Interest Rate Surprises and Financial Heterogeneity: The Role of External Financing

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Abstract

I study the role of financial heterogeneity in the transmission of monetary policy to aggregate investment. I show that if the Federal Reserve (Fed) simultaneously conveys information about the future path of the interest rates and private information about macroeconomic fundamentals, firms' heterogeneous response of investment to interest rate surprises depends on the information inherent in the Fed announcements. Empirically, firms with high leverage are more responsive to pure monetary policy shocks, whereas they are less responsive to info-laden policy surprises. I develop a dynamic general equilibrium model with firm idiosyncratic productivity and financial frictions to explain the empirical findings and study the monetary policy implications. In the model, the aggregate effect of monetary policy on investment depends on the firms' leverage distribution and the communication tool used by the Fed to stimulate investment. In addition to uncovering a new empirical fact, this paper helps in explaining recent contrasting findings in the literature.

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1 Introduction

There is a consensus that differences in firms' financial positions are of primary importance to understanding the effectiveness of monetary policy interventions. Traditionally, the literature has considered the level of indebtedness as a gauge of the overall level of financial frictions of non-financial corporations. Due to this, since the Global Financial Crisis, a great effort has been devoted to understanding how the level of debt affects firms' investment decisions and the potency of economic stimulus. However, at this date, there is no agreement in either the theoretical or the empirical literature on the role that firms' financial heterogeneity plays in the transmission of monetary policy.

The theoretical literature suggests that an answer to these questions is ambiguous because of how monetary policy affects the marginal cost and the marginal benefit of capital across firms with different level of financial frictions. On the one hand, highly indebted firms may find borrowing an additional unit of funds more costly or unfeasible than less indebted firms. Thus, they should be less sensitive to monetary policy interventions. On the other hand, high leverage firms are more exposed to the financial accelerator mechanism. So, they should experience a more significant response of investment than low leverage firms, in line with the seminal works of Bernanke et al. (1999), Kiyotaki and Moore (1997). Which one of these effects prevails is theoretically a quantitative matter that requires empirical support.

In search of an empirical answer to these questions, two recent papers have come under the spotlight for their contrasting findings. Ottonello and Winberry (2018) find that firms with higher default risk or debt are less responsive to monetary policy shocks, suggesting indeed that the financial accelerator mechanism is not enough to compensate for the lower sensitivity of highly indebted firms. However, Jeenas (2018b) reach the opposite conclusion. Firms with higher leverage or fewer liquid assets are more sensitive to monetary policy shocks. These contrasting findings have raised doubts about the robustness of the results and the potential role that financial frictions may play in boosting the effects of monetary policy interventions on aggregate investment.

The main contribution of my paper is to show that the firms' heterogeneous response to investment to a Federal Reserve (Fed) announcement depends upon the information inherent in the Fed announcements and its effects on agents' beliefs about the future state of the economy. To the best of my knowledge, this is the first paper that studies the role of financial frictions in the transmission of policy shocks, allowing for the heterogeneity in the information revealed at the Federal Open Market Committee (FOMC) meetings. Compared to other papers in the literature, I consider the possibility that the Fed communicates both its intended monetary policy action and private information about macroeconomic fundamentals during the policy announcements. If this is true, observed interest rate surprises identified through market-based measures of interest rate expectations confound an exogenous variation due to a change in the policy rule and the additional information revealed. By using firm-level data from Compustat, I show that separating these two components is crucial for understanding the role that firms' financial positions play in the transmission of policy communication to investment.

I organize this paper into two parts. In the first part, I replicate the previous work of Jarociński and Karadi (2020) and disentangle interest rate surprises in two series of exogenous shocks by looking at the co-movement between changes in the federal funds future and stock market prices in a short window of time around the FOMC announcements. I separate interest rate surprises into two aggregate series: surprises induced by communication of a change in the policy rule, *pure monetary policy shock* and surprises induced by communication of additional information about macroeconomic fundamentals, *information shock*[1]. With this separation in hand, I use Jorda's local projection with an instrumental variable to estimate the dynamic heterogeneous effect of interest rate surprises on firms' capital accumulation following Cloyne et al. (2018). My results are twofold: first, I show that, on average, firms with higher leverage are more sensitive to an unexpected hike in the policy rates, with the effects peaking after around ten quarters, in line with the findings of Jeenas (2018b). Second, I document a new empirical fact. High leverage firms are relatively less sensitive to information-driven interest rate hikes. I found that, on average, firms with 1% more leverage accumulate around 0.4% less capital around three years after an information shock that increases the 1-year interest rate by 25bp.

In the second part, I develop a New-Keynesian dynamic general equilibrium heterogeneous firm model with idiosyncratic productivity and real and financial frictions to interpret my empirical findings and study monetary policy implications. The key actors in the model are a set of heterogeneous investment firms. 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 facing convex adjustment costs. They finance investment with internal and external funding, debt, and equity issuance. Debt pays a fixed interest rate to the bondholders, and it is 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

[1]This distinction is equivalent to the separation between pure monetary policy shocks and central bank information shock in Jarociński and Karadi (2020).

and Hansen (2000). I model a pure monetary policy shock as an exogenous deviation from the systematic Taylor rule. Instead, to introduce an information shock, I assume that the central bank has private information about macroeconomic fundamentals, and it can reveal it to the agents during an announcement. In the model, an information shock is a positive or negative signal about the unobserved state of the economy.

The model helps understand the heterogeneous investment responses to a central bank announcement as observed in the data. A central bank announcement has a different effect on more highly leveraged firms depending upon its nature. A Taylor rule shock decreases firms' internal funds by decreasing operating profits and increasing the cost of debt. High leverage firms suffer the most because of decreasing their cash on hand and increasing their dependence on external financing proportionally to their outstanding debt and equity issuance. This effect translates into an increase in their marginal cost of capital that induces them to invest relatively less than low-indebted firms. Instead, an information shock has an ambiguous effect on firms' internal funds because it fosters positive expectations about the state of the economy. Firms' internal funds increase because of the positive shock on output and operating profits but decrease as borrowing and debt repayment costs increase. It follows that high leverage firms before the announcement may experience a higher marginal cost of capital which leads them to react even less to an information shock. In other words, an information shock dampens the financial accelerator mechanism crucial to explain the heterogeneity to a pure monetary policy shock.

Finally, I use the model to study the monetary policy implication of my findings. A growing part of the literature assumes information policy as an extra tool to stimulate the economy in a period of recession. To this end, I use the model to study state dependence on the aggregate transmission of the policy interventions distinguishing between pure monetary and information shocks. I consider the case where the economy is in a recession and the central bank has to choose how to stimulate investment by cutting the interest rates or releasing good news about the state of the economy. I find that an unexpected interest rate cut stimulates investment by 10pp more in a recession than in regular periods. At the same time, a positive signal about the state of the economy increases investment by 8pp less in a downturn. This paper is the first to document that the effectiveness of monetary policy intervention depends on both the business cycle and the information content of the Fed announcements.

Literature review. This paper contributes to several strands of the literature. First, it contributes to the growing literature that studies the effect of the information shocks on the economy. Following the previous works of Cieslak and Schrimpf (2019), Miranda-Agrippino and Ricco (2018) and Jarociński and Karadi (2020) I use a novel identification strategy to disentangle central bank interventions into monetary and information shocks from the FOMC announcements. To the best of my knowledge, this paper is the first to study the effect of information shocks on firms' investment decisions at the micro-level. At the same time, previous research has only focused on the dynamics of aggregate variables.

Second, it contributes to the literature that studies the effects of firms' balance sheet heterogeneity in the transmission of monetary policy shock to investment dynamics. The closest papers to my work are Ottonello and Winberry (2018) and Jeenas (2018a). Ottonello and Winberry (2018) study Compustat firms' capital accumulation responses to monetary policy shocks conditional on a set of firms' characteristics, leverage, credit ratings, and distance to default as proxies for the level of financial friction. They find that firms with low default risk or low leverage are the most responsive to monetary policy shocks. Jeenas (2018a) finds instead that the high leverage firms are relatively more sensitive to monetary policy shocks and, once they control for liquidity holdings, leverage is not able to explain the difference in heterogeneity in the dynamics of investment. As in these papers, I combine a high-frequency approach and quarterly data from US Compustat to study the effects of firms' heterogeneity on monetary policy intervention. The key difference between these two papers and mine is that I disentangle interest rate surprises in monetary and information policy shocks. My findings suggest that the effects of firms' heterogeneity on investment decisions can be ambiguous because of information component in interest rate surprises.

Other important papers in this literature are Gertler and Gilchrist (1994) that studies the implication of firms' heterogeneity in size for the transmission of monetary policy shocks and, more recently, Cloyne et al. (2018) which instead focus on the implication of firms' age/dividend decisions and monetary policy. In particular, in this last paper, the authors suggest that being young firms and do not pay dividends is a better proxy than other measures of financial frictions proposed in the literature. They find that younger firms that do not pay dividends are more responsive to monetary policy shocks as they are more likely to be financially constrained. The Appendix shows that my main results are robust if I use the variable age/dividends to measure financial friction. Other notable contributions that study the implication of heterogeneity in firm or industry behavior in response to monetary policy shocks include Gaiotti and Generale (2002), Ehrmann and Fratzscher (2004), Peersman and Smets (2005), Crouzet and Mehrotra (2020), Ferrando et al. (2020).

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 discuss the problem of identification of central bank shocks from market-based measures of interest rate expectations and illustrate one way proposed in the literature to identify two series of shocks from the surprises in the interest rates, namely, a pure monetary policy shock and an information shock. To this end, I replicate and extend the results in Jarociński and Karadi (2020) by adding aggregate investment and cost of debt to their specification. In the second part, I study the role of financial heterogeneity in the monetary policy transmission following the recent works of Jeenas (2018a) and Ottonello and Winberry (2018) among others.

2.1 Disentangling monetary policy disturbances

The literature that studies monetary policy and firm heterogeneity identifies shocks to monetary policy following the standard high-frequency identification approach pioneered by Kuttner (2001)[2]. 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) announcements are attributable merely 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 announcements are a valid proxy for monetary policy shocks[3].

However, a large part of the literature highlighted that interest rate surprises around the FOMC announcements are contaminated with an information component that may reflect the possibility that during the FOMC announcements, together and independent of the actual policy actions, the Fed conveys private information about the economy that directly affects the agents' beliefs about future fundamentals[4]. The Fed information view brings two problems in identifying monetary policy shocks. First, because market-based measures of the interest rate expectations can respond to communication about a change in the policy rule

[2]In the recent firm heterogeneity literature, 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.

[3]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.

[4]Empirical evidence of the presence of information component in interest rate surprises are highlighted in Romer and Romer (2000), Nakamura and Steinsson (2018) and Campbell et al. (2012).

and communication about macroeconomic fundamentals revealed by the Fed, an observed interest rate surprise confound an exogenous variation due to an unexpected change in the policy rate, a pure monetary policy shock, and an exogenous variation due to the change in the expectations about future macroeconomic fundamentals, an information shock. Second, observed interest rate surprises around FOMC announcements are insufficient to identify both components requiring the imposition of additional assumptions.

To see this formally, for any FOMC announcement, denote with $i^e_{\bar{t}}$ and $i^e_{\underline{t}}$ respectively a measure of market interest rate expectations 20 minutes after and 20 minutes before the FOMC announcements. At any point in time, i^e_t reflect the expectation on the upcoming change in the policy rule and the expectation on future economic fundamentals $\sum_{j=0}^{\infty} \gamma_j d_{t+j}$. Suppose that during an announcement, the central bank surprises the economy with a change in the policy rates but at the same time provides additional information about economic fundamentals beyond the policy rates, for instance, sharing its optimistic view about future economic conditions. In this case, the econometrician that only observes the interest rate surprise would confound two components, a variation in the interest rate surprise driven by the action of changing the policy rate, ε_t^{mps} and a variation driven by the additional information released along with the change in the policy rate $\gamma \varepsilon_t^{\text{info}} = \sum_{j=0}^{\infty} \gamma_j \Delta d_{t+j}$:

$$\left(i^e_{\bar{t}} - i^e_{\underline{t}}\right) \equiv \Delta i^e_t = \varepsilon_t^{mps} + \sum_{j=0}^{\infty} \gamma_j \Delta d_{t+j}$$

If γ_js are all zeros, then Δi^e_t do not respond to change in the beliefs about fundamentals, and interest surprises perfectly identify an exogenous change in the policy rule ϵ_t^{mps}. If γ_j are different from zero for some j instead, a problem of identification arises as agents do not observe the decomposition of Δi^e_t. So, a variation in Δi^e_t could reflect both changes in the belief about future fundamentals $\varepsilon_t^{\text{info}}$ or unexpected changes in the policy rates ϵ_t^{mps}. This is the view taken in this paper.

Sign restriction identification. I replicate the previous work of Jarociński and Karadi (2020) to disentangle a variation in the interest rate surprises driven by an unexpected policy change ε_t^{mps} and beliefs about fundamentals $\varepsilon_t^{\text{info}}$[5]. Under the assumption that during an FOMC announcement, the Fed simultaneously reveals information about the future path of the interest rate (communication of a change in the policy rule) and additional information about the state of the economy (communication about economic fundamentals),

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

Jarociński and Karadi (2020) suggest identifying ε_t^{mps} and $\varepsilon_t^{\text{info}}$ based on the high-frequency co-movement between the 3-month federal funds rate future and the stock market prices. The empirical separation comes from identifying a shock that increases stock market prices p_t and the interest rates expectations i_t^e simultaneously versus a shock that decreases p_t while increasing i_t^e.

