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# Monetary Policy, External Finance and Investment*

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**Abstract**

In response to a change in interest rates, younger firms not paying dividends adjust both their capital expenditure and borrowing significantly more than older firms paying dividends. The reason is that the debt of younger non-dividend payers is far more sensitive to fluctuations in collateral values, which are significantly affected by monetary policy. The results are robust to a wide range of possible confounding factors. Other channels, including movements in interest payments, product demand, profitability and mark-ups, are also significant but seem unlikely to explain the heterogeneity in the response of capital expenditure. Our findings suggest that financial frictions play a significant role in the transmission of monetary policy to investment.

JEL classification: E22, E32, E52.
Key words: monetary policy, investment, firm's debt, collateral, financial frictions.

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# 1 Introduction

Investment plays an important role in the business cycle. It accounts for a significant share of domestic output, is one of its most volatile components and plays a prominent role in many macroeconomic theories. From a policy perspective, a commonly held view is that investment is a key channel of monetary transmission. This is reflected in a sizable literature in empirical macroeconomics which, using aggregate time series data, finds that movements in interest rates have a large and persistent impact on business investment.

There remains, however, a surprising degree of uncertainty about the specific channels through which monetary policy affects investment. On the one hand, neoclassical models emphasize the direct effects of interest rate changes on the user cost of capital and firms' expected returns. In contrast, the financial accelerator literature appeals to the more indirect effects that work through the revaluation of assets and net worth, which subsequently affects firms' ability to borrow for investment (see for instance Kiyotaki and Moore (1997) and Bernanke et al. (1999)). In this second strand of the literature, monetary policy can gain extra traction over investment by influencing the borrowing constraints facing firms. There has been much debate about the empirical relevance of these financial accelerator effects, especially in the aftermath of the 2008 financial crisis, but evidence remains elusive.[1]

We use firm-level panel data for the United States to examine the relevance of financial constraints in the transmission of monetary policy. The first challenge we face is that financial constraints are not directly observable. In this paper we focus on firm age and whether a firm pays dividends as likely correlates of exposure to a financial accelerator mechanism at the firm-level. The motivation for this comes from a number of observations. First, firms who (i) pay dividends and (ii) use debt counter-cyclically are unlikely to be constrained. A main reason is that, in the face of adverse shocks, dividend payers can reduce payouts. But, non-dividend payers are more likely to require external finance and face a larger wedge between internal and external funding costs. Indeed, in a number of models with financial frictions, credit constrained firms do *not* pay dividends, particularly in transition to their optimal scale.[2] Second, and relatedly, firms are more likely to face financial constraints earlier in their life cycle, when they typically lack stable cash flows and

[1] We note that financial frictions might dampen the response of a constrained firm precisely because it is harder to access funds. Our focus is therefore on whether financial frictions generate large indirect effects.

[2] See, for example, Khan and Thomas (2013), Begenau and Salomao (2018), Crouzet and Mehrotra (2020), Albuquerque and Hopenhayn (2004).

have yet to develop a long credit history, a point emphasized in the firm dynamics literature (e.g. Haltiwanger et al. (2013) and Davis and Haltiwanger (2019)). Finally, younger firms secure a far larger share of their borrowing using assets rather than earnings whereas the opposite is true for older companies (Lian and Ma (2020)).[3]

We establish four main findings. First, *both* the investment and borrowing of younger firms not paying dividends exhibit a large and significant decline in response to a tightening of monetary policy. Second, collateral values fall significantly for all firms when interest rates increase. Third, the borrowing of the younger non-dividend payers is far more sensitive to fluctuations in collateral values than other firms. Fourth, relative to younger non-dividend payers, the investment adjustments of older companies are much smaller (both in terms of economic and statistical significance) and the change in borrowing is insignificant. The heterogeneity we document is robust to a wide range of sensitivity analyses, including controlling for other individual characteristics such as size, leverage and liquidity, exploiting within-firm variation over the life-cycle and using alternative strategies to identify monetary policy innovations.

What do these facts tell us about the transmission mechanism? Our preferred interpretation is that younger non-dividend payers are more likely to face financial frictions. When collateral values fall, borrowing constraints tighten, amplifying the effects of monetary policy on the investment of financially constrained firms. In the Appendix, we corroborate this intuition using a stylized financial accelerator model featuring a collateral constraint. Firms differ in their optimal scale and the borrowing constraint may become less binding as they approach the optimal size. We interpret distance to optimal scale as firm age. When the indirect effects via asset prices are large, the investment *and* borrowing of constrained firms is more sensitive to changes in the interest rate. In Section 5, we show that other channels, including direct movements in interest payments, product demand, profitability, firms' costs and mark-ups are associated with more homogeneous effects and, thus, cannot easily account for the estimated heterogeneity in the investment and borrowing responses across firms in the data.

Turning to the aggregate implications, we document that, despite accounting for less than one tenth of aggregate investment, younger firms paying no dividends account for around two thirds of the average effect on the investment rate (which normalizes capital expenditure by the firm's

[3] Interestingly, Gertler and Gilchrist (1994) note that 'the informational frictions that add to the costs of external finance apply mainly to *younger firms*, firms with a high degree of idiosyncratic risk, and firms that are *not well collateralized*. These are, on average, smaller firms.' (pp. 312-313. Emphasis added). We are grateful to Ayşegül Şahin for kindly reminding us of this quote.

capital stock) and for about one quarter of the response of aggregate investment to monetary policy. Furthermore, differences in the behaviour of constrained and unconstrained firms is informative about the importance of the indirect effects associated with financial frictions. Our results suggest that these indirect effects —working through changes in collateral values and corporate debt— can account for around one third of the average response of the investment rate and around one fifth of the aggregate investment response.

Looking at financial heterogeneity has a long tradition in empirical macroeconomics and finance. Yet, a more recent literature has shown that traditional characteristics — such as size, liquidity and leverage — are unlikely to measure financial conditions. For instance, Crouzet and Mehrotra (2020) find that the investment of small firms is more sensitive to the business cycle than for large firms but their debt is not, which is hard to square with size capturing access to credit. Indeed, while many firms are born small and wish to grow over time, others have no ambition to expand (see Hurst and Pugsley (2011)). According to Bates et al. (2009), firms tend to accumulate cash holdings to hedge against future borrowing constraints, implying that businesses with high liquidity may not be unconstrained. Finally, Lian and Ma (2020) note that many companies tend to finance M&A activities with debt rather than equity, thereby becoming significantly more levered despite having good access to financial markets.

More generally, many of the individual characteristics that have been previously used to measure heterogeneity in financial conditions tend to mix-up firms at different points in their life cycle. This chimes with the conclusion in Dinlersoz et al. (2018) who argue that one cannot fully understand the link between firm characteristics and financial frictions without conditioning on age. Our results based on age/dividend status are robust to controlling for other individual characteristics (such as size, leverage and liquidity), whereas the heterogeneity estimated along these latter dimensions tends to disappear after controlling for age/dividend status. Furthermore, our strategy has a significant econometric advantage. Grouping strategies based on size, liquidity and leverage suffer from several endogeneity and selection issues discussed in Section 2. In contrast, age is fully pre-determined and dividends payouts occur independently from monetary policy changes: we find that when firms begin paying dividends, they rarely stop.

Based on the age/dividend grouping strategy, our empirical analysis looks at heterogeneity in the dynamic responses of groups of firms to interest rate changes across a wide range of firm-level variables. We focus on U.S. public firms from S&P Compustat, which has excellent coverage and a long time dimension. In the working paper version of our work (Cloyne et al. (2018)), we also show a companion set of results for the United Kingdom. To study the dynamic effects of monetary policy, we need a time series of identified exogenous innovations to policy interest rates. This ensures that our exogenous variation is not driven by other macro factors and also limits any potential reverse causality issues. We exploit the high frequency surprises in interest rate futures contracts within a 30 minute window around policy announcements, following Gurkaynak et al. (2005), Gertler and Karadi (2015) and Nakamura and Steinsson (2018a). We then employ a local projection instrumental variable panel approach to estimate the dynamic effects of monetary policy. To explore heterogeneity across firms, we interact policy rates with bins of the age/size/leverage/liquidity distribution. This strategy allows us to conduct a semi-parametric multivariate analysis by flexibly defining our bins using the outer product of various firm characteristics. For instance, we can compare the behaviour of younger and smaller firms with the relative behaviour of younger and larger companies to isolate the contribution of size conditional on age. A similar strategy allows us to examine the contribution of age conditional on size, for example.

**Related literature.** Our findings connect to four strands of empirical work. A recent line of research reveals that the use of asset-based, cash flow-based, interest coverage-based covenants and credit lines is pervasive among U.S. public firms (Lian and Ma (2020), Drechsel (2018), Greenwald (2019)) and Greenwald et al. (2020). In particular, Lian and Ma (2020) report that asset-based borrowing is the primary form of corporate debt among small, young and low-profit firms whereas large, old and high-margin companies rely mainly on cash flow-based lending. We show that young non-dividend paying firms are indeed the group whose (i) investment and borrowing exhibit the largest and most significant response to interest rate changes and (ii) borrowing is most correlated with changes in collateral values.

A well-established empirical literature, exemplified by the studies of Davis et al. (1996), Haltiwanger et al. (2013), Dinlersoz et al. (2018), Pugsley et al. (2019), and Sedláček (2019) has shown that firm age is a key determinant of employment and leverage dynamics over the business cycle. Relative to these influential works, we focus on identified monetary policy changes and investigate the dynamic responses of investment, borrowing, debt composition and collateral values at the firm-level across demographic groups.

The importance of collateral constraints for firms is the focus of Chaney et al. (2012), Liu et al.

(2013), Catherine et al. (2018) and Bahaj et al. (2020). Relative to these contributions, we look at heterogeneity in the response of borrowing by age/dividends and associate this with heterogeneity in the investment responses to identified monetary policy shocks. The behaviour of constrained and unconstrained firms is particularly important for assessing the indirect effects of monetary policy via financial frictions.

A large empirical literature on investment has proposed various measures of financial conditions, including cash flows (Fazzari et al. (1988), Oliner and Rudebusch (1992)), size (Gertler and Gilchrist (1994)), paying dividends (Fazzari et al. (1988)), bank debt (Ippolito et al. (2018)), leverage (Ottonello and Winberry (2020)) and liquidity (Jeenas (2018)).[4] We find that sorting firms along the joint distribution of age and dividend payouts (i) generates the largest and most significant comovement between investment and borrowing, (ii) is robust to further conditioning on size, leverage and liquidity, while the reverse is not true.

On the theoretical side, our evidence provides support for the notion that financial frictions amplify the effects of macroeconomic shocks in the spirit of Kiyotaki and Moore (1997) and Bernanke et al. (1999). Unlike these contributions where constrained firms are more levered, however, we show that being younger and paying no dividends is a far stronger predictor of a significant comovement between investment and debt, consistent with those firms being more dependent on external finance to fund their projects. Albuquerque and Hopenhayn (2004), Khan and Thomas (2013) and Begenau and Salomao (2018) feature models where firms may grow out of their borrowing constraints as they approach their optimal scale but, along this path, dividends are zero.

**Structure of the paper.** In Section 2, we present the data, discuss our age/dividend grouping strategy and document how balance sheet variables and other characteristics vary over a firm's life-cycle. In Section 3, we discuss our empirical framework and identification strategy before presenting the average effect in our firm-level panel data. The heterogeneous response of capital expenditure following a change in monetary policy is the focus of Section 4. We show that our grouping strategy based on age and dividends predicts a larger capital expenditure response than size, leverage and liquidity, but also that our finding is robust to conditioning on these more traditional proxies. In Section 5, we investigate the channels that may explain the heterogeneous effects on investment

[4] Several later studies have warned that the investment sensitivity to cash flows should not be interpreted as evidence in favour of financial frictions as cash flows can be shown to be a determinant of investment in both theoretical models with and without financial frictions (see for instance Kaplan and Zingales (1997) and Gomes (2001)).

and show that the response of borrowing and collateral values to changes in the interest rate is the most likely candidate. We also conduct a simple calculation of the likely contribution of financial frictions to the aggregate investment response to monetary policy shocks. In Section 6, we show that our results are robust to exploiting variation within firms and across collateral shares, to alternative strategies for identifying the time series of monetary policy shocks and to potential sub-sample instability across sectors and over time. The online appendix contains further robustness checks and a simple financial accelerator model whose predictions are consistent with our empirical findings.

# 2 Data

In this section, we briefly describe the firm-level data and discuss the construction of the main variables of interest for our empirical analysis. In particular, we introduce our measure of firm age and argue that, together with dividend payment status, are informative of the financial and life-cycle position of a firm. Finally, we present a number of descriptive statistics suggesting that younger firms may face worse access to financial markets. A more detailed description of the sources, definitions and sample selection can be found in Appendix A.

## 2.1 Sources and variables definition

Detailed, high quality balance sheet and income statement data for publicly listed companies are available quarterly from Compustat. Consistent information for a sufficiently large number of firms and variables only begins around 1986, when our sample starts. The sample ends in 2016, when the data were collected for this project. Turning to our main variables of interest, the investment *rate* is defined as capital expenditures in period $t$ relative to the level of physical capital, as measured by net plant, property and equipment at the *beginning* of the period.[5] In addition to being a widely-used measure (see for example Chaney et al. (2012)), it allows us to compare the investment decision of firms with different levels of capital.

The main balance sheet variables of interest are cash-flows, which we proxy with EBITDA (earnings before interest, tax, depreciation and allowances) as is common in the literature, total and long term debt, collateral values (market value of corporate real estate), sales and interest

[5] Although data are assigned to calendar quarters in Compustat, some variables are cumulative within the fiscal year. In line with the literature, we difference these variables within the fiscal year to reconstruct the quarterly series.

expenditure. In our analysis, we will also use information on dividends paid, firm size (book value of total assets), leverage (total debt divided by the book value of total assets), liquidity (short term cash and investments divided by the book value of total assets), growth (growth in total assets), Tobin's (average) Q (the ratio of market value of assets to book value).[6] More detailed information on data sources, variable definitions and sample selection are provided in Appendix A.

As a first step toward a macro analysis with micro data, we are interested in understanding how much of the aggregate investment dynamics is captured by publicly traded firms.[7] To do so, we aggregate the investment reported by each firm for a given period of time into a measure of investment at calendar frequency. Appendix A Figure A.1 compares the growth rate of this series from Compustat with the growth rate of aggregate investment from the U.S. Bureau of Economic Analysis, which includes investment by both public and private firms.

While publicly listed companies account for about 60% of the level of investment in the U.S. economy, the dynamics of the capital expenditure series aggregated from micro data are very similar to the dynamics of the official investment data from national accounts. More specifically, the correlation of the growth rate of capital expenditure from the micro data and the growth rate of official aggregate business investment is around 0.8. Understanding the dynamic behaviour of publicly listed companies can therefore provide important insights about the transmission of economic shocks to the aggregate economy.

Finally, to the extent that private firms face similar or even tighter financial conditions than public firms, our findings may be interpreted as a lower bound for the relevance of financial constraints for the transmission of monetary policy to business investment.

### 2.2 Grouping firms by age and dividend payouts

The first step in our research design is to identify which type of firm is most likely to face financial frictions. In a broad class of theoretical macro finance models, it can be shown that financially constrained firms do not engage in dividend payouts, see, for example, Khan and Thomas (2013), Begenau and Salomao (2018) and Albuquerque and Hopenhayn (2004). In these set-ups, a firm that is currently financially constrained (or may become so in the near future) might eventually grow and become unconstrained. Until that happens, however, the firm finds it optimal to use any

[6]We proxy size using total assets rather than employment because the employment variable is less well populated.

[7]Unlike survey data where we would use sampling weights to evaluate the representativeness relative to the population, here we are not dealing with a sampling issue as we observe the universe of publicly listed companies.

available resources for growth and it does not pay dividends along this path. Contributions in the financial accelerator tradition such as Crouzet and Mehrotra (2020), Ottonello and Winberry (2020) and Jeenas (2018) also feature constrained firms that do not pay dividends.

As for age, a long-standing tradition in the empirical literature on consumption using household-level data (see for example Attanasio and Browning (1995) and Wong (2018)) and on employment using firm-level data (see for instance Haltiwanger et al. (2013) and Davis and Haltiwanger (2019)) has provided evidence consistent with the notion that being young is correlated with the unobserved characteristics driving access to external finance. Younger firms typically have less experience in credit markets, have a shorter credit history (and therefore lower rating) and tend to have lower earnings and fewer assets to pledge than their older counterparts, implying they might have less funds available for investment.

Taking these two sets of results together, younger firms paying no dividends may face a more limited access to credit markets than older dividend payers. Our favourite interpretation is that we are capturing a firm at the point in their life cycle when they are most likely to face financial frictions: when they are younger and not paying dividends. Younger firms are likely to be further away from their optimal scale, are seeking to grow but may lack the credit history to reduce their costs of external finance.[8]

Other measures of heterogeneity in financial conditions suffer from several potential challenges and are likely to mix-up firms at different points in their life cycle. This is consistent with Dinlersoz et al. (2018) who show that, to understand the relationship between firm characteristics and financial frictions, it is important to consider the age of the firm. As documented by Hurst and Pugsley (2011), most small businesses have little ambition to grow and while young businesses tend not to be large, many old companies choose to remain small and are therefore likely to be unconstrained. The absolute size measure of financial conditions traditionally used in earlier applied work would classify these old firms as constrained simply because they are small in absolute sense. In contrast, younger firms paying no dividends are more likely to be faraway from their optimal size and, as such, face a higher probability that financial frictions might constrain their growth. In this sense, firm age is capturing a firm's relative size.

Similar concerns apply to using liquidity or leverage as measures of financial conditions at the

[8] Younger firms tend to be growing faster and are, therefore, often raising finance in order to expand. We will show in Section 5 that this fact alone does not seem to explain our results. Fast growing old firms do not respond as much to changes in monetary policy.

firm-level. A large body of empirical work has shown that firms hold more cash to hedge against the possibility of a financial constraint binding in the future (Bates et al. (2009)): firms with large cash holding have a strong precautionary motive that makes them fundamentally different from businesses with low liquidity. As noted by Lian and Ma (2020) and Begenau and Salomao (2018), many older and larger firms have a higher leverage ratio because have good access to capital markets and tend to finance large projects with debt rather than equity. On the other hand, a lower debt to asset ratio may be the very result of a younger company with insufficient internal funds being denied further external funds.[9]

Another advantage of our age/dividend grouping strategy is rank invariance. A company's starting date is fully pre-determined and age cannot vary as a result of changes in monetary policy or the business cycle. Furthermore, we find that the decision to pay dividends is independent from movements in interest rates and when a company starts paying dividends it rarely stops.[10] In contrast, size, leverage and liquidity *endogenously* respond to shocks or vary over the cycle, which affect the ranking of firms in the distribution of these variables. Accordingly, it is hard to interpret any (ex-post) heterogeneity as being driven exclusively (or even partially) by ex-ante differences in these specific firm characteristics.[11]

Many papers examining firm-level investment have focused on U.S. Compustat data where the native age variable is sparsely populated. Interestingly, however, the year of *incorporation* is available for U.S. publicly listed companies from WorldScope. We therefore merge these datasets to provide a consistent measure of the incorporation date. To help address some missing observations as well as the issue of mergers and acquisitions, we also make use of the first date the firm appears in the Center for Research in Security Prices data. More details on the construction of the age variable are provided in Appendix A. While it is possible to use information on the founding years of firms,

[9]Similar selection and endogeneity issues apply to measures of 'distance to default', which load heavily on leverage. As shown by Ottonello and Winberry (2020) in a sample of U.S. public firms from Compustat, distance to default and leverage exhibit a strongly negative correlation at the firm-level.

[10]A firm's decision to buy back stocks appears quite cyclical, possibly because of the uncertain future returns or different tax treatment. More formally, we run two separate sets of panel regressions (for dividend payouts and buy backs, respectively) in which the left hand side variable takes the value of one if a firm at time $t$ paid dividends/bought back shares and zero otherwise. The regressors are firm fixed effects and two years of monetary policy shocks interacted with dummies for each age group. We find that monetary policy shocks are significant predictors of whether a firm buys backs shares whereas the probability of paying dividends in any given period is not statistically affected by changes in the interest rate. Accordingly, we exclude buybacks and focus exclusively on further splitting the age groups between firms who have or have not paid dividends before the shock hits.

[11]Heterogeneity in the investment responses also suggests that total assets respond heterogeneously. Bahaj et al. (2018) show that firms (especially younger) vary their number of employees when interest rates change. In Section 5.1, we find that the effects on net debt flows are also heterogeneous, implying that leverage responds endogenously. In Section 5.2, cash flows and liquidity exhibit significant adjustments after a monetary policy shock.

these are only available for a limited number of companies.[12] Reassuringly, however, the descriptive statistics reported in the next section using our age proxy are very similar to the correlations reported by Dinlersoz et al. (2018) measuring age as years since foundation among publicly listed companies using the Census Bureaus Longitudinal Business Database from 2005-2012.

### 2.3 Descriptive statistics

In the previous section, we have discussed the conceptual reasons for why capturing a firm at a particular point in its life cycle might be a better proxy for financial frictions. In this section, we want to establish the main empirical characteristics of younger and older companies to illustrate this point further. While the evidence in this section is of course only suggestive, in the rest of the paper we will show that younger non-dividend payers is the group of firms displaying the strongest positive co-movement between investment and debt following a monetary policy shock. This comovement is consistent with the predictions of a class of financial frictions models emphasizing the role of collateral constraints.

A simple but formal way of assessing the association between our measure of corporate age and other firm characteristics is to regress each of the characteristics of interest against a polynomial in age together with a measure of firm size (for all regressions except the one for size) and the interaction between sector and year fixed effects, which are designed to clean for common trends at the sectoral level. This specification is similar to the regressions used by Dinlersoz et al. (2018) and facilitates a comparison with their results based on administrative data.[13] Our dependent variables in the first column of Figure 1 are (i) size, in the first row (ii) asset growth, in the second row, (iii) Tobin's Q, in the third row and (iv) EBITDA (as a share of past assets), in the fourth row. In the second column, we report the relationship between age and selected firms' financial variables such as: (v) leverage, in the first row, (vi) the probability of having engaged in dividend payouts or buy back shares in the previous year or ever having issued bonds, in the second row, (vii) credit performance — measured by credit ratings among bond issuers — in the third row and (viii) liquidity, in the last row.[14]

[12]This can be done using Jay Ritter's database and we have verified that our main findings are robust to exploiting years since foundation as a measure of age in this more selected sample of firms. This robustness check is also useful to confirm that structural changes in the firm over time are not significantly biasing our measure of firm age.

[13]As a robustness check, we follow a more semi-parametric approach using dummies to capture the firm's position in the age distribution in each period. It is also worth noting that while we focus on age rather than birth cohorts, the empirical specifications behind the charts in Figure 1 include time fixed effects (interacted with industry fixed effects). This implies that the evidence in this section can be interpreted as about firm dynamics over their life-cycle.

