relying on equity issuance and thus, distribute dividends to the shareholders. Second, figure (4) shows that firms' financing decisions and investment choices are intimately connected (second column). Investment rates are decreasing in the amount of leverage, given a fixed amount of capital. This is because, as firms with a high level of debt are more likely to raise funds through equity, high leverage firms would find raising one additional unit of capital more costly (third column) and thus, they optimally reduce their size in equilibrium.

Model steady-state policy predictions in figure (4) are consistent with the equivalent in the data. I construct actual steady-state policy in the data computing the long-term averages of leverage, equity issuance, dividends payout and investment rates for each firm in my dataset from 1990 to 2016. I plot the cross-sectional correlation between firms' leverage and dividends payout, equity issuance, and investment rates in Appendix, figure (25). As in the model, the data shows a very strong relationship between firms' leverage, payout policy and equity issuance. In the long run, firms with high leverage are the ones that, on average, pay fewer dividends to the shareholders and, at the same time, are more likely to issue equity to finance their activity, in line with the previous works of Fazzari et al. (1987).[41] Besides, from figure (25), firms with high leverage have lower investment rates, presumably because they find raising funds to finance long-term investment policies more costly, which is consistent with using leverage as a measure of financial friction.

[40] This definition is similar to the one of Ottonello and Winberry (2018) and Jeenas (2018a)

[41] Based on this evidence Cloyne et al. (2018) suggest identifying financially constrained firms as young firms that do not pay dividends in last three years.

Figure 4: Dividend policy and the marginal cost of capital in the steady state.



Note: I plot the average shareholder payout, investment rate (in percentage points) and the cost of capital (marginal cost of capital divided by capital) function in the stationary equilibrium along the leverage dimension. The idiosyncratic productivity is fixed at the steady state level and, for all three plots, I average the policy functions across firms that weight in the population distribution for more then 1% of total capital. For each subplot, I add a linear fitted line (red line).

6 Quantitative analysis

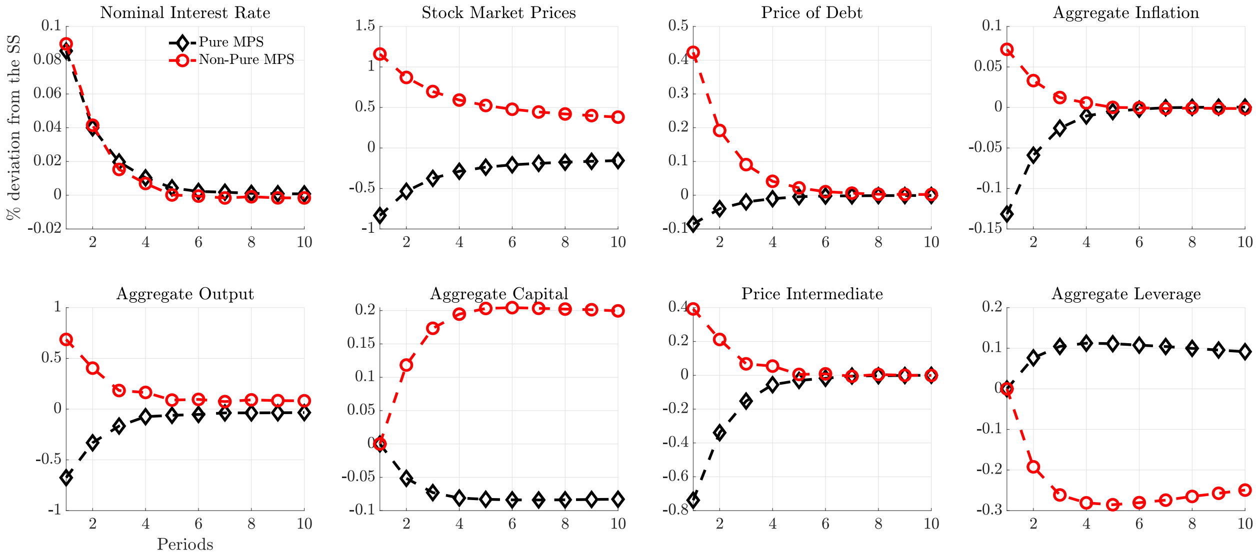
This section studies aggregate implications and provide an explanation of the findings in the empirical part of this paper. Section 6.1 reports the aggregate impulse response function to different monetary policy surprises in the model. Section 6.2 and 6.3 tests heterogeneous sensitivity in the model and provide a explanation of the mechanism using the optimal condition for capital. Section 6.4 explore the heterogeneous responses of bond prices to a risk premium shock and provide a set of counterfactual experiments. Section 6.5 revisits the distributional effects of a pure monetary policy shock depending on the market response.

6.1 Aggregate impulse response in the model

The model can qualitatively match the aggregate impulse responses observed in the data. To do that, I study the aggregate effects of different interest rate surprises along the perfect foresight transition path back to the steady-state. At time t a policy shock arises and the economy temporary departs from its steady state and slowly comes back to equilibrium as in Jeenas (2018a) and Ottonello and Winberry (2018). The impulse response function are obtained simulating a transition path back to the steady state after 100 periods.[42] In order to have comparable results across simulations, I calibrate the standard deviation and the persistence parameters of the two exogenous components to increase the nominal interest

[42]More details of the algorithm are in the Appendix.

Figure 5: The baseline IRFs in the model



Note: The impulse response function to different monetary policy surprises in the model. The black line shows the response of the aggregate variables to an interest rate surprise purely driven by a pure monetary policy shock. The red line represents the aggregate response to an interest rate surprise fully driven by a non-pure monetary policy shock. All responses are in percentage deviation for the steady state.

rate at impact by roughly 0.1% and to induce a temporary fluctuations for around eight quarters in the model.[43] I plot the impulse responses to the two shocks in figure (5).

In the event that the monetary authority unexpectedly raises the nominal interest rate (i.e., pure monetary policy shock), a monetary shock leads to the contraction of output, consumption, and labor in the model. Because prices are sticky, they are slow to adjust, inflation and the price of the intermediate output falls, decreasing incentives to invest in new capital. Firms divest since the marginal benefit of capital decreases as the discounted return on future capital and the expected output decline. Furthermore, in response to a Taylor rule shock the cost of raising funds on the bond market increases, and firms that were hit by the shock experience a decline in their cash on hand. In turn, a decline in the amount of internal resources leads firms to raise more funds externally, i.e., via debt and equity issues. It follows that the distribution of firms over leverage shift towards the right hand-side.

A non-pure monetary policy shock (red line) instead, leads the economy on a pattern similar to an expansionary demand shock and it operates mainly through the cost of borrowing. A non-pure monetary policy shock decreases the risk-premium in the bond market thus, increasing the price of corporate bonds. Higher price of bonds increases the marginal benefit

[43] Ottonello and Winberry (2018) calibrates the persistence of the monetary shock to be 0.5.

of debt and decrease in the marginal cost of capital. Differently from a pure monetary shock, labor and output increase and prices slowly adjust upward, producing a period of inflation. As a result of higher inflation, the Fed reacts by increasing the nominal interest rate. Firms increase investment because the shock increases firms operating profits and lower the marginal cost of financing new capital at debt. Since firms in expectations increases the capacity to generate profits and dividends, stock market price increases along the transition path. Both shocks produce a response in the economy consistent with the aggregate impulse responses obtained in figure (11) in the Appendix.

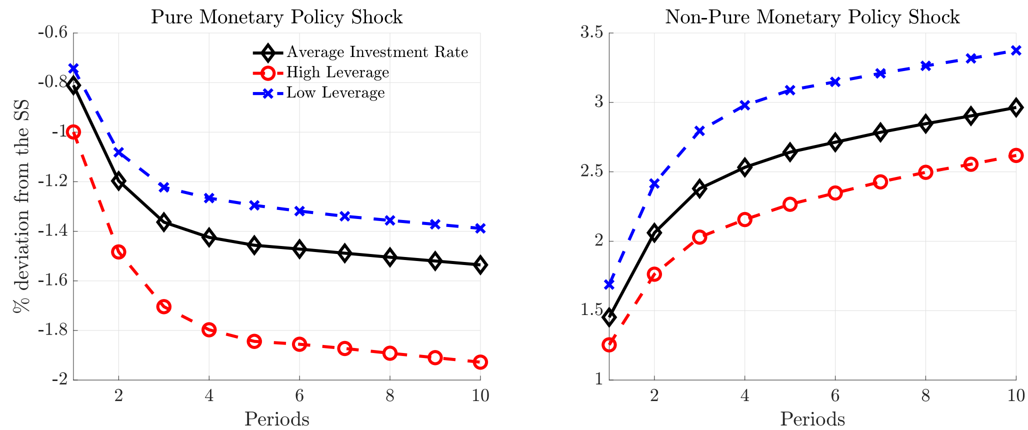
6.2 Heterogeneous response of investment

In the previous section, I show that the aggregate impulse responses predicted by the model are consistent with the data. Here, I show that the model also accounts for the heterogeneous responses to the two shocks at the firm level. To see this, I examine the response of investment at the firm level to the two shocks. I group the firm-level responses based on past leverage into two bins. I consider firms to be low leverage if their leverage is lower than 50 percent and high if their leverage exceeds 50 percent. In order to obtain an average estimate of the sensitivity of firms to the shock, I average the response of investment across firms within the same category (i.e., high or low leverage).[44] I plot the average responses to the two shocks in figure (6).

The figure (6) illustrates that firms with different leverage respond differently to the shocks in the model, consistent with the empirical findings documented in this paper. In particular, in response to a one standard deviation pure monetary policy shock (first graph), firm investment rate drops by around 0.8pp at impact (black line). Firms with different levels of leverage respond differently to the shock. Low leverage firms reduce their investment rates by almost 10 percent less than the average (blue dotted line). Viceversa, firms with high levels of leverage reduce investment rates by 20pp more than low leverage firms at the time of the impact (red dotted line). In response to a non-pure monetary policy shock instead, firm investment rates increase by around 1.5 percent points at impact (black line). In the cross-sections, firms with low levels of leverage prior the shock increase their investment rates by 10 percent more than the average (blue dotted line), while firms with high levels of leverage increase their investment rates by 10 percent less than the average (red dotted). These results are consistent with previous results in the empirical part of the paper.

[44] I only consider firms that constitute more than 1 per cent of the total number of firms in the stationary distribution.

Figure 6: Heterogeneous firm-level response in the model



Note: The average cumulative impulse response function for investment rate across firms. The black line represents the average firm-level response of the investment rate respectively to a pure monetary policy shock (first graph) and non-pure monetary policy shock (second graph). The blue line shows the average firm-level response of the investment rate for firms that have less than 50% of leverage (i.e., low leverage). The red line illustrates the average response of the investment rate at the firm level for firms with more than 50% leverage (i.e., high leverage). The averages are calculated by equally weighting firms that constitute more than 1 percent of the total firms.

6.3 Explaining the mechanism

The intuitions behind the heterogeneous investment responses in figure (6) can be understood by looking at the first order condition for capital and how different monetary shocks affect firms' financial positions across firms, which I plot respectively in figures (7) and (8). The optimality condition for capital across firms can be obtained by differentiating the Bellman equation (14) for K' and combining with the respective envelope condition.

$$\left(1 + c_0 \frac{\mathrm{I}}{\mathrm{K}} - \underbrace{\varepsilon_t^{\text{risk}} e^{-\theta_l \text{lev}'} \theta_l \cdot \text{lev}'^{,2}}_{\approx 0}\right)(1 - a_1 \mathcal{D} \mathbb{1}_{\mathcal{D}<0}) =$$
$$\Lambda_{t,t+1} \mathbb{E}\left[\Pi_k(\varepsilon', \mathrm{K}') + (1-\delta)\left(1 + c_0 \frac{\mathrm{I}'}{\mathrm{K}'}\right) + \frac{c_0}{2}\left(\frac{\mathrm{I}'}{\mathrm{K}'}\right)^2\right](1 - a_1 \mathcal{D}' \mathbb{1}_{\mathcal{D}'<0}) - \theta_k \lambda' \tag{19}$$

The term on the left-hand side of the equation (19) is the marginal cost of capital that is increasing in the amount of capital to purchase for the next period K' and, varies among constrained and unconstrained firms. In particular, firms issuing equity ($\mathcal{D} < 0$) face higher and steeper marginal cost of capital (i.e. $a_1 |\mathcal{D}| \mathbb{1}_{\mathcal{D}<0}$ is positive). It follows that low-leveraged firms, that do not issue equity, are more sensitive to variations in the marginal benefit of capital. Intuitively, this is because firms that rely on equity financing to finance investment find increasing capital by one unit more expensive than unconstrained firms. The right-hand side of the equation (19) is the marginal benefit of capital instead. The marginal benefit of capital is decreasing in K' because of diminishing return of capital and it is higher if a firm is expected to equity issuance in the future. Equation (19) provides a simple intuition to explain the heterogeneous response of investment to different type of policy shocks observed in the data.