This identification assumes that communication of change in the policy rule affects stock market prices negatively (presumably through the stochastic discount factor). In contrast, communication of economic fundamentals positively affects stock market prices (presumably through the expected dividends). To see this formally, let the stock market price p_t at any point in time be the discounted value of the expectations of future dividends conditional to the time t information set. Thus, surprises in the stock market prices Δp_t around the FOMC announcement can be approximated as:

$$(p_{\bar{t}} - p_{\underline{t}}) \equiv \Delta p_t = \sum_{j=0}^{\infty} \beta_j \Delta d_{t+j} - \sum_{j=0}^{\infty} \alpha_j \varepsilon_{t+j}^{mps}$$

Information revealed during the FOMC that changes the market belief about the future state of the economy increases stock market prices (more optimistic about the future) $\sum_{j=0}^{\infty} \beta_j \Delta d_{t+j}$. Information about the present and future path of the policy rule $\sum_{j=0}^{\infty} \alpha_j \varepsilon_{t+j}^{mps}$ affect negatively stock market prices (future dividends are less worthy). In a naive world where monetary authority only moves the interest rates, and no other information is revealed, a monetary policy tightening would directly decrease firms' stock market prices through the discount factor, causing the stock prices to fall. This assumption is behind the standard identification approach described in the previous paragraph. In a world instead where monetary authority generates a forecasting revision on expected output growth and profits, the sign of the stock prices is ambiguous. In this case, there are two main effects in place. The change in the policy rate (i.e., pure monetary policy intervention) causes the stock prices to fall by increasing the interest rate and lowering the discount factor. Instead, the second effect increases the stock market prices by raising the expectation of the value of future dividends (i.e., communication on economic fundamentals). If the effect on firms' profits is stronger than on the discount rate, the stock market prices go up when the interest rate increases.

I identify a pure monetary policy shock as a shock that generates a negative co-movement between a surprise in the interest rates and the stock market prices. In contrast, an information shock causes the interest rates and stock prices to co-move positively. The former is a shock affecting stock market prices mainly through the interest rate or the discount factor. The latter is a shock that influences stock market prices mainly through the expectations about future fundamentals. I disentangle these two shocks using a structural Bayesian VAR with a sign restriction between the innovations in the 3-months fed funds future and stock market prices around the FOMC announcements.

Aggregate response and IRFs. To capture the response of aggregate business investment to a structural monetary policy disturbance, I employ a Bayesian structural VAR model with aggregate macroeconomic variables and monthly high-frequency financial market surprises as in Jarociński and Karadi (2020). For the financial surprises, I include high-frequency variations in the 3-month federal funds rate future and stock market prices to capture respectively unexpected changes in the policy rates and unexpected changes in the future economic path[6]. For the aggregate macroeconomic variable, consistently with their work, I include the monthly average of the 1-year Treasury yield as a measure of the short-term interest rate, the monthly average of the S&P 500 in log levels as a measure of stock market prices, the interpolated series of the real GDP, the GDP deflator and real business investment in log levels to measure real aggregate activities. Finally, I calculate the firms' cost of debt as the sum of the Gilchrist and Zakrajšek (2012) excess bond premium and the 1-year Treasury yield. I estimate a 12 lags VAR using data from 1990-Q1 to 2016-Q4 and standard Minnesota prior on the parameters[7] as in Jarociński and Karadi (2020). I plot in figure (1) the impulse response function to an identified pure monetary policy shock (first row) and an information shock (second row).

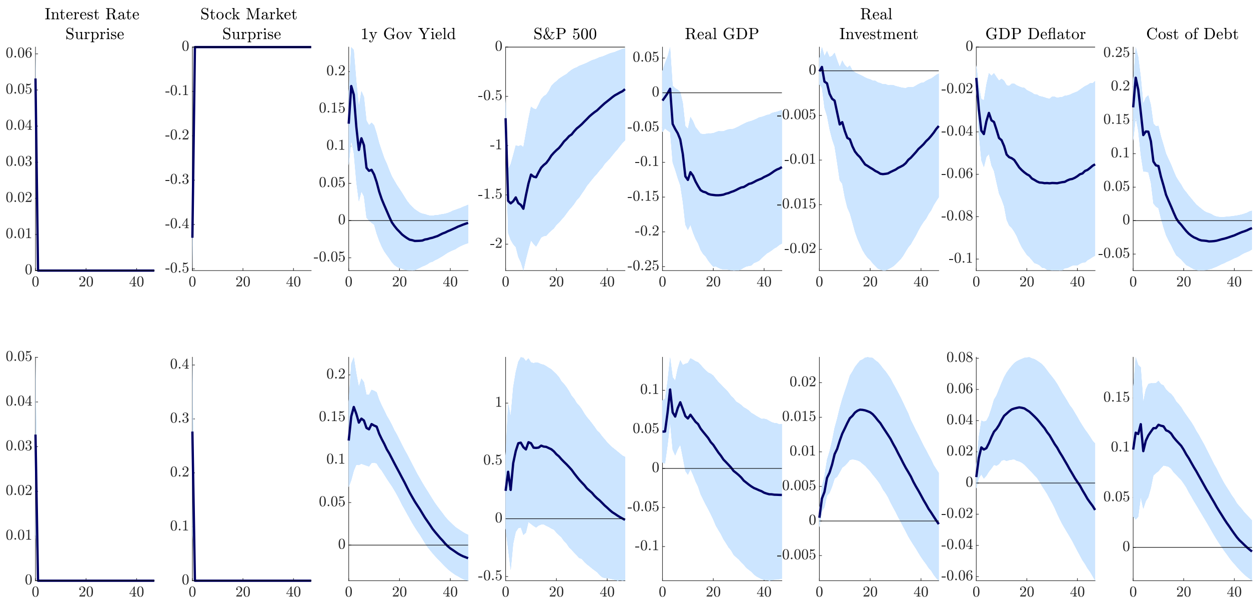
The results show that an interest rate surprise produces sizable and different effects on the economy depending on how it co-moves with the stock market prices. In particular, when the agents expect the central bank to raise the interest rates and the stock market falls at the announcement (i.e., the information effect is weaker than monetary policy effect), a monetary policy intervention 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, if the central bank surprises the market with an increase in the fed funds rate but the stock market reacts positively (i.e., the information effect is stronger than monetary policy effect), a monetary policy intervention 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. The critical difference is in the response of the cost of debt

[6] I calculate financial surprises in a 20-minutes window surrounding scheduled FOMC announcements and sum up at monthly level. More details are in the Appendix.

[7] The presence of Minnesota prior for the VAR parameters in the specification allows to avoid the problem of over-fitting, Litterman et al. (1979).

Figure 1: Aggregate IRFs to the identified shocks



Note: The aggregate impulse responses to a contractionary one-standard deviation pure monetary policy shock (first row) and an expansionary information shock (second raw) identified using Jarociński and Karadi (2020) decomposition. I plot the median response along with the [14,86] percent confidence intervals.

which is procyclical, conditional to an information shock, countercyclical conditional to a monetary policy shock. These results are in line with the main findings of Jarociński and Karadi (2020)[8]. I sum the high-frequency shocks to the quarterly frequency to merge them with the firm-level data as standard in the literature.

2.2 Firm-level data

I estimate the effects of firms' heterogeneity on the financial position in the transmission of monetary policy as in Ottonello and Winberry (2018). I extract firm-level data from the quarterly Compustat database from 1990-Q1 to 2016-Q4 and combine it with the monetary and information shocks identified in the previous section[9]. The Compustat database is a reliable source of information about firms' financial statements, and it has been widely used to study the implication of firms' heterogeneity and the effectiveness of monetary policy to stimulate investment.

[8]In the Appendix figure 8, I also compare them with the effects of an orthogonal monetary policy shock identified using the standard identification approach by Gertler and Karadi (2015).

[9]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).

Following the literature, I estimate the response of the two shocks on capital accumulation rather than on capital investment. I use the book value of capital stock $k_{i,t}$ as a measure of firm i's capital accumulation at the end of the quarter t as in Jeenas (2018a), and Ottonello and Winberry (2018)[10].

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. I choose this variable because of two reasons. First, is correlated with other measures of financial frictions. Ottonello and Winberry (2018) show that firms' leverage is 60% correlated with measures of default risk, providing the same conclusions when studying the dynamic heterogeneous responsiveness to a monetary policy shock. Second, more practical, it has an immediate counterpart in a theoretical framework with firm heterogeneity and financial frictions[11]. 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.

2.3 Heterogeneity to investment response

I study the heterogeneous effects of interest surprises on investment using Jorda'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 does not suffer from the generated regressor problem highlighted by Pagan (1984). Unlike other papers in the literature, I distinguish between interest rate surprises generated by a change in the policy rule, pure monetary policy shocks, and interest rate surprises due to information revelation about economic fundamentals during a Fed announcement. I estimate the heterogeneous effect of interest rate surprises in two steps. In the first step, I estimate the average investment response to the two shocks separately. In the second step, I estimate the heterogeneous effect of the two shocks across firms with different leverage levels.

Average response of investment. To estimate the average response of investment, I regress the exogenous shocks on capital change h-period ahead $\Delta_h \log(k_{i,t+h}) = \log(k_{i,t+h}) - \log(k_{i,t-1})$. I use the variation in 1-year Treasury rate Δi_t as the endogenous policy variable and the two exogenous shocks ε_t^{mps} and $\varepsilon_t^{\text{info}}$ as external instruments. In the baseline

[10] The literature agrees to look at the dynamics of firms' capital stocks rather than the variable investment because of measurement errors issues which make difficult to precisely detect systematic responses in investment rates in the cross-section, Doms and Dunne (1998).

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

specification I estimate the average effect using the entire data sample as follows:

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

I instrument the endogenous variable $\Delta \mathrm{i}_t$ separately with the two exogenous shocks ε_t^{mps} and $\varepsilon_t^{\text{info}}$ identified in the previous section. I re-scale the estimated coefficient to a 25bp change in the interest rate $\Delta \mathrm{i}_t$ as standard in the literature. I add additional controls to improve the efficiency and robustness of the estimates as standard in the literature. I control for firm fix effect to capture time in-varying unobserved heterogeneity at firm level $\alpha_{i,h}$, a set macro-aggregates Z_{t-q} to control for business cycle fluctuations: 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. I cluster the errors at the firm-quarter level as standard in the literature.

The coefficients γ_h are the point estimates of the firm-level impulse response to a pure monetary policy shock and information shock. They can be interpreted as the micro-level equivalent of the aggregate impulse response function in figure (1) and serve as a benchmark to understand the sensitivity across firms to interest rate surprises. To be more specific, γ_h captures the average firm-level response of capital to a monetary and information shock, normalized so that it increases the 1-year Treasury rate by 0.25%. In terms of the sign, if $\gamma_h > 0$, I conclude that on average, firms increase investment by γ_h percentage points h periods after the shock hits, while if $\gamma_h < 0$ on average, firms decrease investment by γ_h percentage points h periods after the shock.

Heterogeneous effect of interest rate surprises. After estimating the average firm-level IRFs, I investigate which firms are more sensitive to the two shocks. To this end, I estimate the dynamic heterogeneous response for capital accumulation $\Delta \log \mathrm{k}_{i,t+h}$ h period ahead using LP-IV with an interaction term following Cloyne et al. (2018) among others[12]. In the baseline specification, I treat the variable leverage as a continuous variable when interacting with the two shocks. I run the following regression:

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

[12] 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.

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 policy disturbances ε_t^{mps} and $\varepsilon_t^{\text{info}}$ separately. I control for firm fixed effects α_i to capture time in-varying 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.

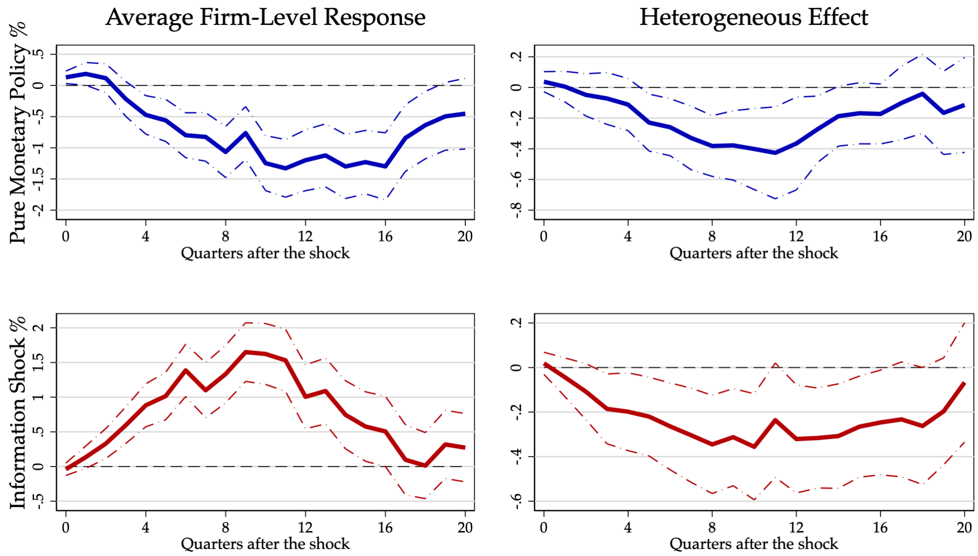
The coefficient of interest is β_h which captures the heterogeneity effect of an interest rate shock on capital accumulation h period ahead. More in details, since the partial derivative $\frac{\partial \Delta \log k_{t+h}}{\partial \Delta i_t}$ in equation (2) captures the firm-level impulse response function to a policy shock, the cross derivative with respect to Δi_t and lev_{t-1}, $\frac{\partial \Delta log k_{t+h}}{\partial \Delta i_t \partial lev_{t-1}} = \beta_h$ can be interpreted as an estimate of the average difference in the impulse responses of capital expenditure between two firms with 1pp difference in past leverage. In this baseline specification, the heterogeneous effect to an interest rate surprise is independent on the level of past leverage.

The sign of β_h and γ_h allows us to understand the sensitivity to the two shocks. Suppose β_h and γ_h have the same sign (positive or negative). In that case, high-leverage firms are more sensitive to the shock, and I conclude that firm leverage is a source of amplification for monetary policy. If β_h and γ_h have different signs, high-leverage firms are less sensitive than low-leverage firms, and firm leverage is a source of dampening for Fed announcements. I plot the impulse response function for the average and heterogeneous response in figure (2). In response to a pure monetary policy intervention (i.e., interest rate surprise with no information revelation) that increases the interest rate by 0.25%, firms reduce, on average, the capital stock by around 1.25% ten quarters after the shock. In the cross-section, high leverage firms are more sensitive to a pure monetary policy surprise. On average, firms with 1pp more leverage before the shock accumulate around 0.4% less capital after two years.