[14]Credit ratings come from the Center for Research in Security Prices and is only available for the small group of

The top row in the first column of Figure 1 reveals that firm size is monotonically increasing with age, both in the full sample of firms that record assets and the smaller sample reporting also the number of employees. In line with Davis et al. (1996), the second row confirms a sharp negative association between growth and years since incorporation; the third row shows that older companies tend to have lower Tobin's Q values, while the fourth row reveals that younger firms have smaller or even negative operating profits early in their life.

The second column of Figure 1 examines the financial variables. Less experienced companies appear less levered (first row),[15] are less likely to pay dividends or issue bonds (second row), have worse credit scores (third row) and tend to hold a higher share of liquid assets (last row).[16] The results on the relationship between leverage and age is consistent with the results based on years since foundation for publicly listed companies in Dinlersoz et al. (2018). The statistical association of age with the probability of paying dividends and Tobin's Q is consistent with the predictions of the model in Cooley and Quadrini (2001).

In summary, our descriptive analysis reveals that, on average, younger firms are smaller, have lower cash-flows/earnings, worse credit scores and a lower probability of paying dividends or issuing bonds. On average, they also grow faster, have a higher Tobin's Q, hold more cash and have lower leverage. Finally, a comparison with the results in Dinlersoz et al. (2018) suggests that years since incorporation (used in this paper) and years since foundation (used in their paper) correlate similarly with other firm characteristics.

## 3 Empirical framework

In this section, we describe our identification and empirical strategy. In particular, we first discuss the way we construct the time series of monetary policy shocks. We move then to our main empirical specifications. In the final part of this section, we present the estimates of the average effect of interest rate changes on investment in the micro-data at the firm-level and show this compares well with standard results from the macro literature using data from national statistics.

bond issuers. On average, less than 7% of U.S. traded firms issue bonds yearly and only one fifth have ever done so over their entire life. While credit ratings are, in principle, an appealing –albeit endogenous– metric, the lack of coverage is one reason why finding a good proxy for financial conditions is necessary.

[15]Instead, the regression curve of leverage on age is negatively sloped for private firms (Dinlersoz et al. (2018)).

[16]The larger liquidity holding observed among younger firms chimes with the evidence in Bates et al. (2009), who identify a precautionary motive (in anticipation of possible financial constraints in the future) as a main driver of larger cash holdings among U.S. traded firms, especially non-dividend payers (which are likely to be younger firms).

### 3.1 Identification

Identifying the dynamic causal effects of monetary policy on investment requires tackling the potential reverse causality: interest rates respond to the economy and also affect it. This is a standard problem in the empirical macro literature (see Nakamura and Steinsson (2018b)) but it poses a further challenge in the context of our panel micro data analysis. We need our estimated effects to be driven by exogenous changes in monetary policy and by not some other macro factors causing movements in interest rates. Furthermore, some of the firm groups that we consider account for sizable movements in aggregate variables. This implies that some monetary policy responses to aggregate conditions may be, in fact, correlated with specific conditions in a particular group. As in the macro literature, we need some exogenous variation in policy rates.

Our identification strategy is based on the proxy-VAR/external instrument approach of Mertens and Ravn (2013) and Stock and Watson (2018), applied to monetary policy by Gertler and Karadi (2015). The idea is to isolate interest rate surprises using the movements in financial markets data within a short window around central bank policy announcements. Building on Gurkaynak et al. (2005), Gertler and Karadi (2015) measure financial market surprises from Fed Funds Futures, using a 30 minutes interval around the FOMC policy announcements. The plausible identifying assumption is that nothing else occurs within this time window which could drive both private sector behavior and monetary policy decisions. The technical innovation in Gertler and Karadi (2015) is to use these high frequency surprises as proxies for the true structural monetary policy shocks in a Vector Autoregression.[17]

Data on Fed Funds Futures are available since 1991 while the firm-level data span the period 1986-2016. One advantage of the Mertens and Ravn (2013) and Stock and Watson (2018) proxy-VAR used by Gertler and Karadi (2015) is that even if the identification of the contemporaneous causal relationships is based on the sample for which the proxy/instrument is available, the VAR can be estimated over a longer sample. This allows us to identify a sequence of monetary policy

[17]A recent literature, for example Nakamura and Steinsson (2018a) and Miranda-Agrippino and Ricco (2018), emphasize that the monetary surprises identified using high frequency movements in short-rate futures around policy announcements may also capture changes in the central bank information set as perceived by the private sector. Several factors make this issue less acute in our context. First, as we show below, we are not using the high frequency surprises directly but we will extract shocks from a VAR (where the high frequency surprises are used as an instrument) that already controls for a range of macro variables. Furthermore, in Section 6, we condition our estimates also on the changes in the central bank's forecasts at the time of the policy announcement as a way of controlling for changes in the central bank's view of the economy. Finally, in that same Section 6, we also present results using the identification strategy in Romer and Romer (2004), which is rather different from the high frequency strategy and is not subject to the information effect concern.

shocks for a longer period than the instrument is available for. We use the implied monetary policy shocks from the Gertler and Karadi (2015) VAR as our measure of monetary policy shocks in the micro data, obtaining a time series of monetary policy innovations for the full sample: 1986-2016.[18] The approach only requires the high frequency surprises to be contemporaneously exogenous and the VAR will purge any remaining predictability. Furthermore, by directly following Gertler and Karadi (2015), our micro results will be more directly comparable to the macro literature (as we show in Appendix C). For all these reasons this method is preferable to using the financial surprises directly in the panel estimation.[19]

We estimate a reduced-form VAR for the period 1986-2016, keeping as close as possible to the specification in Gertler and Karadi (2015). The VAR includes a measure of interest rates, log industrial production, the employment rate, the log of the consumer prices index and a measure of corporate interest spreads.[20] The time series of the monetary policy shocks is shown in Appendix B, together with the time series of the high-frequency monetary policy surprises. These policy shocks are then used in our firms' panel regressions: as these are exogenous disturbances, there is no need to include further macro controls.

To estimate the dynamic causal effects from the micro data, we use a panel Local Projection Instrumental Variable (LP-IV) set up, following Jorda et al. (2017). This is very flexible and allows us to estimate impulse response functions on firm-level panel data using the identified monetary shocks as instruments for interest rate changes. There are two advantages of using the monetary policy shocks as an instrument rather than as a regressor directly. First, the scale of the shock (from the proxy-VAR) is indeterminate but as shown by Stock and Watson (2018) (page 11), the LP-IV estimation automatically imposes the unit effect normalization, implying that the size of the shock can then be interpreted in terms of the units of the endogenous variable, namely the interest rate. Second, as discussed by Wooldridge (2002) (p.117), *generated instruments* do not suffer from the inference problem associated with generated regressors highlighted by Pagan (1984).[21]

[18] These can simply be obtained by inverting the structural VAR impact matrix in Gertler and Karadi (2015). While this requires invertibility, Stock and Watson (2018) show that adding further controls in a pure local projections framework — as is typically necessary when using high frequency surprises — imposes similar restrictions. This assumption is, therefore, standard.

[19] This approach does not, therefore, require the more restrictive assumption that the high frequency surprises are the true monetary policy shocks.

[20] Following Gertler and Karadi (2015), the interest rate is the one-year government bond yield while the credit spread is the excess bond premium compiled by Gilchrist and Zakrajsek (2012). We are grateful to Peter Karadi who has kindly provided us with an updated set of financial market surprises to 2016. The updated Gilchrist and Zakrajsek (2012) spreads data are available from the authors' websites.

[21] As a useful check, using aggregate data from national accounts and the LP-IV set up, in Appendix C we show that

### 3.2 Baseline specification

In order to capture the heterogeneous effects of monetary policy, in our benchmark empirical specification, we estimate impulse response functions using an instrumental variable (IV) variation of the local projection (LP) approach, LP-IV:

$$\Delta_h X_{i,t+h} = \gamma_i^h + \sum_{g=1}^{G} \beta_g^h \cdot \mathrm{I}\left[Z_{i,t-1} \in g\right] \cdot R_t + \sum_{g=1}^{G} \alpha_g^h \cdot \mathrm{I}\left[Z_{i,t-1} \in g\right] + \epsilon_{i,t+h} \tag{1}$$

The dependent variable $X$ will be the variable of interest: the investment rate in Section 4 and borrowing, collateral value, sales and cash flows in Section 5.[22]. $R_t$ is the end-of-quarter one year interest rate used in Gertler and Karadi (2015), instrumented using our extracted series of monetary policy shocks.[23] $Z_{t-1}$ is a set of firm characteristics and the indicator function takes a value of 1 if the firm characteristic falls in a particular "bin" of the distribution, which we will refer to as the firm's group. Importantly, $Z$ can be multidimensional and we can have separate slopes for finer groups, for example young/small/low leverage, old/large/high leverage, etc. In essence, this is a semi-parametric way of estimating the heterogeneous effects of monetary policy by different (and possibly multivariate) firm characteristics. We are not, therefore, imposing the restrictive assumption of linearity in these interactions. This is something that turns out to be important and also distinguishes us from virtually all earlier contributions working on investment heterogeneity at the firm-level. We also do not include other time or sector-time fixed effects as we want to interpret these coefficients as group specific impulse response functions, including any general equilibrium effects (though, in Section 6, we show this does not affect our conclusions). This allows us to estimate conditional impulse response function as flexibly as possible. But we do add firm fixed effects, which not only absorb any sector fixed effect but also allows us to exploit also within-firm variation. Furthermore, we include quarterly dummies to control for seasonal factors.[24] The end of quarter interest rate (interacted with the dummies) will be instrumented by the monetary policy shock (also interacted with the dummies). Standard errors are clustered by firm and time using the approach in Driscoll and Kraay (1998) for dealing with possible serial correlation in the forecast

an initial 25bp rise in the interest rate leads to a fall in business investment of around 0.6-0.8% after two years. We also report the results for industrial production, employment and credit spreads to show that this method produces results that are qualitatively and quantitatively consistent with the findings in Gertler and Karadi (2015).

[22] Our results for investment are also robust to considering only investment rates above 1%.

[23] Including a lag of $R_t$ or using $\Delta R_t$ on the right hand side does not affect our results.

[24] Given this is a local projection, it is not necessary to include lags of the firm-level variables (including investment) unless we believe the firm level variables influence the monetary policy shock.

errors $\epsilon_{i,t+h}$, which is a feature of the local projections technique. The number of lags is set to 12. Finally, we estimate IRFs over a forecast horizon of five years, so we restrict the sample to firms that we observe for at least five years (20 quarters).

### 3.3 The average effect

Before presenting the results for different groups, it is useful to estimate the average response of the investment rate to a change in monetary policy in our firm-level panel data. This provides a benchmark against which we can evaluate the contribution of each group of firms. It also allows us to see whether the dynamic response of investment in the micro data resembles the impulse response functions we typically see in the time series macro literature.

To estimate the average effect, we drop the group dummies from equation (1) and replace the group-specific coefficients on the interest rate with a single parameter $\beta_h$. $\beta_h$ therefore captures the average effect of interest rates on the investment rate at horizon $h$.

Figure 2 reports the impulse response function up to 20 quarters. The investment rate declines significantly following a 25bp rise in the interest rate. The effect becomes significant towards the end of the first year and the peak effect is reached between the second and third year after the shock, at a value around $-0.5$pp. The shape of the dynamic response is broadly consistent with the impulse response functions obtained using aggregate data. These are shown in Appendix C. The dynamics of the average investment rate (estimated from the micro data) therefore lines up well with the macro response of business investment from national statistics.

Having established a benchmark against which to study the heterogeneous responses of capital expenditure across different groups of firms, our goal in the next section is to "disaggregate" this average effect and examine which groups drive the response and why.

## 4 The response of investment across firms

In the previous section, we have shown that younger firms tend to be smaller, earn less, have lower a credit rating and lower leverage, pay no dividends, issue no bonds and accumulate more cash. While we have argued that these descriptive statistics are consistent with worse access to credit markets, our goal is to evaluate this claim by looking at the joint behaviour of investment and the firm balance sheet in response to a change in monetary policy. The hypothesis is that in the presence of financial frictions which link net worth or asset values to a firm's borrowing capacity, constrained firms should adjust *both* their investment *and* debt more than unconstrained firms. This logic is sketched out in the simple model in the appendix.

In this section, we show that younger non-dividend payers indeed change their capital expenditure far more than any other group. We also show that while more traditional proxies of financial frictions — such as size, liquidity and leverage — also generate some heterogeneity in the dynamic effects of monetary policy, the marginal predictive power of each of these traditional measures disappears once we conditions on our age/dividends proxy. The reverse, however, is not true: the heterogeneity by age and dividends status is robust to controlling for other proxies. Finally, we quantify the contribution of younger firms paying no dividends to the average investment response to monetary policy and find that this is significant. In the next section, we examine the channels of monetary transmission in more detail by showing the responses of debt and other variables.

## 4.1 Results based on age and dividends

In this section we explore the role of financial heterogeneity using our grouping strategy. More specifically, we allow the effects of monetary policy to vary across the age and the dividend status distribution. We split the sample into four groups depending on whether a firm is younger (less than 15 years since incorporation) and whether it has ever paid dividends before the monetary policy shock. While there is no conceptual reason to prefer one specific age cutoff over another, the results are not sensitive to the precise threshold.[25] The first (second) row of Figure 3 shows the impulse response functions for younger (older) firms. The first (second) column in each block refers to non-dividend (dividend) payers. Comparing the two rows reveals the marginal contribution of age, controlling for dividend status. Comparing the columns reveals the marginal contribution of paying dividends, controlling for age.

There are three main results that emerge from Figure 3. First, the response of younger non-dividend payers at the peak is twice as large as for younger firms paying dividends. Second, among non-dividend payers, younger firms (top-left corner) have the largest and most significant response, with the peak effect around 1% in absolute value. Third, the adjustment of capital expenditure to a monetary policy shock for older dividend payers (bottom-right corner) is economically small and only marginally significant, being on average only one fourth than the response of younger firms

[25]In the Appendix, we will further divide the older group into relatively younger and relatively less young firms and document that above the 15 years threshold the heterogeneity within this older group is modest.

who paid no dividends.

To assess formally the statistical difference between groups, in Figure 4, we re-run our baseline regressions adding the interest rate as a separate regressor and making older dividend payers the base category (given that this is the set of firms most likely to be unconstrained). While this strategy has the disadvantage of losing track of the average effect of monetary policy, it has the advantage that the significance of the estimated impulse responses for each group can now be interpreted as a test on whether the behaviour of that group is different from the old-dividend payers. The figure shows that the investment response of younger non-dividend payers is statistically larger than for older dividend payers. Furthermore, we can reject the null hypothesis that younger dividend payers and old firms paying dividends display no significant differences in their investment adjustments to monetary policy shocks.

Finally, in Appendix D, we report results based on splitting the sample only along the age dimension (Figure D.1) or only according to whether a firm paid dividend or not (Figure D.2). Consistent with the estimates in Figure 3, we find in Figure D.1 that younger firms respond far more than either middle-aged firms (with incorporation date between fifteen and fifty years before the shock) or older firms (with more than fifty years since incorporation). Similarly, in Figure D.2, we document than non-dividend payers respond far more than dividend payers. Interestingly, however, the response of younger non-dividend payers in Figure 3 is larger than either younger firms in Figure D.1 or non-dividend payers in Figure D.2. Indeed, this is the reason why we conclude that the combination of age and dividends status is a stronger predictor of a larger investment response than each of these dimensions in isolation.

### 4.2 Conditioning on other firm-level characteristics

The evidence above reveals that being younger and paying no dividends is a strong predictor of a larger response of investment to monetary policy changes. In Section 2, we have shown that younger firms tend to be smaller, are less levered and hold more cash relative to older firms. In Appendix E, we consider each of these dimensions in isolation and find that the adjustment of smaller firms is stronger than for larger ones, that the investment response of less levered companies is larger than for more levered ones and that businesses with higher liquidity change capital expenditure more than firms holding less cash. This is not surprising given that all these proxies, including age, are correlated with each other. In Section 2, we have argued on a conceptual basis that age and dividend paying status combined are likely to be better proxies for financial constraints than these more traditional characteristics. In this section, we want to assess the relative merits of the age-dividend split on statistical grounds.[26]

Unlike traditional panel regression analyses in which the identification exploits exogenous variation in the cross section, our identification strategy is based on exogenous changes (in monetary policy) that vary over time but are common across firms, while allowing for heterogeneous slopes along a variety of dimensions. Accordingly, the notion of controlling for other characteristics requires a different approach than simply adding further regressors to our baseline empirical specification. To examine the marginal contribution of age conditional on other characteristics, we interact the four age/dividends groups with quartiles of the size/leverage/liquidity distribution. This is essentially controlling for the third variable in a semi-parametric manner, a strategy that we refer to as triple-cutting the data or triple sorting.

By looking at the differences between the response of smaller-younger-paying no dividends firms and the estimated effects on smaller-older-paying dividends companies, for instance, one can infer the marginal contribution of age and paying dividends status for a given (smaller) size. Similarly, by comparing smaller-younger-paying no dividends firms to larger-younger-paying no dividends companies, we will be able to assess the marginal contribution of size for a given (younger) age and (paying no) dividends status.

As triple sorting is very demanding on the data, we maximize the number of observations per sub-group by using only two categories for age and two categories for the other characteristics. We maintain the same two age groups from above (based on fifteen years since incorporation). Dividend status is already binary. In terms of the third dimension of interest, we use the most responsive quartile versus the rest of the distribution. To stick with the size example, this means comparing the bottom quartile of size (smaller firms) with the rest of the distribution. This outer product generates eight bins. The results by size, leverage and liquidity in isolation are reported in Appendix E. The full set of impulse response functions for all 8 groups generated by the triple-interaction are reported in Appendix F. For sake of exposition, Figure 5 focuses on younger firms paying no dividends vs. older firms paying dividends, conditional on the most responsive group according to the third dimension.

In the first row of Figure 5, we show that among the smaller companies, only the younger non-

[26] As a prelude to the findings below, it is interesting to note that in Appendix E each of these traditional measures of financial frictions generate far less heterogeneity (if any) than age or dividend status, on their own.

dividend payers in the first column adjust their capital expenditure significantly after a monetary policy shock. In contrast, the investment of small older dividend payers in the second column is not affected statistically by the change in the interest rate. The third column shows the relative effect, revealing that the difference between the two groups is statistically and economically significant. The rest of Figure 5 paints a very similar picture for leverage and liquidity. Among the firms with lower leverage (second row) or with more liquidity (third row), younger non-dividend payers is always the group that adjusts investment the most, as measured by the point estimates. Furthermore, the relative effect in the third column reveals that the response of younger non-dividend payers is significantly larger than for old paying dividend firms.[27]

Overall, the results in Figure 5 shows that younger non-dividend payers drive the larger responses of smaller firms, of less levered companies and of more liquid businesses reported in Appendix E (where we split the sample according to each of these characteristics in isolation). Finally, the predictive power of size, leverage and liquidity is *not* robust to 'controlling for' age. The results are shown in Appendix Figure F.1: once we condition on being young and paying no dividends, we find little differences among firms based on size, leverage and liquidity. The full set of results for all groups are also shown in Appendix F.

In summary, age and dividend status are strong predictors of significant heterogeneity in the response of capital expenditure to changes in monetary policy. This is true over and above any possible heterogeneity by size, leverage and liquidity. In contrast, the heterogeneity along these traditional (and arguably endogenous) proxies for financial constraints appears weaker than the heterogeneity based on age and dividend status and, more importantly, becomes marginally insignificant once we condition on being young and paying no dividends.

### 4.3 Contribution to the average effect and to aggregate investment response

The evidence in Figure 3 suggests that younger non-dividend payers are likely to drive the average effect on the investment rate in Figure 2. To verify this more formally, we now compute the share of the average response accounted for by this group. We first calculate the (discounted) cumulative percent response in the investment rate for younger non-dividend payers' and multiply this by their average investment share (relative to the total investment in the sample). Dividing this object by the sum of the same statistics across all groups provides an estimate of the contribution of

[27] In Appendix H, we relate our analysis to two recent conflicting pieces of evidence in Ottonello and Winberry (2020) and Jeenas (2018), and argue that the behaviour of younger firms is likely to drive both sets of results.

younger no-dividend firms to the average response of the investment rate. As might be expected from Figures 2 and 3, this is a sizable number: younger non-dividend payers account for around 2/3 of the average movement in the investment rate in the sample.

A related question is about the contribution of younger non-dividend payers to the response of *aggregate* investment (rather than of the average investment rate, which normalizes a firm's capital expenditure by its capital stock). To answer this, we make use of the approximation in continuous time below. A detailed derivation can be found in Appendix G. The contribution of each group to the effect of monetary policy on aggregate investment ($I_t$) can be expressed as a function of the response of the investment rate $i_{j,t}$ for firm group $j$ and the size of that group. Specifically, the overall percentage change in aggregate investment, $\frac{\dot{I}_t}{I_t}$ can be decomposed as follows:

$$\frac{\dot{I}_t}{I_t} \simeq \frac{1}{\frac{I_t}{K_t}} \sum_j \omega^k_{j,t} \dot{i}^{net}_{j,t} + \sum_j \omega^I_{j,t} \dot{i}^{net}_{j,t} \qquad (2)$$

where $\omega^k_{j,t} \equiv \frac{k_{j,t}}{K_t}$ (average capital for group $j$ relative to the aggregate capital stock) and $\omega^I_{j,t} \equiv \frac{I_{j,t}}{I_t}$ (average investment for group $j$ relative to aggregate investment). $\dot{i}^{net}_{j,t} \equiv \frac{\partial(i_{j,t}-\delta)}{\partial r_t}$ is the estimated group response of the investment rate to monetary policy in Figure 3 and $\omega^k_{j,t}$, $\omega^I_{j,t}$ and $\frac{I_t}{K_t}$ are computed from Compustat. Finally, $t$ refers to the entire IRF horizon and we focus on the average response over 20 quarters.

Applying this decomposition reveals that young non-dividend payers account for around 25% of the response of aggregate investment to monetary policy. This is remarkable given that the capital stock of this group is only 6% and their share of aggregate investment is only 8%. In short, while younger no dividend firms account for a rather small share of the investment *level*, their contribution to the aggregate investment *changes* due to monetary policy is considerably larger.[28]

# 5 The channels of monetary transmission

In the previous section, we have shown that younger firms paying no dividends exhibit the largest and most significant adjustment in capital expenditure following a change in interest rates. While traditional proxies of financial constraints — such as size, leverage and liquidity — also generate

[28]Implicit in these calculations is the assumption that the behaviour of private and public firms is similar. However, to the extent that private firms tend to be younger, not to pay dividends and are more likely to face worse credit market access, the 25% share computed in the main text would probably be a *lower bound* on the actual contribution of younger non-dividend payers to the response of aggregate investment to monetary policy in the whole economy.

heterogeneity in capital expenditure, the differences across groups are smaller and disappear after conditioning on age and dividend status.