Pure monetary policy shock. The mechanism behind the investment responses in figure (6) to a pure monetary policy shock is similar to the one in Ottonello and Winberry (2018). In the event of a Taylor rule shock, the nominal interest rate increases exogenously and the economy moves on a recessionary path. As prices do not adjust fast enough, this eventually transfers to the real interest rate, which increases as well. As the real interest rate increases, the stochastic discount factor falls together with lower marginal profit of capital and the marginal value of increasing capital by one additional unit tomorrow declines. Therefore, firms are prone to reducing their investment (i.e., *interest channel*), regardless of their level of leverage.

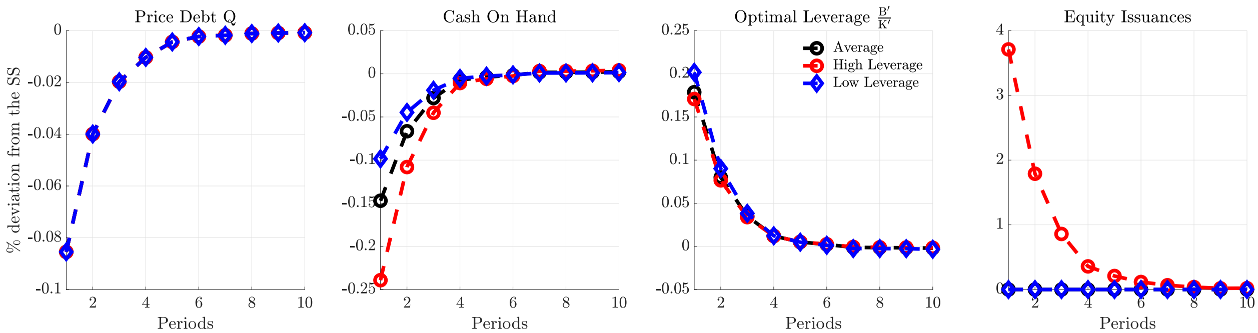
However, firms may react differently to shocks in the cross-section. In a partial equilibrium setting and without additional forces, high leveraged firms (or financial constrained firms) would be less adversely affected by the shock because they face a steeper marginal cost of capital curve than low leverage firms (high leverage firms are more likely to embark on equity issuance).[45] However, a pure monetary policy shock results in a decrease in operating profits Π, as a result of a decrease in labor and output, and an increase in borrowing costs on newly issued debt (i.e., Q falls). A decrease in firms' operating profits and cash-on-hand will result in firms becoming more dependent on external financing in order to replace their new investments.

Firms with low leverage prior to the shock do not suffer much from a fall in their operating profits since they have sufficient cash to offset it. Conversely, high leverage firms, that are already dependent on external financing, respond to this by increasing their equity issuance, resulting in an increase in marginal costs of capital, which further reduces investment.[46] High leverage firms would be more sensitive to this second effect if a drop in their cash-on-hand is strong enough to offset the steeper marginal cost of capital for these firms. Figure (7) plots

[45] This is the mechanism prevalent in Ottonello and Winberry (2018).

[46] This mechanism is equivalent to the one in the model of Ottonello and Winberry (2018) with risky debt. In a model with risky debt, high leverage are more sensitive to a policy hike if a change in the nominal rate significantly affects firms' probability of default and thus, their price of debt. In a model with risk-free, the heterogeneous mechanism is more general in the sense that it only requires a firms' shift towards more expensive source of external financing.

Figure 7: Financial variables response to a $\varepsilon_t^{\text{mps}}$ shock



Note: The average impulse response function for the price of debt, debt and equity issuance across firms in response to a pure monetary policy shock. The blue line shows the average firm-level responses of the main variables for firms that prior the shock have less than 50% of leverage (i.e., low leverage). The red line illustrates the average response for the same variables for firms with more than 50% leverage (i.e., high leverage). The averages are calculated by equally weighting firms that constitute more than 1 percent of the total firms.

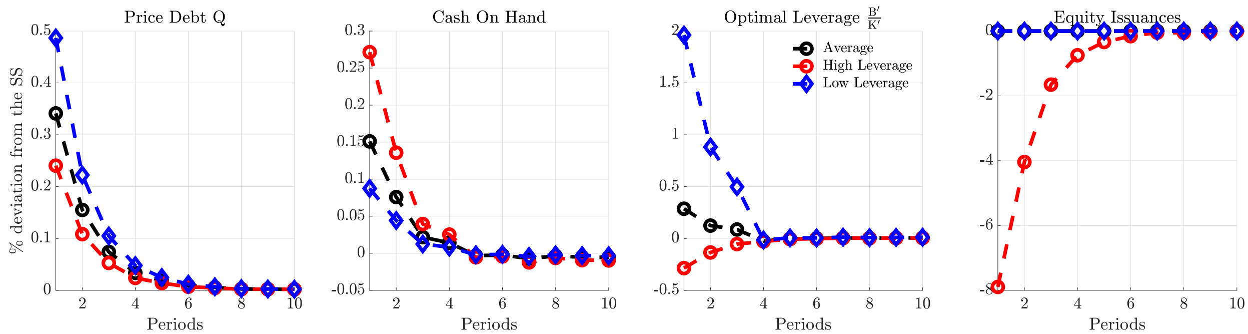
the responses for the key financial variables, cash on hand, equity and debt across firms with different levels of leverage after a pure monetary policy shock.

Non-pure monetary policy shock. The mechanism behind the investment responses in figure (6) to a non-pure monetary policy shock is novel instead. In the event of a non-pure monetary policy shock $\varepsilon_t^{\text{risk}}$, the price of corporate bonds rises exogenously and the economy moves on an expansionary path. A shock to $\varepsilon_t^{\text{risk}}$ produces two main effects on the firms' optimal decisions. First, on average, firms increase their debt exposure B' because rising bond prices increase the marginal benefit of debt, making it more attractive for all firms (e.g., they can issue more debt to raise more money). Second, firms start to accumulate more capital K' as the expected marginal benefit of capital tomorrow increases due to higher expected profits in the future (e.g., firms foresee an improvement in future economic conditions).

Based on their initial leverage, different firms will, however, have different incentives to raise capital in response to the shock. First, a positive $\varepsilon_t^{\text{risk}}$ shock increases the marginal benefit of capital through general equilibrium forces.[47] Similarly to the previous case, firms with low leverage experience a greater response of investment to $\varepsilon_t^{\text{risk}}$ because they face a flatter marginal cost of capital curve (i.e., firms with low leverage are more likely to raise capital without relying on equity issuance $\mathcal{D} > 0$ in equilibrium). It follows that, in all other respects, low-leverage firms tend to respond more strongly to an exogenous increase in the price of debt.

[47]Even though the real interest rate increases, an improvement in the future economic conditions dominates the negative effect on the marginal value of capital due to the stochastic discount factor.

Figure 8: Financial variables response to a $\varepsilon_t^{\text{risk}}$ shock



Note: The average impulse response function for the price of debt, debt and equity issuance across firms in response to a non-pure monetary policy shock. The blue line shows the average firm-level responses of the main variables for firms that prior the shock have less than 50% of leverage (i.e., low leverage). The red line illustrates the average response for the same variables for firms with more than 50% leverage (i.e., high leverage). The averages are calculated by equally weighting firms that constitute more than 1 percent of the total firms.

Second, a positive $\varepsilon_t^{\text{risk}}$ shock decreases the marginal cost of capital for all firms depending on their future optimal leverage.[48] This effect, however, is ambiguous and negligible in the cross-sectional distribution, as a result of the functional form assumed for the price of debt. The effect is ambiguous because non-pure monetary policy shocks increase the price of debt more in low leverage firms (tomorrow) than in high leverage firms, but those firms are less likely to increase their leverage position to avoid increasing the probability to issue costly equity issuance in the future. Because the combined effect of the two quantities is approximately zero, the overall effect is negligible.

However, as in the previous case, the heterogeneity of investment responses to a non-pure monetary policy shock may be ambiguous across firms. By saving on equity issuance costs, high-leverage firms may also experience a significant drop in their marginal cost of capital that can lead them to experience a larger increase in their investment positions. There are two different forces at work here. First, similar to the previous case, a positive $\varepsilon_t^{\text{risk}}$ increases firms' operating profits and cash-on-hand along the transition path. Firms with high leverage can use those resources to save from equity issuance costs, improving their financial conditions (i.e., *cash effect*). Second, a positive $\varepsilon_t^{\text{risk}}$ shock increases the marginal benefit of debt, pushing firms to raise more debt B' (i.e., for each unit of new debt issued they will collect more resources). As the marginal benefit of debt increases, firms have a stronger incentive to raise funds externally on the bond market. Firms with low leverage use debt issuances to finance

[48] If a firm decides to raise one additional unit of capital today, the price of debt increases proportionally to the elasticity of the price of debt to leverage. In other words, higher capital in the future increases the price of debt on new bond issuance and thus, reduces the cost of capital.

new investments and pay dividends to shareholders. In contrast, high-leverage firms find optimal to utilize new debt issuance to repay equity issuances. As high-leverage firms repay equity, they reduce their marginal cost of capital proportionally to their equity issuance costs, Strebulaev et al. (2012). In the event that those effects are sufficiently strong, high leverage firms may experience a significant drop in their marginal cost of capital, which may provide higher incentives to these firms to increase their investment levels. I will show that this has implication for the dynamics of investment in the next section.

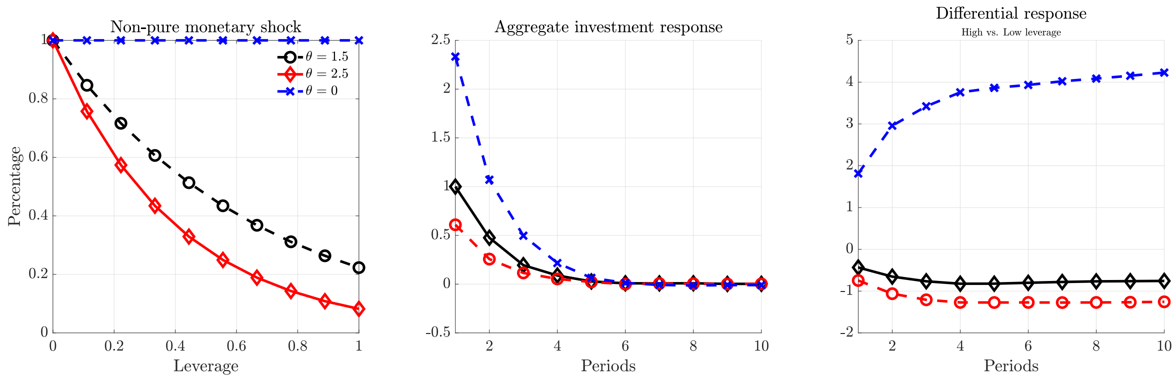
6.4 A counterfactual experiment

As observed in the previous section, heterogeneous responses of bond prices to a non-pure monetary policy shock are crucial to explain the heterogeneity of firm-level investment observed in the data. With the price of debt being less sensitive to risk premium variations, high-leverage firms have less incentive to increase their debt positions and replace it with equity issuance. Nevertheless, high-leverage firms in the model have a larger propensity to invest, since they face a relatively steeper marginal costs of capital curve. This implies that if the price of debt for high leverage firms increased more in response to an $\varepsilon_t^{\text{risk}}$ shock, they would be able to save out of financial frictions, thus increasing their capital position by more. This source of heterogeneity is therefore, a dampener for non-pure monetary policy shocks. To quantify the dampening effect of this channel, I simulate the response of aggregate investment to the same shock using different parameters of θ_l. The parameter θ_l in the price of debt function controls the extent to which high leverage firms benefit less from a change in the risk premium. I compare the results on aggregate and average investment of the benchmark model, $\theta_l = 1.5$, with two different values of $\theta_l = \{0, 2.5\}$.

The results are in figure (9). Black lines indicate the results of the benchmark case. In the benchmark model $\theta_l = 1.5$, a shock to the risk premium affects the price of debt for high-leverage firms 4 time less than it does for a firm at 0 leverage. It follows that investment increases in the economy (i.e., I standardize the increase at 1pp at impact) and low-leverage firms contribute relatively more to the aggregate response.

If $\theta_l = 0$ (blue line), non-pure monetary policy shocks increase debt prices equally across firms, regardless of the future leverage conditions. Now, firms with high-leverage have greater incentives to acquire more resources from the bond market to replace equity issuance. As high-leverage firms reduce their reliance on external equity issuance, they experience a decrease in their marginal cost of capital, thereby increasing their capital position. There are two effects that follow from this. First, high-leverage firms will be more sensitive to

Figure 9: Counterfactual experiments to a $\varepsilon_t^{\text{risk}}$ shock



Note: The results to a set of counterfactual experiments in the model for various values of θ_l. Black lines represents benchmark calibration, $\theta_l = 1.5$. Blue lines represents the model responses when $\theta_l = 0$. Red lines represents the model responses when $\theta_l = 2.5$. I report the heterogeneous effects of the shock along the leverage dimension in the first graph. The second graph illustrates the aggregate response to investment. All aggregate responses are rescaled so that aggregate investment increases by one percentage point under the benchmark case. In the third graph, the average differential firm leverage response of the investment between high and low leverage firms. The averages are calculated by equally weighting firms that constitute more than 1 percent of the total firms.

non-pure monetary policy shocks and will increase their investments more than low-leverage firms (third column). Second, because high leverage firms increase investment by more, aggregate investment increases significantly more in response to the shock. According to my calibration, aggregate investment would increase more than twofold if $\theta_l = 0$, as compared to the benchmark case.