In response to an information shock (i.e., interest rate surprise driven by information) that equally increases the interest rate by 0.25% instead, firms increase, on average, their capital stock by 1.6% after around two years. Unlike a pure monetary policy shock, high leverage firms prior to the shock are less sensitive to an information shock. Firms that have higher debt are the ones that tend to accumulate less capital. On average, I found that firms with 1% more leverage accumulate around 0.3pp less capital around ten quarters after an information shock.

The first result is in line with the findings of Jeenas (2018a) while the second finding is novel to the literature. These results complement the existing literature that investigates

Figure 2: Heterogeneous response of investment



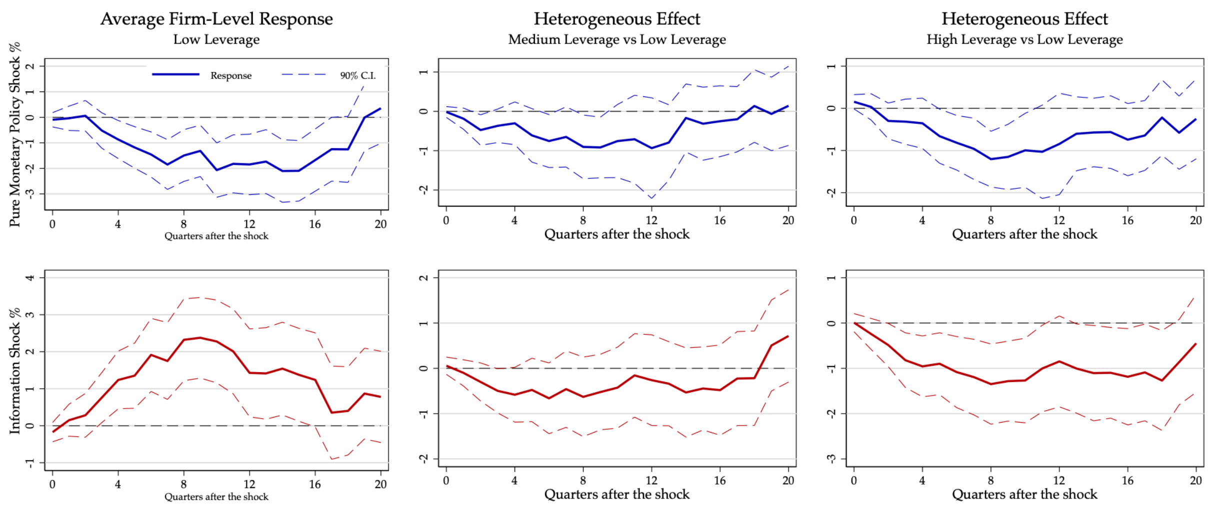
Note: Plot the impulse response function on capital accumulation to one standard deviation shock to a monetary policy shock (first row) and to an information shock (second row). In the first column, the average firm-level response to the exogenous shock; in the second column, the heterogeneous effect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

the role of financial heterogeneity in the transmission of policy shocks. My results show that a priori, the presence of information in interest rate surprises can flip the micro-level results heterogeneous sensitivity to a Fed policy intervention. In the Appendix figure (9), I show that an econometrician would lead to an incomplete conclusion if he did not separate interest surprises as done in the literature.

2.4 Non-linear heterogeneous effect of interest rate surprises

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

Figure 3: Heterogeneous response of investment by leverage group



Note: Note: Plot the impulse response function on capital accumulation to one standard deviation shock to a monetary policy shock (first row) and to an information shock (second row). I report the 90% confidence intervals constructed based on two-way clustered standard errors at firm and quarter levels.

the $[0, 20]$ percentile of leverage) as in equation (1). I then estimate the differential response by groups relative to the low leverage firm as follows:

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

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. Figure (3) show the results of this exercise.

Two things are worth to be mention. First, figure (3) 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 an information shock (second row). In response to an information 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 effect, while high leverage firms increase capital significantly by around 1pp less. The results are not surprising and 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.

2.5 Discussion and robustness

The presence of financial frictions in the economy is a necessary condition to explain the heterogeneous response of investment to aggregate shocks documented in the previous section. If all firms have equal access to capital markets, the firms' capacity to undertake investment does not depend upon the mode of financing, and consequently, firms' responses to aggregate fluctuations should not differ because of differences in the levels of leverage. Contrary, in the presence of financial frictions, firms' financing decisions and investment choices are intimately connected, and firms' responses to aggregate fluctuations may differ because of differences in the financial positions. As a comprehensive measure of the level of financial frictions is not available, earlier works on firms' heterogeneity have found contrasting results on the role that firms' financial positions play in the effectiveness of central bank interventions when using different proxies for financial frictions and specifications.

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 policy shocks. 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 the firm that would otherwise be left in the error term and potentially bias the results. In the Appendix figure (13), I show that my results are robust to demeaning leverage at the firm level, and they 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[13]. Second, he suggests using cash liquidity as a proxy for financial frictions. In the Appendix figure (10), I show that

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

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 policy rates, produce opposite conclusions when studying the firms' average and the heterogeneous investment response[14].

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 used the variable size based on past sales growth to measure financial friction. Their findings suggest 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 while less sensitive to information shocks, figure (12). In another work, Whited (1992) suggests using credit ratings as a measure of the strength of financial frictions. Compared to leverage, credit rating reflects the firm's probability of default and does not adjust over time as frequently as debt. 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 (11), I show that my results are less robust to this specification.

Finally, my results are robust to different periods. In particular, for the identification to be valid, it must be the case that additional pieces of information in the small window of time around the FOMC announcement are released. In principle, the Fed can only do that via the FOMC statement. However, from 1990 to 2000, the Fed did not use to communicate information during the FOMC meeting other than the changes in the policy rule[15]. This fact poses a problem to the validity of the identifying assumption in the empirical analysis since my sample firms are observed from 1990 to 2016. In order to control for this possibility, I cut the sample before 2000 and run the regression in the 2000-2016 interval. Figure (15) shows the results of this exercise.

[14] 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.

[15] On the Fed website, it says about the Policy Statement: *The FOMC first announced the outcome of a meeting in February 1994. After making several further post-meeting statements in 1994, the Committee formally announced in February 1995 that all changes in the stance of monetary policy would be immediately communicated to the public. In January 2000, the Committee announced that it would issue a statement following each regularly scheduled meeting, regardless of whether there had been a change in monetary policy.*

Implication for monetary policy. In recent years, the Fed has relied more and more on non-monetary communication to influence the state of the economy without resorting to its conventional policy tool. Although a large number of papers on the topic, the presence and the importance of this informational component in the Fed's action is still under debate. In this paper, I take the position that information effects arise exogenously and explicitly from the announcement of the Fed in the FOMC window. Unlike standard monetary policy operations, pure information policy affects the economy by influencing agents' macroeconomic expectations about the future state of the economy[16]. The role and the characterization of information policy is well-documented in the literature.

Guthrie and Wright (2000) refer in a general way to communications by the central bank that affects the interest rates and economic expectations without significantly changing their daily monetary operations as Open Mouth Operations. Mario Draghi's 2012 statement that "the ECB will do whatever it takes to preserve the euro, and believe me, it will be enough" is maybe the most notorious example of a successful Open Mouth Operation used to lower the interest rates of the Spanish government bonds during the European government crisis. In the US, Campbell et al. (2012) argue that the presence of information effects reflects the fact that during the FOMC statement, the Fed telegraphs its projections for the state of the economy to the public and that this component is significant in a large group of policy decisions. In favor of this, Cieslak and Schrimpf (2019), and Jarociński and Karadi (2020) show that non-monetary news prevails in about 40% of policy decision announcements by the Fed and the ECB. Central bank information shocks explain more that the 30% of the variability of the interest rate surprises[17].

Regarding the qualification and the role of information shocks, the literature supporting the Fed Information view considers pure information policy an additional tool in the hand of the Fed to stimulate the economy, similar to pure monetary policy interventions. Speaking to this literature, this paper introduces a new element to understanding the effectiveness of the Fed communication policy. My results suggest that financial heterogeneity plays an opposite role in stimulating monetary policy interventions depending on the content of the Fed statement. Suppose the central bank decides to stimulate the economy by cutting the interest rates without significantly affecting the agents' expectations about the future state of the economy (i.e., no pure information content). In that case, monetary policy gains an extra-kick from firms with a high level of debt that are more sensitive to pure monetary

[16]The assumption behind the exogenous Fed information view is that the Fed has private information about the state of the economy and it reveals it to the agents directly during its announcement.

[17]Cieslak and Schrimpf (2019) also show that most of this news is related to growth information, i.e., information about the future economic outlook.

policy changes. Financial friction is a source of amplification for pure monetary policy rate shocks. If the central bank instead decides to stimulate the economy by releasing good news about the future instead, making agents more optimistic, high leverage firms are less sensitive. In this case, financial friction is a source of dampening for policy intervention. The micro-level findings on the heterogeneous sensitivity to different monetary policy surprises introduce a new layer of complexity to the role financial frictions play in the transmission of communication policy shocks.

In the next section, I investigate the state dependency of monetary policy transmission through the lens of a general equilibrium model with firm heterogeneity and frictions. I will show that, indeed, pure monetary policy intervention and information interventions have a different effects in a period of recession.

3 Model

In this section, I develop a New-Keynesian dynamic general equilibrium heterogeneous firm model with idiosyncratic productivity to interpret my empirical findings and study monetary policy implications along the business cycle. The key actors in the model are a set of heterogeneous investment firms that are different because of idiosyncratic productivity shocks. 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 funding, debt, and equity issuance. In the model, heterogeneous investment 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.

The model is close to the previous works of Ottonello and Winberry (2018) and Koby and Wolf (2020) among the others. Compared to Ottonello and Winberry (2018), I assume debt is risk-free and firms never default in equilibrium, whereas in their paper, firms can endogenously default and exit from the market[18]. I decided to model debt as risk-free for two reasons. First, in Compustat data, the firm leverage distribution over S&P credit quality scores is statistically identical, suggesting that firms with a higher probability of default have similar leverage profiles. Second, the heterogeneous results in the empirical analysis survive even if I restrict the sample to high credit quality firms, which unlikely will change their probability of default significantly after the shock. Both results are not surprising since

[18] Ottonello and Winberry (2018) argue that leverage is a proxy for the firms' default risk in the data as it is 60% correlated with the standard corporate finance measure of distance to default.

Compustat includes mostly large firms with a relatively stable and low-risk profile. The main difference with Koby and Wolf (2020) instead is that I add nominal rigidity to introduce a Taylor rule shock and model inflation.

3.1 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 $\Gamma_t = \Gamma(\varepsilon_{j,t}, k_{j,t}, b_{j,t})$ over idiosyncratic productivity $\varepsilon_{j,t}$, capital $k_{j,t}$ and debt $b_{j,t}$. Firms are owned by a representative household. Firms produce an homogeneous wholesale good $y_{j,t}$ 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.

Production and investment. Firms produce an homogeneous wholesale good $y_{j,t}$ using capital $k_{j,t}$ and labor $n_{j,t}$ with a decreasing return to scale technology: $y_{j,t} = z_t \varepsilon_{j,t} k_{j,t}^{\alpha} n_{j,t}^{\nu}$ 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 which follows an auto regressive process in logs:

$$\log z_t = \rho_z \log z_{t-1} + \sigma_z u_t^z, \quad u_t^z \sim N(0,1) \tag{3}$$

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 $\sum_s^N \pi_{is} = 1, \forall i$.

Each period, firms hire labor in a competitive labor market at the equilibrium wage w_t, invest in new capital $k_{j,t+1}$[19] and issue debt $b_{j,t+1}$. Because firms do not face any frictions in adjusting labor $n_{j,t}$, the optimal labor policy $n_{j,t}^*$ solves the static problem:

$$n^*(\varepsilon_{j,t}, k_{j,t}, b_{j,t}) = \underset{n_{j,t} \geq 0}{\arg\max} \left\{ p_t^w z_t \varepsilon_{j,t} k_{j,t}^{\alpha} n_{j,t}^{\nu} - w_t n_{j,t} \right\}$$

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 law motion $k_{j,t+1} = q_t i_{j,t} + (1-\delta) k_{j,t}$, where q_t is an aggregate shock to the marginal

[19]Without loss of generality I normalize the price of capital to one.

efficiency of investment that follows a first-order auto regressive process in logs:

$$\log q_t = \rho_q \log q_{t-1} + \sigma_q u_t^q, \qquad u_t^q \sim N(0,1)$$

I assume that agents have imperfect knowledge of the realization of q_t, but they know its law motion. Justiniano et al. (2011) shows that a shock to the marginal efficiency of investment can be interpret as a shock to the capacity of the financial system to intermediate resources. To generate a more realistic firm size distribution I assume that firms face adjustment costs whenever they invest or divest in new capital. I model the adjustment cost function as follows:

$$g\left(k_{j,t+1} - (1-\delta)k_{j,t}, k_{j,t}\right) = c_0 \left(\frac{k_{j,t+1} - (1-\delta)k_{j,t}}{k_{j,t}}\right)^2 k_{j,t} + c_1 \mathbb{1}_{i_{j,t}\neq 0}$$

where $\mathbb{1}_{i_{j,t}\neq 0}$ 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 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, it allows breaking the connection 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 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.

Financing policy and frictions. Firms jointly decide the capital to buy for the next period and its financing policy. To finance investment, firms use a combination of internal and external funds, where the sources of external funds are debt $b_{j,t}$ and new equity issuance. Firms prefer debt over equity financing because of a tax advantage[20]. The corporate tax rate is a model parameter, denoted by τ.

Internal financing is represented by the cash flows generated from production and debt

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

repayment. 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 type $(\varepsilon_{j,t}, k_{j,t}, b_{j,t})$ firm after production debt repayment and taxes in every period is:

$$x(\varepsilon_{j,t}, k_{j,t}, b_{j,t}) = (1-\tau)(p_t^w z_t \varepsilon_{j,t} k_{j,t}^{\alpha} n_{j,t}^{*\nu} - w_t n_{j,t}^* - \eta) - (1+i_t^n) b_{j,t} + \tau\left(\delta k_{j,t} + i_t^n b_{j,t}\right)$$

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 average cross-sectional distribution of the firms over leverage. As firms are heterogeneous by debt $b_{j,t}$, a variation in the cost of borrowing ${}^n i_t$ affects mainly highly indebted firms through the debt repayment and the tax shield on the interests.