In this section, we examine why younger non-dividend payers respond more. To evaluate the financial frictions hypothesis, we look at a number of variables from firms' balance sheet and income statements, paying special attention to the response of collateral values and debt. In particular, we show that the heterogeneity in the response of capital expenditure is mirrored by the response of debt. In contrast, the change in earnings, sales and interest payments are more homogeneous across groups. This sizable co-movement of debt and investment supports the idea that our proxy is indeed capturing financial frictions, which are more acute for younger non-dividend payers. This latter group is populated by firms that are also more profitable, growing faster and/or exhibit higher return volatility. These factors, however, do not explain the results in the previous section: we will show that, although more profitable and higher volatility companies tend to respond more to monetary policy, the effect is driven by the sub-group of younger non-dividend payers.

### 5.1 Borrowing, collateral values and financial frictions

A number of theories emphasize the role of firm balance sheets in amplifying the effects of changes in monetary policy. Higher interest rates lower asset prices and push down equity values. This may lead to a rise in the external finance premium and generate a further decline in investment (as in Bernanke et al. (1999)). Higher interest rates can also trigger a fall in collateral values and lead to a tightening of borrowing constraints whenever a significant portion of debt is secured against collateral (as in Kiyotaki and Moore (1997)). The key is that these indirect effects are sufficiently large to trigger amplification though a sizable reduction in borrowing and investment for constrained firms. The simple model in the appendix corroborates this interpretation.[29] Since these asset-based channels have important implications for firms' financing decisions and their balance sheets, in this section we look at how firms' borrowing decisions and collateral values respond to changes in monetary policy.

A natural place to start with is the response of borrowing. Financial accelerator theories predict that the borrowing of constrained firms should respond more whenever (i) their debt is secured against collateral, and (ii) collateral values are highly sensitive to changes in monetary policy. In the top row of Figure 6, we report the response real debt growth, which we take as a measure of debt

[29] Firms differ in their optimal scale and the borrowing constraint may become less binding as they approach the optimal size. We interpret distance to optimal scale as firm age.

issuance. In the bottom row, we show the response of firms' collateral at market value (bottom row). This is constructed using changes in the book value of real estate collateral and movements in real estate prices at the state-level, in the spirit of Lian and Ma (2020) and Chaney et al. (2012).[30] The left column shows the findings for younger non-dividend payers, the middle column refers to older firms paying dividends. To test for a statistically significant difference between the groups, the third column estimates the *relative* response of younger no-dividend firms, using older dividend payers as reference group in a specification that includes also the interest rate as a separate regressor.

Two main findings emerge from Figure 6. First, the decline in borrowing after a monetary policy tightening is large and significant mostly for younger non-dividend payers.[31] In contrast, the change in borrowing for older firms paying dividends is economically and statistically modest, being on average less than one third of the effects for younger non-dividend payers. Second, collateral values (in the bottom row) decline for all firms after an increase in interest rates. This is consistent with the notion that credit conditions tighten for financially constrained firms whose borrowing is secured against the value of their collateral.[32]

To examine further whether the debt of younger non-dividend payers is more sensitive to fluctuations in collateral values, we follow a recent and growing literature on debt covenants which has documented significant heterogeneity in the types of borrowing contracts across groups of firms. Lian and Ma (2020), for instance, report that asset-based borrowing is more prevalent among younger firms, who lack stable cash flows and typically have not an extensive credit history. On the other hand, earning-based borrowing is predominant among old and large companies. To explore this heterogeneity, we project changes in long-term debt on collateral values and earnings, measured by EBITDA as in Lian and Ma (2020) and Drechsel (2018). We also control for firm fixed

[30] More detail on this variable is given in the Appendix.

[31] The decline for younger non-dividend payers applies to both short-term and long-term borrowing.

[32] Another way to interpret this result is to consider the IRFs for investment, borrowing and collateral values is as a series of instrumental variable regressions where we examine the effect of collateral values and debt on investment, using monetary policy shocks as the instrument. Following the IV terminology, the dynamic effects of monetary policy on investment can be interpreted as the reduced-form model whereas the dynamic effects of monetary policy on debt and collateral values can be viewed as the first-stage regressions. The ratio of these two sets of impulse responses at each forecast horizon represents the IV estimate of the causal effect of corporate debt and collateral values on firm investment at that horizon. This also helps interpret the relative magnitudes of the effects presented in this section. For example, consider the response of investment to changes in the market value of collateral (or debt) at the peak of the investment response, quarter 12. We cumulate the IRF for the investment rate and divide by the associated cumulative response of the growth rate of the market value of collateral (or debt). We then multiply by the average PPE to collateral value (or debt) ratio. This number then has a dollar-for-dollar interpretation. For young non-dividend payers, this is 0.8 for the effect of collateral values on investment and 0.7 for the effect of debt on investment. In contrast the effect of collateral values on investment for old dividend payers is only 0.1, which illustrates the greater sensitivity of investment to collateral values for the young non-dividend paying group.

effects, as well as other characteristics including size, leverage, liquidity and Tobin's Q. Our focus is on heterogeneity in the correlations of borrowing with collateral values and with earnings, by age/dividend status. Standard errors are clustered by firm and time. Table 1 reports the results. The first four rows display the coefficients on collateral (real estate at market value scaled by lagged total assets) while the bottom four rows show the coefficients on earnings scaled by lagged total assets. The four columns analyse the sensitivity of our estimates across several specifications where we vary the fixed effects included in the regression.

The estimates in Table 1 offer two main insights. First, the borrowing of younger non-dividend payers is significantly correlated only with firm collateral. The coefficient on earnings is much smaller and statistically indistinguishable from zero. Second, older-dividend payers exhibit a sizable and very significant coefficient on earnings, which is much larger than their coefficient on collateral. Interestingly, young dividend payers display occasionally significant estimates on both collateral and earnings, which are roughly of equal magnitude. As in Figure 6, these findings reveal that the borrowing of younger non-dividend payers is far more correlated with collateral values than for older companies or for firms paying dividends. The results in this section are in line with the evidence on debt covenants presented by Lian and Ma (2020), who show that — among U.S. traded companies — only the borrowing of younger firms is predominantly secured against assets whereas the majority of older firms' debt is secured against earnings. Lian and Ma's finding points to the prevalence of asset-based borrowing constraints among younger non-dividend payers, consistent with the large responses and comovement between investment and debt for this group that we have documented above.

Our inference, that the response of younger-non dividend payers reflects tightening borrowing constraints, chimes with two additional pieces of evidence. First, using data on corporate bond yields, Andreson and Cesa-Bianchi (2018) show that the corporate spread increases significantly only for firms with a lower credit rating (younger firms in our sample) following a monetary policy contraction. Second, the aggregate evidence from national statistics in Appendix C reveals that, on average, corporate spreads and the policy rate are positively correlated after a monetary policy shock. The positive correlation between interest rates and corporate spreads is also consistent with the evidence in Gertler and Karadi (2015) and Caldara and Herbst (2018). The first finding is consistent with younger firms facing more severe financial frictions; the second result is consistent with financial frictions amplifying the effects of monetary policy.

## 5.2 The responses of cash flows

In the previous section, we discussed a prominent example of an amplification channel: monetary policy affects firm investment via collateral values and tighter borrowing conditions. In this section, we look at three cash-flow variables that could reflect alternative channels. First, some younger non-dividend payers may have a larger share of shorter maturity debt and/or more variable rate debt. Accordingly, *direct* movements in interest payments might account for the heterogeneity in the capital expenditure responses reported in Section 4. Furthermore, younger firms paying no-dividends might face a product demand or a cost schedule with a higher cyclical sensitivity. If so, the response of gross sales and earnings (which are essentially sales net of costs) will be informative about whether this is driving the heterogeneous effects of monetary policy on investment. These potential explanations are explored in Figure 7 where the rows report the response of interest payments, sales and earnings, respectively, for younger firms not paying dividends (left column) and older companies paying dividends (middle column). The relative effect between these two groups is reported in the third column for formal hypothesis testing purposes.

At face value, the response of interest expenditure is hard to interpret because this is a function of both interest rates and debt decisions. However, the time profile of the impulse responses in the first row of Figure 7 is very revealing. Within the first year of the shock, interest payments increase significantly. As we have seen in Figures 3 and 6, however, neither investment nor debt respond significantly within the first year, suggesting that the movement in interest expenditure is more likely to reflect the increase in the interest rate. During the second year, the adjustment of interest payments become insignificant and after the second year it turns negative. This is consistent with the significant decline in borrowing during the first year after the shock in Figure 6 but is inconsistent with interest payments being a main driver of the significant investment responses at the horizons of two and three years in Figure 3. Furthermore, there is little heterogeneity in the responses of interest payments across groups, which is formally verified in the third column of Figure 7.

Younger non-dividend paying firms may also respond more to monetary policy because the demand for their product may be more sensitive to changes in interest rates. This interpretation can be assessed from the second row of Figure 7, which reports the results for the growth of sales. These charts show that the response of sales growth *over the first two years after the shock* is far more homogeneous than the response of investment, with the difference recorded in the third column being statistically insignificant. For example, the average effect in the first six quarters is around

0.2% for both the younger non-dividends payers and the older dividend payers. Interestingly, some heterogeneity emerges only during the third year (after the investment responses in Figure 3 have peaked), with the highest point estimate for younger non-dividend payers around $-0.8$ and for older dividend payers at about $-0.5$. We conclude that the *time profile* of the impulse responses of sales is inconsistent with the hypothesis that heterogeneity in product demand is a main driver of the heterogeneity in investment after a change in interest rates.

Another relevant measure of firms' cash flows are earnings (measured by EBITDA), which — unlike gross sales — could change heterogeneously also if costs were differentially affected by monetary policy across groups. Alternatively, following an interest rate increase, a fall in earnings could further accelerate the decline in capital expenditure if a significant fraction of firm debt is earnings-based. While we have already shown in the previous section that the debt of younger non-dividend payers is secured mostly against assets, a decline in cash flows could also trigger a shortage of internal funds, which may result in a further contraction of investment for firms struggling to attract external funds. This earning-based amplification hypothesis is explored in the third row of Figure 7. The responses of earnings are relatively homogeneous across the age/dividends groups and are not particularly sizable, especially in comparison to the response of borrowing and investment. The peak effects in the third row are around 0.5 - 1%, which is considerably smaller than the movements in borrowing and collateral values recorded in Figure 6. Furthermore, in dollars terms, debt is typically larger than earnings, which on average is true at all ages, as shown in Figure 1. This implies that — in dollars — the decline in borrowing for young non-dividend payers is much larger than the fall in their cash flows/earnings. This suggests that an earnings-based borrowing constraint would be less likely to explain the movements in corporate debt and investment that we observe among younger firms paying no dividends.

Together with the evidence in Section 5.1, we interpret the relatively smaller and more uniform estimates for interest payments, sales and earnings across groups as evidence that these channels, on their own, seem unlikely to play a quantitatively major role in accounting for the heterogeneity in the capital expenditure responses in Figure 3. That said, although an earnings-based channel may be less important than an asset-based channel for younger firms, both channels would be consistent with financial frictions amplifying the dynamic effects of monetary policy.

### 5.3 Profitability and growth

Another possible interpretation of the strong response of younger no-dividend firms is that, rather than being driven by financial constraints, this might reflect the fact that younger businesses may be more profitable, growing faster and more sensitive to interest rate changes. Indeed, in Section 3 we have documented that, on average, younger firms tend to have a higher Tobin's Q and experience faster growth rates. In Appendix Figure E.2, without controlling for age or dividend status, we show that the investment of firms in the top quartile of the yearly distribution of Tobin's Q or Alpha (from CAPM-type of regressions) respond more to monetary policy than the other groups. It should be noted, however, that the differences are less marked than using the age/dividends grouping strategy, especially for Tobin's Q.

To consider the role of age/dividend status controlling for profitability, in Figure 8 we split the group of more profitable firms into young non-dividend payers (left column) and old dividend payers (right column) using Tobin's Q (top row) and Alpha (bottom row). To the extent that profitability (rather than age/dividend) is the genuine driver of the heterogeneous responses of investment in Section 4, we should observe no difference between more profitable young firms and more profitable old firms. To the extent that age/dividend (rather than profitability) is the key trait associated with a larger response, then among the more profitable businesses, younger firms should adjust their investment more than old more profitable firms. Figure 8 shows that this is indeed the case: even among more profitable companies, younger non-dividend payers respond significantly more than older dividend payers, which corroborates an independent role for age/dividend status. For completeness, in Appendix F and Appendix Figure J.2, we show that within the group of younger firms paying no dividends, there is far less variation by Alpha and Tobin's Q.

Younger firms are not only more profitable on average but also tend to grow faster. Some profitable firms may, of course, already be at (or close to) their optimal scale. We can therefore also repeat the same exercise conditioning on firm growth. These results are also reported in Appendix F. Again, faster growing firms respond more to monetary policy, but within this group it is the younger non-dividend payers that drive the result.

It is important to note that while younger firms may have a higher Tobin's Q, not all highly profitable firms are young and paying no dividends. Some profitable firms may be unconstrained while others may still face financial frictions, especially if they are younger, not paying dividends and still growing towards their optimal scale. If profitability or growth prospects alone were the underlying driver of the heterogeneity found in Section 4, this would survive even conditional on age/dividends. This section shows this is not the case. Even among more profitable firms, it is the younger no-dividend firms that respond considerably, as in our main results in Section 4. This reinforces the notion that our proxy is capturing firms at a particular point in their life cycle when they are most likely to face financial frictions.

### 5.4 Mark-ups, volatility and risk

Another confounding factor could be heterogeneity in mark-ups. Some firms, for instance, may choose a lower frequency of price adjustments and charge higher mark-ups. In Section 5.2, however, we have already documented little heterogeneity in the responses of sales and earnings across firms, which seems inconsistent with the hypothesis that mark-up heterogeneity is driving the results in Section 4. Another way of looking at this is to exploit a fact documented by Gorodinchenko and Weber (2016), that firms with stickier prices exhibit a higher volatility of stock market returns after a monetary policy shock. In Appendix Figure E.2, we show that firms in the top quartile of the stock market volatility distribution change their capital expenditure slightly more than their low volatility counterparts. However, Figure 9 reveals that within the high return volatility group, only younger firms paying no dividends (left column) display a large and significant response. The effect on older firms paying dividends (middle column) tends to be small and not statistically different from zero. Furthermore, the *relative* effect in the third column reveals that the difference across groups is statistically significant.

A corollary of these findings is that our main results in Section 4 are not simply driven by firms with a higher return volatility (with no role for age/dividend status). It is possible that the effects of monetary policy vary with the riskiness of the firm. This could, in principle, provide an explanation for the heterogeneity by age/dividend status. But the results in this section suggest this is unlikely to be the case. To provide further evidence on this point, we consider a further measure of risk. Appendix Figure E.2 shows that firms with a higher Beta (from a CAPM type of regression) — a measure of systematic risk — are more responsive to monetary policy, without conditioning on age/dividend status. In Figure 9, however, we show that this is entirely driven by younger non-dividend payers among the higher Beta group. In contrast, older dividend payers with higher Beta exhibit only a modest change in capital expenditure. Furthermore, as shown in Appendix Figure J.6, there is little heterogeneity by Beta once we condition on age/dividend status.

## 5.5 The contribution of financial frictions

In Section 4, we have shown that younger non-dividend payers account for around 2/3 of the average movement in the investment rate and about 1/4 of the aggregate investment response to monetary policy. Earlier in this section, we have argued that the larger effects on younger non-dividend paying firms is consistent with financing frictions playing a significant role for this group. In this section we ask: What can these results tell us about the overall importance of financial frictions in the monetary transmission mechanism?

To do this, we conduct the following back-of-the-envelope calculation. First, note that the behaviour of the other three groups is more consistent with these firms being financially unconstrained. This is either because the response of investment is not mirrored by the response of debt, or because these firms keep paying dividends after a monetary contraction. As discussed earlier, dividend payers and older firms account for around 1/3 of the average response of the investment rate. By comparing the contribution of younger non-dividend payers to the average effect with the contribution of the other groups, we can therefore have an indication of the importance of credit constraints. Since younger non-dividend payers account for 2/3 of the average response, this implies that the indirect effects coming from financial frictions are responsible for about 1/3 of the average effect of monetary policy on the investment rate.

Following a similar logic, we can also provide a back-of-the-envelope calculation for the contribution of financial frictions to the response of aggregate investment. As shown earlier, younger non-dividend payers account for around one quarter of the response of aggregate investment. How much of this contribution comes from non-financial frictions channels? To answer this question, we need to come up with a counterfactual estimate of what the contribution of younger non-dividend payers would have been if there were financially unconstrained. Using the investment response of the old dividend payers (which we view as the 'unconstrained' group) and the capital share of the younger non-dividend payers, we calculate this counterfactual contribution to be around 3%.[33] Subtracting this from the actual 25% contribution of younger no-dividend firms implies that financial

[33] The capital share of older dividend payers is 73% and they account for around 39% of the overall investment response. Making use of our previous approximations, per 1pp capital share the contribution of 'unconstrained' firms to the aggregate investment response is $0.39/0.73 = 0.53$. Applying this ratio to the 6% capital share of the constrained firms (i.e. younger non-dividend payers) leads to a counterfactual 3% contribution for this group. In other words, if younger non-dividend payers had the same marginal response to monetary policy as older dividend payers, their current capital share would have implied a contribution to the aggregate response of only 3%. It is counterfactual because this calculation is based on the assumption that younger non-dividend payers behaved 'as if' they were older dividend payers (who we view as 'unconstrained').

frictions account for approximately 20% of the aggregate investment response to monetary policy. Note, because we only observe public firms in Compustat, this calculation assumes that private firms behave in a similar manner to public firms. In fact, 20% is likely to be a lower bound as the type of collateral constraints we consider seem likely to be even more prevalent among private firms.

**External Validity.** One may reasonably ask whether our results for the U.S. are applicable more generally to other countries and samples. While we have focused on the U.S. here, in the working paper version of our work (Cloyne et al. (2018)) we also repeat all the exercises presented in this paper for the United Kingdom. We omit these here for brevity but the similarity in all the results is striking. This is interesting because the results are informative about whether the type of transmission mechanical that we have documented may be at work also in other countries. We find this is the case. More specifically, we document that younger non-dividend payers display the largest and most significant capital expenditure response after a U.K. monetary policy shock and they are also the firms whose debt adjusts the most. Once age and dividend status is controlled for, however, other proxies for financial constraints no longer generate sizable heterogeneity. In line with the U.S. results, younger British firms paying no dividends tend to be smaller, have lower leverage, lower earnings, lower credit scores and their borrowing is significantly more asset-based than any other group of firms. Finally, we show that the response of earnings and interest rate payments is more homogeneous across groups and that the indirect effects may account for more than one third of the effects of monetary policy on investment in the U.K.

# 6 Sensitivity analysis

In this section, we show that our main result — that younger non-dividend payers adjust their investment the most following a monetary policy shock — is robust across a range of additional exercises and specifications. In particular, our findings are confirmed when: (i) exploiting only within-firm variation for a group of firms that we observe over their entire life-cycle and examining potential cohort effects (ii) considering a different cut of the data using the market value of collateral across firms (iii) using three different identification strategies to isolate exogenous movements in monetary policy and (iv) possible sub-sample instability, both over time and across sectors.

## 6.1 Within-firm variation over the life-cycle and cohort effects

Our baseline result compares the investment response of younger non-dividend payers to the other groups. Since our sample includes young firms who eventually become old and young firms who died or entered over the period, one concern is that these composition effects might be blurring the distinction between groups.

To address this concern, in this section we focus on a restricted sample of old dividend paying firms who we also observe when they were young and paying no dividends. To the extent that age and dividend status are the genuine drivers of heterogeneity, we should see results that mirror our baseline findings: these firms should respond little when old but have responded significantly more when they were young and paying no dividends.

This hypothesis is confirmed in Figure 10. The chart shows the response of older firms paying dividends (in the right column), together with the response of the same firms when they were young and not paying dividends (in the left column). The capital expenditure response of these firms when they were young and not paying dividends is large and statitically significant, looking remarkably similar to the impulse response functions in Section 4. This corroborates the view that our finding of heterogeneity is genuinely driven by age and dividend status, rather than by changes in groups composition over time.

An additional concern is that our results might be influenced by cohort effects, where being young in the early part of the sample has different implications from being young later in the sample. To assess the empirical relevance of this challenge, we have also reproduced the analysis behind Figure 3 by cohort (rather than age directly) and dividend status where cohort is defined based on the incorporation date of the firm. Younger firms are those incorporated after 1977. The 1977 threshold ensures that 'older' companies are at least ten years old at the start of the sample. The results are very similar to Figure K.1, revealing that the heterogeneous responses that we document in this paper are not driven by this type of cohort effects.

## 6.2 Low versus highly collateralized firms

In Section 4, we have argued that a firm facing higher costs of external finance may be less likely to pay dividends earlier in their life-cycle in an effort to retain internal funds for investment. Indeed, in the previous section, we showed that the same companies whose investment was most sensitive to monetary policy when younger and paying no dividends, became unresponsive after growing old and starting to pay dividends.

As argued by Gertler and Gilchrist (1994) (pp. 312-313), informational frictions can add to the costs of external finance if companies are not well collateralized. Whenever external funds are secured against a lower level of collateral, these firms may be particularly sensitive to movements in collateral values. This is indeed the type of mechanism discussed in Section 5. But is also suggests an alternative measure of financial conditions: the share of assets that can be used as collateral. In this section we therefore consider grouping firms based on the market value of their collateral (scaled by total assets).

There are pros and cons to this strategy. On the one hand, grouping firms by their collateral share may speak more directly to the type of financial frictions that we seek to investigate in our empirical analysis. On the other hand, there are several disadvantages. First, the market value of collateral has to be imputed (which, as discussed in Section 5, we do by constructing a measure of the market value of real estate) and thus is likely to be measured with error. In contrast, dividend payment status is based on whether a company pays dividends or not, which is observed with virtually no measurement error in every quarter of our sample. Second, relative to our age/dividends grouping strategy, the market value of collateral is endogenous and firms may move groups over time and in response to monetary policy.

Despite the drawbacks, it is still instructive to consider this further split of the data. Prima facie evidence that our age/dividend grouping strategy may be correlated with a firm's collateral position comes from noting that, on average, younger non-dividend payers tend to have less collateral on their balance sheets. For example, the market value of real estate relative to overall (net) plant, property and equipment is 17% and only 5% when measured as a share of total assets. On the other hand, the same ratios for older companies paying dividends is much higher, at 46% and 13% respectively. Of course, not all young firms have a low collateral share and, conversely, not all old firms have a high share.

In Figure 11, we therefore split firms in eight bins depending on their age (below or above 15 years since incorporation), whether they pay dividends or not *and* whether their collateral share (market value of real estate as a share of total assets) is above or below the median of the sample distribution in each year. The rows denote age. The even (odd) columns refer to paying (no) dividends. The four panels on the left (right) represent firms with below- (above-) median collateral share within each group.