If $\theta_l = 2.5$ (red line) instead, non-pure monetary policy shocks worsen the lower sensitivity of high leverage firms to price shocks. Firms with higher leverage find that issuing debt is even less beneficial compared to the benchmark case. Because of this, the differential investment response between high and low leverage decreases more, and aggregate investment increases by around 40 per cent less than in the benchmark scenario.

6.5 Revisiting the state dependency of monetary policy

I use the model to revisit the distributional effects of monetary policy. Previous literature has focused on studying the effect of monetary policy in a recession compared to normal times without taking into account the potential confouding effect of a non-pure monetary policy component (Koby and Wolf (2020), Ottonello and Winberry (2018)). In practice however, as the Fed releases an easing statement, investors may misinterpret the information released triggering an negative shock.[49] Because this shock produces direct effects on the marginal

[49] In the Appendix, figure (22), I show that this case is indeed widespread from 1990 to 2016.

cost of capital and distributional effects over time, the effectiveness of an expansionary Taylor rule shock in a recession may be dampened by a negative market response.

I study the response of aggregate investment to different types of (expansionary) monetary policy surprises in a recession and compare them in normal times. I consider two types of monetary policy surprises. One with a positive one standard deviation Taylor rule shock with no contamination and, a second surprised, mixed with a negative market response (half stanrdad deviation). I simulate separately the transition path of the two monetary policy surprises jointly with a negative aggregate TFP shock. I calibrate the standard deviation and the persistence parameters of the TFP shock to lower output at impact by roughly 4% and to generate a recession for around eight quarters in the model.[50] I obtain the effect of an expansionary Taylor rule shock under recession by subtracting the impulse responses of the aggregate TFP shock from the joint transition path. I normalize the response of aggregate investment to the two shocks in normal times to 1 to ease the interpretation. I plot the results of this exercise in figure (10).

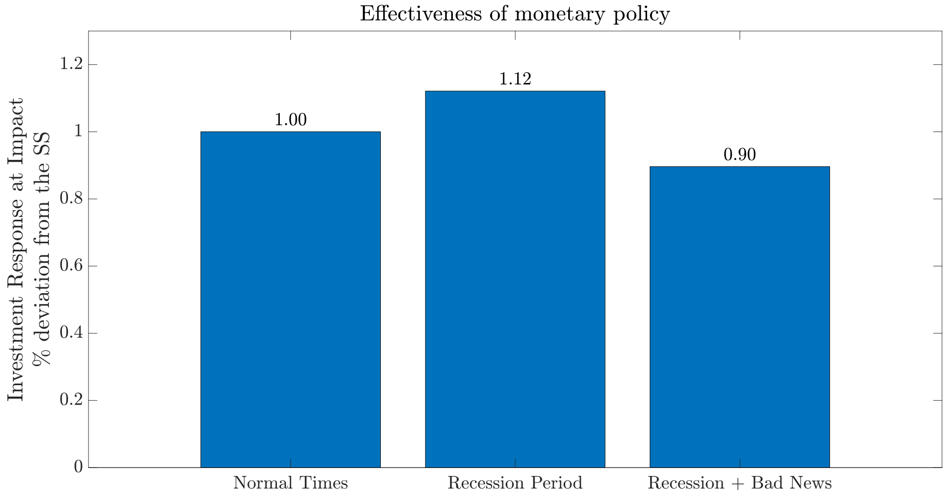
Figure (10) shows two facts. First, given my calibration, a an expansionary Taylor rule shock that cuts the nominal rate by 10bp in a recession is 12% more effective in stimulating investment than in normal times. This result depends on the strength of real and financial frictions. A TFP-induced recession produces two effects on the economy that may affect the potency of a monetary policy shock. First, it increases the share of financially constrained firms (i.e., firms that issue equity increases) that, given the results in figure (6), are relatively more sensitive to interest rate changes. Second, it increases the relative cost of capital financing due to the presence of fixed adjustment costs which, in turn, discourages firms from investing in response to any expansionary policy shock during a recession. This mechanism is reminiscent of the one in Caballero and Engel (1999) and discussed in Koby and Wolf (2020).[51] Given my calibration, the distributional effects of leverage dominate the dampening effect of real frictions.

Second, figure (10) shows that a negative market response to a FOMC statement may dampen the effectiveness of an expansionary monetary policy shock in a recession, and this effect is not negligible. Based on my calibration, a negative miscomunication in an FOMC statement dampens the elasticity of investment to an interest rate cut by more than 20% compared to the equivalent non-market response case. The economic intuition is a negative

[50]Similar to this paper, Koby and Wolf (2020) calibrates the standard deviation of the TFP shock to lower output at impact by 5%.

[51]In a downturn, firms are less sensitive to expansionary shocks because they are closer to their target capital and find it more expensive to adjust investment. As the fixed cost of investment does not change during a recession, the burden of paying the fixed cost is relatively higher in a recession than in normal times.

Figure 10: Revisiting state dependency of monetary policy



Note: Response at impact of aggregate investment to an expansionary monetary policy shock under three different scenario. In the first column, the response of aggregate investment to a positive Taylor rule shock in normal times, which I normalize to 1. In the second column, the response of aggregate investment to an exogenous Taylor rule shock in a recession. In the last column, the response of investment to to an exogenous Taylor rule shock in a recession followed by a negative market reaction.

market reaction increases the cost of capital at the margin for all firms in the economy. It follows that even though a recession increases the share of financially constrained firms in the economy, a steepening in the marginal cost of capital dampens the effectiveness of a monetary policy cut in a period of recession.

7 Conclusion

Previous studies have examined the heterogeneous effect of interest rate surprises on firms' investment, reaching conflicting conclusions. I show that the policy response is heterogeneous depending upon firm leverage and the nature of the shock. More specifically, by looking at the response of financial markets in the Fed announcement window, I show that when stock prices fall in response to a positive interest rate surprise, firms reduce their investments, and financial frictions amplify this effect. Conversely, if stock prices increase in response to a positive interest rate surprise, firms accumulate more capital and financial frictions dampen investment growth.

In order to understand the empirical findings, I investigate the nature of the non-pure monetary policy shocks. A negative stock price response to interest rate surprise is consistent with the central bank deviating from a systematic Taylor rule. I show instead, that a positive stock price response to an interest rate tightening is empirically consistent with a risk premium hypothesis. A tightening FOMC statement may lead agents to become more confident about the future, which in turn may lower the compensation they require to invest in risky assets. Stock market and corporate bond prices increase as a result of a lower risk premium in the economy.

In additional to providing econometric firm-level evidence, I also develop a dynamic general equilibrium model with firm idiosyncratic productivity and financial frictions to rationalize the empirical findings and quantify the distributional effects of monetary policy announcements depending on the market response to a Fed statement. A monetary tightening followed by a negative stock market response, increases the nominal interest rate and reduces the marginal benefit of capital through the stochastic discount factor. Firms with high levels of leverage are the most adversely affected because their cash on hand falls relatively more and their marginal cost of capital increase. A monetary tightening followed by a positive stock market response does not only increases the nominal interest rate, it also raises the price of corporate bonds via the risk premium. Eventually, as the price of debt rises, the marginal cost of capital falls, outweighing the negative effects of an increase in real interest rates. It follows that, on average, firms increase investment while high-leverage firms take fewer advantage of it due to lower sensitivity to changes in debt prices and higher marginal cost of capital.

Finally, I use the model to revisit the state dependency of monetary policy transmission and show that, in my calibration, a negative market reaction to an easing Taylor rule shock reduces the effectiveness of conventional monetary policy interventions in a period of recession by almost 20% compared to the no market reaction.

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Appendix

A. Construction of the dataset and cleaning

A.1 Macro-time series

I replicate Jarociński and Karadi (2020) to study the effects of an identified monetary and non-monetary policy shock on aggregate investment. My dataset includes: (i) two financial market surprises at a high frequency of the stock market prices and the 3-month federal funds rate future; (ii) six macroeconomics aggregates. All the macro data series used in this paper except the variables real investment and cost of borrowing are available in the Jarociński and Karadi (2020) replication file. The variable real investment is constructed from the interpolated data from Stock and Watson (2017) and divided by the level of prices.

A.2 Firm-level variables on Compustat

I construct the firm-level variables in the Compustat database as follows.

- **Capital Stock.** Capital stock is equal to the book value of capital. I use the perpetual inventory method to calculate the capital value for each firm i at a time t. I measure the initial value of firm i's capital stock as the earliest available entry of $ppegtq_{i,t}$, and then iteratively construct $k_{i,t}$ from $ppentq_{i,t}$ as:

$$k_{i,t+1} = k_{i,t} + ppentq_{i,t+1} - ppentq_{i,t}$$

- **Leverage.** Leverage is the ratio of debt in current liabilities $dlcq_{i,t}$ and long-term debt $dlttq_{i,t}$ on total assets, $atq_{i,t}$. I average leverage within the year.

- **Cash liquidity.** I calculate cash holdings as the ratio of cash and short-term investments $cheq_{i,t}$ on total assets $atq_{i,t}$. I average cash liquidity within the year.

- **Investment Rate.** Investment rate is the ratio of the variation of capital stock as calculated in (i) on the past value of capital $k_{i,t-1}$.

- **Rating.** Rating is the S&P domestic long term issuer credit rating $spcsrc_{i,t}$. I divide the sample in three groups based on 2-quarters lag ratings. I assign value 2 if *spcsrc* is between A+ and A-, value 1 if *spcsrc* is between B+ and B-, value 0 otherwise.

- **Dividends.** Dividends is the sum of common dividends $dvy_{i,t}$ and preferred dividends, $dvpq_{i,t}$.
- **Firm Size.** I construct a measure of size for each firm following Gertler and Gilchrist (1994). For each firm i, I calculate the moving average of the sales over the past ten years. For each quarter t, a firm i is a large firm (value 0) if it is above the 30th percentile of the distribution for average sales of that year or is a small firm (value 1) if it is below the threshold.
- **Total assets.** Total assets is the variable $atq_{i,t}$ in Compustat.
- **Sectoral dummies.** I construct a sectoral dummies following Ottonello and Winberry (2018): (i) agriculture, forestry and fishing: sic < 999; (ii) mining: sic $\in [1000, 1499]$; (iii) construction: sic $\in [1500, 1799]$; (iv) manufacturing: sic $\in [2000, 3999]$; (v) transportation, communications, electric, gas, and sanitary services: sic $\in [4000, 4999]$; (vi) wholesale trade: sic $\in [5000, 5199]$; (vii) retail trade: sic $\in [5200, 5999]$; (viii) services: sic $\in [7000, 8999]$.
- **Average Q.** The average Q is the sum of the market value of the firm *mkval* net of Common/Ordinary Equity *ceqq*, total assets atq and investment tax credit *txditcq*, divided by *atq*.

I deflate capital stock, sales, and total assets using the implied price index of gross value added in the U.S. non-farm business sector. To control for outliers in the regressors, I trim the variables, leverage, cash holdings, total assets at the 1% top-level and sales growth at the 1% top and bottom level as standard in the main reference literature. I transform all regressors in logarithm before the estimation.

A.3 Sample selections

The sample period is 1990Q1 to 2016Q4. I perform the following cleaning steps:

- I keep only US-based firms, $fic_{i,t} =$"USA".
- To avoid firms with strange production functions, drop regulated utilities and financial companies, I drop all firm-quarters for which the 4-digit sic code is in the range [4900,5000) or [6000,7000).

- To get rid of years with extremely large values for acquisitions to avoid the influence of large mergers, I drop all firm-quarters for which the value of acquisitions $acq_{i,t}$ is greater than 5% of total assets $atq_{i,t}$.

- I drop all firm-quarters for which the measurement of Total Assets $atq_{i,t}$, Sales $saleq_{i,t}$, Property, Plant and Equipment (Net) $ppentq_{i,t}$, Cash and Short-Term Investments $cheq_{i,t}$, Debt in Current Liabilities $dlcq_{i,t}$, Total Long-Term Debt $dlttq_{i,t}$, Total Inventories $invtq_{i,t}$ are missing or negative.