Beyond internal funds, firms have access to the bond market. Firms can finance investments by issuing one-period bonds that pay $(1+i_t^n)$ unit of output to its bondholders next period. I assume that firms never default in equilibrium and always repay their debt. Since I do not restrict debt to be positive, $b_{j,t}$ can take both positive or negative values, with a positive value denoting debt and a negative value denoting cash.

As debt is risk-free, the bondholders require firms to be able to repay their debt in every state of the world, Hennessy and Whited (2007). This condition is guaranteed by introducing a limited liability constraint 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 fraction of the future capital stock[21]. The limited liability constraint is as follows:

$$b_{j,t+1} \leq \theta_k k_{j,t+1} \tag{4}$$

This linearity in the limited liability constraint 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 collateral 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.

[21]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. Both approaches are equivalent to mine at the first-order approximation for some constant term.

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:

$$d(\varepsilon_{j,t}, k_{j,t}, b_{j,t}) = x(\varepsilon_{j,t}, k_{j,t}, b_{j,t}) - g\left(k_{j,t+1} - (1-\delta)k_{j,t}, k_{j,t}\right) - i_{j,t} + b_{j,t+1}$$

If $d(\varepsilon_{j,t}, k_{j,t}, b_{j,t})$ 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:

$$h\left(x_{j,t}, b_{j,t+1}, k_{j,t+1}\right) = a_1 d_{j,t}^2 \mathbb{1}_{d_{j,t}<0} \tag{5}$$

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 parameter a_1 controls the degree of financial friction[22]. The equity payout left to the shareholders is equal to the dividends net of equity issuance cost.

3.2 Retailers

There is a unit continuum of retailers indexed by i. Retailers purchase the homogeneous good $y_{j,t}$ produced by the wholesale heterogeneous firms at price p_t^w and transform it into a differentiated good $\tilde{y}_{i,t}$ using a linear technology $\tilde{y}_{i,t} = y_{j,t}$. Retailers set the prices $p_{i,t}$ for the differentiated good $\tilde{y}_{i,t}$ in a monopolistic competitive market, taking the demand of their goods from the final good producers as given. In setting their prices, they are subject to Rotemberg quadratic adjustment costs. The retailer problem is the following:

$$\max_{\{p_{i,t}\}} \quad \mathbb{E}_0 \sum_{t=0}^{\infty} \Lambda_{t,t+1} \left(p_{i,t}\tilde{y}_{i,t} - p_t^w y_{j,t} - \frac{\phi_p}{2}\left(\frac{p_{i,t}}{p_{i,t-1}} - 1\right)^2 Y_t \right) \tag{6}$$

where $\Lambda_{t,t+1}$ is the household stochastic discount factor and $\tilde{y}_{i,t}$ is the demand of differ-

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

ential good from the final good producers.

3.3 Final good producers

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

$$Y_t = \left[\int \tilde{y}_{i,t}^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}} \tag{7}$$

The cost minimization problem of the final good producers pin down the demand for the differentiated goods $\tilde{y}_{i,t}$

$$\tilde{y}_{i,t} = \left(\frac{p_{i,t}}{P_t}\right)^{-\theta} Y_t \tag{8}$$

Where P_t is the price of the consumption good paid by the households, normalized to 1. The retailers and the final good producers aggregate to derive the standard New 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.

3.4 Households

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

$$\max_{\{c_t,\ell_t,b_t\}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{\frac{c_t^{1-\gamma} - 1}{1-\gamma} - \kappa\ell_t\right\} \tag{10}$$

such that

$$c_t + b_t = w_t\ell_t + \frac{1 + i_{t-1}^n}{1 + \pi_t}b_{t-1} + d_t + d_t^R + d_t^F + g_t \tag{11}$$

where d_t , d_t^R and 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. The marginal utility of consumption is:

$$\lambda_t = c_t^{-\gamma} \tag{12}$$

The consumption Euler equation and labor supply are:

$$\lambda_t = \beta \mathbb{E}_t \left[\frac{1 + i_t^n}{1 + \pi_{t+1}} \lambda_{t+1} \right] \tag{13}$$

$$w_t = \kappa c_t^{\gamma} \tag{14}$$

Finally, the dynamics of the household's stochastic discount factor follows:

$$\Lambda_{t,t+1} = \beta \mathbb{E}_t \left[\frac{\lambda_{t+1}}{\lambda_t} \right] \tag{15}$$

Given a path for aggregate consumption and labor, equation (12)-(15) are sufficient to pin down the price of labor w_t,the real interest rate $r_t = \frac{1+i_t^n}{1+\pi_{t+1}}$ and the stochastic discount factor $\Lambda_{t,t+1}$. Since households own the entire distribution of firms, firms discount future dividends according to the household's stochastic discount factor. As a result, a shock to the consumption path affects the firms' choices by changing the marginal benefit of capital and the weight associated with future profits.

3.5 Central bank and government

I close the model by adding a monetary authority that sets the nominal interest rate and a government that redistributes taxes to the households.

Central bank. I model a pure monetary and an information shock in a perfect foresight economy. Central bank sets the nominal interest rate i_t^n following a standard Taylor rule written as:

$$\log(1 + i_t^n) = \log(1 + \bar{i}) + \phi_\pi \log \left(\frac{1 + \pi_t}{1 + \bar{\pi}} \right) + \phi_y \log \left(\frac{y_t}{\bar{y}} \right) + \varepsilon_t^m \tag{16}$$

where, i_t^n is the nominal policy rate, $\bar{i}$ is its stationary value, $\bar{\pi}$ is the inflation target, and $\bar{y}$ is the steady-state level of output. The parameter ϕ_π and ϕ_y measure respectively the response of monetary policy to deviations in inflation and output from their targeted values[23]. To introduce the information shock, I assume that the central bank has private information about q_t and it can share this information with the other agents in the economy.

In a given period t, the central bank makes an announcement. Central bank communicates the path of the interest rate i_t^n to the agents and it sends a signal $s_t = q_t + \varepsilon_t^n$ to the firms about the realization of q_t. I assume that the signal is infinitely precise, so s_t coincides with q_t, i.e., ε_t^n has zero variance . In this setting, a pure monetary policy shock is an exogenous temporary deviation from the systematic Taylor rule ε_t^m, and an information shock is a realization of the signal about q_t[24].

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

$$g_t = \int \tau \left(p_t^w y_{i,t} - w_t n_{j,t} \right) - \tau \left(\delta k_{j,t} + i_t b_{j,t} \right) d\Gamma \tag{17}$$

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

4 Calibration and aggregate response

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

[23] I fix the parameter ϕ_y to zero as standard in firm heterogeneous literature.

[24] This setting is nevertheless similar to Jarociński and Karadi (2020). In Jarociński and Karadi (2020) the central bank learns about a shock to capital quality k-period ahead before it materializes, and it communicates it in advance to the agents.

at quarterly frequency[25]. 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 $u_{i,t} \sim N(0, \sigma_\varepsilon^2)$. I discretize the stochastic process for the logarithm of idiosyncratic productivity using 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 $\tau = 0.2$[26]. 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 sustainability 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. 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 (1.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 to match a set of empirical moments drawn from Compustat. I chose the moments to target based on the previous works in the literature. I 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[27] 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.

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

[26]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).

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

Table 1: 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 $\approx$ 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

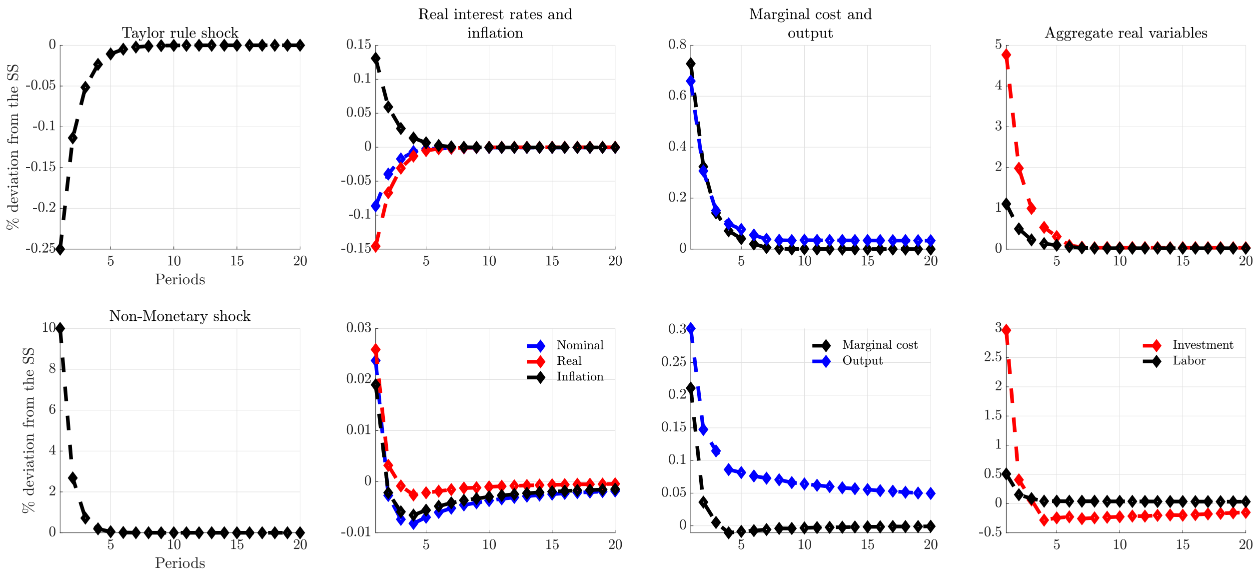
Note: I report the calibrated and the estimated parameters of the model in panel A and panel B.

I also target the inaction rate of investment, defined as the percentage of the firms with an 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[28].

The estimation procedure returns the following estimated parameters: the quadratic adjustment cost parameter $c_0 = 4.9$, the non-convex adjustment cost parameter $c_1 = 0.125$, 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 (1.B) reports a summary of the parameters that are estimated and the target moments.

[28] 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.

Figure 4: The baseline IRFs in the model



Note: The impulse response function to a central bank announcement in the model. In the first row, the response of the aggregate variables to an exogenous cut in the interest rate, i.e. pure monetary policy shock. In the second row, the response of the aggregate variables to a good signal about investment productivity, i.e. information shock.

4.1 Aggregate impulse response in the model

I start by showing that the model can match qualitatively the aggregate impulse responses observed in the data[29]. To do that, I study the aggregate effects of the two shocks separately along the perfect foresight transition path back to the steady-state as in Jeenas (2018a), and Ottonello and Winberry (2018). Details of the algorithm are in the Appendix. I report the impulse responses in figure (4). In the first raw, the impulse response function to an exogenous shock to the Taylor rule shock (i.e., an exogenous decrease in the nominal interest rate); in the second raw, the impulse response function to a positive information shock (i.e., Fed signals a good realization of q_t).

If the central bank temporarily deviates from the Taylor rule (by decreasing the nominal interest rate) a pure monetary policy shock produces expansionary effects in the economy, increasing output, consumption, and labor. Because prices are sticky, they are slow to adjust, and the economy experiences a period of inflation that causes the real interest rate to deviate from the nominal. Investment increases because of two reasons. First, the marginal benefit

[29]In the Appendix, I study the impulse responses to a set of shocks that are potential candidates for an information shock and conclude that none of them are consistent with the impulse responses found in the data.

of capital increases thanks to the rise in the discounted return of future capital and the expected output. Second, the firms' financial position improves due to the increase in the overall firms internal revenue and a decrease in the cost of debt.

Instead, a positive signal s_t about investment productivity q_t leads the economy on a path similar to a positive demand shock. Because of the signal, firms learn that turning investment into capital is more efficient, so they respond by accumulating more capital. The value of consumption falls since investment becomes more valuable. Again, labor and output increase, and prices slowly adjust upward, producing inflation that triggers the central bank to increase the nominal interest rate. Both shocks produce a response in the economy consistent with the aggregate impulse responses obtained in figure (1).

5 Analysis and stationary equilibrium

The section describes the model's mechanism and provides intuition behind the heterogeneous firm-level response to a monetary and information shock. I start by describing the firms' problem and then analyze constrained and unconstrained firms' behavior in the stationary equilibrium looking at the first-order condition for capital.

5.1 Firms' problem and financial frictions

To build an intuition of the key mechanism of the model I re-write the firms' problem using the Bellman equation. Denote with $V(\varepsilon, k, b)$ the value function at time t of a firm with initial states (ε, k, b). Then, each firm solve the following dynamic profit maximization problem subject to a set of constraints:

$$V(\varepsilon, k, b) = \max_{k',b'} \Big\{ x(\varepsilon, k, b) - g\left(k' - (1-\delta)k, k\right) - i + b' - (a_0 + a_1 d^2)\mathbb{1}_{d<0} + \Lambda_{t,t+1} \sum_{\varepsilon'} \pi\left(\varepsilon'|\varepsilon\right) V'\left(\varepsilon', k', b'|\varepsilon\right) \Big\} \quad (18)$$

subject to:

$$d(\varepsilon, k, b) = x(\varepsilon, k, b) - g\left(k' - (1-\delta)k, k\right) - i + b' \quad (19)$$

$$g\left(k' - (1-\delta)k, k\right) = c_0 \left(\frac{k' - (1-\delta)k}{k}\right)^2 k + c_1 \mathbb{1}_{i\neq 0} \quad (20)$$

$$x(\varepsilon, k, b) = (1-\tau)(p_t^w z_t \varepsilon k^\alpha n^{*\nu} - w_t n^* - \eta) - (1 + i_t^n)b + \tau\left(\delta k + i_t b\right) \quad (21)$$

$$b' \leq \theta_k k' \quad (22)$$

$$h(x, k', b') = (a_0 + a_1 d^2)\mathbb{1}_{d<0} \quad (23)$$

where $x(\varepsilon, k, b)$ is the cash on hand available at beginning of the period t, $g\left(k' - (1-\delta)k, k\right)$ are the adjustment costs, $d(x, k', b')$ are the dividends to the shareholders and $h(x, k', b')$ are the equity issuance cost which occur when a firm decides to finance investment with equity.