To the extent that the share of pledgable assets drives access to external finance and thus the investment response of younger non-dividend payers, we would expect that —within this group— younger non-dividend payers with a *below* median collateral share would adjust their capital expenditure in response to monetary policy much more than younger non-dividend payers with an *above* median collateral share. On the other hand, within each of the other groups, which are unlikely to face significant collateral constraints, there should be little difference in the investment responses of low versus highly collaterized firms.

Two main results emerge from Figure 11. First, the response of low-collateral younger non-dividend payers (in the top left corner) is twice as large as the response of high-collateral younger non-dividend payers (in the panel on the first row of the third column). Second, whether a firm is below or above the median collateral share makes little difference to the investment responses within each of the other three age/dividend groups (in the second and fourth columns as well as in the bottom row of the first and third columns).

The findings in this section are consistent with the notion that the larger investment response of younger non-dividend payers reported in Section 4 reflects, at least partially, the heterogeneity in collateral shares exploited in this section. While we still favour the grouping strategy based on dividend payment status because of its higher coverage, absence of measurement error and independence from changes in monetary policy, we interpret the results in this section as further evidence that we are identifying the exposure of a firm to collateral-based financial frictions.

### 6.3 Identification of monetary policy shocks

In this section, we consider a number of alternative ways of identifying exogenous variation in monetary policy. One popular method has been proposed by Romer and Romer (2004), who isolate the residuals of a Taylor-type rule by projecting changes in the target federal funds rate on the Federal Reserve Greenbook forecasts of the change in inflation, unemployment and output growth. In the first row of Figure 12, we show the results based on Romer and Romer's identification for the period 1986 to 2007.[34] In keeping with our baseline specification, we use the Romer and Romer shock as an instrument for the interest rate. We focus on the results for younger non-dividend payers (left column) versus older dividend payers (right column). The third column reports the relative effect. The estimates confirm, by and large, the heterogeneity in the capital expenditure

[34] We use the series in Wieland and Yang (2019), which extend Romer and Romer (2004) calculations after 1996.

responses along the age/dividend dimension.

As a second robustness check, we use a different measure of the high frequency monetary surprise. Instead of using the high frequency surprises from Gertler and Karadi (2015) to identify our monetary policy shocks, we follow Nakamura and Steinsson (2018a) and use their Policy News Shock as the instrument. This variable is the first principal component of the change in several interest rate variables in the 30 minute window around the policy announcement. This shock may contain richer information about the policy surprise and is therefore a very useful alternative. The second row of Figure 12 reveals that our findings are robust also to using this alternative high frequency instrument.

Finally, a recent literature, pioneered by Nakamura and Steinsson (2018a), Miranda-Agrippino and Ricco (2018) and Karadi and Jarocinski (2019), emphasize that high frequency movements in short-rate futures around the policy announcements may also reveal information about the central bank's view of the economy. Romer and Romer (2000) document that Federal Reserve policy announcements contain signals about the Fed's private information and private forecasters tend to update their forecasts as a result. High frequency surprises might therefore be a mix of a genuine monetary policy surprise and an information effect (e.g. the central bank becomes more/less optimistic about the economy than previously thought). While this does not invalidate our strategy to isolate exogenous variation in monetary policy, it may affect the interpretation of our results. In the final row of Figure 12, we therefore conduct a further robustness check. Miranda-Agrippino and Ricco (2018) suggest controlling for central bank forecasts as a way of netting-out the information effect. We reproduce our main specification augmented with the changes in the central bank forecasts for inflation, GDP and unemployment around the policy decisions. The estimates are very similar to the baseline results in Figure 3: the response of young non-dividend payers is large and significant whereas the response of old firms paying dividends is small and statistically negligible. We conclude that our results are not being driven by an information effect.

### 6.4 Sub-sample stability and sectoral effects

This section considers whether our estimates are overturned by dropping the recent financial crisis, controlling for differential time trends and effects across industrial sectors. Since these exercises either limit the number of observations or greatly increase the number of parameters to be estimated, we show these results as sensitivity analyses.

The top row of Appendix Figure L.1, shows the investment response of younger non-dividend payers dropping the period after 2007. While the bands are marginally wider, the responses are still large and significant for this group. In contrast, older firms paying dividends do not respond at all over this shorter sample, confirming that the heterogeneity we find in Figure 3 is not driven by the financial crisis. To some extent, this result could have been anticipated from the previous section where we showed that a completely different shock identification scheme (Romer and Romer (2004)) that ends in 2007 also produced similar estimates.

Next, we consider whether our results are sensitive to controlling for industrial sectors. We do this in two ways. First, the second row of Appendix Figure L.1 shows the dynamic effects of monetary policy on the capital expenditure of younger firms not paying dividends when we add sector-time fixed effects. This specification allows for different time trends by industrial sector. The third row allows the marginal effect of interest rate changes to vary by industrial sector.[35] In using time fixed effects, the impulse response functions in both exercises are relative to one of the age-dividend groups. Without loss of generality, we report the results relative to the old firms paying dividends group, which is the least responsive group. We still find a relatively stronger investment adjustment for younger firms paying no-dividends. The main result in Figure 3 therefore holds over and above any possible heterogeneity across sectors.

## 7 Conclusions

This paper asks two main questions: (i) Do financial frictions amplify the transmission of monetary policy? (ii) How much do financial frictions contribute to the aggregate investment response? The answer to the first question is: "yes, they do". The answer to the second question is: "about 20%". We reach these conclusions after a detailed firm-level analysis of the heterogeneous responses of balance sheet and income statement variables from the universe of U.S. public firms. The quest for these answers allows us to identify the firm's characteristics that are most likely to correlate with the presence of financial constraints.

Younger firms paying no dividends tend to be smaller, have lower credit ratings, earn less and access less credit. Most importantly, the borrowing of this group is most sensitive to fluctuations in collateral values. As interest rate increases significantly affect firms' collateral values, younger

[35]The second exercise allows the marginal effect of monetary policy to vary by sectors defined at the 1-digit SIC level. The first exercise allows us to be more flexible, defining sectors at the 2-digit level.

non-dividend payers are forced to reduce borrowing and therefore cut investment. In contrast, older firms paying dividends adjust their investment by much less and the change in their borrowing is modest, statistically and economically. Other channels, including changes in interest payments, product demand, firms costs and mark-ups, generate little heterogeneity across firms and thus seem unlikely to explain our findings.

A further contribution of our analysis is to show that the combination of age and dividend-payment status is a far stronger and more robust predictor of a large positive comovement between investment and borrowing than other firm characteristics such as size, leverage and liquidity. In our favourite interpretation, we are capturing a firm at the point in their life cycle in which they are most likely to face financial frictions: when they are younger and not paying dividends. Younger firms are likely to be some distance from their optimal scale, are seeking to grow but are probably still missing the necessary historical record in credit markets to access low cost external finance. A simple collateral constraint model with heterogeneity in optimal size generates predictions on the heterogeneous effects of monetary policy on investment and borrowing across constrained and unconstrained firms that are in line with our empirical evidence by age/dividends status. Overall, our findings highlight the role of financial frictions in the transmission of monetary policy to investment.

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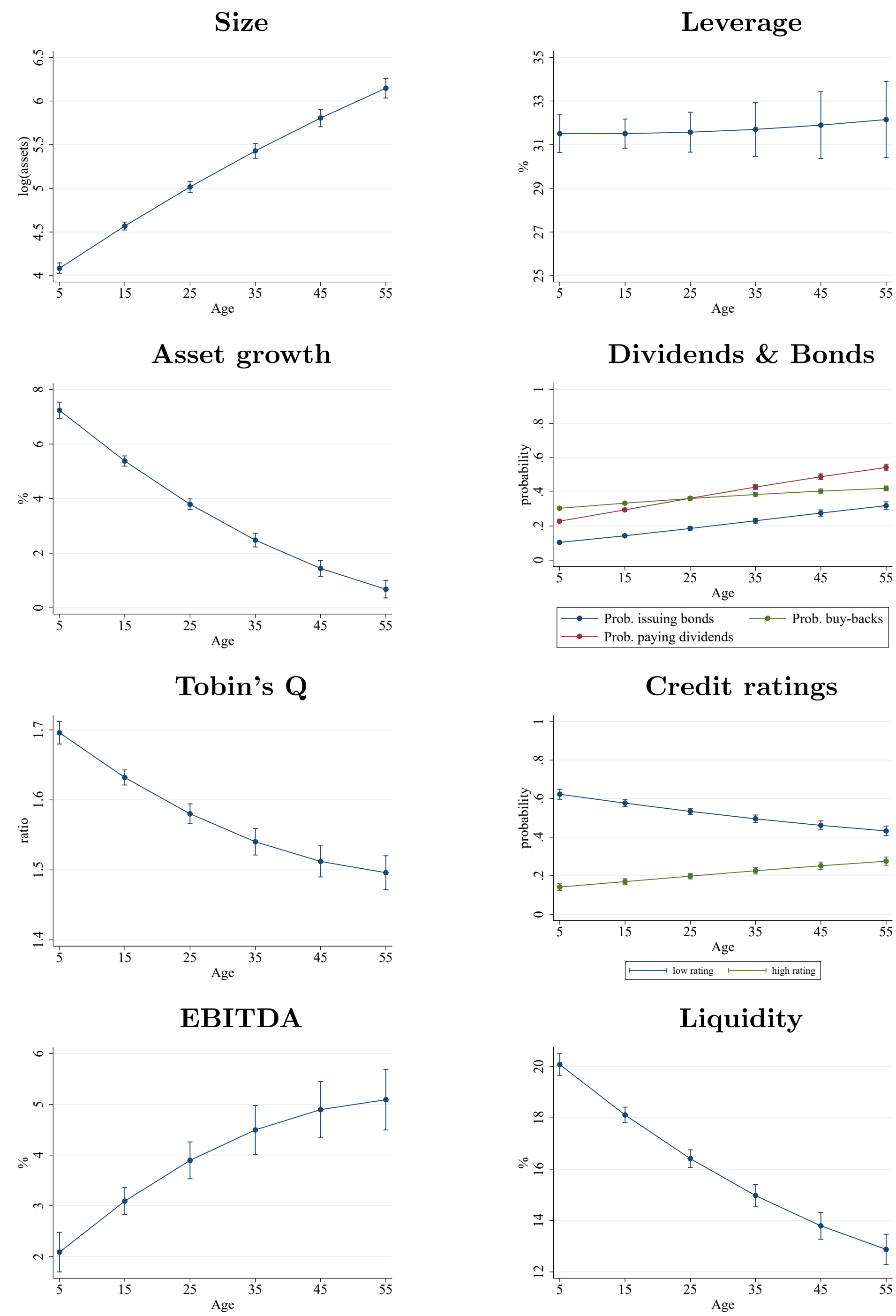
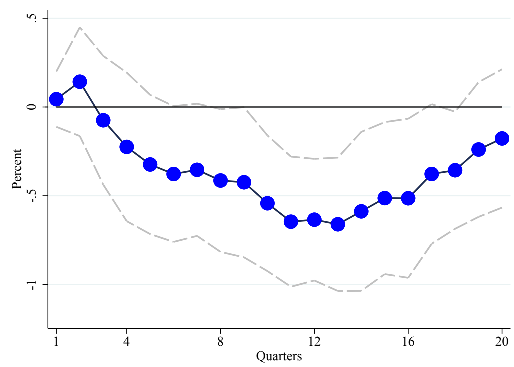
Figure 1: **Descriptive statistics by Age**



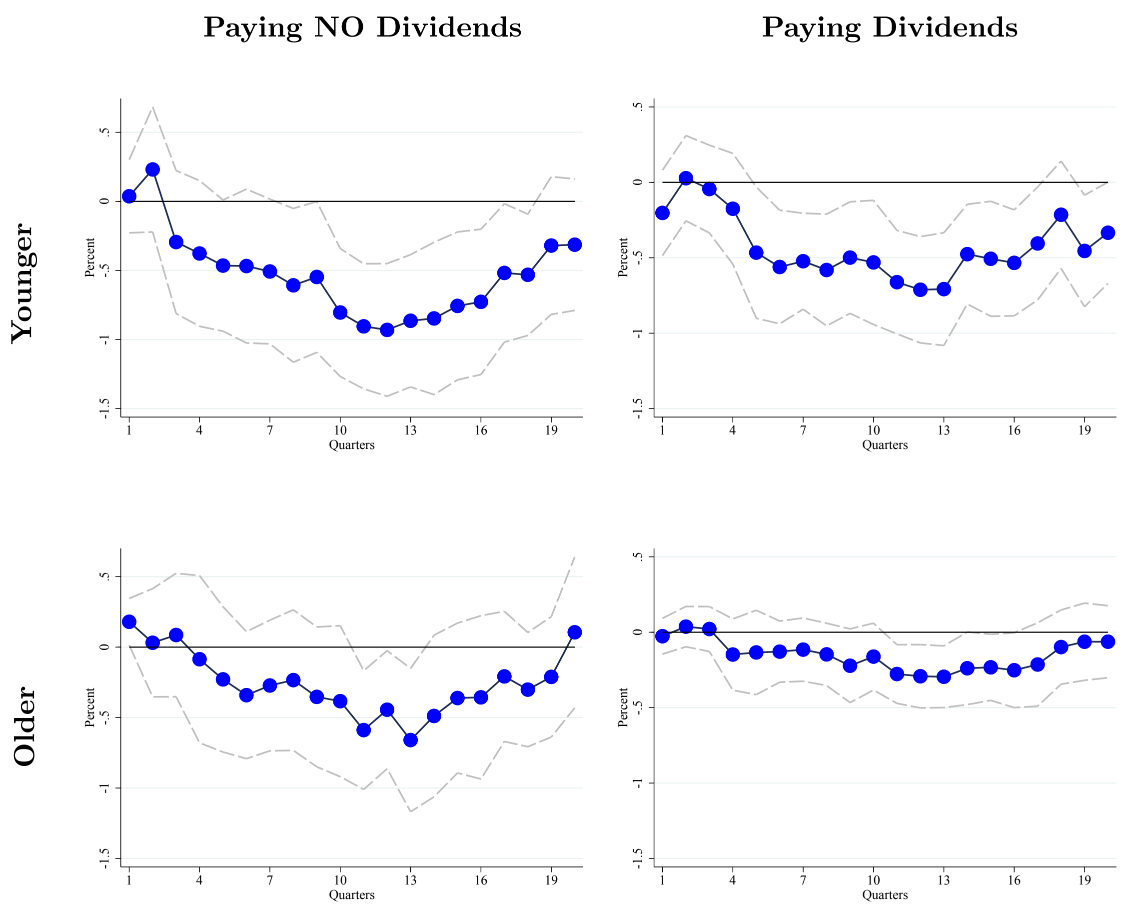

Notes: Each panel reports the predicted values for each variable by age. Each panels uses a regression of the variable of interest on age and age squared conditional on sector-time fixed effects and firms' controls as detailed in Section 2. 90% standard error bands. Standard errors are clustered by firm and time. Size is measured by the log of total assets. Asset growth is the growth rate of total assets. Tobins' Q is the ratio of the market value of total assets to the book value. EBITDA is earnings before interest tax and depreciation, measured as sales net of costs divided by total assets. Leverage is total debt relative to total assets. Dividends and bonds are based the probability of paying cash dividends, buying back stock or having a issued a bond. A high credit rating means investment grade debt (higher than BBB). Liquidity means total short term cash and investments relative to total assets.

Figure 2: **Average Response of Investment to an Increase in Interest Rates**



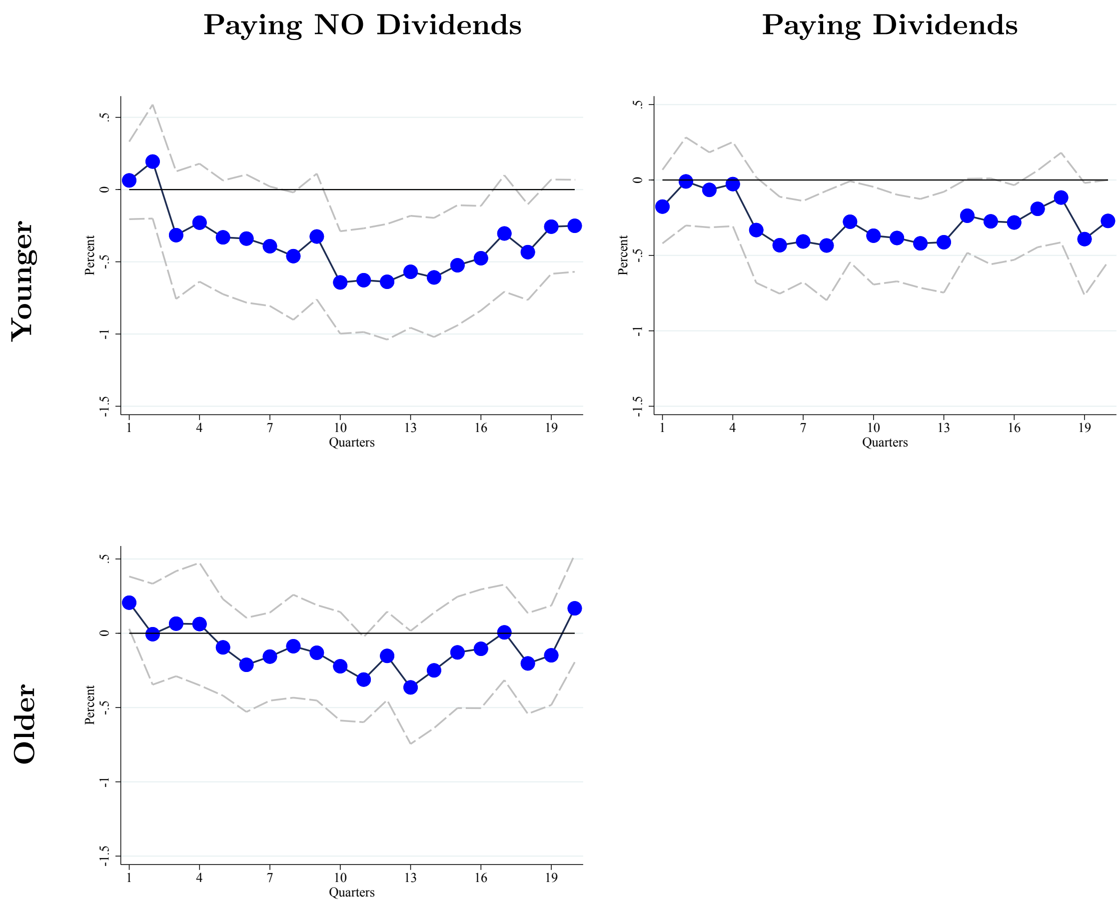

Notes: This figure shows the impulse response function (IRF) for the investment rate following a 25bps increase in the one year interest rate. The IRFs are estimated using the local projection IV approach described in the text. The regression does not allows for heterogeneity across groups and the IRF is therefore the average effect across all firms in the sample and facilitates comparison with macroeconomic IRFs using time series data. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

Figure 3: **Response of Investment by Age and Dividend Status**



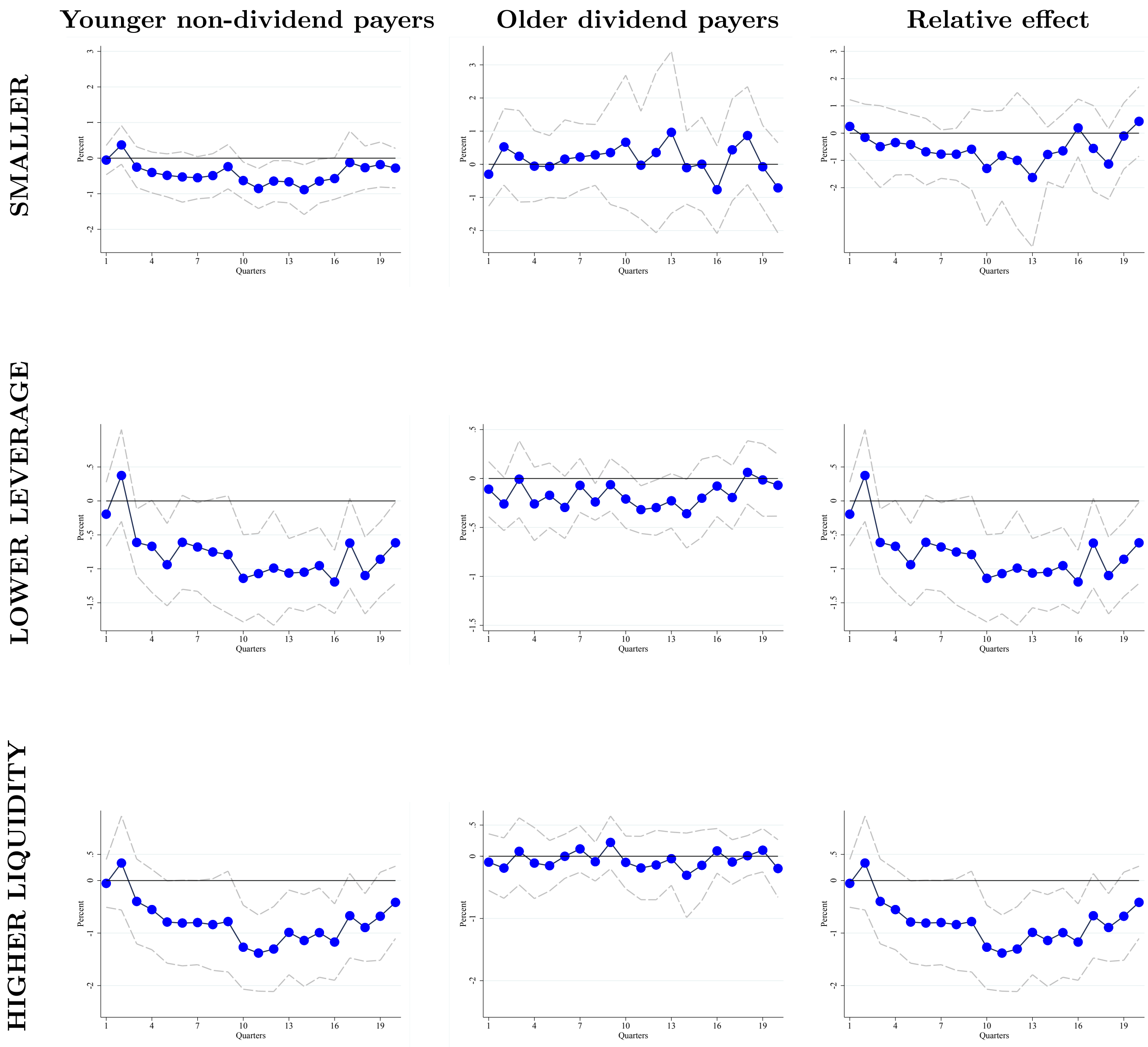

Notes: This figure shows the impulse response functions for the investment rate following a 25bps increase in the one year interest rate. The interest rate is interacted with binary indicators based on age and dividend status. Younger refers to $<$ 15 years since incorporation and older refers to $>$ 15 years since incorporation. No dividends means the firm did not pay cash dividends in the previous year. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