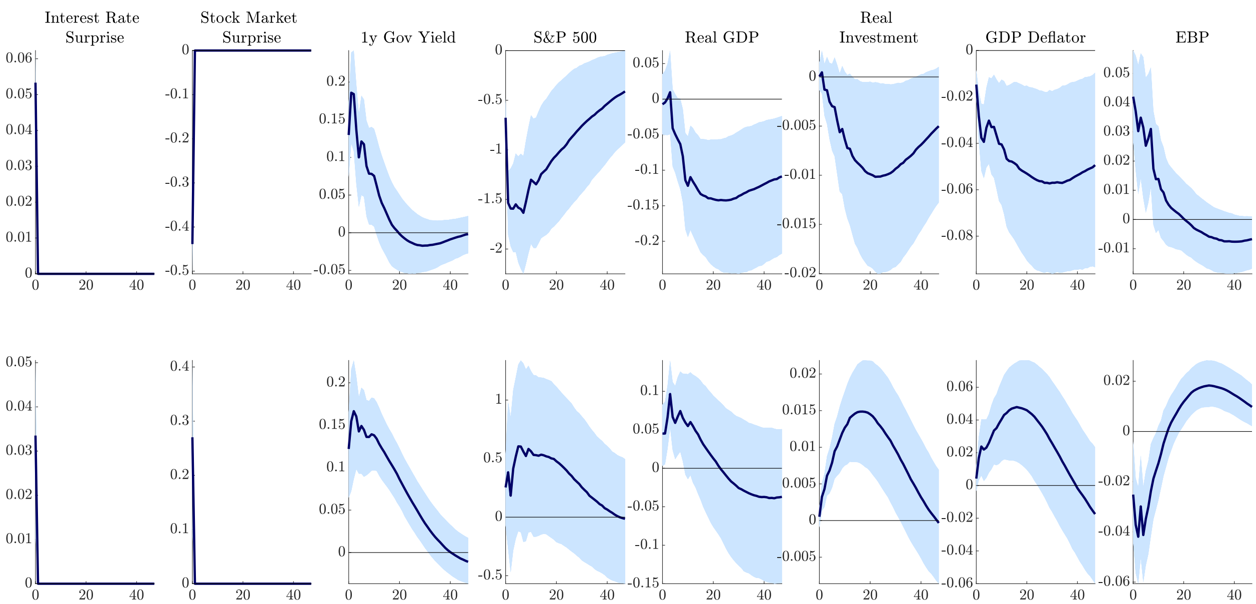
- I drop all firm-quarters before a firm's first observation of Property, Plant, and Equipment (Gross) $ppegtq_{i,t}$.

After computing the yearly moving averages for leverage and liquid asset ratios but before estimating (1), I drop all firms observed between 1990Q1-2016Q4 for less than 40 quarters.

B. Additional results and robustness

B.1 Aggregate response to identified shocks

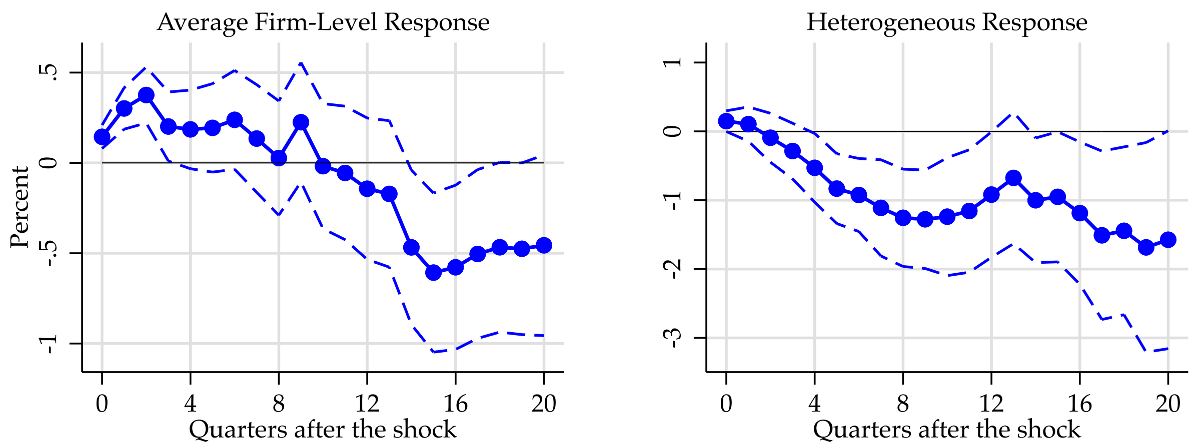
Figure 11: Aggregate IRFs to the identified shocks



Note: The aggregate impulse responses to a contractionary one-standard deviation pure monetary policy shock (first row) and a non-pure monetary policy shock (second raw) identified using Jarociński and Karadi (2020) decomposition. I plot the median response along with the [14,86] percent confidence intervals. The results show that a pure monetary policy shock produces contractionary effects on the economy that are similar to a standard Taylor rule shock in a New-Keynesian framework. The variables real investment, real GDP, and prices unambiguously fall after the shock while the cost of borrowing rises. Instead, a non-pure monetary policy shock produces expansionary effects on the economy that are instead similar to a demand shock, the variables real investment, real GDP, and prices increase after the shock.

B.2 Heterogeneous response without separation

Figure 12: Heterogeneous response using interest rate surprises as monetary shocks



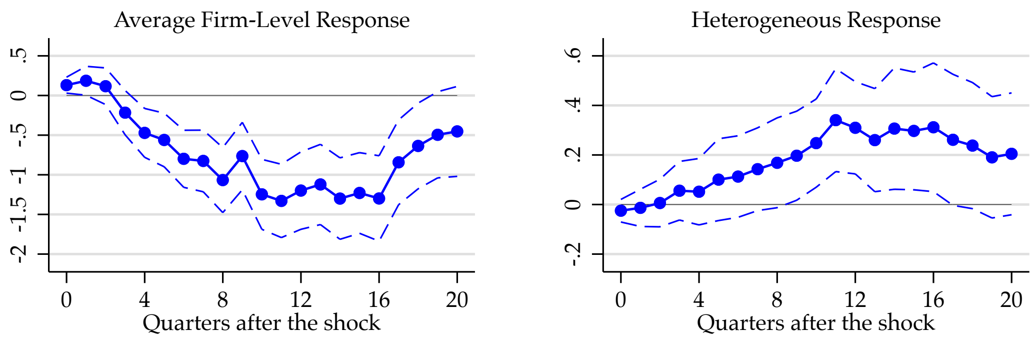
$$\Delta_h \log\left(k_{i,t+h}\right) = \alpha_{i,h} + \alpha_{t,j,h} + \left(\beta_h \Delta \mathrm{i}_t^e + \delta_h\right) \mathrm{lev}_{i,t-4} + \Gamma_h' W_{i,t-1} + u_{i,h,t+h}$$

Note: Plot the impulse response function on capital accumulation to one standard deviation shock to an interest rate surprise that confound a pure and a non-pure monetary policy shock. In the first column, the average firm-level response to a positive interest rate surprise; in the second column, the heterogeneous effect across firms with different levels of leverage. I report the 90% confidence intervals constructed based on two-way clustered standard errors at firm and quarter levels.

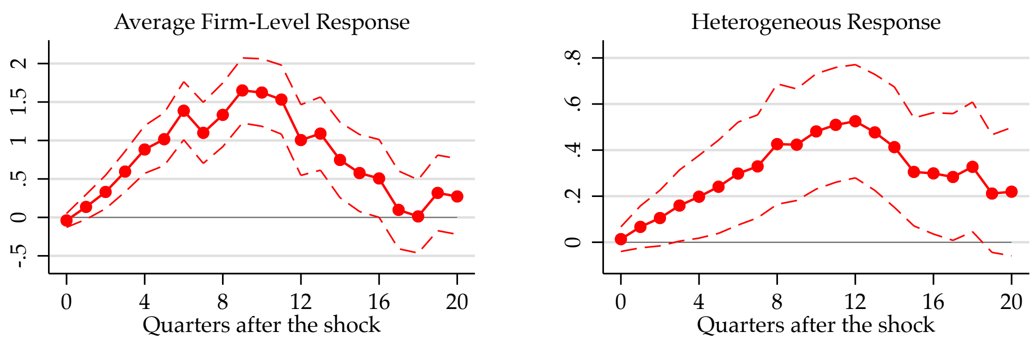
B.3 Heterogenous sensitivity by cash liquiditiy, Jeenas (2018a)

Figure 13: Heterogeneous response using cash holdings

(a) Pure Monetary Policy Shock



(b) Non-Pure Monetary Policy Shock



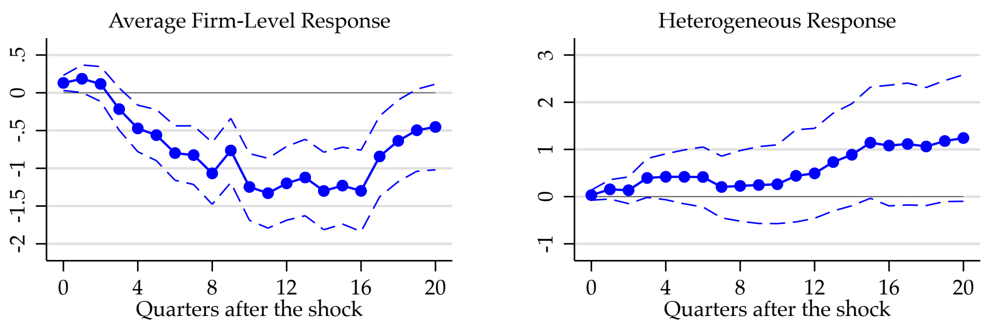
$$\Delta_h \log\left(k_{i,t+h}\right) = \alpha_{i,h} + \alpha_{t,j,h} + \left(\beta_h \Delta i_t + \delta_h\right) \frac{\text{cash}}{\text{asset}}_{i,t-1} + \Gamma_h' W_{i,t-1} + u_{i,h,t+h}$$

Note: Plot the impulse response function on capital accumulation to one standard deviation shock to a pure monetary policy shock (first row) and a non-pure monetary policy shock (second row). In the first column, the average firm-level response to the exogenous shock; in the second column, the heterogeneous effect across firms with different levels of cash liquidity. I estimate the average firm-level response and average heterogenous effect using LP-IV as explained in the paper. Jeenas (2018a) uses negative cash liquidity as an interaction term. I report the 90% confidence intervals constructed based on two-way clustered standard errors at firm and quarter levels.

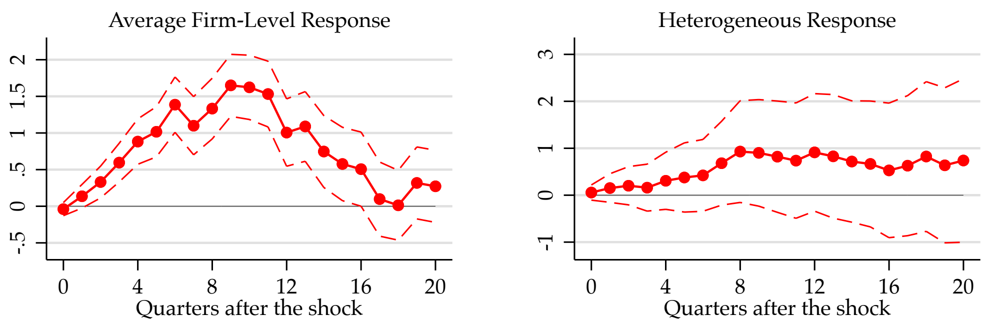
B.4 Heterogenous sensitivity by ratings, Whited (1992)

Figure 14: Heterogeneous response using S&P credit rating

(a) Pure Monetary Policy Shock



(b) Non-Pure Monetary Policy Shock



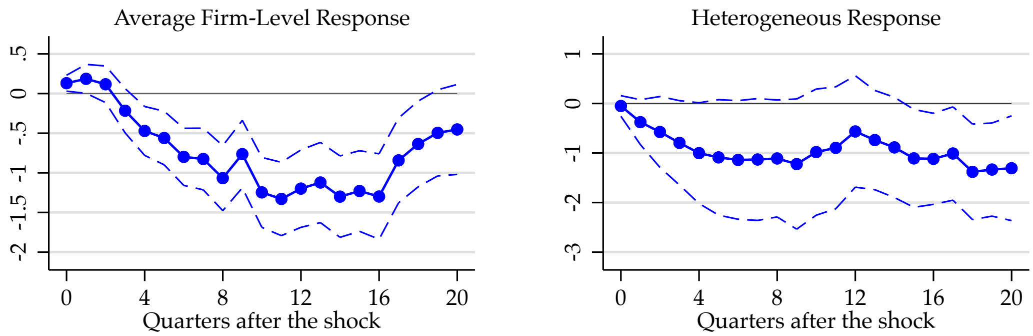
$$\Delta_h \log\left(k_{i,t+h}\right) = \alpha_{i,h} + \alpha_{t,j,h} + \left(\beta_h \Delta i_t + \delta_h\right) S\&P^{rat}_{i,t-4} + \Gamma'_h W_{i,t-1} + u_{i,h,t+h}$$

Note: Plot the impulse response function on capital accumulation to one standard deviation shock to a monetary policy shock (first row) and to a non-pure monetary policy shock (second row). In the first column, the average firm-level response to the exogenous shock; in the second column, the heterogeneous effect across firms with different credit rating level. I assign a higher value to an higher S&P credit score. I estimate the average firm-level response and average heterogeneous effect using LP-IV as explained in the paper. I report the 90% confidence intervals constructed based on two-way clustered standard errors at firm and quarter levels.