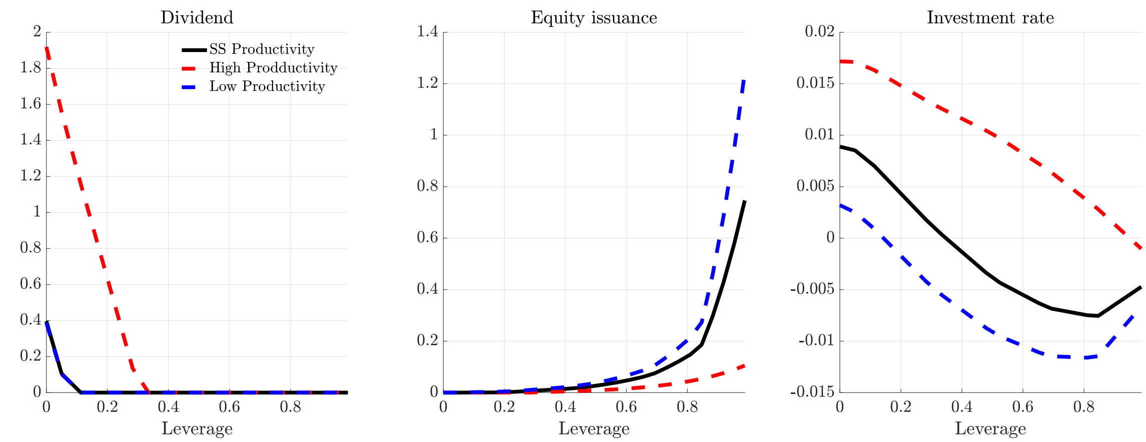
In the model, firms make two substantial choices. They choose the amount of capital to buy for the next period k' and the amount of debt b' to issue for financing investment. The choice of equity financing is better understood as residual once a firm optimally chooses its investment and debt policy, given the internal funds available at the beginning of the period. The introduction of equity issuance cost implies a natural way to define whether a firm is financially constrained[30].

At the beginning of every period, firms are distinct by the internal funds available to finance investment. I define a firm as *unconstrained* 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, $h = 0$. A firm is *constrained* 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, $h > 0$. This definition introduces a linkage between firms' leverage, investment and financial frictions that can be seen by looking at the steady-state policy function along the leverage dimension which, I report in figure (5).

Figure (5) shows two main facts. First, given a fixed amount of capital, high leverage firms are more likely to be financially constrained (first and second columns). In the model, equity issuance and dividend payments are mutually exclusive. In equilibrium, low leverage firms are more likely to pay dividends to the shareholders while high leverage firms 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 investment policy with generated cash and debt, so they never issue equity and distribute dividends to the shareholders. Second, figure (5) (third column) shows that firms' financing decisions and investment choices are intimately connected. High-leverage firms have lower

[30] 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.

Figure 5: Dividend policy and the marginal cost of capital.



Note: I plot the dividend policy, the level of financial friction (marginal cost of capital divided by capital) and the investment rate along leverage dimension. I choose a firm with capital at the median level in the population distribution. I also plot the policy functions at the stationary productivity level (solid black line) and ±1.5 unconditional standard deviation as the representative high and low productivity states, red and blue dotted line.

investment rates than firms with low leverage, given a fixed amount of capital. This fact is a consequence of the presence of equity issuance costs. As equity issuance are costly, and firms with a high level of debt are more likely to raise external funds, high leverage firms have a higher marginal cost of capital, and thus, they invest less.

The model produces steady-state predictions consistent with the data. To check this, I look at the cross-sectional correlation between firms' leverage and dividends payout, equity issuance, and investment rates across Compustat firms from 1990 to 2016. I compute firms' averages on the entire time sample and plot a binscatter of the cross-sectional correlation in figure (19). Figure (19) shows that model steady-state predictions are in line with the data. First, the data shows a very strong relationship between firms' leverage and payout policy. 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), and Cloyne et al. (2018) that suggest identifying financial constraint firms as firms that do not pay dividends or issue equity. Second, 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.

My model is also theoretically equivalent to the one of Ottonello and Winberry (2018) and Jeenas (2018a). In Jeenas (2018a), firms face a non-negativity constraint on dividends, and so, they cannot issue equity in equilibrium. Jeenas (2018a) define a firm as constrained if it optimally decides not to distribute dividends to the shareholders. His way of modeling financial friction is equivalent to mine because a non-negativity constraint on dividends introduces a shadow value on dividends at the boundary equivalent to explicitly modeling equity issuance cost. In Ottonello and Winberry (2018) instead, firms can default in equilibrium, and dividend policy is informative for the default choice. In their model, the price of debt is the discriminating element between constrained and unconstrained firms. Constrained firms are the ones that face a positive probability of default in equilibrium, and thus, they issue debt paying a premium on debt. In contrast, unconstrained firms can finance investment by issuing debt and paying the risk-free rate.

All these modeling approaches and unconstrained firms have one element in common. Relative to unconstrained firms, both methods imply a steeper upward-slope marginal cost function of capital for high leverage firms. This is crucial to explain the model's heterogeneous response to monetary policy shocks. I examine the first-order conditions for capital to understand how firms behave in the stationary equilibrium and the heterogeneous response to the shocks.

5.2 Capital optimality and heterogeneous response.

I examine the first-order condition for capital. When I study the optimal condition for capital k', I follow Hennessy and Whited (2005) and DeAngelo et al. (2011) by taking the current state (ε, k, b) as given, and then imagining that firms have already chosen their debt and dividend policy.

Capital optimality condition. The optimality condition for capital can be obtained by differentiating the Bellman equation for k' and combining with the respective envelope condition. Assume for simplicity that there is no taxes, $\tau = 0$, price are fixed, $p^w_{t+1} = 1$ and capital fully depreciate after one period $\delta = 1$. The optimality condition for capital is then:

$$\text{FOC:} \qquad (1 + c_0 \frac{k'}{k})(1 + a_1 |d| \mathbb{1}_{d<0}) =$$

$$\Lambda_{t,t+1} \int (\alpha \varepsilon' k_{j,t+1}^{\alpha-1} n^{\nu} + \left(\frac{k''}{k'}\right)^2 + q_t)(1 + a_1 |d'| \mathbb{1}_{d'<0}) - \theta_k \lambda_{t+1} d(\varepsilon'|\varepsilon) \tag{24}$$

The first term on the left-hand side of the equation (24) is the marginal cost of capital. Because of the presence of convex adjustment cost, the marginal cost of capital is increasing in the amount of capital to purchase for the next period k'. The presence of convex adjustment cost prevents firms from varying their capital stock considerably, and as a result, firms move slowly toward their optimal size. Equation (24) also suggests that the marginal cost of capital varies among constrained and unconstrained firms. In particular, financially constrained firms ($d < 0$) face higher and steeper marginal cost of capital (i.e. $a_1|d|\mathbb{1}_{d<0}$ is positive for constrained firms). Intuitively, this is because constrained firms rely on equity financing to finance investment, and therefore, they find increasing capital by 1 unit more expensive than unconstrained firms. Finally, because equity issuance costs marginally increase in the amount of equity issued, the marginal cost of capital for constrained firms is steeper in k'[31].

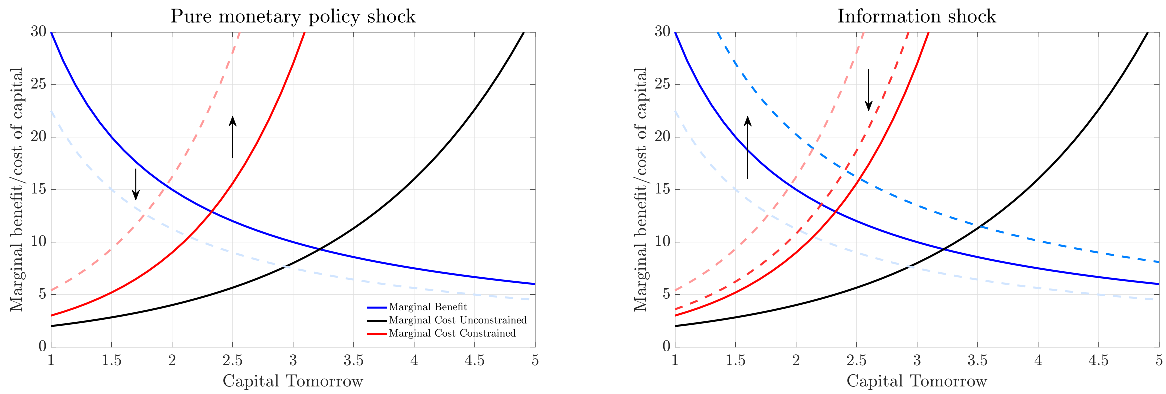
On the right-hand side of the equation (24) is the marginal benefit of capital. At a glance, the marginal benefit of capital is decreasing in k' because of decreasing marginal return of capital so that small firms find a greater benefit in investing in one additional unit of capital. In addition, the marginal benefit of capital depends positively on the likelihood of issuing equity in the next period $a_1|d'|\mathbb{1}_{d'<0}$. The intuition is that an additional unit of capital reduces the probability of being financially constrained tomorrow, increasing the value of investment today. This is because an additional unit of investment today raises the amount of firms' internal funds tomorrow proportionally and reduces the cost of relying on equity issuance in the future. Because of convex issuance cost, this effect becomes stronger as the amount of expected equity injections increases. It follows that the marginal benefit of capital is decreasing in k' and relatively flattened for firms that expect to face a greater probability to resort to equity issuance tomorrow.

Firms choose the amount of investment to match the marginal cost and marginal benefit of capital. These mechanisms bring two consequences in terms of investment policy. First, the investment rate is decreasing along the capital dimension. The intuition is that small firms have higher marginal capital productivity since they are further away from optimal size. Thus, they find it optimal to increase capital holdings relatively more than larger firms. Second, the investment policy is slightly decreasing along the leverage dimension. Given a certain level of productivity and capital holding, high leverage firms have lower internal funds. Therefore, they are more likely to rely on equity financing to finance investments. It follows that high leverage firms have relatively lower investment rates.

Heterogeneous responsiveness in the model. Equation (24) also provides a simple intuition to explain the heterogeneous responses to different policy interventions observed in the data. I describe the intuition behind the mechanism in figure (6). From equation (24), the marginal benefit of capital (blue line) can be represented as a decreasing function

[31] In case of linear equity issuance cost as in Gomes (2001), the marginal cost of capital for constrained firms would be just shifted higher without changing slope.

Figure 6: The heterogeneous response mechanism in the model.



Note: In the figure, the marginal benefit of capital (blue line) and the marginal cost of capital of a firm that is financially constrained (red line) and unconstrained (black line). The heterogeneous response mechanism to monetary policy intervention is on the left-hand side, while on the right-hand side is the heterogeneous response to an information shock.

of capital tomorrow while the marginal cost of capital (black and red lines) is increasing in k' and is steeper if a firm is financially constrained (red line).

In the data, high leverage firms are more sensitive to a monetary policy shock than low leverage firms, while the reverse happens in response to an information shock. I argue that in the model, two mechanisms drive these results, the capacity to adjust investment in response to an aggregate shock and the variation in firms' wealth due to changes in the cost of borrowing and operating profits, a cash effect. The first element depends upon the steepness of the marginal cost of capital. Financially constrained firms (high leverage) face a steeper marginal cost of capital because they issue equity, making them less reactive to a variation in the marginal benefit of capital. Instead, the second element depends on the shift in the marginal cost of capital across firms with different levels of leverage. Since high leverage firms are more likely to finance investment by issuing equity, an aggregate fluctuation in the economy causes a sudden change in their marginal cost of capital by altering their internal funds and dependence on external financing.

To see how these effects play a role, assume that the agents observe the interest rate to increase. If the central bank does not signal any information about fundamentals, the observed interest rate change coincides with an exogenous deviation from the Taylor rule (i.e., pure monetary policy shock). Because of higher real interest rates, the marginal value of investing in one additional unit of capital today decreases, and firms reduce investment on average. Graphically the blue line shifts down in the figure (6) left-hand side. Furthermore, financially constrained firms are fully exposed to a negative cash effect. First, through a decrease in the operating profits, due to a fall in the output, and second, through an increase in the cost of borrowing that decreases the amount of firms' internal funds proportionally to the firms' outstanding debt. As these two channels push in the same direction, constrained firms become more dependent on external financing in response to a contractionary Taylor rule shock. Consecutively, more leveraged firms may be more sensitive to a pure monetary policy shock if the effect on cash causes a sufficiently large increase in their marginal cost of capital. Graphically, a contractionary monetary policy intervention shifts the marginal cost of capital for constrained firms unambiguously up.

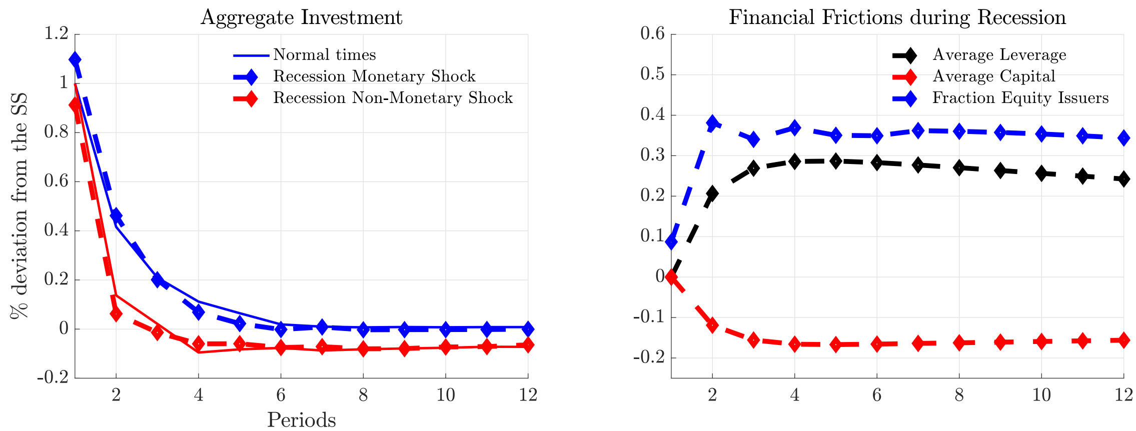
An information shock, right-hand side in figure (6), is expected to increase investment in low leverage more than in high leverage firms instead. Assume that the agents observe the interest rate increase, but they learn that it is driven by the fact that the central bank signals positive information about fundamentals (i.e., info-laden interest rate hike). On the one hand, the marginal value of investing in one additional unit of capital today decreases because of higher real interest rates. On the other hand, because of positive information about q_t, the value of investing in 1 unit of capital rises. If this second effect dominates, the marginal product of capital increases, and firms increase investment on average. Graphically the blue line shifts up in the figure (6). As in the previous case, high leverage firms (or constrained firms) are less responsive to a shift in the marginal benefit of capital because of their steeper marginal cost. Unlike the previous case, the effect of the information shock on firms' internal funds and, thus, on the marginal cost of capital for constrained firms is ambiguous. A positive information shock decreases the firms' internal funds by increasing the cost of borrowing and debt repayment, but it raises their cash in hand through an increase in the operating profits. In other words, an information shock dampens the cash effect on constrained firms. Graphically, an information interest hike can shift the marginal cost of capital for unconstrained firms ambiguously, up or down.