Figure 4: **Response of Investment by Age and Dividends *Relative* to Older Firms Paying Dividends**



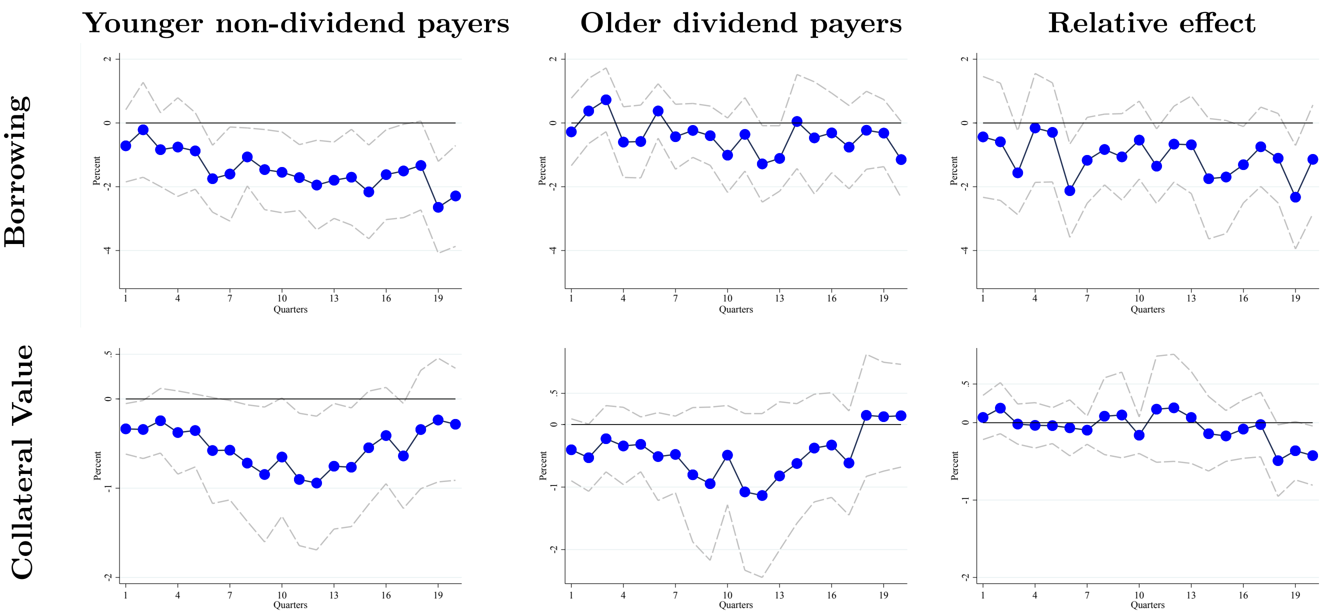

Notes: This figure shows the impulse response functions for the investment rate following a 25bps increase in the one year interest rate. The interest rate is interacted with binary indicators based on age and dividend status. Younger refers to $< 15$ years since incorporation and older refers to $> 15$ years since incorporation. No dividends means the firm did not pay cash dividends in the previous year. Relative to the results in Figure 3, this specification includes the interest rate as a regressor on its own. The IRFs are relative to older dividend-paying firms. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

Figure 5: **Controlling For Other Firm Characteristics**



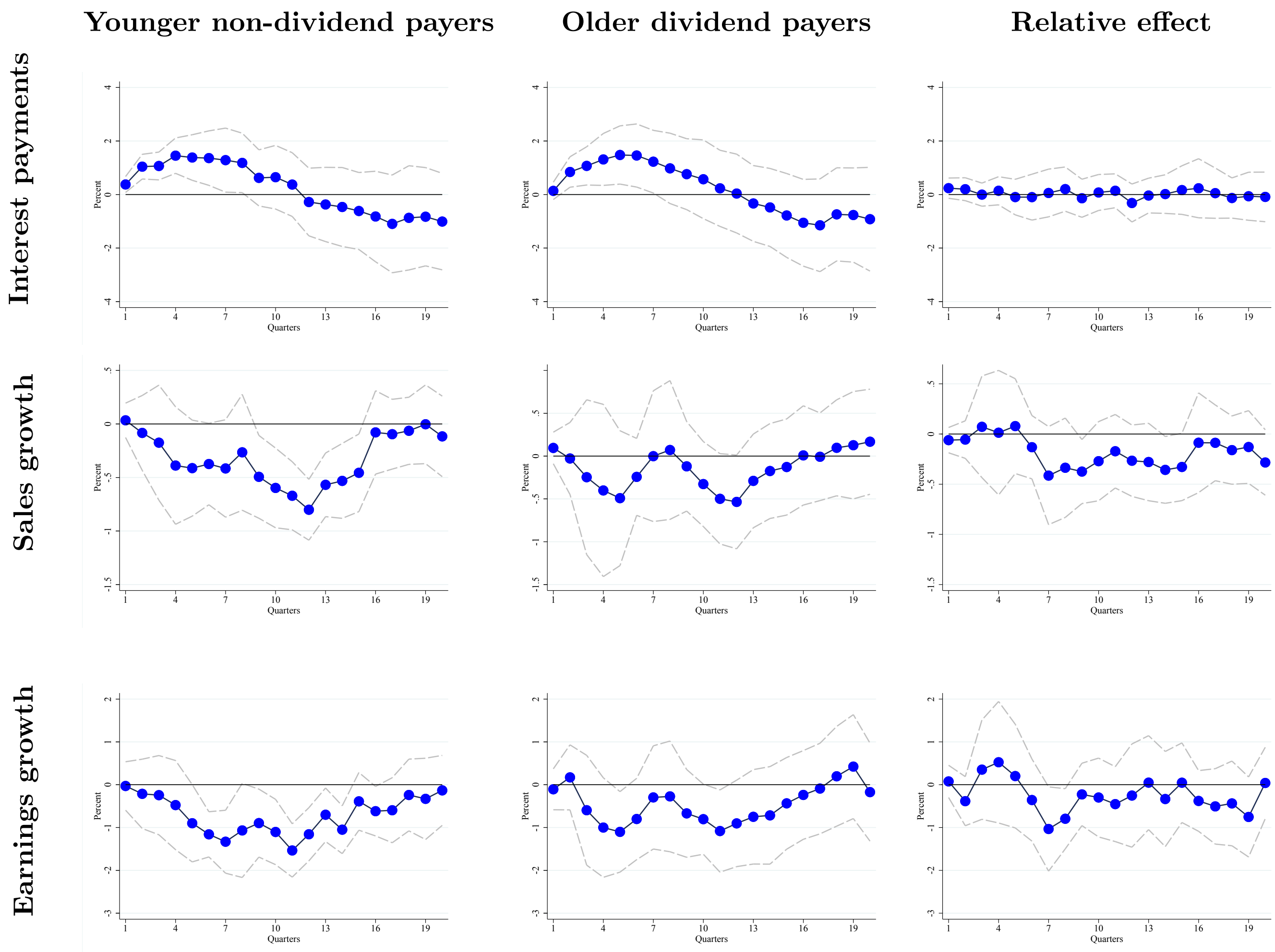

Notes: This figure shows the IRFs for the investment rate following a 25bps increase in the one year interest rate. We run separate regressions for each row. In each row, the interest rate is interacted with three sets of group dummies based on a firm's age, dividend status and their position in either the size, leverage or liquidity distribution. Younger means less than 15 years since incorporation. Size refers to total assets in the previous year. Leverage is total debt relative to assets in the previous year. Liquidity is cash relative to total assets in the previous year. For size, leverage and liquidity we display the results using the most responsive quartile when the data are cut using these variables alone (see Appendix E). Smaller and lower leverage refers to the bottom quartile of each distribution. Higher liquidity refers to the top quartile of the liquidity distribution. The relative effect column refers to separate specifications where the IRFs are estimated relative to older firms paying dividends. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

Figure 6: **Response of Firm Finance: Borrowing and Collateral**



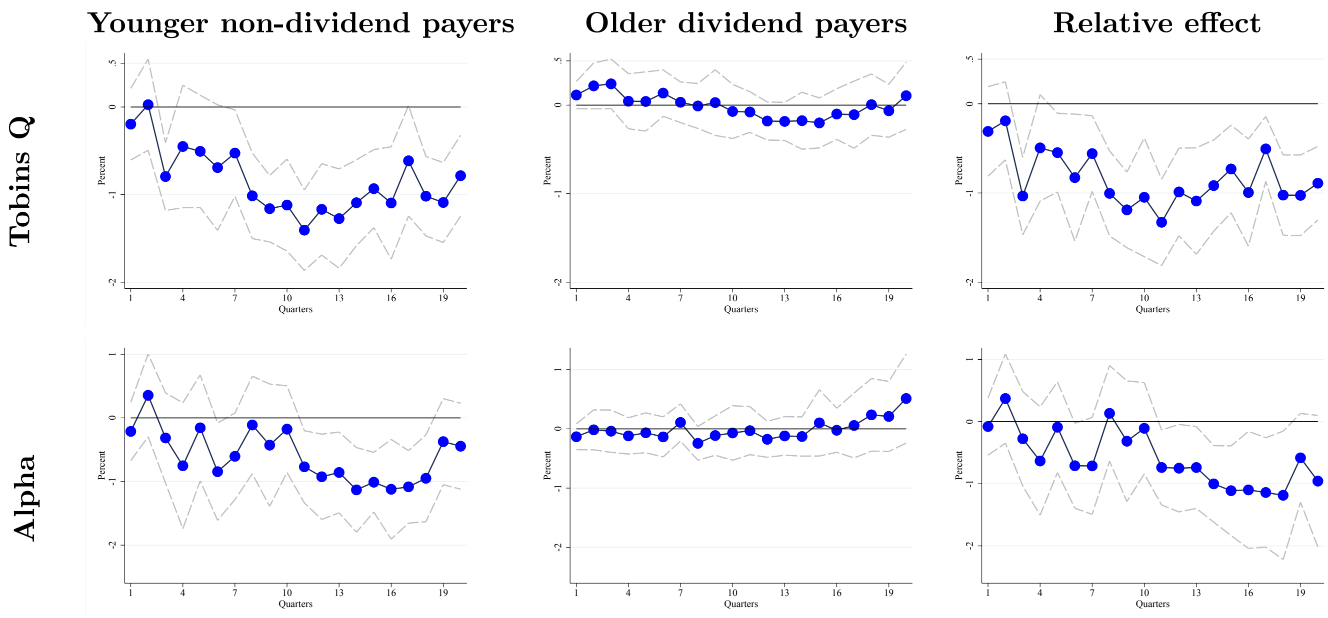

Notes: This figure shows the IRFs for the investment rate following a 25bps increase in the one year interest rate. We run separate regressions per each row. The first row shows the response of total real debt growth (annualized). The second row shows the response of real collateral value growth (market value). The market value of collateral is constructed using the change in the book value of corporate real estate assets and using state house price variation as discussed in the data appendix. Young refers to less than 15 years since incorporation. The relative effect column refers to separate specifications where the IRFs are estimated relative to older firms paying dividends. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

Figure 7: **Response of Firm Finance: Sales, Earnings and Interest Payments**



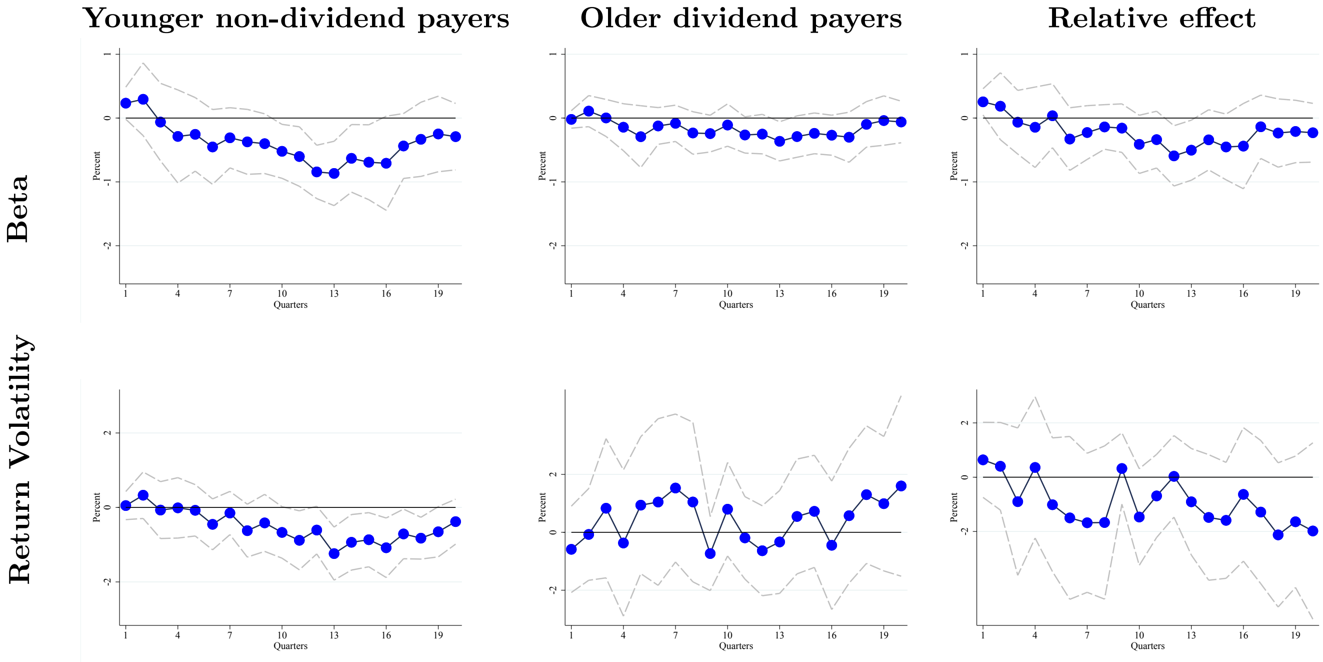

Notes: This figure shows the IRFs for the investment rate following a 25bps increase in the one year interest rate. We run separate regressions per each row. The first row shows the response of (log) interest payments. The second row shows the response of real sales growth (year on year). The third row shows the response of real earnings growth (measured using the real growth rate of EBITDA). The relative effect column refers to separate specifications where the IRFs are estimated relative to older firms paying dividends. Young means less than 15 years since incorporation. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

Figure 8: **Response of Investment: Conditioning on Tobin's Q and Alpha**




Notes: This figure shows the IRFs for the investment rate following a 25bps increase in the one year interest rate. We run separate regressions for each row. In each row, the interest rate is interacted with three sets of group dummies based on a firm's age, dividend payment status and the distribution of each firm's Tobin's Q, and Alpha, which we estimate from a CAPM type regression. For both variables we display the results using the top quartile of the distribution, which is most responsive group when the data are cut using these variables alone (see the online appendix). The relative effect column refers to separate specifications where the IRFs are estimated relative to older firms paying dividends. Young refers to less than 15 years since incorporation. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

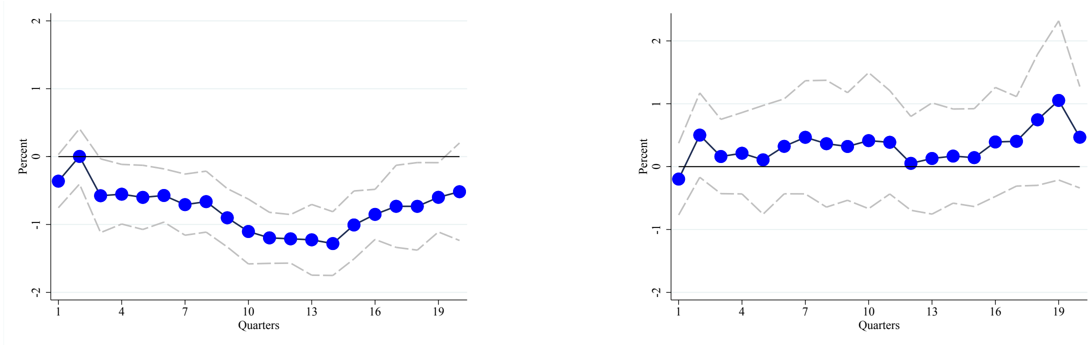
Figure 9: **Response of Investment: Conditioning on Beta and Volatility**




Notes: This figure shows the IRFs for the investment rate following a 25bps increase in the one year interest rate. We run separate regressions for each row. In each row, the interest rate is interacted with three sets of group dummies based on the distribution of each firm's return volatility and Beta, which we estimate from a CAPM type regression. For both variables we display the results using the most responsive group when the data are cut using these variables alone (see the online appendix). For volatility we use the top quartile of the distribution, for Beta we use firms with a Beta greater than 1. The relative effect column refers to separate specifications where the IRFs are estimated relative to older firms paying dividends. Young refers to less than 15 years since incorporation. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands.

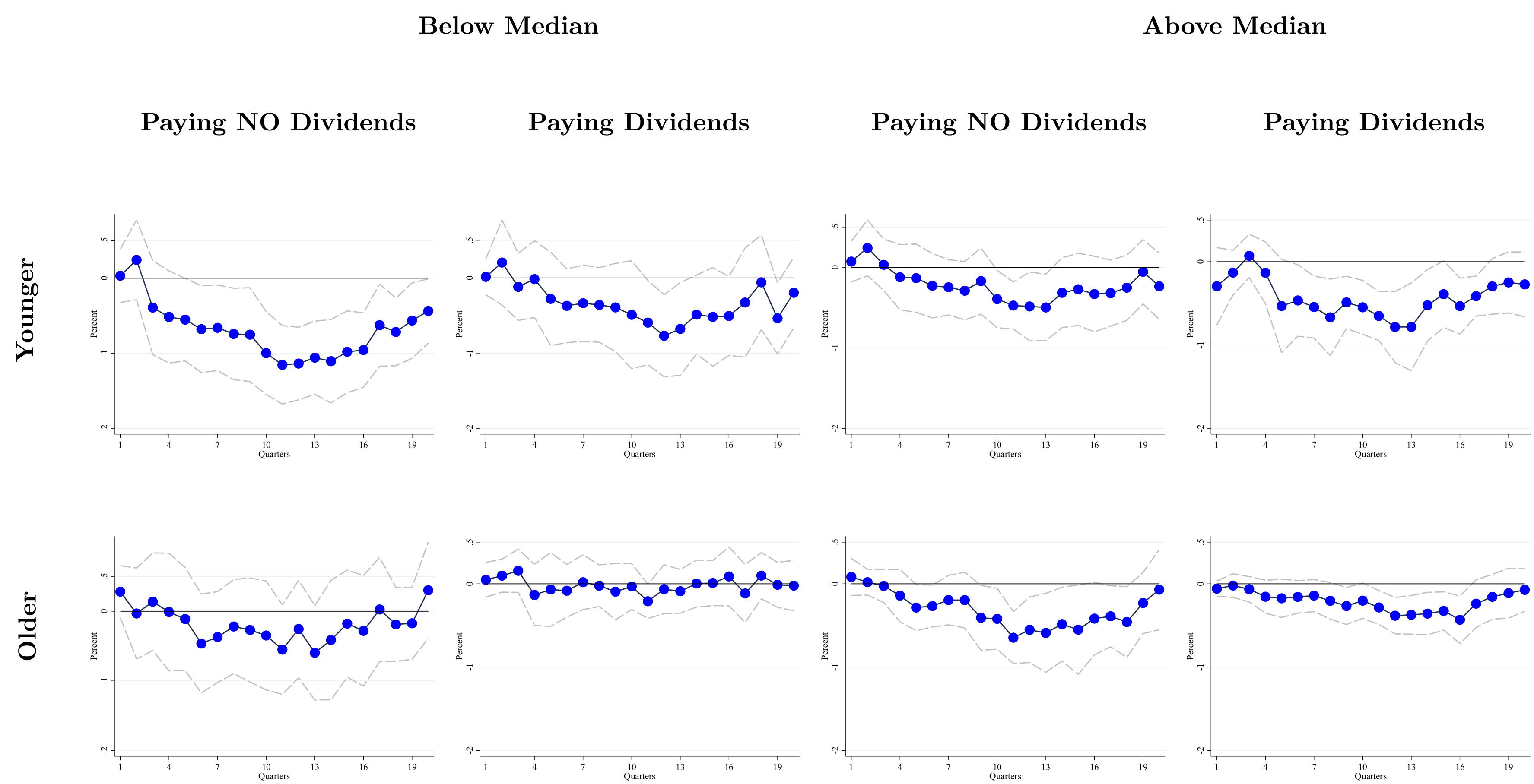
Figure 10: **Exploiting Only Within-Firm Variation Over the Life-Cycle**