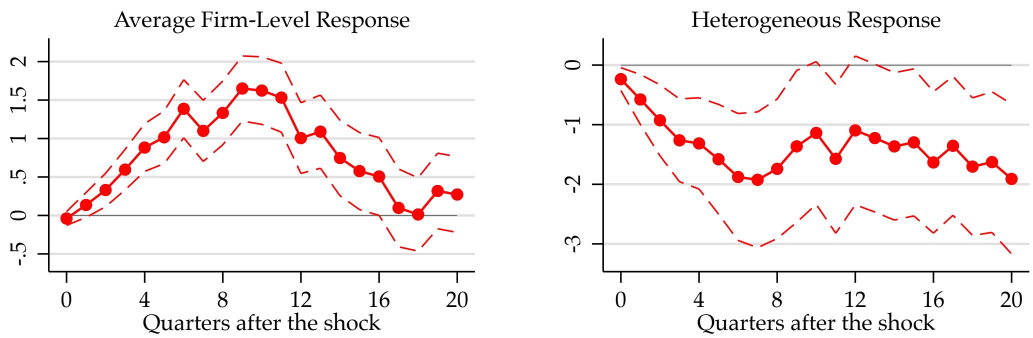
B.5 Heterogenous sensitivity by size, Gertler and Gilchrist (1994)

Figure 15: Heterogeneous response using size

(a) Pure Monetary Policy Shock



(b) Non-Pure Monetary Policy Shock



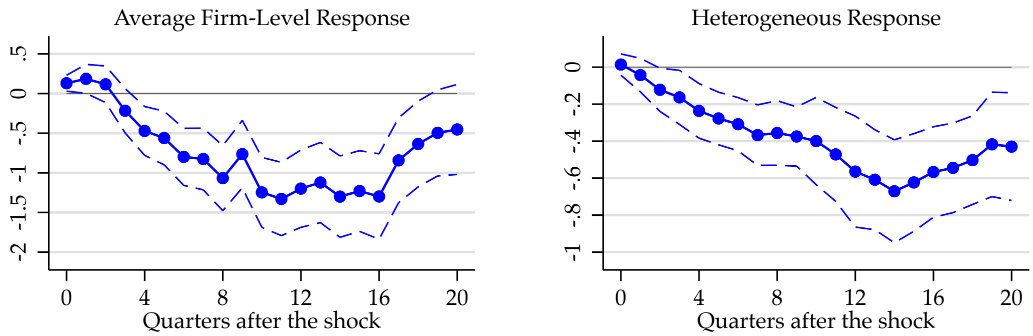
$$\Delta_h \log\left(k_{i,t+h}\right) = \alpha_{i,h} + \alpha_{t,j,h} + \left(\beta_h \Delta i_t + \delta_h\right) \text{small}_{i,t-1} + \Gamma_h' W_{i,t-1} + u_{i,h,t+h}$$

Note: Plot the impulse response function on capital accumulation to one standard deviation shock to a pure monetary policy shock (first row) and to a non-pure monetary policy shock (second row). In the first column, the average firm-level response to the exogenous shock; in the second column, the heterogeneous effect across firms with different size. I estimate the average firm-level response and average heterogeneous effect using LP-IV as explained in the paper. I report the 90% confidence intervals constructed based on two-way clustered standard errors at firm and quarter levels.

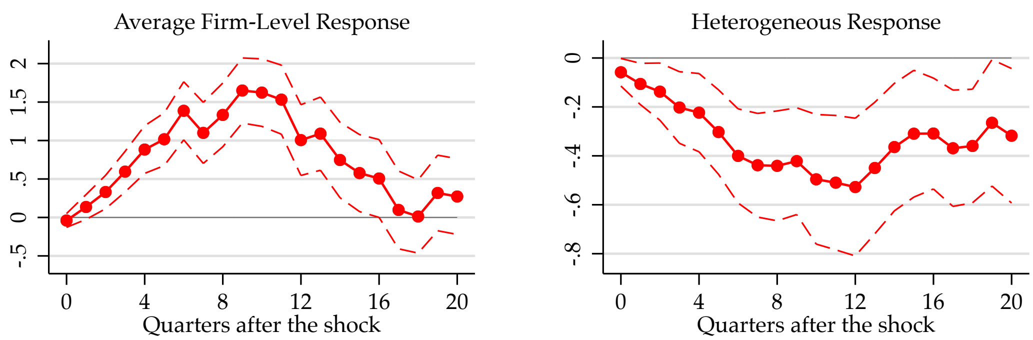
B.6 Results demeaning leverage, Ottonello and Winberry (2018)

Figure 16: Heterogeneous response using de-meaned leverage

(a) Pure Monetary Policy Shock



(b) Non-Pure Monetary Policy Shock



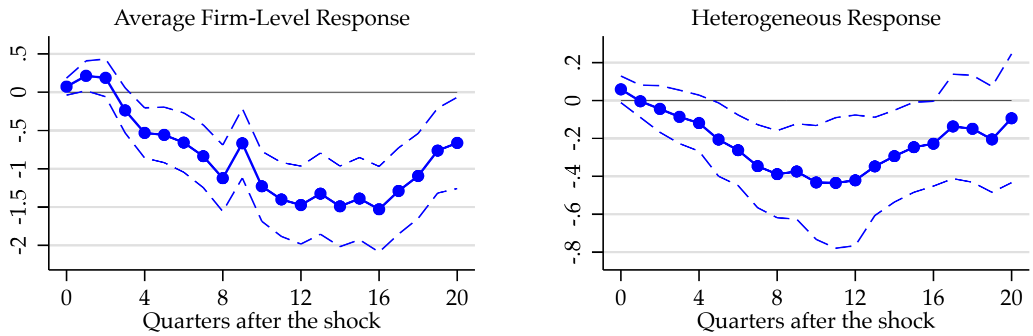
$$\Delta_h \log\left(k_{i,t+h}\right) = \alpha_{i,h} + \alpha_{t,j,h} + \left(\beta_h \Delta i_t + \delta_h\right)\left[\text{lev}_{i,t-4} - \mathbb{E}\ \text{lev}_{i,t-1}\right] + \Gamma_h' W_{i,t-1} + u_{i,h,t+h}$$

Note: Plot the impulse response function on capital accumulation to one standard deviation shock to a pure monetary policy shock (first row) and to a non-pure monetary policy shock (second row). In the first column, the average firm-level response to the exogenous shock; in the second column, the heterogeneous effect across firms with different levels of leverage. In this specification the variable leverage is demeaned at the firm level to control for permanent heterogeneity between firms. I estimate the average firm-level response and average heterogeneous effect using LP-IV as explained in the paper. I report the 90% confidence intervals constructed based on two-way clustered standard errors at firm and quarter levels.

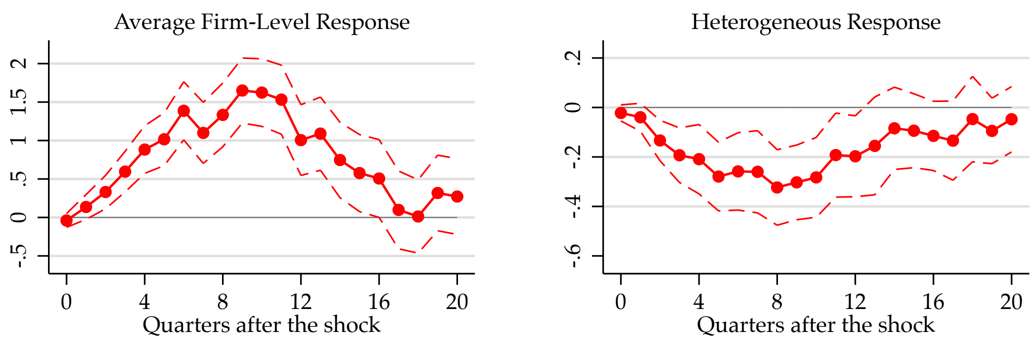
B.7 Results using poor-man, Jarociński and Karadi (2020)

Figure 17: Heterogeneous response using poor-man shocks

(a) Pure Monetary Policy Shock



(b) Non-Pure Monetary Policy Shock



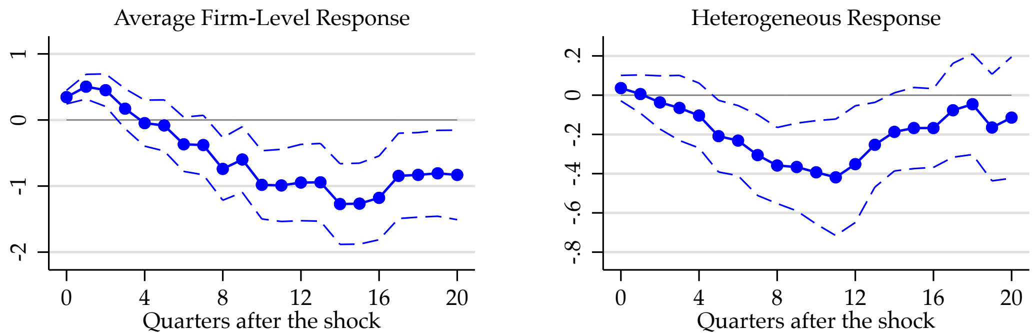
$$\Delta_h \log\left(k_{i,t+h}\right) = \alpha_{i,h} + \alpha_{t,j,h} + \left(\beta_h \Delta i_t + \delta_h\right) \mathrm{lev}_{i,t-4} + \Gamma_h' W_{i,t-1} + u_{i,h,t+h}$$

Note: Plot the impulse response function on capital accumulation to one standard deviation shock to a pure monetary policy shock (first row) and to a non-pure monetary policy shock (second row). In the first column, the average firm-level response to the exogenous shock; in the second column, the heterogeneous effect across firms with different levels of leverage. I estimate the average firm-level response and average heterogeneous effect using LP-IV as explained in the paper. The shocks used as instrument in this exercise are identified based on the simple co-movement between the interest rate and stock market surprises in a 20 minutes window around the FOMC announcement. I report the 90% confidence intervals constructed based on two-way clustered standard errors at firm and quarter levels.

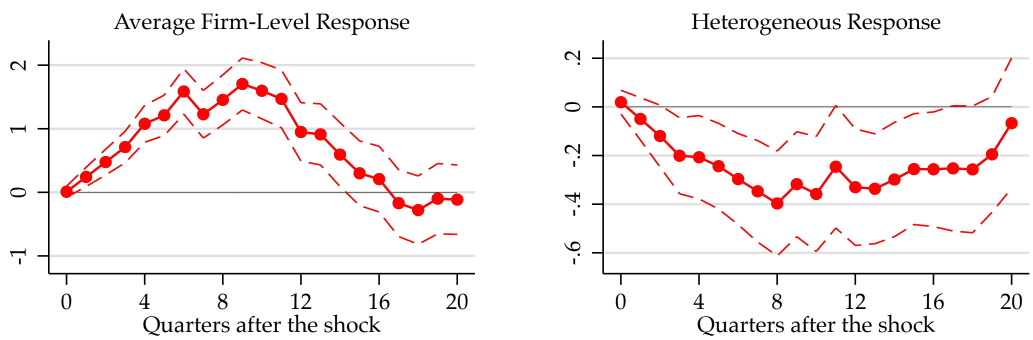
B.8.1 Results on a restricted sample 1990-2010

Figure 18: Heterogeneous response using 1990-2010 sample

(a) Pure Monetary Policy Shock



(b) Non-Pure Monetary Policy Shock



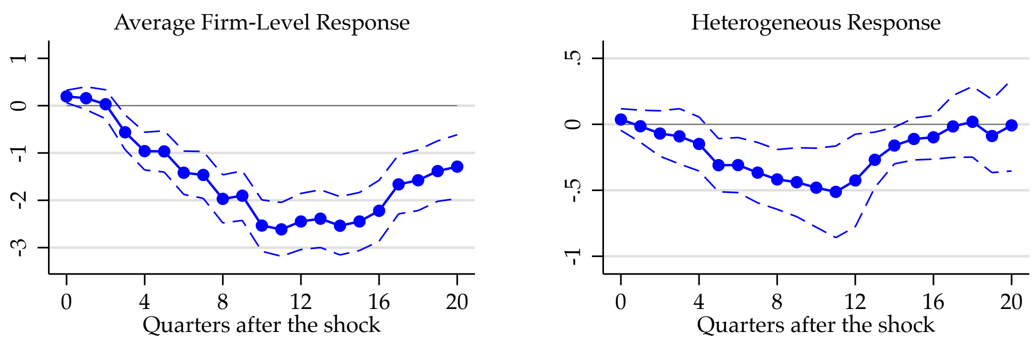
$$\Delta_h \log\left(k_{i,t+h}\right) = \alpha_{i,h} + \alpha_{t,j,h} + \left(\beta_h \Delta i_t + \delta_h\right) \text{lev}_{i,t-4} + \Gamma_h' W_{i,t-1} + u_{i,h,t+h}$$

Note: Plot the impulse response function on capital accumulation to one standard deviation shock to a pure monetary policy shock (first row) and to a non-pure monetary policy shock (second row) on the period sample 1990-2010. In the first column, the average firm-level response to the exogenous shock; in the second column, the heterogeneous effect across firms with different levels of leverage. I estimate the average firm-level response and average heterogeneous effect using LP-IV as explained in the paper. I report the 90% confidence intervals constructed based on two-way clustered standard errors at firm and quarter levels.