6 Implications for monetary policy

In this section, I study the implication of my results for monetary policy through the lens of the model. I use the model to investigate the time-varying response of the aggregate investment to an expansionary central bank intervention in a period of recession. Compared to other paper in the literature, I assume that the central bank has the opportunity to stimulate investment either by announcing a cut in the interest rate or by communicating information about fundamentals (i.e., pure monetary policy shock or an information shock).

To study state dependence of aggregate transition, I simulate the transition path of a

Figure 7: The state dependence of monetary policy.



Note: On the left-hand side, the impulse response function during a recession of an expansionary monetary policy shock (blue line) and an expansionary non-monetary policy shock (red line). On the right-hand side, the effect of a recession of the extensive margin of financial frictions.

pure and an information shock 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 2% and to generate a recession for around eight quarters in the model[32]. I obtain the effect of the central bank shocks under recession by subtracting the impulse responses of the aggregate TFP shock only from the join transition path. I plot the results of this exercise in figure (7)[33].

Figure (7) suggests that the effects of a pure monetary policy shocks on investment are amplified during a recession while the impact of information shocks is dampened. In particular, given the calibration of the model, I estimate that an unexpected interest rate cut stimulates investment by 10% more in a recession than in regular periods. At the same time, a positive information shock increases investment by 8% less in a downturn.

Financial and real frictions play an essential role in understanding the state dependency of aggregate transmission in the model. The intuition behind the role of financial frictions is similar to the one in Ottonello and Winberry (2018), and it can be explained by looking at the effects that a recessionary TFP shock has on the distribution of firms along the transition path (i.e., left-hand side in figure (7)). Following a negative TFP shock, the level of indebtedness of the firms in the economy increases, and firms divest as the marginal benefit of capital decreases. It follows that the share of firms that rely on external financing to finance investment increases, and more firms become financially constrained. Since the

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

[33] I assume that the policy shock and the TFP shock hit the economy at the same time.

elasticity of investment to a pure monetary policy shock is relatively higher for financially constrained firms, financial frictions boost the effect of an expansionary policy shock during a recession. For the opposite reason, financial frictions dampen the response of investment to an information shock.

Real frictions push in the opposite direction instead. The effect of the fixed investment adjustment cost for state dependency of aggregate transmission is reminiscent of the mechanism in Caballero and Engel (1999) and discussed in Koby and Wolf (2020). In a TFP-induced recession, firms are less sensitive to expansionary shocks because they are closer to their target capital and do not adjust investment. Since more firms do not change their capital stock, an economic downturn dampens the effects of an expansionary shock.

These results are not in contrast with the empirical results of Tenreyro and Thwaites (2016) that find that pure monetary policy shocks tend to be more effective during an economic boom rather than an economic downturn. My contribution shows that real and financial frictions may play an opposite role for the state dependency of aggregate transmission of central bank announcements. Hence, it is important to separate them.

7 Conclusion

Firms' financial position plays a role of primary importance to how monetary policy affects the response of aggregate investment. The current stand of the literature has found contrasting results on the role that firms' financial position plays in transmitting monetary surprises into the economy. I show that disentangling policy announcements into pure monetary and information shocks allows solving this puzzle in the literature.

My empirical results are twofold. First, I show that high leverage firms are more sensitive to interest rate surprises induced by communication of a change in the policy rule, pure monetary policy shock. Hence, confirming the current wisdom in the literature that suggests that financial friction amplifies the effects of pure monetary policy intervention. Second, I find that high leverage firms are less sensitive to interest rate surprises induced by communication of additional information about macroeconomic fundamentals, information shock. This last result is novel in the literature and adds a new layer to our understanding of the effectiveness of monetary policy.

To understand the empirical results and study the implications for monetary policy, I estimate a dynamic general equilibrium model with firm idiosyncratic productivity and financial frictions. In the model, the heterogeneous dynamic response to a monetary and an information shock on investment depends on the size of the cash effect generated by the shock. A monetary policy shock decreases firms' operating profits and the cost of debt, which amplifies investment response for financially constrained firms unambiguously. Instead, an information shock increases both the firms' operating profits and the cost of debt, which may increase the dependence on external financing in high leverage firms. It follows that the sign of the effect on net worth and, therefore, on the marginal cost of capital on constrained firms to a positive information shock is ambiguous.

I show that my results have implications for state dependency of aggregate transmission. The effectiveness of monetary policy is conditional to the business cycle fluctuations, e.g., high or low leverage period, and how central banks practically implement monetary policy. In the model, an unexpected interest rate cut stimulates investment by 10pp more in a recession than in regular periods. At the same time, a positive information announcement increases investment by 8pp less in a downturn.

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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. In contrast, I calculate the cost of borrowing as the sum of the excess premium and the 1-year treasury rate.

A.2 Firm-level variables on Compustat

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

i. **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:

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

ii. **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.

iii. **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.

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

v. **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.

vi. **Dividends.** Dividends is the sum of common dividends $dvy_{i,t}$ and preferred dividends, $dvpq_{i,t}$.

vii. **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.

viii. **Total assets.** Total assets is the variable $atq_{i,t}$ in Compustat.

ix. **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 $\in [7000, 8999]$.

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. I keep only US-based firms, $fic_{i,t} =$"USA".

ii. 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).

iii. 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 $atq_{i,t}$.

iv. 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.

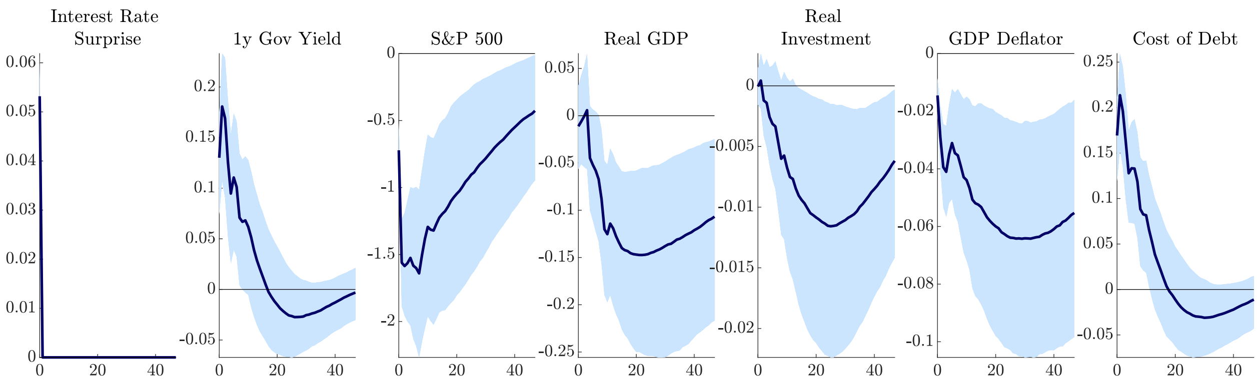
v. I drop all firm-quarters before a firm's first observation of Property, Plant, and Equipment (Gross) $ppegtq_{i,t}$.

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 dynamics with standard identification.

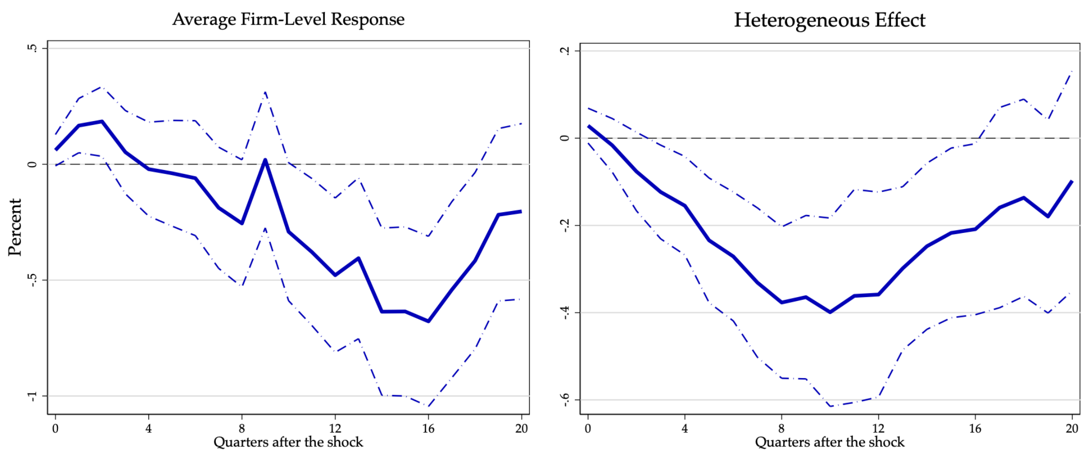
Figure 8: Aggregate impulse response with standard HF identification



Note: The aggregate impulse responses to a contractionary one-standard deviation monetary policy shock identified using Cholesky decomposition. I plot the median response along with the [14,86] percent confidence intervals.

B.2 Heterogeneous response without separating interest surprises

Figure 9: Heterogeneous response using interest rate surprises as monetary shocks

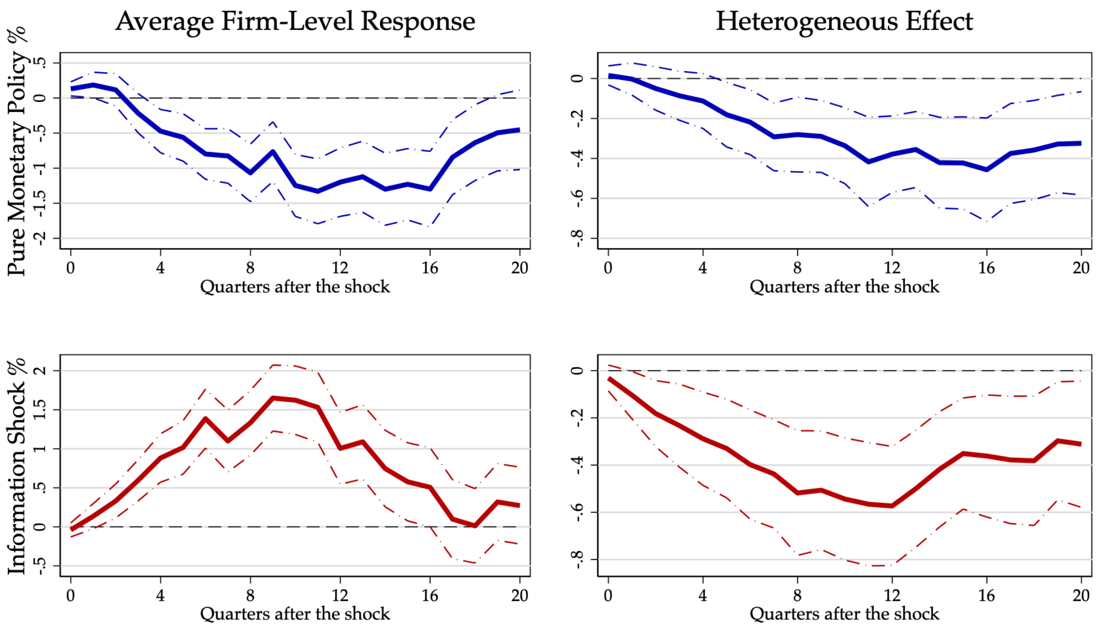


$$\Delta_h \log\left(k_{i,t+h}\right) = \alpha_{i,h} + \alpha_{t,j,h} + \left(\beta_h \Delta \mathrm{i}_t^e + \delta_h\right) \mathrm{lev}_{i,t-4} + \Gamma_h' W_{i,t-1} + u_{i,h,t+h}$$

Note: Plot the impulse response function on capital accumulation to one standard deviation shock to an interest rate surprise that confound a pure and an information 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 10: Heterogeneous response using cash holdings

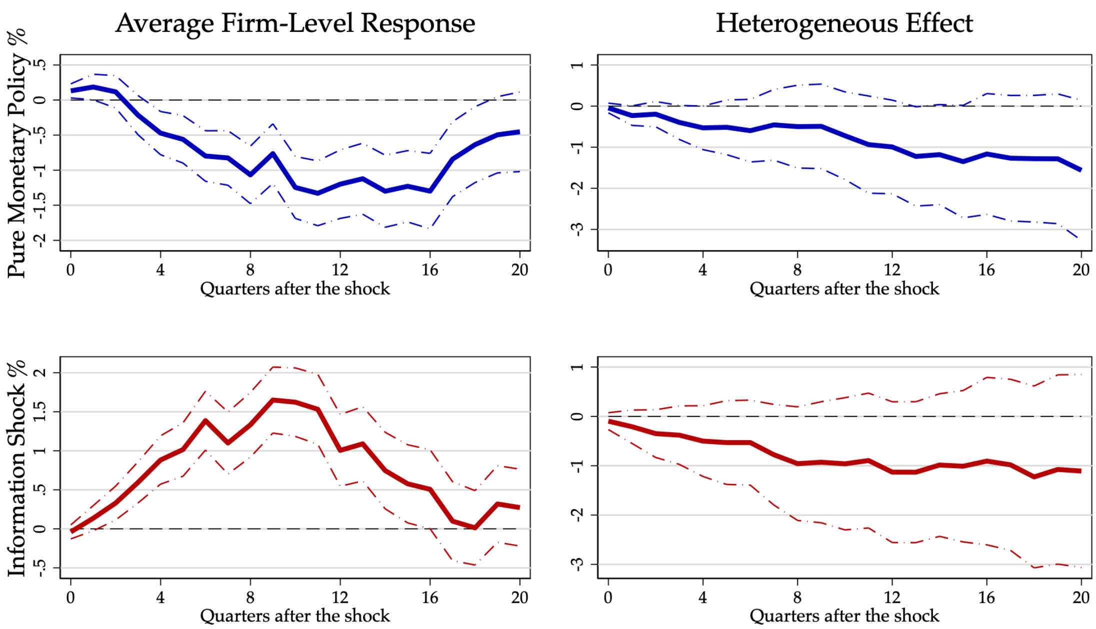


$$\Delta_h \log\left(k_{i,t+h}\right) = \alpha_{i,h} + \alpha_{t,j,h} + \left(\beta_h \Delta i_t + \delta_h\right) - \text{cash/asset}_{i,t-1} + \Gamma_h' W_{i,t-1} + u_{i,h,t+h}$$