**WHEN Younger and Not Paying Dividends** **WHEN Older and Paying Dividends**



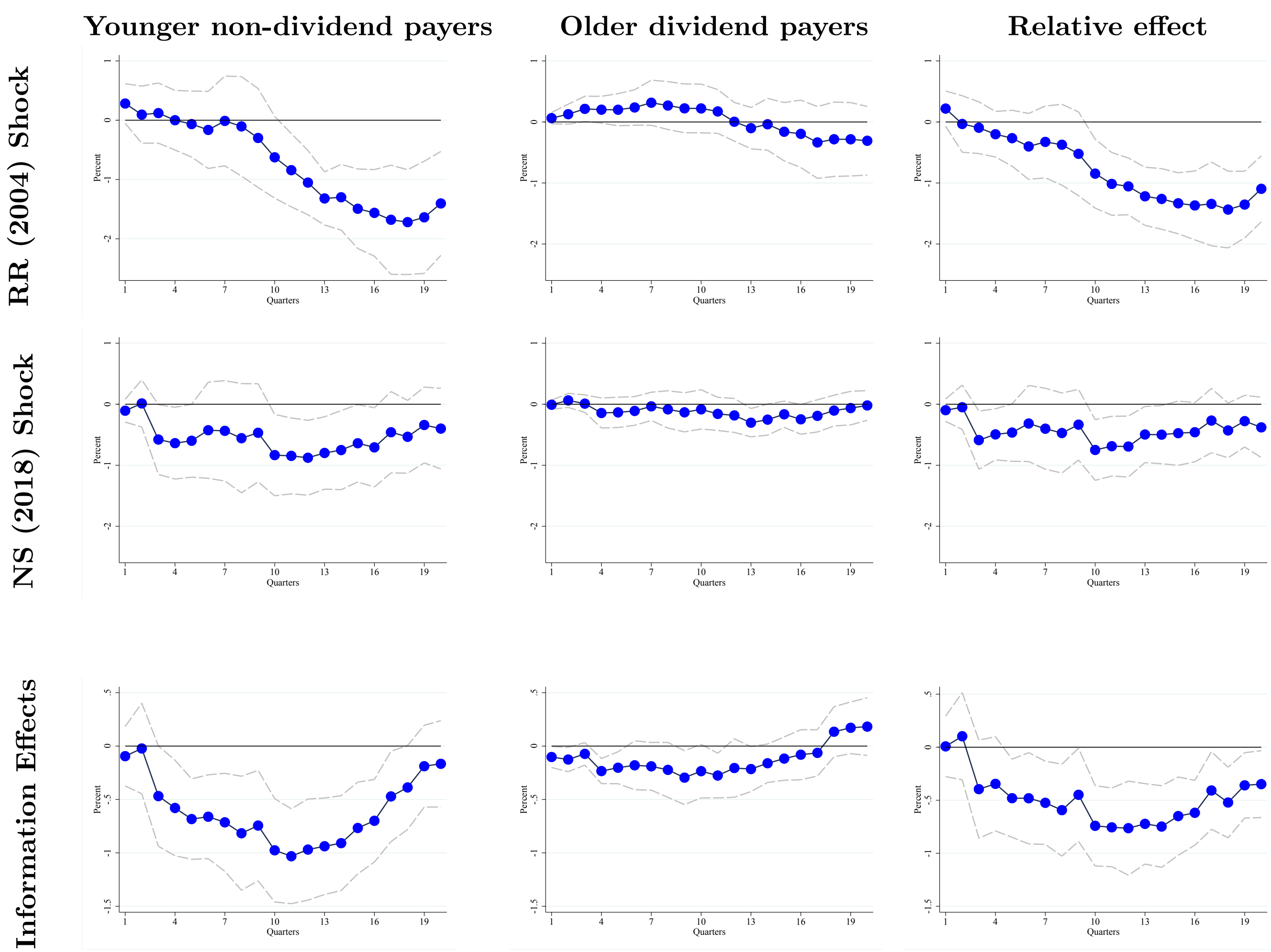

Notes: This figure shows the IRFs for the investment rate following a 25bps increase in the one year interest rate. Only firms who eventually become old and pay dividends are kept for this exercise. We then examine the response of these firms to a monetary policy shock when they are old and when they are young. Young refers to less than 15 years since incorporation. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

Figure 11: **Response of Investment by Age, Dividends Paid and Collateral share**




Notes: This figure shows the IRFs for the investment rate following a 25bps increase in the one year interest rate. The interest rate is interacted with binary indicators based on age, dividend status, size. Younger refers to $< 15$ and older refers to $> 15$ years since incorporation. No dividends means the firm did not pay cash dividends in the previous year. Below median refers to those firms below the median market value of collateral/lagged total assets in the previous year. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

Figure 12: **Response of Investment using Different Shock Identification Schemes**




Notes: This figure shows the IRFs for the investment rate following a 25bps increase in the one year interest rate. Relative to Figure 3: (i) The first row uses the Romer and Romer (2004) shocks (extended by Wieland and Yang (2019) to 2007) to instrument for the one year interest rate. This series only uses data to 2007 given the lack of variation in the Federal Funds Rate after 2008. (ii) The second row reconstructs the monetary policy shocks by re-estimating the Gertler and Karadi (2015) proxy-VAR using the high frequency "Policy News Shock" from Nakamura and Steinsson (2018a). (iii) The third row includes controls for the change in the central bank's forecast for GDP, inflation and unemployment for the current quarter and two and four quarters ahead. Forecast data come from the Philadelphia Fed's Greenbook Data Set. Results are similar including more forecasts although the standard errors become wider. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

Table 1: The Correlation of Borrowing with Collateral Values and Earnings

| | | (1) Baseline | (2) No Group FEs | (3) Sector FEs | (4) Region FEs |
|---|---|---|---|---|---|
| **Collateral** | Young No Dividends | 0.096*** | 0.096*** | 0.088*** | 0.097*** |
| | | ( 0.022 ) | ( 0.022 ) | ( 0.021 ) | ( 0.023 ) |
| | Young Paying Dividends | 0.047 | 0.066** | 0.052 | 0.049 |
| | | ( 0.033 ) | ( 0.031 ) | ( 0.032 ) | ( 0.032 ) |
| | Old No Dividends | 0.025 | 0.018 | 0.023 | 0.031 |
| | | ( 0.019 ) | ( 0.020 ) | ( 0.018 ) | ( 0.020 ) |
| | Old Paying Dividends | 0.057*** | 0.061*** | 0.058*** | 0.061*** |
| | | ( 0.017 ) | ( 0.016 ) | ( 0.016 ) | ( 0.016 ) |
| **Earnings** | Young No Dividends | 0.020 | 0.020 | 0.018 | 0.018 |
| | | ( 0.013 ) | ( 0.013 ) | ( 0.013 ) | ( 0.013 ) |
| | Young Paying Dividends | 0.067** | 0.068** | 0.064** | 0.065** |
| | | ( 0.030 ) | ( 0.031 ) | ( 0.031 ) | ( 0.030 ) |
| | Old No Dividends | 0.018 | 0.019 | 0.015 | 0.015 |
| | | ( 0.015 ) | ( 0.015 ) | ( 0.015 ) | ( 0.016 ) |
| | Old Paying Dividends | 0.125*** | 0.126*** | 0.113*** | 0.104*** |
| | | ( 0.028 ) | ( 0.028 ) | ( 0.026 ) | ( 0.028 ) |
| Time varying firm controls | | × | × | × | × |
| Firm FE | | × | × | × | × |
| Group FE | | × | | × | × |
| Sector × Time FE | | | | × | |
| Region × Time FE | | | | | × |

Standard errors in parentheses

$^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

Notes: Standard errors are in parentheses. $\text{Collateral}_t$ is the market value of real estate (calculated using the method outlined in the text and the appendix) in period $t$ relative to total assets at the beginning of the year. Earnings refers to EBITDA in period $t$ relative to total assets at the beginning of the year. The table shows the sum of the coefficients for years $t$ and $t-1$ for both collateral and earnings. Firm and time-two-digit-sector fixed effects are included. Additional firm-level controls are total debt, cash holdings, cash flows from operations all measured relative to total assets, and Tobin's Q. Standard errors are clustered by firm and time.

# ON-LINE APPENDICES

# A Data Appendix

**Firm Level Data** Detailed financial statement data for publicly listed companies are available from Compustat (available from Wharton Research Data Services) for the United States. We use the quarterly version of Compustat from 1986 for computing the dynamic effects. We use annual Compustat for the regressions in Table 1.

Table A.1 below provides the precise data definitions and variable codes from Compustat. Size is measured as the book value of assets. The liquidity ratio is the ratio of cash plus short-term investments to total assets. Leverage is the ratio of total debt to total assets, where total debt includes both short and long term obligations. Interest payments are measured using the income statement variable total interest expenses. Sales are defined as gross sales while EBITDA is defined as gross sales minus cost of goods sold and operating expenses. Average Tobin's Q is defined as total assets at market value over total assets at book value. Cash receipts are the sum of cash flows from operations plus interest and related expenses. Variables that are expressed as ratios use the variables from Compustat directly. Variables in levels, for example, sales are deflated using the aggregate GVA deflator, as discussed below. Our dividend payment indicator is based on whether the firm paid cash dividends in the previous year.

Although Compustat is quarterly and the data have been assigned (at source) to calendar quarters, some variables are cumulative within the firm's fiscal year. We therefore difference these variables within the fiscal year to create the quarterly series. There are a small numbers of missing observations in Compustat and we follow others in the literature and interpolate missing values.

The market value of real estate is constructed in the spirit of Chaney et al. (2012) and Lian and Ma (2020). First we compute the book value of real estate holdings exactly as in Chaney et al. (2012). To construct a quarterly measure of the market value we do the following. We initialize the market value of real estate assets using the first non-zero book value observation for the firm. We then inflate this using state level quarterly house price growth (assuming an annual depreciation rate of 2.5%) and then add on any changes in the book value of real estate assets. For house prices, we follow Chaney et al. (2012) and use the state-level house price index provided by the Office of Federal Housing Enterprise Oversight, matching this to Compustat using the location of the firm's headquarters. As for the change in the book value of real estate assets, this is only available in the annual version of Compustat. We therefore need to approximate the quarterly change within the year. We do this by dividing the annual change by 4. For the analysis in the text this series is either converted to real values using the GVA deflator, or expressed as a ratio of lagged total assets.

To measure return volatility, Alpha and Beta we use data on returns from the Center for Research in Security Prices database together with a market factor and the risk free rate. We estimate rolling regressions for a single factor CAPM model, using a window of 36 months. These results are merged with Compustat based on the Compustat/CRSP link-table, which maps the identifier in CRSP (PERMNO) to the identifier in Compustat (GVKEY). CRSP also contains S&P credit rating data for corporate bonds. We use the variables SPLTICRM and SPSTICRM to construct a credit rating index. In Figure 1 a high credit rating means higher than investment grade. Firms without a credit rating are included in the "low" credit rating category. Unfortunately, the majority of firms do not issue bonds, which makes the data on credit ratings less useful for our main regressions.

**Construction of Firm Age** We use WorldScope information on the incorporation date (variable `INCORPDAT`) as our main source for the construction of firm age. We merge WorldScope with Compustat using the CUSIP identifier. The Center for Research in Security Prices database also reports the date when a firm's stocks started trading (variable `BEGDAT`) and we also merge this information into Compustat. These variables are well populated, unlike the native IPO date variable in Compustat.

One important issue is how closely WorldScope's variable captures the true incorporation date of the firm. Differences may arise due to acquisitions or reorganizations over time. For example, the firm may, in a different form, have been incorporated earlier than recorded in WorldScope. To minimize this issue we use the following strategy. We define the incorporation date as the minimum of the WorldScope variable, the CRSP date and the first date the firm appears in Compustat.[36] To further guard against volatility introduced by acquisitions, following Ottonello and Winberry (2020) we also exclude firm observations where acquisitions account for more than 5% of total assets.

Another question, as discussed in the text, is how closely the incorporation date matches the foundation date. As a robustness exercise we also make use of Jay Ritter's database on the Founding Years of US firms. This dataset is available here: `https://site.warrington.ufl.edu/ritter/files/2015/08/age7515.xlsx`. In principle this is a preferable way to measure firm age and avoids issues related to corporate restructuring, but these dates are only available for a subset of firms. That said, as noted in the text, we have confirmed that using Ritter's Founding Year database also produces similar results. Furthermore, note that, given the way we create the bins for age in our regressions, older firms based on incorporation should still be "old" based on foundation date.

**Baseline Sample Restrictions.** The sample period is 1986-2016. We further impose a set of sample restrictions: (i) we drop firms within the finance, insurance, real estate (FIRE) and public administration sectors; (ii) we drop firms which are in the panel for less than 20 quarters (iii) we trim the investment ratio (1% top and bottom); (iv) we drop observations if the liquidity ratio is larger than 1; (v) we trim the top 1% of the leverage ratio; (vi) we trim the top and bottom 1% of real sales growth; (vii) drop firm observations where acquisition are more than 5% of total assets. Trimming is done by year.

**Macro Time Series Data** For the macro data, we use data from the Federal Reserve Bank of St. Louis (FRED) for the United States. We keep as close as possible to the original definitions used in Gertler and Karadi (2015). Industrial production is FRED series `INDPRO`. The one-year risk free rate is the 1-Year Treasury Constant Maturity Rate, FRED series `GS1`. CPI is the Consumer Price Index: Total All Items for the United States (FRED series `CPALTT01USM661S`). Employment is All Employees, Total Nonfarm (FRED series `PAYEMS`). Aggregate business investment is real gross fixed

[36] An alternative strategy that we employed in the 2018 working paper version produces very similar results. That approach primarily uses the WorldScope date, uses the CRSP date in the minority of cases when the WorldScope variable is missing and drops firms that still exhibit a negative age. We prefer the current approach as it rules out negative age by construction.

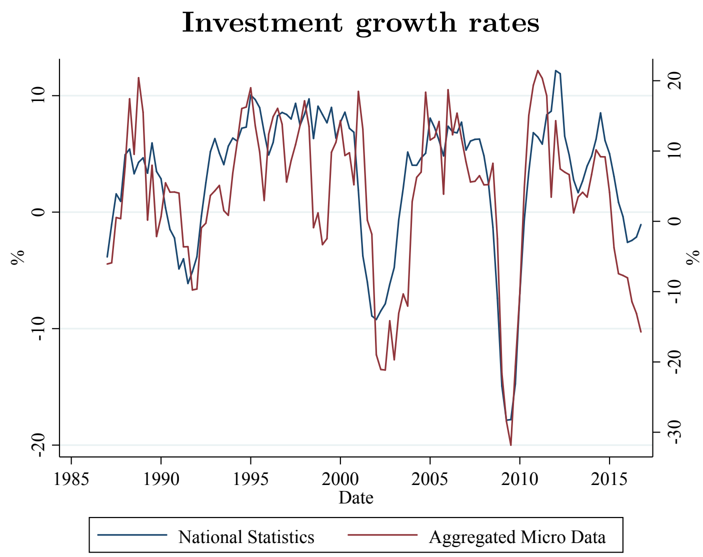
Table A.1: Variable Definitions

| Variable | Compustat Variable |
|---|---|
| Investment ratio | CAPXQ $\times 4$ / L.PPENTQ |
| CAPXQ | D.CAPXY (within year) |
| Total Assets (Book Value) | ATQ |
| Total Debt (Book Value) | DLCQ + DLTTQ |
| Long Term Debt (Book Value) | DLTTQ |
| Leverage (Book Value) | (DLCQ + DLTTQ) / ATQ |
| Liquidity Ratio | CHEQ / ATQ |
| Sales | SALEQ |
| EBITDA | SALEQ - COGS - XSGA |
| Interest Payments | XINTQ |
| Dividends Paid | DVQ |
| Tobin's Q | (ATQ + PRCCQ $\times$ CSHOQ - CEQQ + TXDITCQ) / ATQ |
| Acquisitions | AQCY / ATQ |
| Market value of collateral | Market value real estate (see text) |
| Cash Receipts (Annual) | (OANCF + XINT) / AT |

investment: private, non-residential from BEA NIPA Table 5.3.3 (FRED series B008RA3Q086SBEA). The GVA deflator series is the Price Index for Gross Value Added (Business: Nonfarm), BEA NIPA Table 1.3.4, FRED series B358RG3Q086SBEA. Credit spread data come from Gilchrist and Zakrajsek (2012) and the updated series are obtained from Simon Gilchrist's website: http://people.bu.edu/sgilchri/Data/data.htm.

**Monetary Policy Shocks** Our baseline monetary policy shocks use the high frequency surprises from Gertler and Karadi (2015). We thank Peter Karadi for sharing the updated version of the financial market surprises to 2016. In robustness we make use of Policy News Shock from Nakamura and Steinsson (2018a) (available here: https://eml.berkeley.edu/~enakamura/papers/PolicyNewsShocksWeb.xlsx) and the extended version of the Romer and Romer (2004) shocks from Wieland and Yang (2019) (available here: https://sites.google.com/site/johannesfwieland/Monetary_shocks.zip?attredirects=0). In the robustness section we also control for forecast revisions from the Fed's Greenbook forecasts, available here: https://www.philadelphiafed.org/research-and-data/real-time-center/greenbook-data.

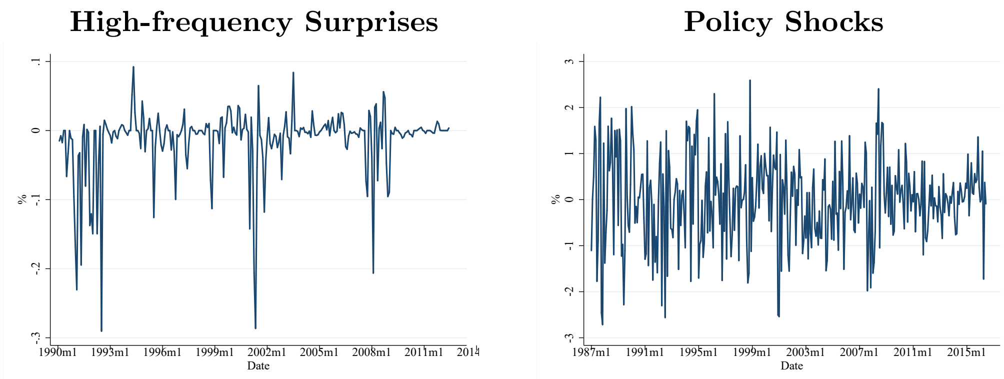
Figure A.1: **Investment over time: aggregated micro data versus national statistics**




This figure shows the year on year growth rate of real capital expenditure aggregated from Compustat compared with the growth rate of real private non-residential fixed investment from the BEA.

# B High-frequency surprises and monetary policy shocks

Figure B.1: **Time series of monetary policy surprises and shocks**




Notes: The first panel shows the raw financial market surprises from Gertler and Karadi (2015)). The second panel show the implies monetary policy shocks from the proxy-VAR in the paper. We deviate from this paper in re-estimating the sample period to match that of our micro-data: 1986-2016.

# C Evidence based on aggregate time series

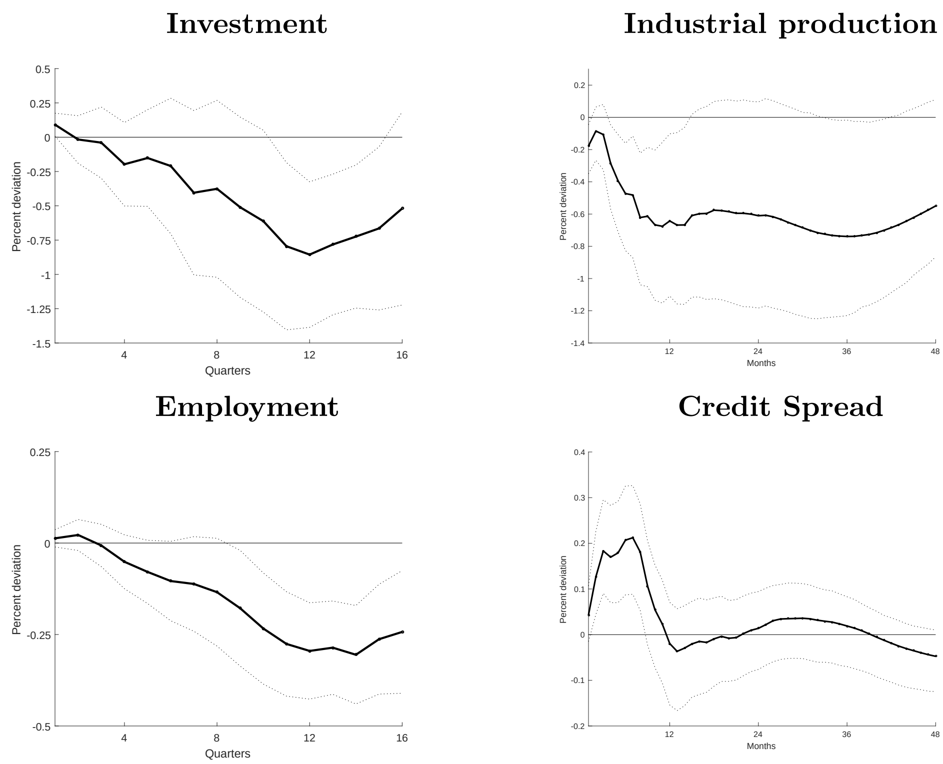
In this appendix we study, using a similar LP-IV set-up as in the main text, whether monetary policy has an effect on business investment in the data from national accounts. Official business investment data are available at quarterly frequency. As is common in the macro literature, we therefore sum our monetary policy shocks to quarterly frequency. A simple regression will then allow us to uncover the impulse response functions for business investment and any other variable of interest. To keep the specification close to the micro regressions, we estimate the following sequence of local projections for any horizon $h$:

$$y_{t+h} - y_{t-1} = \alpha^h + \beta^h R_t + \nu_{t+h} \tag{3}$$

where $R_t$ is the end-of-quarter one year interest rate used in Gertler and Karadi (2015). The nominal rate $R_t$ is instrumented using our extracted series of monetary policy shocks summed to quarterly frequency.The variable $y_{t+h}$ represents log real quarterly business investment and the $\beta^h$ refers to the impulse response function at period $h$. Standard errors are adjusted using the Newey-West method. Note that it is possible to estimate these macro responses in one step using the proxy-VAR, although this requires summing the instruments to quarterly frequency. We prefer to instrument interest rates at a monthly frequency (which is closer to the frequency of monetary policy decisions) and estimate the quarterly IRFs ex-post. This two-step approach is also more consistent with the way we estimate the effects on investment using the micro data but we have verified that it has a negligible impact on the estimated effects using aggregate data.

Figure C.1 shows that an initial 25bp rise in the interest rate leads to a fall in business investment of around 0.6-0.8% after two years. Results for industrial production, employment and credit spreads are also reported. Overall, this method produces results that are qualitatively and quantitatively consistent with the findings in Gertler and Karadi (2015). Higher interest rates contract economic activity and investment in the aggregate.

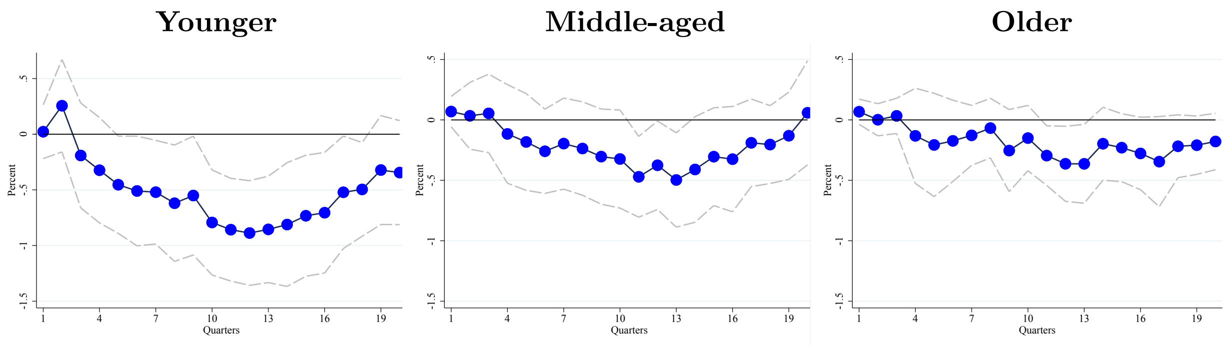
Figure C.1: **Dynamic Effects of Monetary Policy on selected national statistics data**




Notes: This figure shows the impulse response functions to a 25bps increase in the one year interest rate using local projection IV (top row, investment is quarterly) or the proxy-VAR directly (other rows, where the data and the VAR is monthly). Because of data availability, the model in the top (other) row(s) is estimated at quarterly (monthly) frequency. Investment is defined as private non-residential fixed investment divided by the GVA deflator.