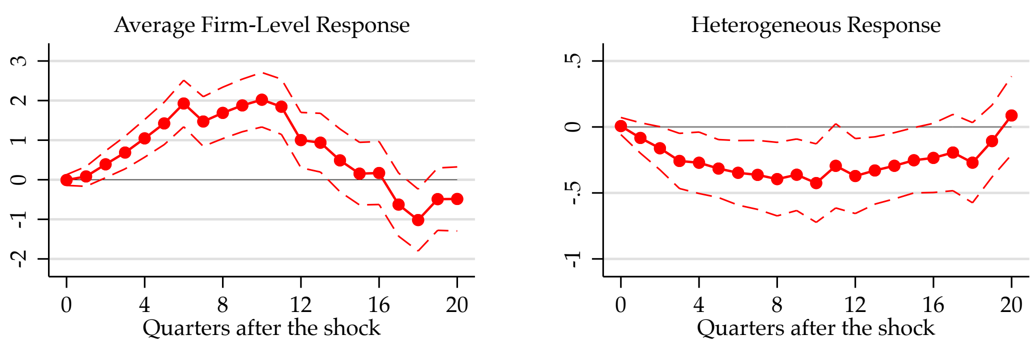
B.8.2 Results on a restricted sample 1994-2016

Figure 19: Heterogeneous response using 1994-2016 sample

(a) Pure Monetary Policy Shock



(b) Non-Pure Monetary Policy Shock

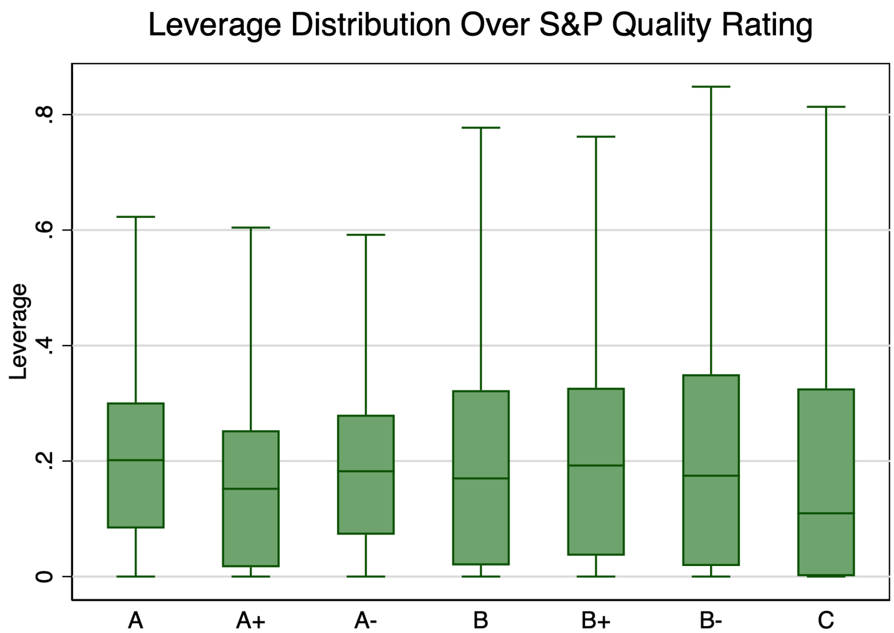


$$\Delta_h \log\left(k_{i,t+h}\right) = \alpha_{i,h} + \alpha_{t,j,h} + \left(\beta_h \Delta i_t + \delta_h\right) \mathrm{lev}_{i,t-4} + \Gamma_h' W_{i,t-1} + u_{i,h,t+h}$$

Note: Plot the impulse response function on capital accumulation to one standard deviation shock to a pure monetary policy shock (first row) and to a non-pure monetary policy shock (second row) on the period sample 1994-2016. In the first column, the average firm-level response to the exogenous shock; in the second column, the heterogeneous effect across firms with different levels of leverage. I estimate the average firm-level response and average heterogeneous effect using LP-IV as explained in the paper. I report the 90% confidence intervals constructed based on two-way clustered standard errors at firm and quarter levels.

B.9 Distribution of leverage by credit score on Compustat

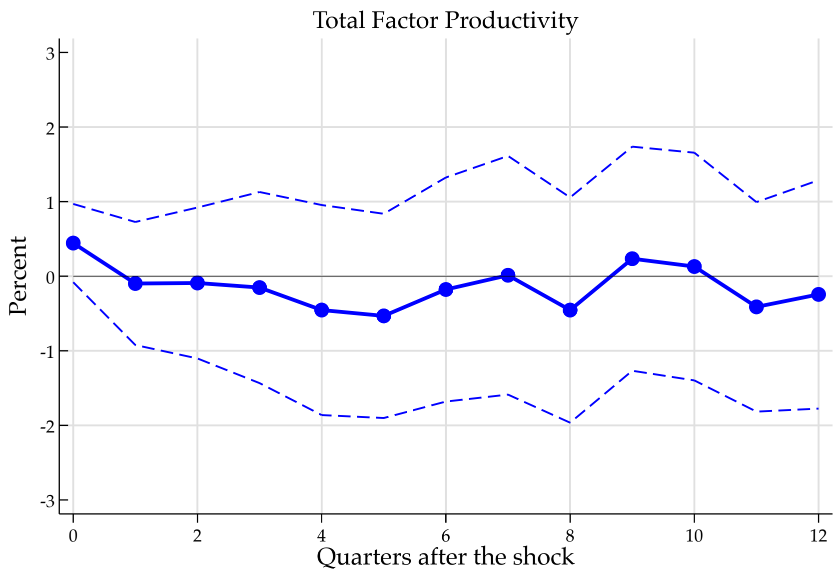
Figure 20: Distribution of leverage by S&P Quality Rating



Note: The boxes of the figure represents the [25,75] percentile of the distribution of leverage by S&P Quality Rating. The extreme values of the distribution of leverage by rating group are excluded from the graph.

B.10 Response of aggregate TFP to a non-pure monetary policy shock

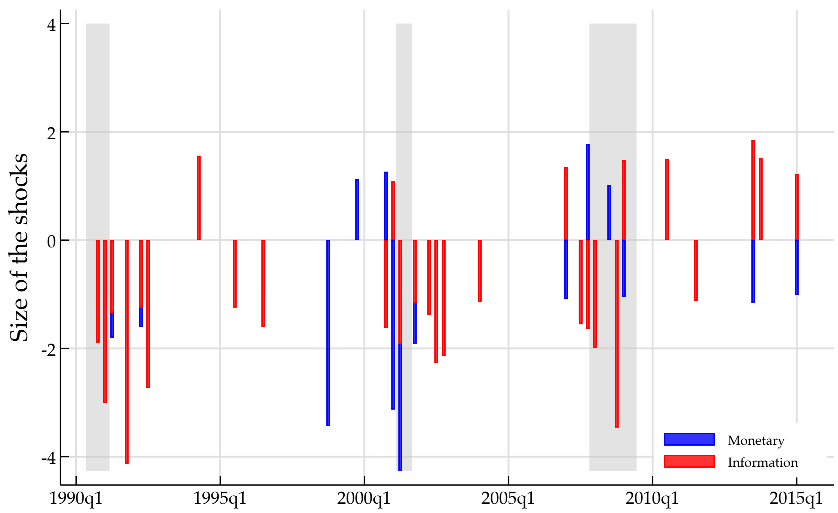
Figure 21: Impulse response of TFP to a non-pure monetary policy shock



Note: Plot the response of aggregate TFP to a non-pure monetary policy shock estimated using standard Local Projection. I use the Basu et al. (2006) utilization-adjusted series of TFP as a measure of aggregate productivity. I control for 4 lags of GDP growth, inflation, interest rate and excess bond premium in the regression. The results do not change if aggregate controls are removed. The impulse response is computed at quarterly frequency. I report the 90% confidence intervals.

B.11 Decomposition of Fed announcement from 1990-2016

Figure 22: Historical decomposition of Fed announcement shocks.



Note: The figure shows point estimates of the historical decomposition of Fed announcement component. The monetary policy shock (blue bars) and a non-pure monetary policy shocks (red bars). Since shocks are only up to scale, I normalize both series of shocks to 1 standard deviation. I only consider quarters where the magnitude of the non-pure monetary policy shock is above one standard deviation. The grey bar are the NBER recession periods from 1990 to 2016.

C. Model Details

C.1 Agents problem

Intermediate good producers. Denote $\{\varepsilon, \mathrm{S}\} = \{\varepsilon, \mathrm{K}, \mathrm{B}\}$ the state of a firm j in the economy. The intermediate good producers solve the following problem:

$$V(\varepsilon, \mathrm{S}) = \max_{\mathrm{K}', \mathrm{B}'} \left\{ \mathcal{D}(\varepsilon, \mathrm{S}, \mathrm{S}') - (a_0 + \frac{a_1}{2}\mathcal{D}^2)\mathbb{1}_{\mathcal{D}<0} + \Lambda_{t,t+1} \sum_{\varepsilon'} \pi\left(\varepsilon'|\varepsilon\right) V'\left(\varepsilon', \mathrm{S}'|\varepsilon\right) \right\} \quad (20)$$

subject to:

$$\mathcal{D}(\varepsilon, \mathrm{S}, \mathrm{S}') = \Pi(\varepsilon, \mathrm{S}) - c_0 \left(\frac{\mathrm{I}}{\mathrm{K}}\right)^2 \mathrm{K} + c_1 \mathbb{1}_{\mathrm{I}\neq 0} - \mathrm{K}' + (1-\delta)\mathrm{K} + \mathcal{Q}B' \quad (21)$$

$$\Pi(\varepsilon, \mathrm{S}) = (1-\tau)(p_t^w \mathrm{Z}_t \varepsilon \mathrm{K}^\alpha \mathrm{N}^{*\nu} - w_t \mathrm{N}^* - \eta) - \mathrm{B} + \tau\left(\delta \mathrm{K} + i_t \mathrm{B}\right) \quad (22)$$

$$N^*\left(\varepsilon, \mathrm{K}\right) = \arg\max_{\mathrm{N}\geq 0} \left\{ p_t^w \mathrm{Z}_t \varepsilon \mathrm{K}^\alpha \mathrm{N}^\nu - w_t \mathrm{N} \right\} \quad (23)$$

$$\mathcal{H}(\varepsilon, S, S') = (a_0 + a_1 \mathcal{D}^2)\mathbb{1}_{\mathcal{D}<0} \quad (24)$$

$$\mathrm{I} = \mathrm{K}' - (1-\delta)\mathrm{K} \quad (25)$$

$$\mathrm{B}' \leq \theta_k \mathrm{K}' \quad (\lambda') \quad (26)$$

where λ is the multiplier associated to the non-binding constrain. The optimality condition for capital can be obtained by taking the FOCs w.r.t to K' and combining with the envelope condition.

The FOC with respect to K' is:

$$-\frac{\partial \mathcal{D}}{\partial \mathrm{K}'}\left(1 - a_1 \mathcal{D} \mathbb{1}_{\mathcal{D}<0}\right) = \Lambda_{t,t+1} \mathbb{E} V_{\mathrm{K}'}\left(\varepsilon', \mathrm{S}'\right) + \theta_k \lambda' \quad (27)$$

The envelope condition allows to characterize intertemporal payoffs for the capital choice:

$$V_k(\varepsilon, \mathrm{S}) = \frac{\partial \mathcal{D}}{\partial \mathrm{K}}\left(1 - a_1 \mathcal{D} \mathbb{1}_{\mathcal{D}<0}\right) \quad (28)$$

Taking the derivatives and combining equations (27) and (28), we have that:

$$\begin{aligned} \left(1-\varepsilon_t^{\text{risk}} e^{-\theta_l \frac{\mathrm{B}'}{\mathrm{K}'}} + c_0 \frac{\mathrm{I}}{\mathrm{K}}\right)\left(1-a_1 \mathcal{D} \mathbb{1}_{\mathcal{D}<0}\right) = \\ \Lambda_{t,t+1}\mathbb{E}\left[\Pi_k(\varepsilon', \mathrm{S}') + (1-\delta)\left(1+c_0\frac{I'}{\mathrm{K}'}\right) + \frac{c_0}{2}\left(\frac{\mathrm{I}'}{\mathrm{K}'}\right)^2\right]\left(1-a_1\mathcal{D}'\mathbb{1}_{\mathcal{D}'<0}\right) + \theta_k \lambda' \end{aligned} \quad (29)$$

which is equal to equation (19) in the paper.