Note: Plot the impulse response function on capital accumulation to one standard deviation shock to a monetary policy shock (first row) and to an information 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. To have consistent results with Jeenas (2018a), I use 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 11: Heterogeneous response using S&P credit rating

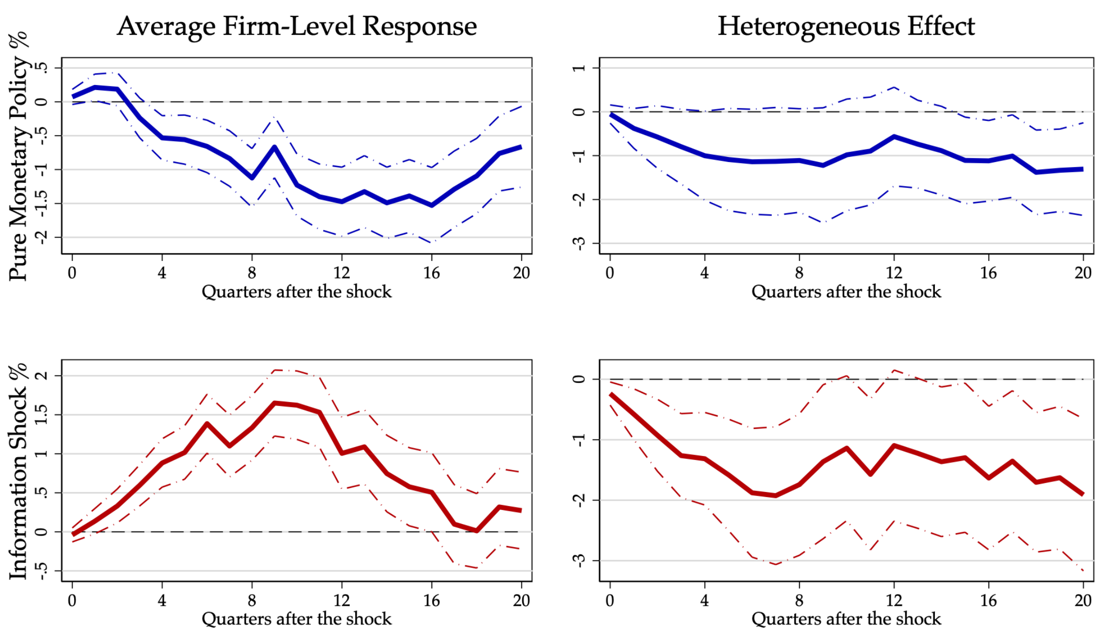


$$\Delta_h \log\left(k_{i,t+h}\right) = \alpha_{i,h} + \alpha_{t,j,h} + \left(\beta_h \Delta i_t + \delta_h\right) - S\&P^{rat}_{i,t-1} + \Gamma'_h W_{i,t-1} + u_{i,h,t+h}$$

Note: Plot the impulse response function on capital accumulation to one standard deviation shock to a monetary policy shock (first row) and to an information 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. To have a consistent interpretation with the main results in the paper, firms with higher S&P credit score are assigned a lower value. 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 12: Heterogeneous response using size

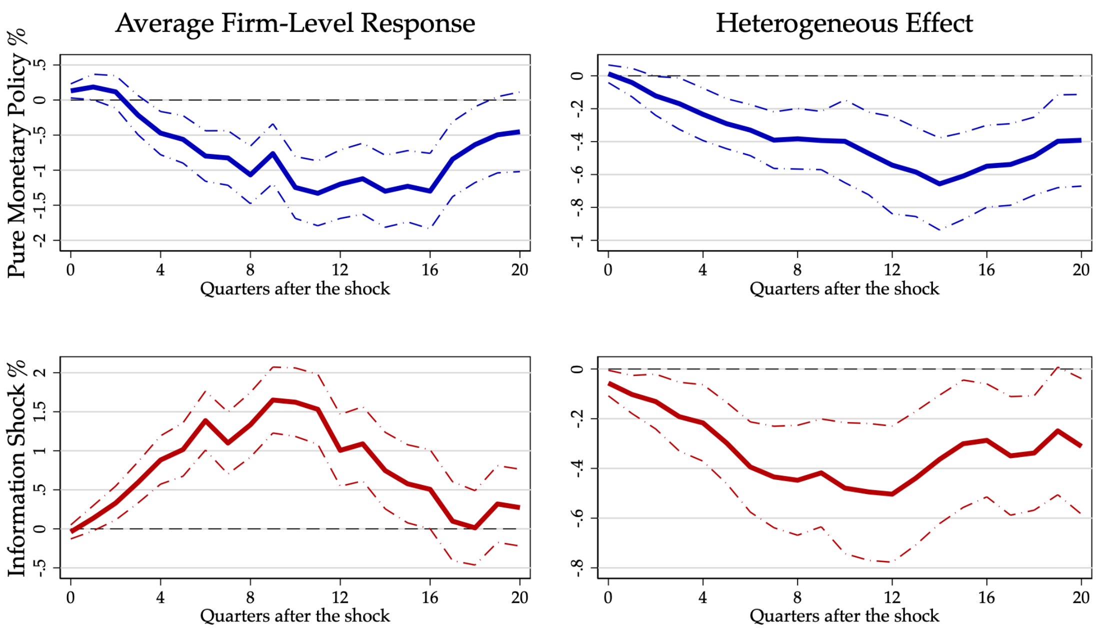


$$\Delta_h \log\left(k_{i,t+h}\right) = \alpha_{i,h} + \alpha_{t,j,h} + \left(\beta_h \Delta i_t + \delta_h\right) \text{-size}_{i,t-1} + \Gamma_h' W_{i,t-1} + u_{i,h,t+h}$$

Note: Plot the impulse response function on capital accumulation to one standard deviation shock to a monetary policy shock (first row) and to an information 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 Panel regression with de-meaned leverage, Ottonello and Winberry (2018)

Figure 13: Heterogeneous response using de-meaning leverage

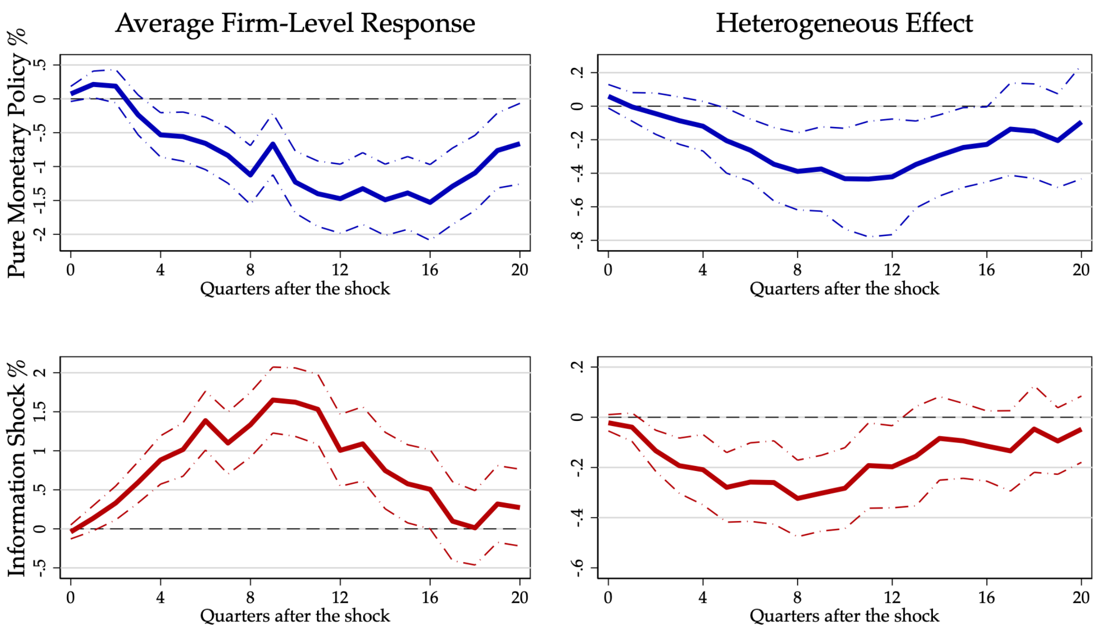


$$\Delta_h \log\left(k_{i,t+h}\right) = \alpha_{i,h} + \alpha_{t,j,h} + \left(\beta_h \Delta i_t + \delta_h\right)\left[\text{lev}_{i,t-4} - \mathbb{E}\text{lev}_{i,t-1}\right] + \Gamma_h' W_{i,t-1} + u_{i,h,t+h}$$

Note: Plot the impulse response function on capital accumulation to one standard deviation shock to a monetary policy shock (first row) and to an information 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 identification, Jarociński and Karadi (2020)

Figure 14: Heterogeneous response using poor-man shocks

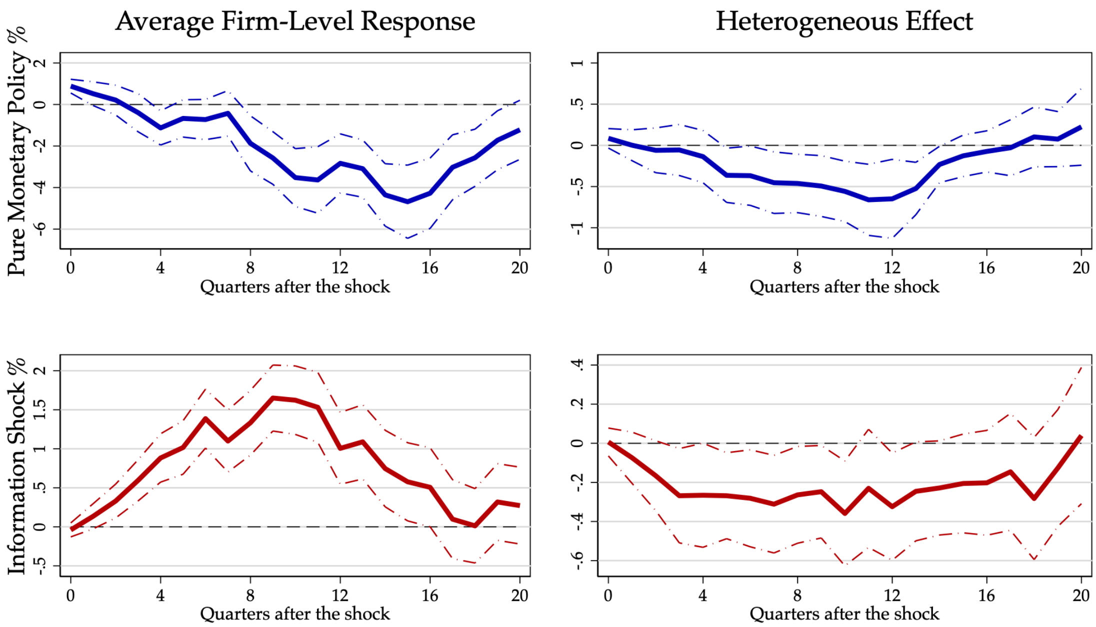


$$\Delta_h \log\left(k_{i,t+h}\right) = \alpha_{i,h} + \alpha_{t,j,h} + \left(\beta_h \Delta i_t + \delta_h\right) \mathrm{lev}_{i,t-4} + \Gamma_h' W_{i,t-1} + u_{i,h,t+h}$$

Note: Plot the impulse response function on capital accumulation to one standard deviation shock to a monetary policy shock (first row) and to an information 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 Results on a restricted sample 2000-2016

Figure 15: Heterogeneous response using 2000-2016 sample

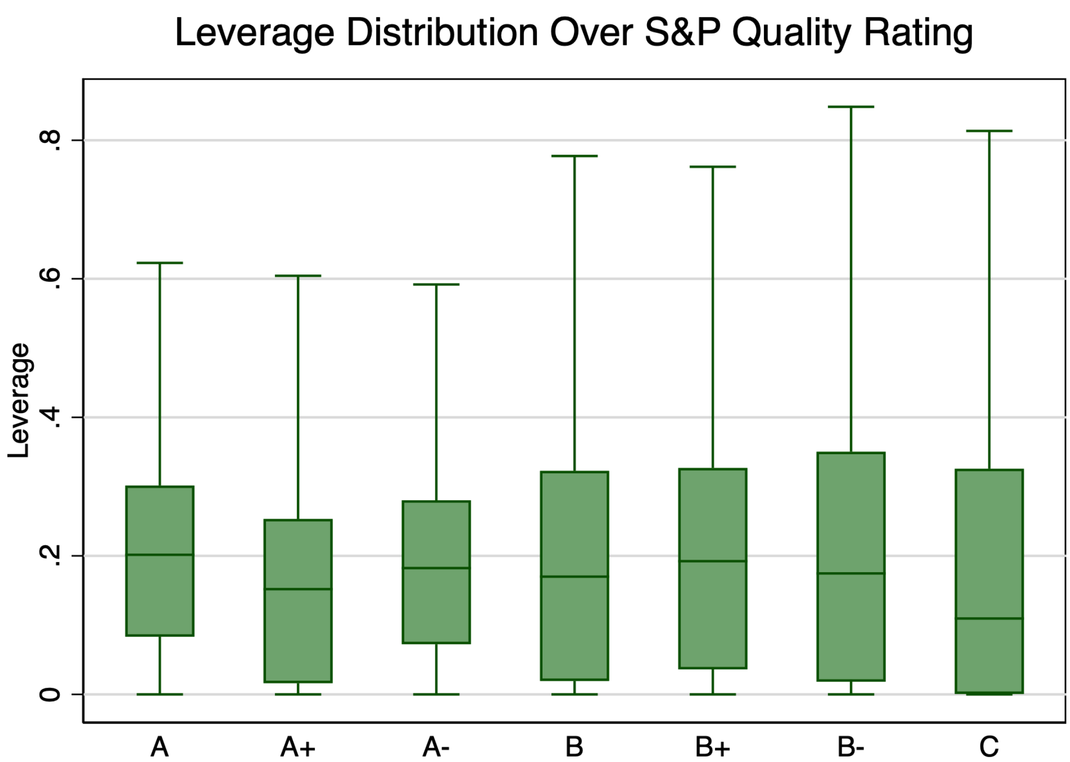


$$\Delta_h \log\left(k_{i,t+h}\right) = \alpha_{i,h} + \alpha_{t,j,h} + \left(\beta_h \Delta i_t + \delta_h\right) \mathrm{lev}_{i,t-4} + \Gamma_h' W_{i,t-1} + u_{i,h,t+h}$$