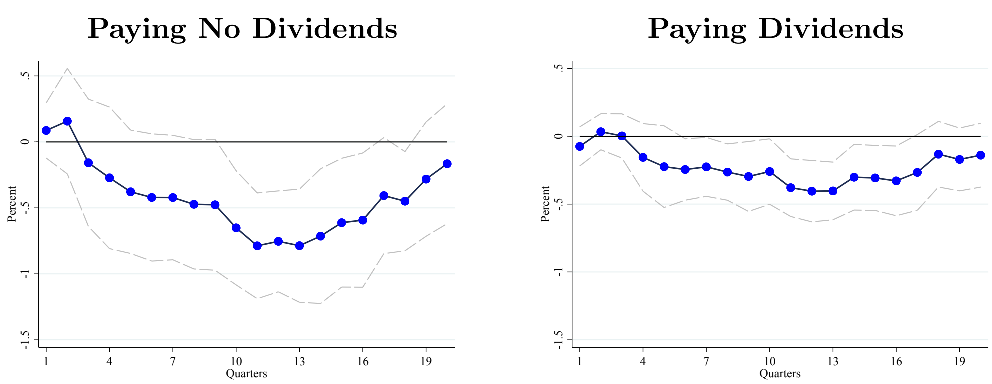
# D Grouping by age and paying dividend status in isolation

Figure D.1: **Response of Investment by Age Only**




Notes: This figure shows the impulse response functions for the investment rate following a 25bps increase in the one year interest rate. The interest rate is interacted with binary indicators for younger ($<15$ years since incorporation), middle-aged ($15-50$ years since incorporation) and older firms ($>50$ years since incorporation). The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

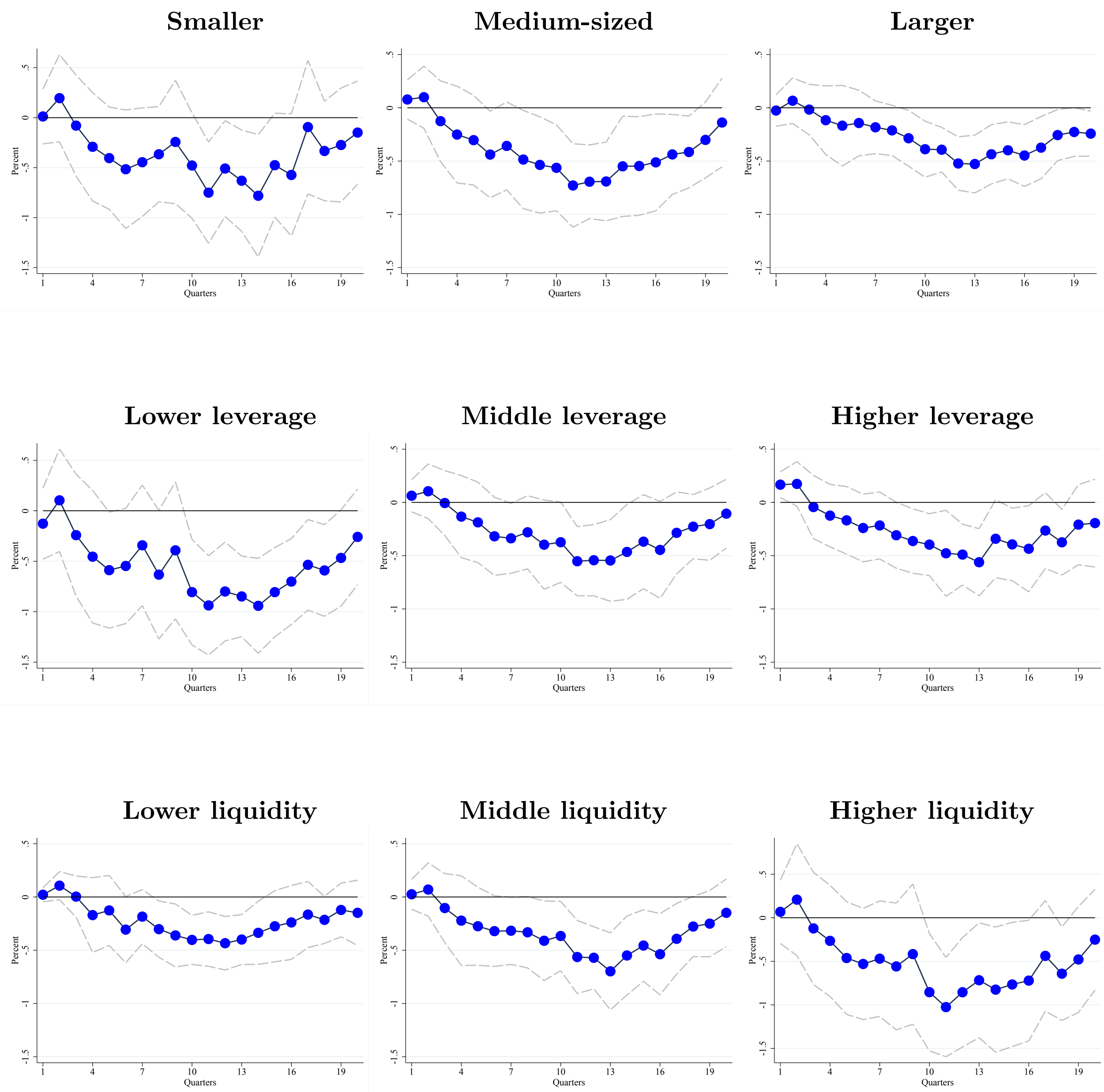
Figure D.2: **Response of Investment by Dividend Status Only**




Notes: This figure shows the IRFs for the investment rate following a 25bps increase in the one year interest rate. The interest rate is interacted with binary indicator for whether dividends were paid in the previous year. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

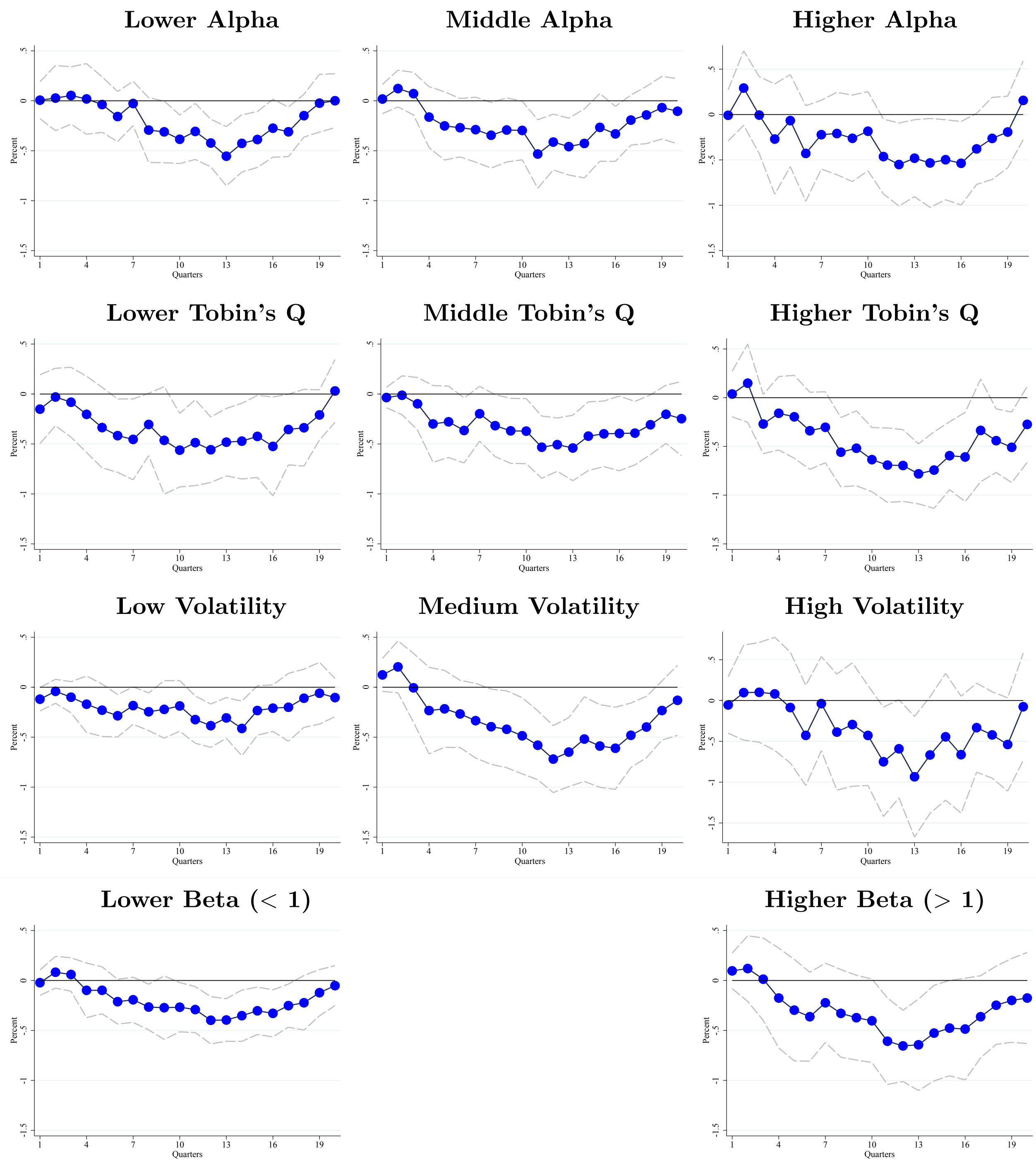
# E Grouping firms by other characteristics in isolation

Figure E.1: **Response of Investment by Size, Leverage and Liquidity**




Notes: This figure shows the IRFs for the investment rate following a 25bps increase in the one year interest rate. We run separate regressions for each row. In each row, the interest rate is interacted dummies based on firm the distribution of each firm's characteristics in isolation. The lower group refers to the bottom quartile, the middle group refers to the middle two quartiles and the highest group refers to the top quartile. Size is based on total assets (book value). Leverage is total debt relative to asset (book value). Liquidity is cash holdings relative to total assets (book value). The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

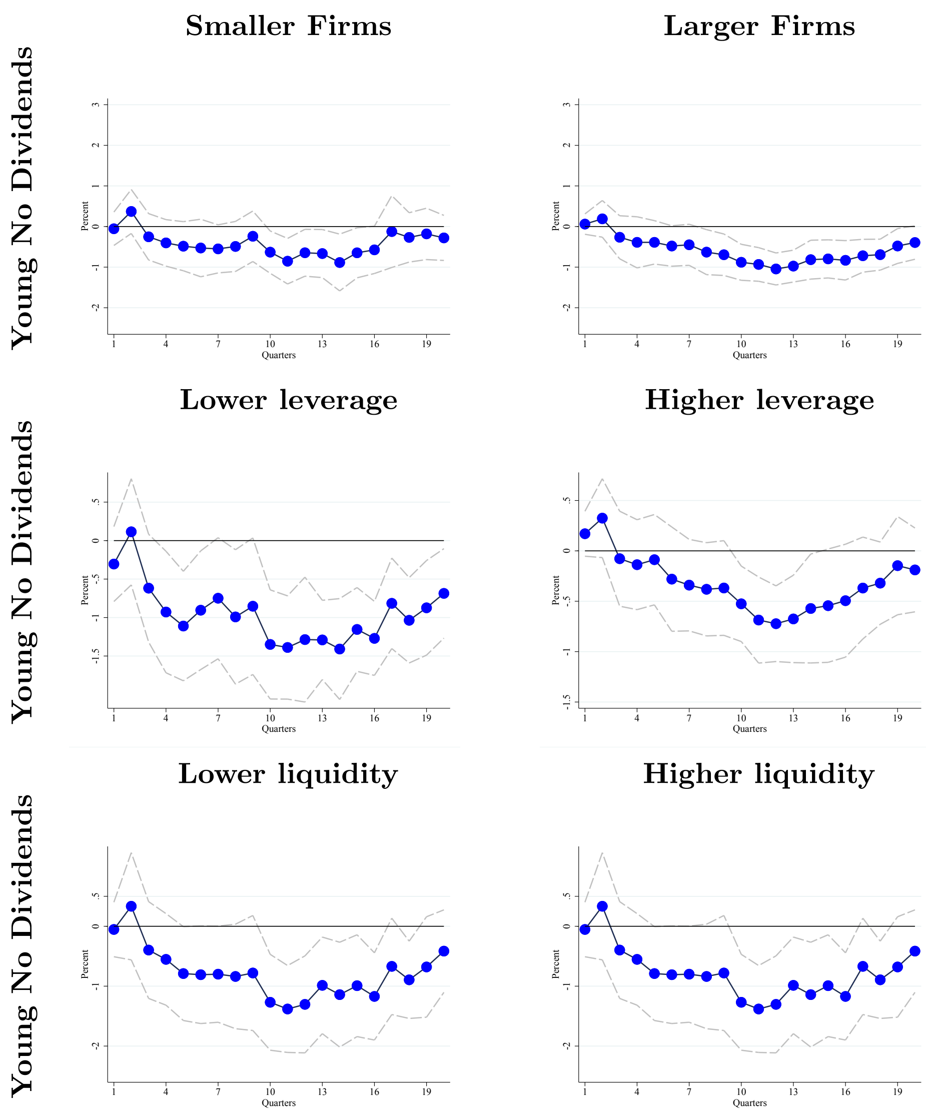
Figure E.2: **Response of Investment by Alpha, Tobins Q, Return Volatility and Beta**




Notes: This figure shows the IRFs for the investment rate following a 25bps increase in the one year interest rate. We run separate regressions for each row. In each row, the interest rate is interacted with three group dummies based on the distribution of each firm's characteristics in isolation. The lower group refers to the bottom quartile, the middle group refers to the middle two quartiles and the highest group refers to the top quartile. For Beta we split the sample into above and below 1. Alpha and Beta are estimated from standard CAPM type regressions. Volatility refers to the volatility of stock returns. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

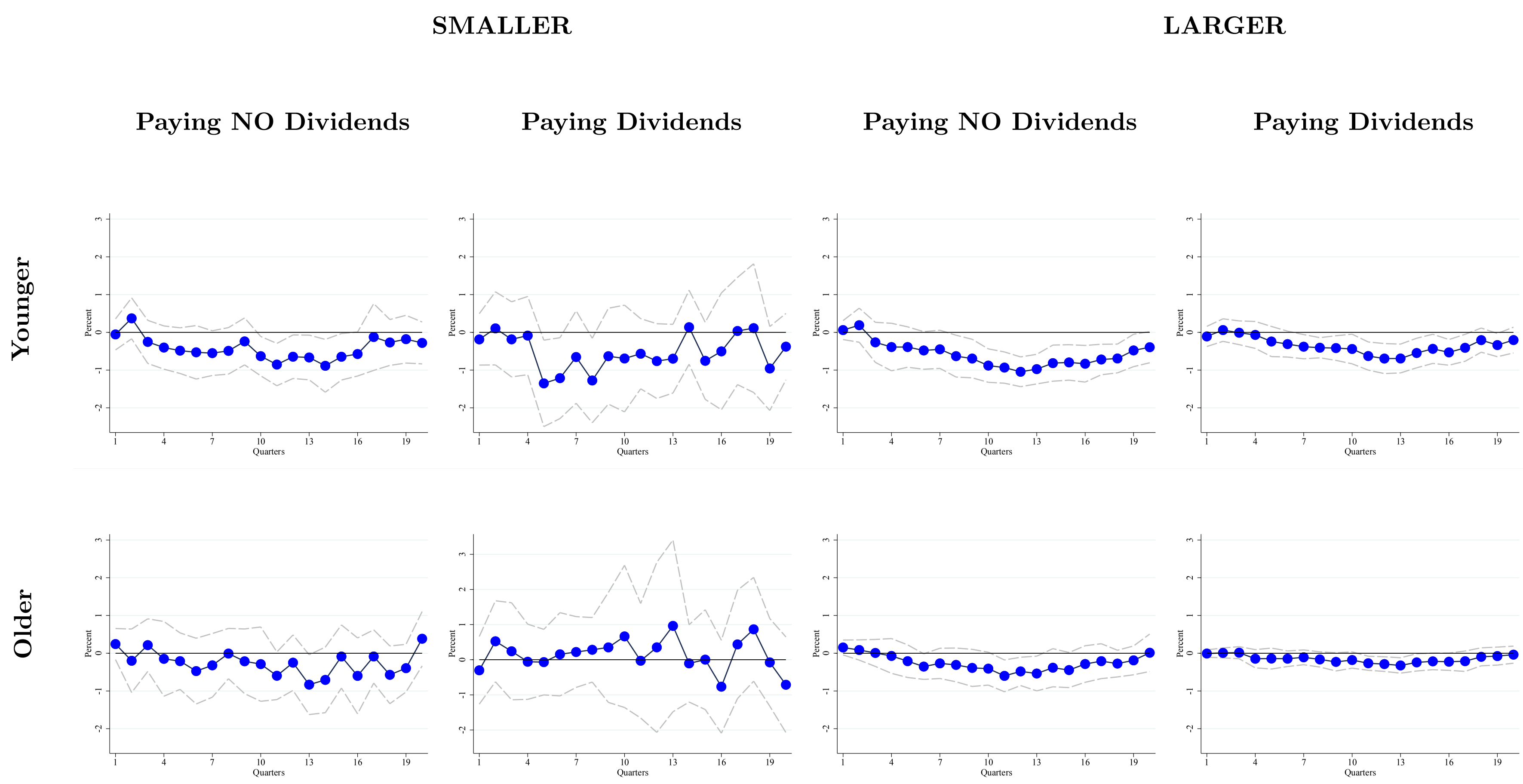
# F Other firm characteristics

Figure F.1: **Response of Investment by Size, Leverage and Liquidity: Controlling for Age and Dividend Status**



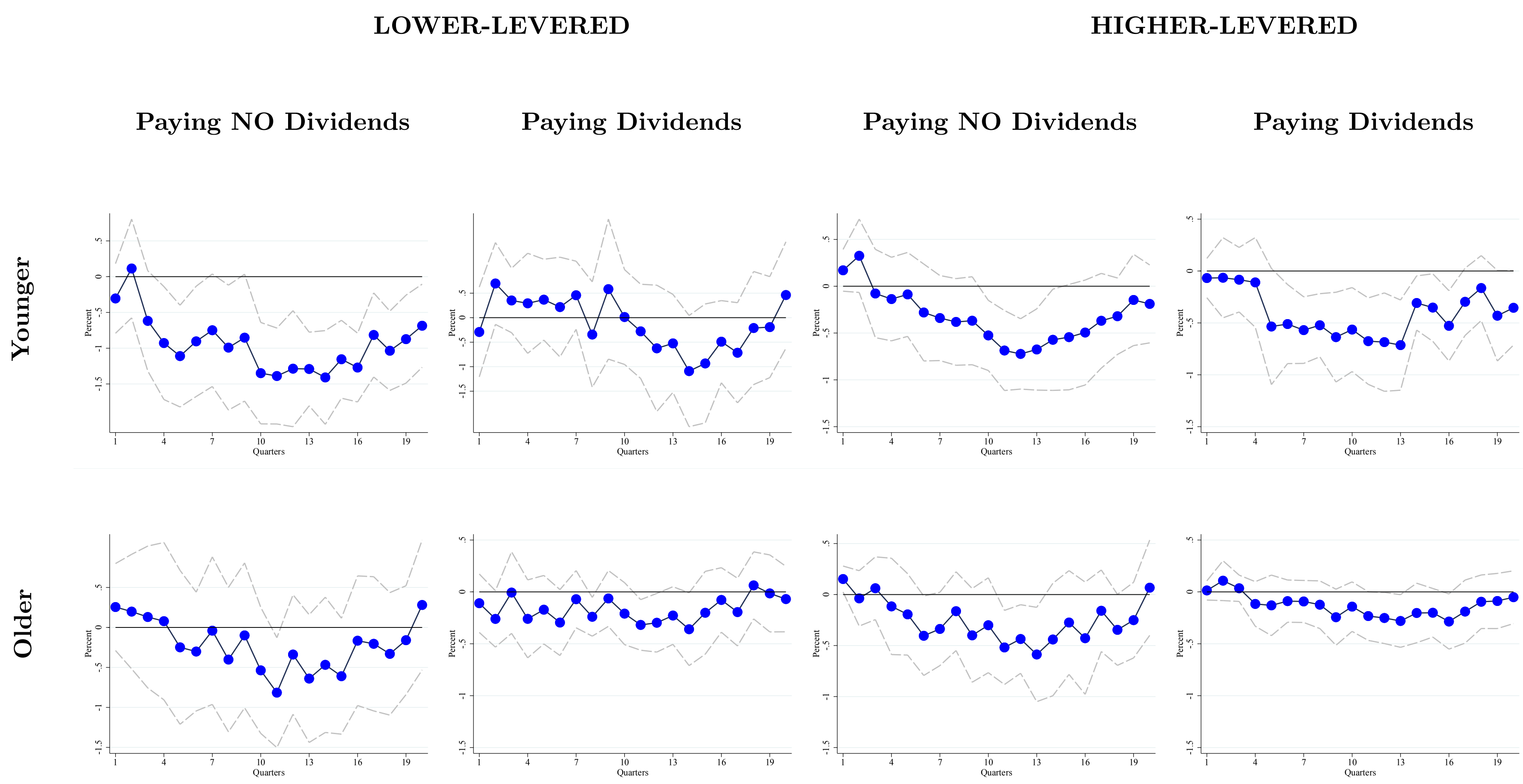

Notes: This figure shows the IRFs for the investment rate following a 25bps increase in the one year interest rate. We run separate regressions for each row. In each row, the interest rate is interacted with three sets of group dummies based on a firm's age, dividend status and their position in either the size, leverage or liquidity distribution. Younger means less than 15 years since incorporation. Size refers to total assets in the previous year. Leverage is total debt relative to assets in the previous year. Liquidity is cash relative to total assets in the previous year. For size, leverage and liquidity we display the results using the most responsive quartile vs the rest of the distribution when the data are cut using these variables alone (see Appendix E). Smaller and lower leverage refers to the bottom quartile of each distribution. Higher liquidity refers to the top quartile of the liquidity distribution. The relative effect column refers to separate specifications where the IRFs are estimated relative to older firms paying dividends. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

Figure F.2: **Firm Size: Response of Investment by Age, Dividends Paid and SIZE**