Final good producers. Final good producers buy from retailers goods $\tilde{Y}_{i,t}$ at price $p_{i,t}$ and aggregate using a CES aggregator:

$$Y_t = \left[\int \tilde{Y}_{i,t}^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}}$$

The demand of retail goods $\tilde{Y}_{i,t}$ is obtained solving:

$$\max_{\{\tilde{Y}_{i,t}\}} \quad P_t Y_t - \int p_{i,t}\tilde{Y}_{i,t} \qquad \text{s.t.} \quad Y_t = \left[\int \tilde{Y}_{i,t}^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}}$$

Taking the FOCs w.r.t to $\tilde{Y}_{i,t}$ we get the demand of the good $\tilde{Y}_{i,t}$.

$$\tilde{Y}_{i,t} = \left(\frac{p_{i,t}}{P_t}\right)^{-\theta} Y_t$$

and substituting in the constraint, we get the aggregate price P_t.

$$P_t = \left(\int p_{i,t}^{1-\theta}\right)^{\frac{1}{1-\theta}}$$

Because final good producers are perfectly competitive, zero profits condition holds.

Retailers Retailers transform homogeneous good products $Y_{i,t}$ using a linear technology $\tilde{Y}_{i,t} = Y_{i,t}$. Retailers sell the heterogeneous good $\tilde{Y}_{i,t}$ to a final good producer at a price $p_{i,t}$ to be determined in a monopolistic competitive market, i.e., they take the demand of goods as given. It follows that retailers solve the following problem:

$$\max_{\{p_{i,t}\}} \quad \mathbb{E}_0 \sum_{t=0}^{\infty} \Lambda_{t,t+1}\left(p_{i,t}\tilde{Y}_{i,t} - p_t^w Y_{j,t} - \frac{\phi_p}{2}\left(\frac{p_{i,t}}{p_{i,t-1}} - 1\right)^2 Y_t\right) \qquad \text{s.t.} \quad \tilde{Y}_{i,t} = \left(\frac{p_{i,t}}{P_t}\right)^{-\theta} Y_t$$

The FOCs for the problem gives:

$$p_{i,t}\frac{d\tilde{y}_{i,t}}{dp_{i,t}}+\tilde{Y}_{i,t}-p_t^w\frac{d\tilde{Y}_{i,t}}{dp_{i,t}}-\phi\left(\frac{p_{i,t}}{p_{i,t-1}}-1\right)\frac{Y_t}{p_{i,t-1}}+\mathbb{E}\Lambda_{t,t+1}\phi\left(\frac{p_{t+1}}{p_{i,t}}-1\right)\frac{Y_{t+1}}{p_{i,t}}\left(\frac{p_{i,t+1}}{p_{i,t}}\right)=0$$

Because all firms are symmetric and from pricing equation, it follows that:

$$\left(P_t-p_t^w\right)\frac{d\tilde{Y}_{i,t}}{dp_{i,t}}+Y_t-\phi\pi\frac{Y_t}{P_{t-1}}+\mathbb{E}\Lambda_{t,t+1}\phi\left(1+\pi_{t+1}\right)\pi_t\frac{Y_{t+1}}{P_t}=0$$

Finally, re-organizing the terms the New-Keynesian Phillips curve is:

$$\pi_t(1+\pi_t)=\frac{1}{\phi_p}\left[\theta p_t^w-(\theta-1)\right]+\mathbb{E}\Lambda_{t,t+1}(1+\pi_{t+1})\pi_{t+1}\frac{Y_{t+1}}{Y_t}$$

Assume that the final good price is the numeraire, $P_t = 1$ and rewrite the NKPK in log-linearized form:

$$\log\Pi_t=\frac{\theta-1}{\phi_p}\log\frac{p_t^w}{p}+\beta\mathbb{E}_t\log\Pi_{t+1}$$

Because retailers operate in a monopolistic environment, their profits are distributed to the household. I omit the household problem since it is described in the paper.

C.2 Equilibrium

A recursive competitive equilibrium of the model is as follows:

Definition 1. A recursive competitive equilibrium of the model is as a set of the firms' value and policy functions $V(\varepsilon,K,B)$, $K^{*\prime}(\varepsilon,K,B)$, $B^{*\prime}(\varepsilon,K,B)$,$N^*(\varepsilon,K,B)$, a consumption and labor function C_t, N_t, a distribution of firms $\Gamma(\varepsilon,K,B)$ and, a set of prices w_t, i_t, p_t^w such that:

i) (Firms optimization) Firms choose $K^{*\prime}(\varepsilon,K,B)$, $B^{*\prime}(\varepsilon,K,B)$ and $N^*(\varepsilon,K,B)$ to maximize the future stream of dividends given their constraints;

ii) (Household optimization) Given the equilibrium prices, households choose consumption and labor paths that are consistent with the equations the Euler Equation and Frish labor supply;

iii) (Retailers and final good producers) Retailers set the price $pi,_t$ for the intermediate goods taking the demand of the final good producers as given. Retailers and final good producer' solutions aggregate to produce the NKP Curve.

iv) (Central bank and government) Central bank set the nominal interest rate i_t following a Taylor rule. Government collect taxes from the firms and redistribute lump-sum to the households;

iv) (Law of motion for the firms' distribution) The law of motion for the firm distribution Γ is generated by the stochastic process for idiosyncratic productivity and the firm policy function $K^{*\prime}(\varepsilon, K, B)$, $B^{*\prime}(\varepsilon, K, B)$:

$$\Gamma' = Q\Gamma$$

where Q is the transition matrix from the states (ε, K, B) to (ε', K', B'):

$$Q((\varepsilon, K, B), \mathcal{E} \times \mathcal{K} \times \mathcal{B}) = \mathbb{1}\left\{K^*(\varepsilon, K, B) \in \mathcal{K}, B^*(\varepsilon, K, B) \in \mathcal{B}\right\} \pi\left(\varepsilon' | \varepsilon\right)$$

vi) (Law of motion for aggregate state) The law of motion for the aggregate states follow the stochastic processes for the aggregate shocks;

vii) (Markets clearing) From the budget constraint, substituting dividends from wholesale producers and retailers. Aggregate prices w_t and p_t^w are consistent with market clearing conditions:

$$Y_t = C_t + I_t + \int \mathcal{G} dj - \int \mathcal{H} dj + \frac{\phi}{2}\pi_t^2 Y_t$$

I solve for the stationary equilibrium of the model and, study the response of the model along the perfect foresight transition path to an anticipated change in the future aggregate technology and unexpected change in the nominal interest rate. I rely on computational methods to study the solution of this problem.

C.3 Computational methods

This section provides details on the computational methods that I use to find the solution to the model in this paper. I solve the model using value function iteration, both in the steady-state and along the perfect-foresight transition path. To calculate the response of the economy to an unexpected aggregate shock, I use a standard backward-forward shooting method following Boppart et al. (2018) algorithm. Finally, to calculate the distribution of firms over the idiosyncratic state-space, I use the non-stochastic simulation approach following Young (2010).

Firm's optimal solution. To find an approximation of the solution in the steady-state, I discretize the state for $(\varepsilon, K, \frac{B}{K})$. I convert the continuous exogenous process for ε into the discretized Markov chain using Tauchen (1986). I fix the number of grid points for ε, $N_\varepsilon = 5$. Instead, the grid for K and $\frac{B}{K}$ is made up of a set of (13 x 8) in an interval $(0, K^{\max}]$ and $[-\theta_k, \theta_k]$ non-equally spaced points so to have more points in the lower part of the capital and higher part of leverage. Once I have set up the grids, I use value function iteration to find a solution.

1. Guess an initial value for the wage w_0^*;
2. Given the value for wage w_0^*, solve the firms' problem using value function iteration:
   i) Approximate the $\mathbb{E}V(\varepsilon, K', \frac{B'}{K'})$ with an higher-order polynomials and guess an initial vector of coefficient c_0;
   ii) Given the expected value function, find the optimal combination $(K', \frac{B'}{K'})$ such that it solve the Bellman equation for each element in the grid $(\varepsilon, K, \frac{B}{K})$;
   iii) Given the solution, calculate the new expected value function;
   iv) Update the coefficient of the expected value function using Newton method and find c_1;
   v) Iterate until $||c_1 - c_0||$ is arbitrary small;
3. Given a solution for K', B' and a coefficient vector c, calculate the distribution Γ of firms over $(\varepsilon, K, \frac{B}{K})$ in the stationary equilibrium using Young (2010). Before computing the ergodic distribution, I interpolate the solution over a finer grids over the states.
4. Using the cross-sectional distribution of firms calculate a new equilibrium value for wage w_1^*. Iterate until $|w_1^* - w_0^*|$ is small enough.

A solution to this problem deliver the policy function for K', B' and a vector of coefficient c^* over the space grid (ε, K, B).

Perfect-Foresight transitional dynamics. I compute the dynamics of the economy to an unexpected aggregate shock using a standard backward-forward algorithm. The algorithm is in 4-steps:

1. Guess a path for aggregate consumption $\left(C_t^{OLD}\right)_{t=1}^{T}$ and calculate the path for aggregate prices w_t, i_t, p_t^w and inflation π_t consistent with the model equations.

2. Backward: Start from time T, calculate backward the policy functions for $K^{*\prime}_{t,t+1}$ and $B^{*\prime}_{t,t+1}$ for all time t.

3. Forward: Given the policy functions obtained, iterate forward to calculate the distribution of firms $\Gamma_t = \Gamma_t(\varepsilon, K, B)$ over time using Young's method.

4. Use the results in (2) to calculate a new equilibrium path for aggregate consumption $(C_t)_{t=1}^{T}$. Iterate (1-4) until $|C_t - C_t^{OLD}|$ is small enough.

One problem with the backward-forward shooting method is that updating the path for "too quickly" may result in the overall procedure to diverge. I compute the new update path for consumption as a convex combination of the previous guess and the newly calculated path, with λ small:

$$\left(C_t^{NEW}\right)_{t=1}^{T} = \lambda \left(C_t\right)_{t=1}^{T} + (1-\lambda)\left(C_t^{OLD}\right)_{t=1}^{T}$$

A solution to the algorithm delivers the impulse response function of the aggregate variable and the distribution of firms in response to an unexpected aggregate shock over time.

C.4 Equivalence with a model with risky debt

This section shows the equivalence of the mechanism presented in the paper and a model with default risk. I only focus on the firms' maximization problem. The setup of the model is similar to the model with risk-free debt as presented in the paper. Firms decide how much to invest, borrow, produce. Like the model with risk-free debt, I assume that the production technology, the adjustment cost $\mathcal{G}(\mathrm{K}, \mathrm{K}')$ have the same functional form as the ones specified in the paper. Unlike the model with risk-free debt, firms can default on their debt before production and issue debt at a discount. Because debt is risky, firms are not subject to a limited borrowing constraint.

The price of debt $\mathcal{Q}(\varepsilon, \mathrm{S}')$ is determined by a financial intermediary to equalize bond return and risk-free asset and compensate lenders for the aggregate risk. In the risky debt model, a firm solves the following problem:

$$V(\varepsilon, \mathrm{S}) = \max_{\mathrm{K}', \mathrm{B}'} \left\{ \mathcal{D}(\varepsilon, \mathrm{S}, \mathrm{S}') + \Lambda_{t,t+1} \sum_{\varepsilon'} \pi\left(\varepsilon' | \varepsilon\right) V'\left(\varepsilon', \mathrm{S}' | \varepsilon\right) \right\} \tag{30}$$

where firms' dividends in a model with risky debt are:

$$\mathcal{D}(\varepsilon, \mathrm{S}, \mathrm{S}') = (1-\tau)(p_t^w \mathrm{Y} - w_t \mathrm{N}^* - \eta) - \mathcal{G}\left(\mathrm{K}, \mathrm{K}'\right) - \mathrm{I} + \mathcal{Q}\left(\varepsilon, \mathrm{S}'\right) \mathrm{B}' - \mathrm{B} + \tau\left(\delta \mathrm{K} + i \mathrm{B}\right) \tag{31}$$

As standard, I derive the optimality condition for capital from the FOCs w.r.t to K' and combining with the envelope condition.

The FOC with respect to K' is:

$$\left(1 - \frac{\partial \mathcal{Q}\left(\varepsilon, \mathrm{S}'\right)}{\partial \mathrm{K}'} \mathrm{K}' \frac{\mathrm{B}'}{\mathrm{K}'} + c_0 \frac{\mathrm{I}}{\mathrm{K}}\right) = \Lambda_{t,t+1} \mathbb{E}\left[\mathrm{Y}_k(\varepsilon', \mathrm{S}') + (1-\delta)\left(1 + c_0 \frac{\mathrm{I}'}{\mathrm{K}'}\right) + \frac{c_0}{2}\left(\frac{\mathrm{I}'}{\mathrm{K}'}\right)^2\right] \tag{32}$$

In equation (32), the marginal cost of capital depends on a new term, $\frac{\partial \mathcal{Q}(\varepsilon, S'|\mu)}{\partial K'} K' = \varepsilon_{q,k}$, that is the semi-elasticity of the price of debt relative to the optimal capital choice tomorrow. $\varepsilon_{q,k}$ tells of how much the price of debt changes if a firm decides to increase capital by 1 pp.

In a model with default risk the price of debt $\mathcal{Q}$ is a function of the probability of default.

If we allow then for a risk-premium component $\mathcal{R}$.