Note: Plot the impulse response function on capital accumulation to one standard deviation shock to a monetary policy shock (first row) and to an information shock (second row) on the period sample 2000-2016. 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

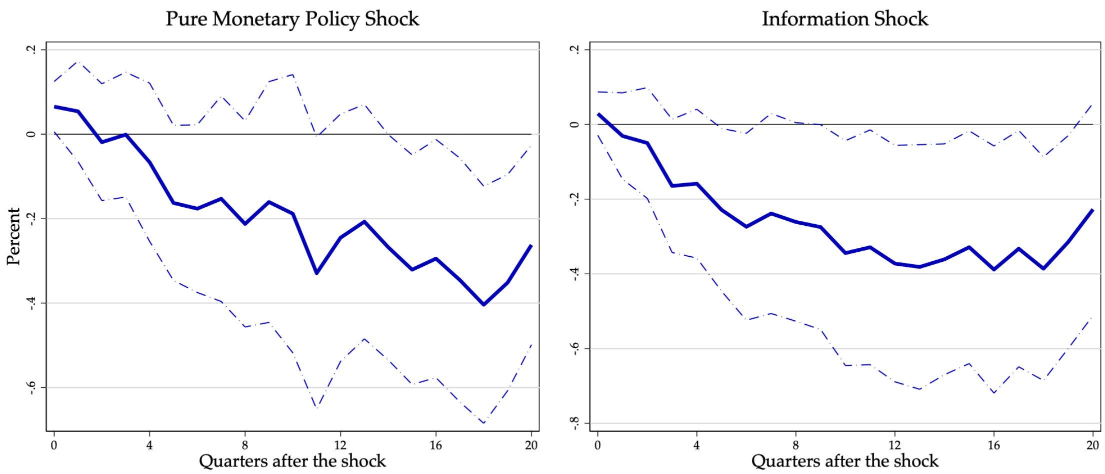
Figure 16: Distribution of leverage by S&P Quality Rating



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 Heterogeneous effects on high $S\&P$ credit quality firms

Figure 17: Heterogeneous response on high $S\&P$ credit quality firms



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

Note: Plot the heterogeneous impulse response function on capital accumulation to one standard deviation shock to a monetary policy shock (first column) and to an information shock (second column). I restrict the sample to high S&P credit quality firms defined as firms with a credit score not lower than B- in Compustat. I report the 90% confidence intervals constructed based on two-way clustered standard errors at firm and quarter levels.

C. Model Details

C.1 Agents problem

Intermediate good producers. The intermediate good producers solve the following problem:

$$V_t(\varepsilon_{j,t}, k_{j,t}, b_{j,t}) = \max_{k_{j,t+1}, b_{j,t+1}} \Bigg\{ x(\varepsilon_{j,t}, k_{j,t}, b_{j,t}) - g\left(k_{j,t+1} - (1-\delta)k_{j,t}, k_{j,t}\right) - i_{j,t} + b_{j,t+1}$$
$$-(a_0 + a_1 d_{j,t}^2)\mathbb{1}_{d_{j,t}<0} + \Lambda_{t,t+1} \sum_s \pi_{i,s} V_{t+1}\left(\varepsilon_{s,t+1}, k_{j,t+1}, b_{j,t+1} | \varepsilon_{i,t}\right) \Bigg\}$$

subject to:

$$d(\varepsilon_{j,t}, k_{j,t}, b_{j,t}) = x(\varepsilon_{j,t}, k_{j,t}, b_{j,t}) - g\left(k_{j,t+1} - (1-\delta)k_{j,t}, k_{j,t}\right) - i_{j,t} + b_{j,t+1}$$
$$g\left(k_{j,t+1} - (1-\delta)k_{j,t}, k_{j,t}\right) = c_0 \left(\frac{k_{j,t+1} - (1-\delta)k_{j,t}}{k_{j,t}}\right)^2 k_{j,t} + c_1 \mathbb{1}_{i_{j,t}\neq 0}$$
$$x(\varepsilon_{j,t}, k_{j,t}, b_{j,t}) = (1-\tau)(p_t^w z_t \varepsilon_{j,t} k_{j,t}^{\alpha} n_{j,t}^{*\nu} - w_t n_{j,t}^* - \eta) - (1+i_t)b_{j,t} + \tau\left(\delta k_{j,t} + i_t b_{j,t}\right)$$
$$b_{j,t+1} \leq \theta_k k_{j,t+1}$$
$$h(x_{j,t}, k_{j,t+1}, b_{j,t+1}) = (a_0 + a_1 d_{j,t}^2)\mathbb{1}_{d_{j,t}<0}$$

A closed-form solution to the problem is not available. I rely on computational methods to find a steady-state solution and study its dynamics.

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:

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

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 $V(\varepsilon, k, b; S)$, $k^{*\prime}(\varepsilon, k, b; S)$, $b^{*\prime}(\varepsilon, k, b; S)$,$n^{*}(\varepsilon, k, b; S)$, 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 $k^{*\prime}(\varepsilon, k, b; S)$, $b^{*\prime}(\varepsilon, k, b; S)$ and $n^{*}(\varepsilon, k, b; S)$ 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:

$$Y_t = C_t + I_t + \int g(.)dj - \int h(.)dj + \frac{\phi}{2}\pi_t^2 Y_t$$

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 $k_{t,t+1}^{*\prime}$ and $b_{t,t+1}^{*\prime}$ 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:

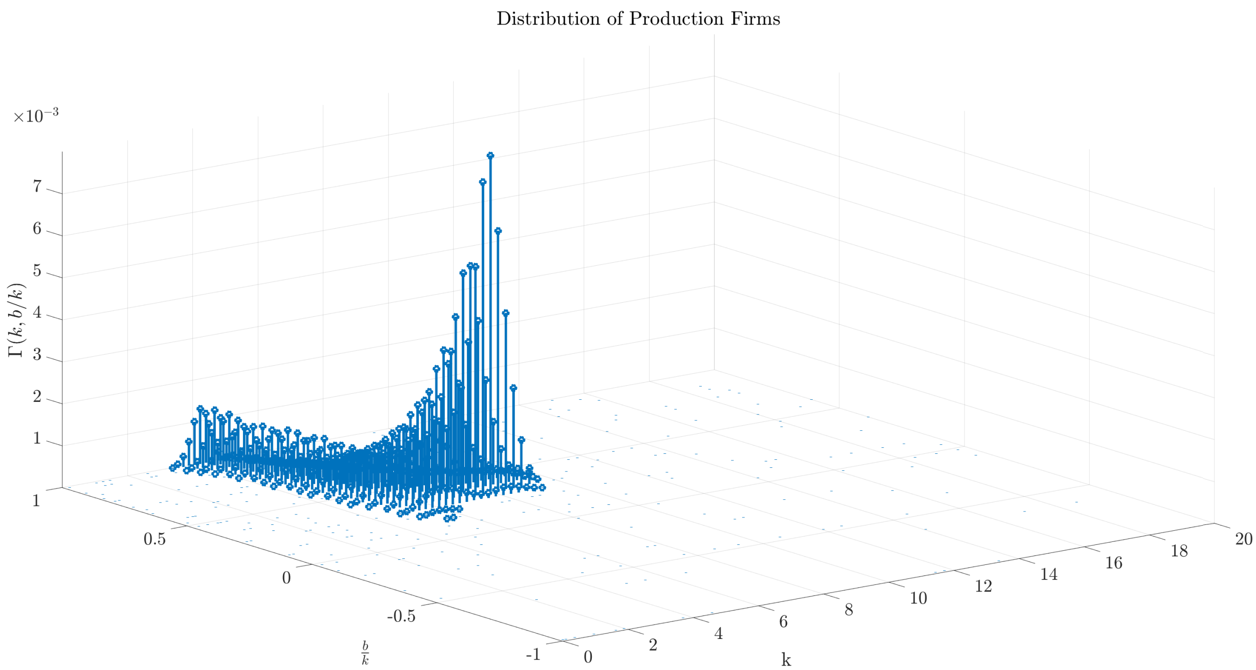
$$\left(C_t^{NEW}\right)_{t=1}^{T} = \lambda\left(C_t\right)_{t=1}^{T} + (1-\lambda)\left(C_t^{OLD}\right)_{t=1}^{T}$$

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.

D. Model results

D.1 Ergodic distribution of the model

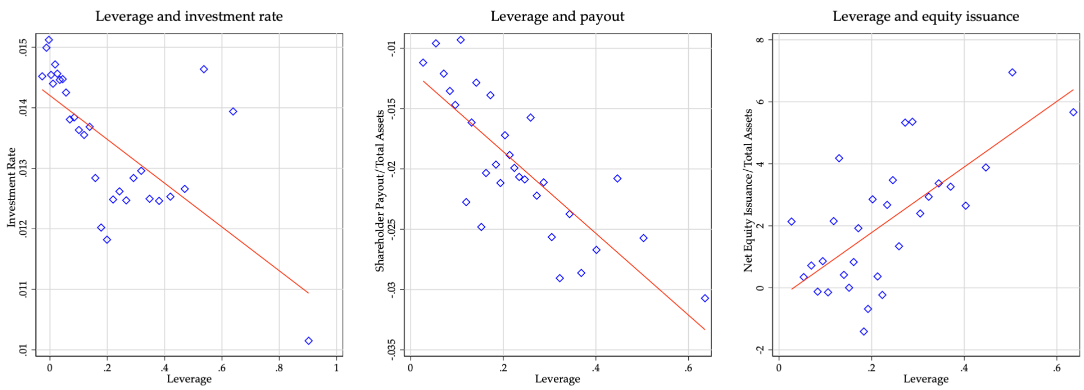
Figure 18: Ergodic distribution of the firms in the steady state.



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 Cross-section correlation between leverage and other financial variables

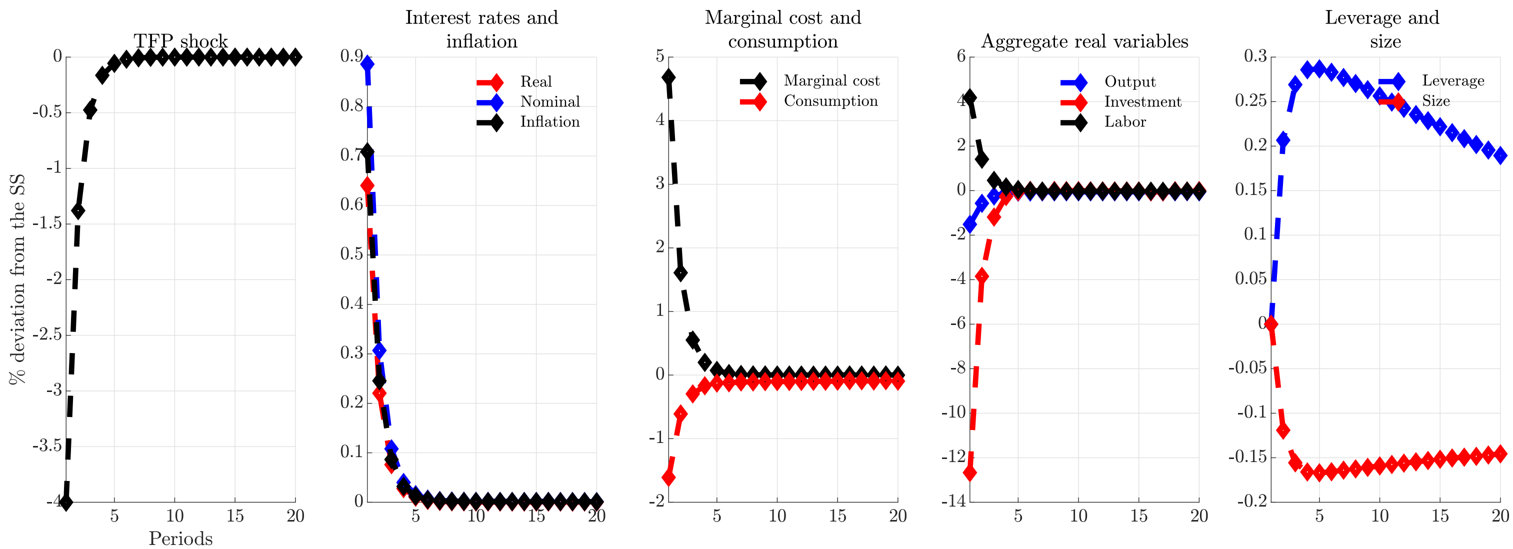
Figure 19: Leverage and other financial variables across US firms 1990-2016



Note: I control for average size, cash and investment rate. Data are firms' average over time between 1990 and 2016. I trim the left and right 1.5% tail of the average firm distribution.

D.3 Impulse response function to a TFP shocks

Figure 20: Impulse response to a TFP shock



Note: Plot the impulse response function of the model to a negative TFP shock in the model.