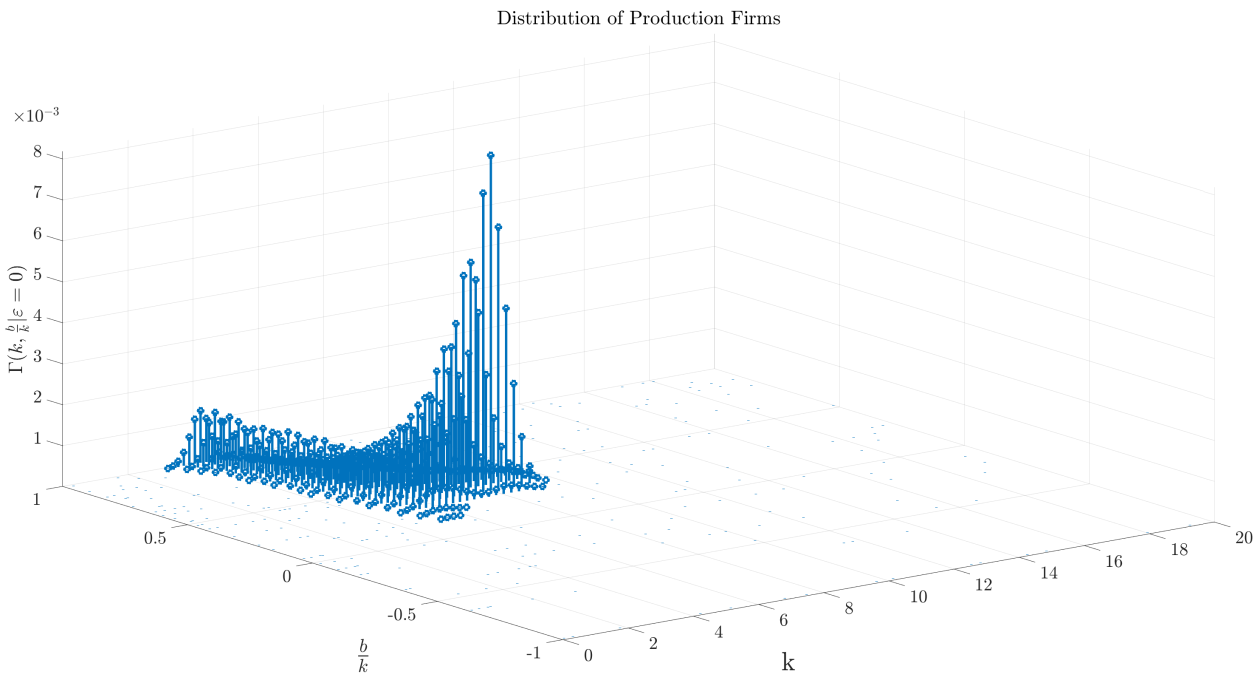
$$\mathcal{Q}\left(\varepsilon, S'\right) = \mathcal{F}\left(\text{Prob. Default}\left(\varepsilon, S'\right), \mathcal{R}\left(\varepsilon, S', \mu\right)\right)$$

As the elasticity of the price of capital depends on the optimal firms' capital policy, a change in the level of the risk bearing capacity in the economy transmits to the firms' capital policy through the marginal cost of capital as in the baseline model.

D. Model results

D.1 Ergodic distribution of the model

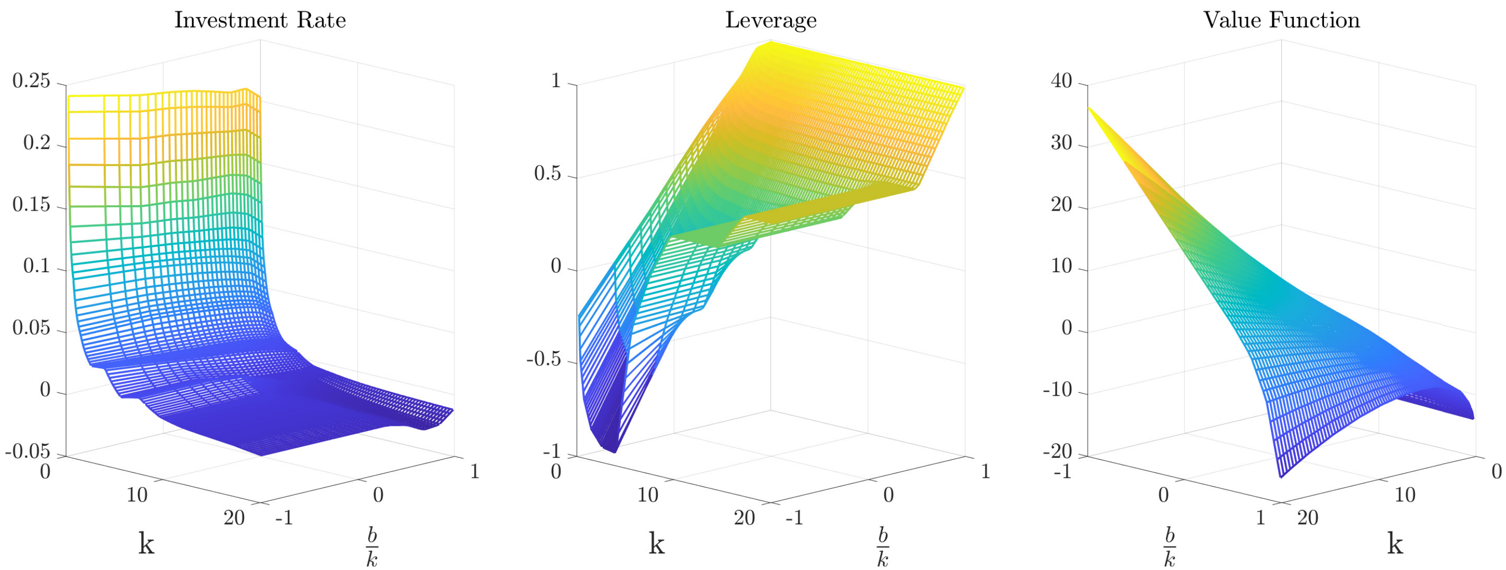
Figure 23: Ergodic distribution of the firms in the steady state.



Note: The ergodic distribution of the investment firms in the stationary equilibrium as a function of capital (x-axis) and leverage (y-axis). I approximate the ergodic distribution with Young (2010) method.

D.2 Policy function in the stationary equilibrium

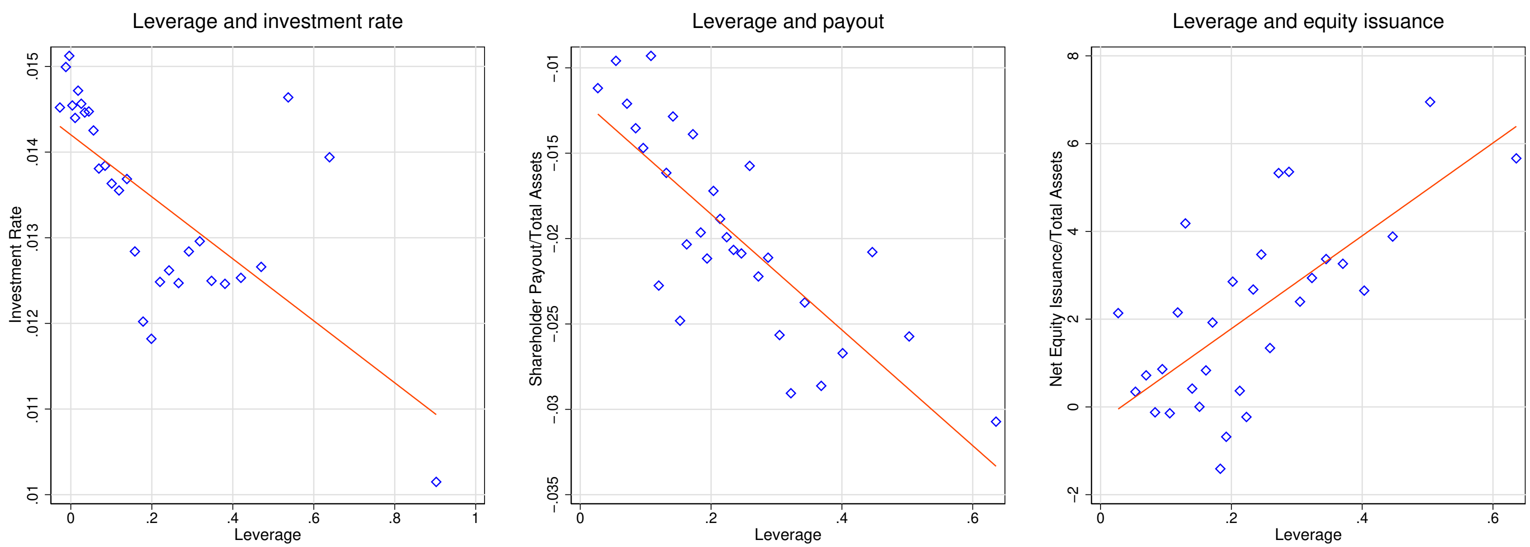
Figure 24: Policy functions in the steady state.



Note: Plot the optimal value and policy functions for investment rate and leverage in the stationary equilibrium over the state state grid $(k, \frac{b}{k})$. I fix the idiosyncratic productivity at the steady state level.

D.3 Cross-section correlation between leverage and other financial variables

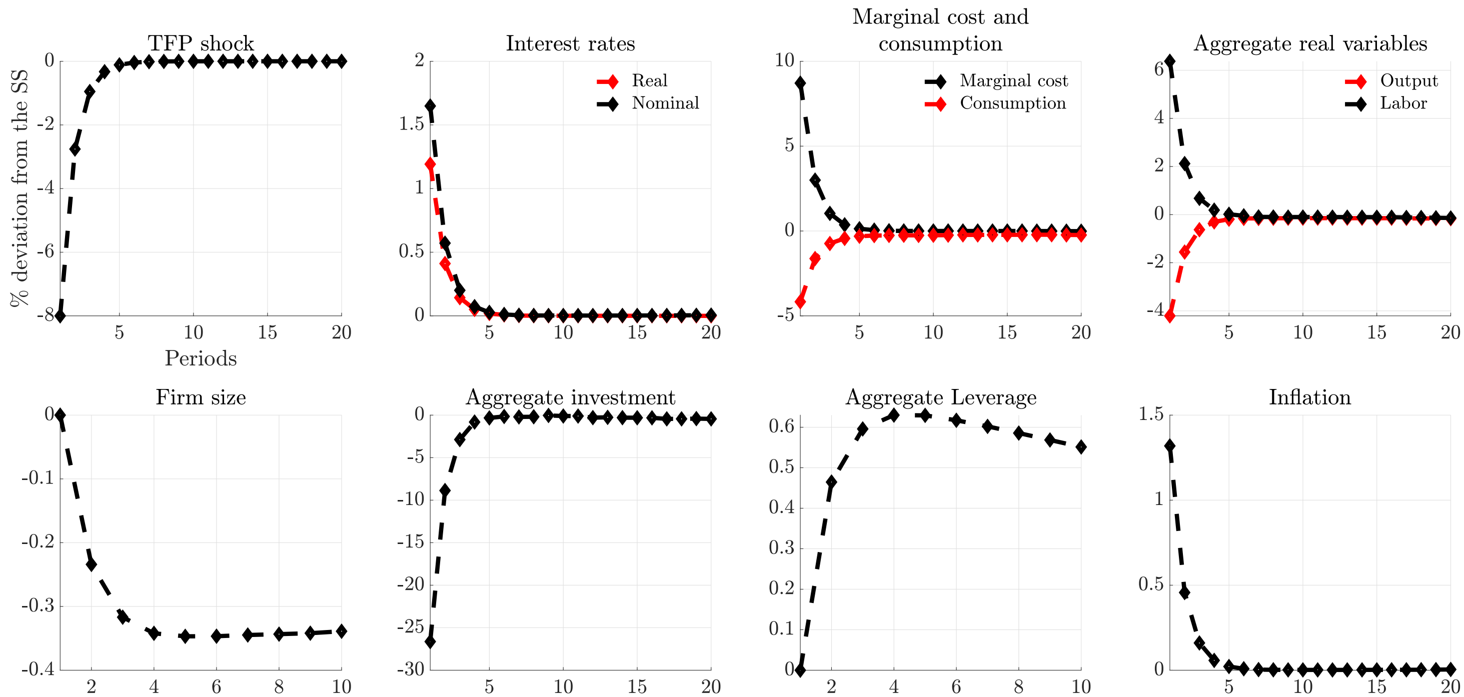
Figure 25: Leverage and other financial variables across US firms 1990-2016



Note: I plot the cross-sectional correlation between firms' leverage, investment rate, dividends payout, and equity issuance across Compustat firms from 1990 to 2016. To mimic steady state correlation, I compute firm averages over time on the entire time sample. Before plotting, I also trim the tails at 1.5% of the firm averages to avoid outliers.

D.4 Aggregate response to a productivity shock

Figure 26: IRFs to an aggregate productivity shock



Note: Plot the impulse response function of the model to a one standard deviation productivity shock in the model. The standard deviation is calibrated to generate a drop in output by 4 percent at impact whereas, the persistence of the shock is calibrated to induce a recession for eight quarters. Responses are presented as deviations with respect to the stationary equilibrium.