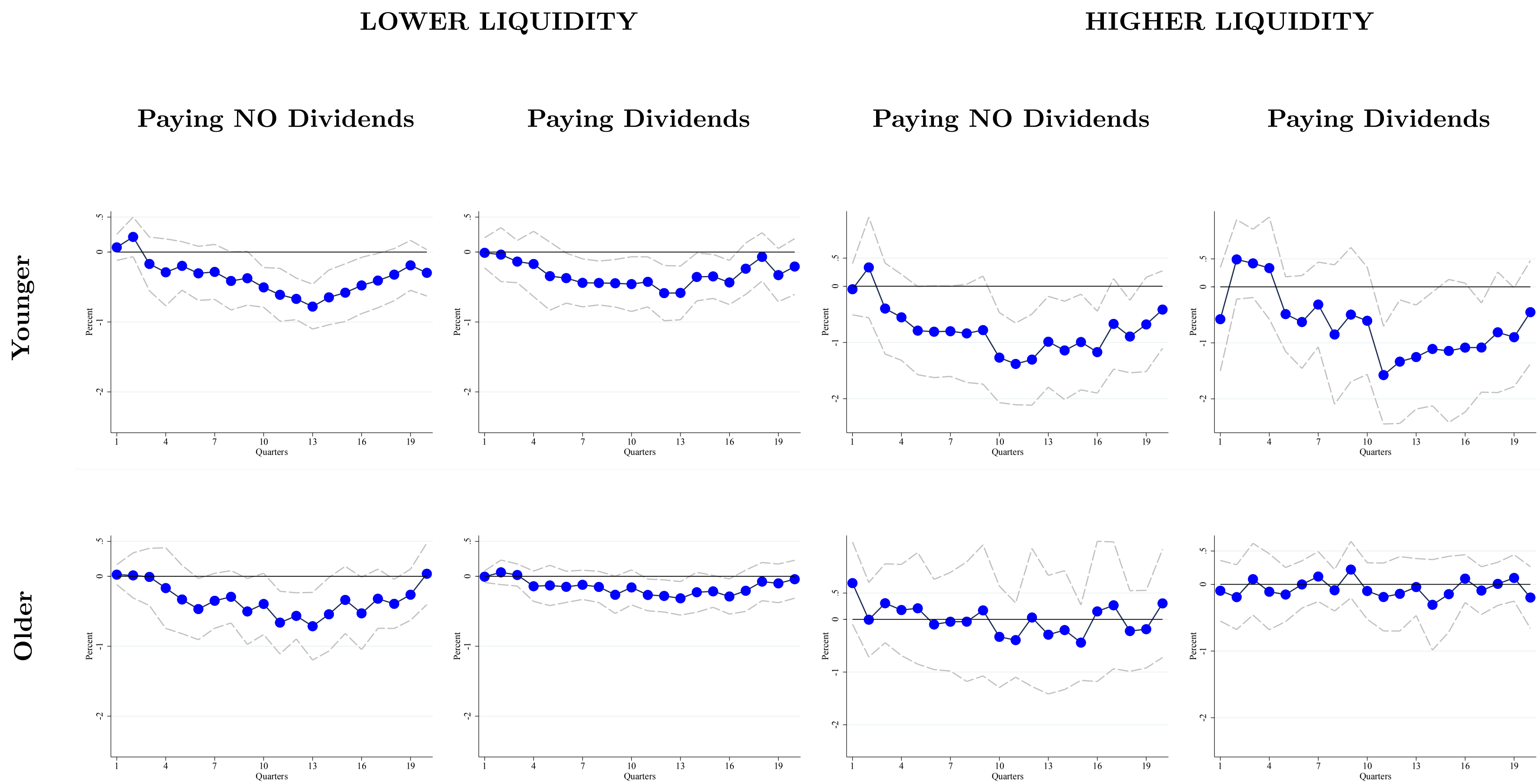

Notes: This figure shows the IRFs for the investment rate following a 25bps increase in the one year interest rate. The interest rate is interacted with binary indicators based on age, dividend status, size. Younger refers to $< 15$ and older refers to $> 15$ years since incorporation. No dividends means the firm did not pay cash dividends in the previous year. Smaller firms refer to those in the bottom quartile of the size distribution in the previous year. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

Figure F.3: **Leverage: Response of Investment by Age, Dividends Paid and LEVERAGE**



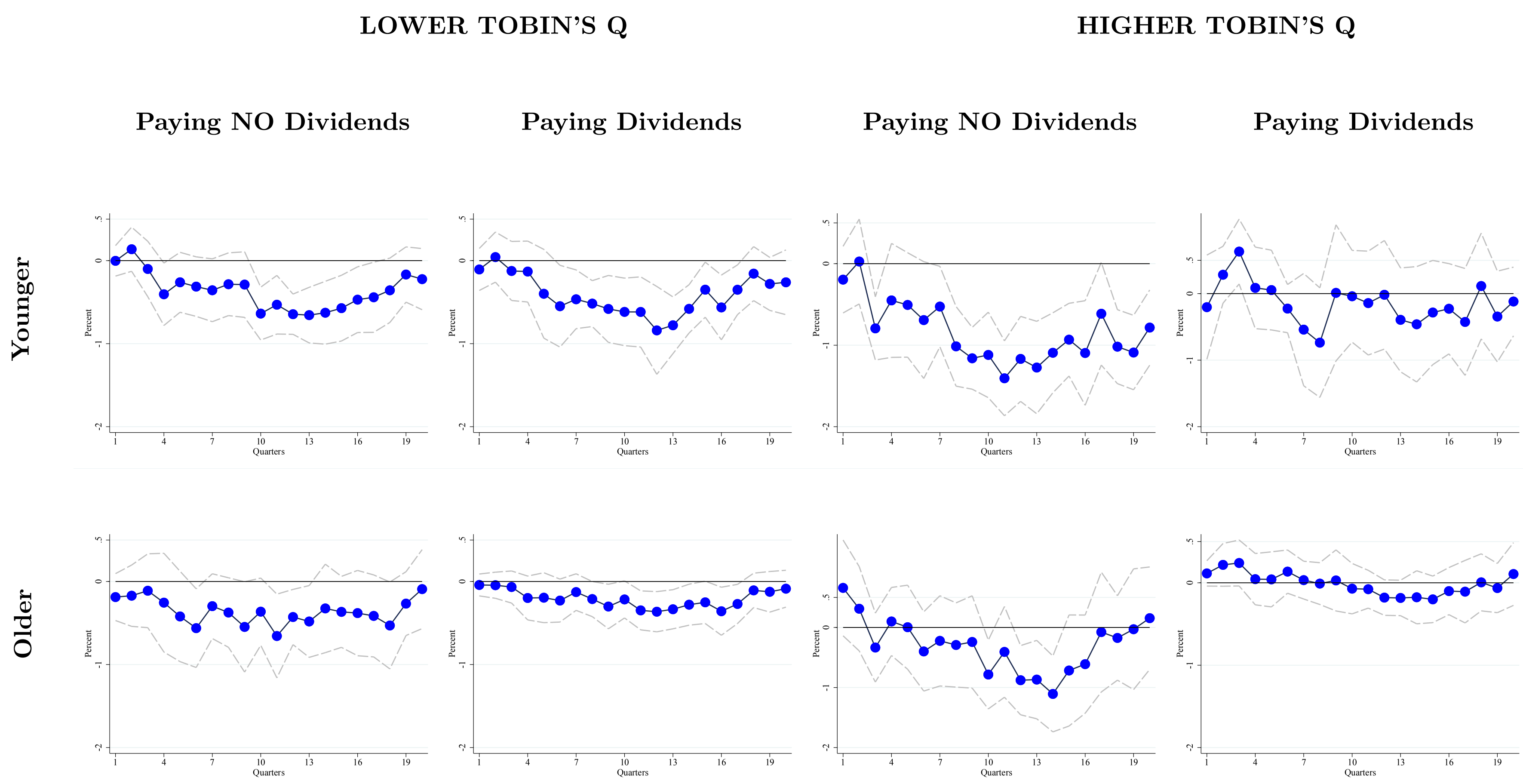

Notes: This figure shows the IRFs for the investment rate following a 25bps increase in the one year interest rate. The interest rate is interacted with binary indicators based on age, dividend status, leverage. Younger refers to $< 15$ and older refers to $> 15$ years since incorporation. No dividends means the firm did not pay cash dividends in the previous year. Lower leverage firms refer to those in the bottom quartile of the distribution in the previous year. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

Figure F.4: **Liquidity: Response of Investment by Age, Dividends Paid and LIQUIDITY**



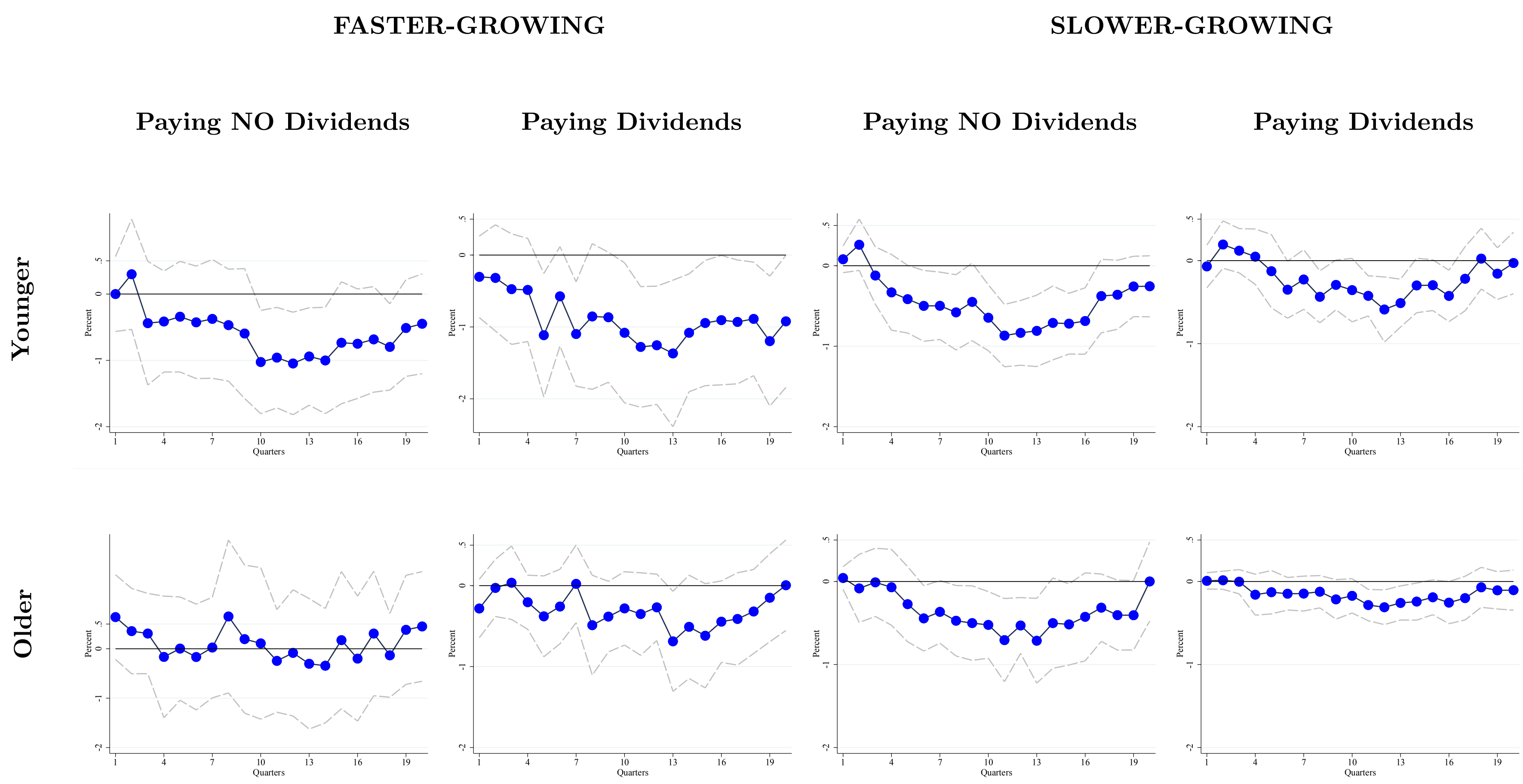

Notes: This figure shows the IRFs for the investment rate following a 25bps increase in the one year interest rate. The interest rate is interacted with binary indicators based on age, dividend status, the liquidity ratio. Younger refers to $<15$ and older refers to $>15$ years since incorporation. No dividends means the firm did not pay cash dividends in the previous year. Higher liquidity refers firms refer to those in the top quartile of the distribution in the previous year. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

Figure F.5: **Tobin's Q: Response of Investment by Age, Dividends Paid and TOBIN'S Q**




Notes: This figure shows the IRFs for the investment rate following a 25bps increase in the one year interest rate. The interest rate is interacted with binary indicators based on age, dividend status, Tobin's Q. Younger refers to $< 15$ and older refers to $> 15$ years since incorporation. No dividends means the firm did not pay cash dividends in the previous year. Higher Tobin's Q refers firms refer to those in the top quartile of the distribution in the previous year. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

Figure F.6: **Growth: Response of Investment by Age, Dividends Paid and ASSET GROWTH**




Notes: This figure shows the IRFs for the investment rate following a 25bps increase in the one year interest rates. The interest rate is interacted with binary indicators based on age, dividend status, asset growth. Younger refers to < 15 years since incorporation and older refers to > 15 years since incorporation. No dividends means the firm did not pay cash dividends in the previous year. Faster growing firms refer to those in the top quartile of the distribution in the previous year. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

# G Decomposing the aggregate investment response

The relationship between the growth rate of aggregate investment, $\Delta \log I_t$, and the average change in the firm level investment rate, $E\left(\Delta \frac{I_{j,t}}{k_{j,t}}\right)$, is non-trivial but we can make use of the following approximation. In continuous time, we can write

$$I_t \equiv \text{ agg. investment } = \sum_j I_{j,t} = \sum_j i_{j,t} \cdot k_{j,t} \tag{4}$$

where $i_{j,t} = \frac{I_{j,t}}{k_{j,t}}$ is firm$j$'s investment rate. Differentiating with respect to monetary policy, $r_t$, yields:

$$\frac{\partial I_t}{\partial r_t}\frac{\partial r_t}{\partial t} \equiv \frac{\partial I_t}{\partial r_t} \times mps_t = \left(\sum_j \frac{\partial i_{j,t}}{\partial r_t} k_{j,t} + \sum_j i_{j,t} \frac{\partial k_{j,t}}{\partial r_t}\right) \times mps_t \tag{5}$$

$mps_t$ denotes the exogenous interest rate adjustment triggered by the monetary policy shock. Assuming that the depreciation rate does not react to monetary policy shocks, note that $\frac{\frac{\partial k_{j,t}}{\partial r_t}}{k_{j,t}} \simeq \frac{\partial i_{j,t}}{\partial r_t}$. Denoting $\frac{\partial x_{j,t}}{\partial r_t} \equiv \dot{x}_{j,t}$ for any $x$, the growth rate of aggregate investment can be expressed as

$$\frac{\dot{I}_t}{I_t} \simeq \frac{1}{\frac{I_t}{K_t}} \sum_j \omega^k_{j,t} \dot{i}^{net}_{j,t} + \sum_j \omega^I_{j,t} \dot{i}^{net}_{j,t} \tag{6}$$

where $\omega^k_{j,t} \equiv \frac{k_{j,t}}{K_t}$ and $\omega^I_{j,t} \equiv \frac{I_{j,t}}{I_t}$ are the capital and investment shares, respectively, for firm group $j$. Note that $\dot{i}^{net}_{j,t} \equiv \frac{\partial (i_{j,t} - \delta)}{\partial r_t}$ is what we measure in the firm-level regressions.

# H The Ottonello and Winberry (2020)-Jeenas (2018) controversy

Two recent, independently developed, empirical studies by Ottonello and Winberry (2020) and Jeenas (2018) look at the investment response of U.S. public firms to monetary policy. Both analyses use Compustat, employ local projections and assume that the high-frequency identified surprises from short-term interest rate contracts (in 30 minute windows around policy announcements) are the actual shock series.[37]

These two studies also share the emphasis on leverage as a possible proxy for financial constraints but differ dramatically in their empirical findings when grouping firms according to their leverage position. On the one hand, Ottonello and Winberry (2020) find that the investment of low-levered firms responds significantly more than the investment of high-levered firms and that the peak effects occur within six months after the shock. In contrast, Jeenas (2018) reports a significantly higher sensitivity of investment to monetary policy for more levered firms, with the peak effect occurring after two years. Given the contrasting set of results, both papers go into great detail to explain the puzzle and conclude that a key differences is that Ottonello and Winberry (2020) group firms according to their leverage in the *previous quarter* while Jeenas (2018) splits the sample using leverage in the *previous year*.

In line with the discussion in Section 2 about the selection and endogeneity issues associated with traditional proxies of financial constraints, this seems yet another example of the fragility of the estimates based on grouping firms by leverage. Further evidence corroborating this lack of robustness can be found in Figure B.5 of Appendix B3 of Jeenas (2018). In the left column of that figure, the paper further splits the high-levered group (which is the most responsive group in his sample along the leverage dimension) into younger/high-levered and older/high-levered firms whereas the right column further splits the low-liquidity group (which is the most responsive group in his sample along the liquidity dimension) into younger/less-liquid and older/less-liquid businesses. Despite the less accurate estimates due to the further sample splits, both exercises reveal that the investment responses of older/high-levered companies and older/less-liquid firms are always statistically indistinguishable from zero. In contrast, the investment adjustments for the younger/high-levered and younger/less-liquid groups are strongly significant and typically much larger than their older counterparts, revealing that younger firms drive the higher responsiveness of both the high-levered and the low-liquidity groups.

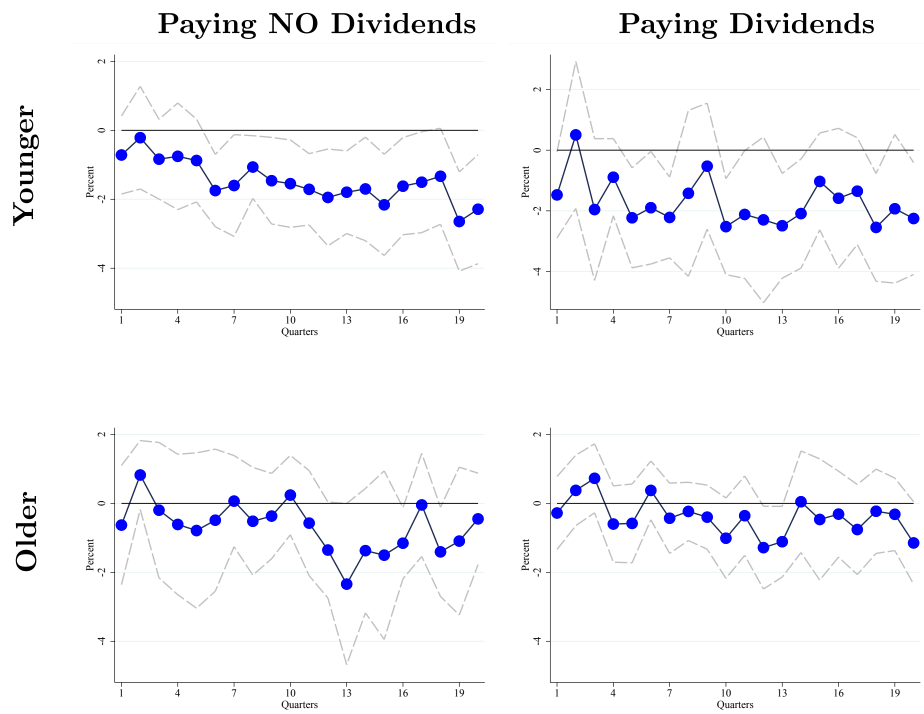
Ottonello and Winberry (2020) do not examine how their results would change by further splitting either the low-levered group or those further from default into younger and older firms. In Figure 16 of their Appendix A.4.2, dummies are added for each of our age groups as well as interaction terms between their monetary surprises and the age group dummies. But, as discussed in Section 2.2, this does not fully control for whether the younger/no dividend firms might be driving the results in the low leverage/high distance from default group. To do that in the context of their empirical linear (in-the-parameter) model, the paper would need to have added a *triple interaction*

[37] Unlike the empirical macro literature that use these policy surprises as external instrument to identify a series of monetary policy shocks and then compute the impulse responses to the identified shocks, Jeenas (2018) and Ottonello and Winberry (2020) report the firm-level investment response to changes in the (policy surprise) instrument itself.

term between (i) leverage/distance from default, (ii) monetary surprises and, most importantly, (iii) age. In Figure F.3 of Appendix F of this paper, we conduct this robustness check in the context of our more flexible, semi-parametric empirical specification, which allows us to split the low-levered group into younger/low-levered and older/low-levered firms. Figure F.3 shows that only the former set of firms adjust investment significantly after a monetary policy shock. Younger firms therefore seem to drive the response of the low-levered group and, once we appropriately controlling for age, leverage seems to lose much of its statistical power to predict sharp heterogeneity across firms.

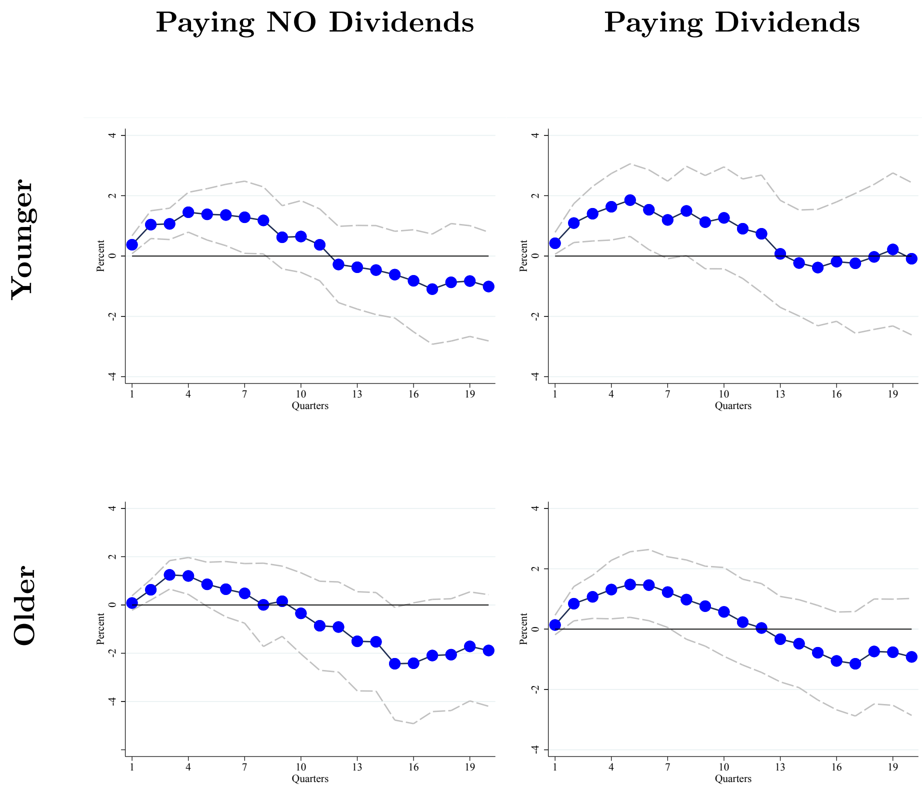
# I Firm Finance: full results

Figure I.1: **Response of Borrowing by Age and Dividend Status**



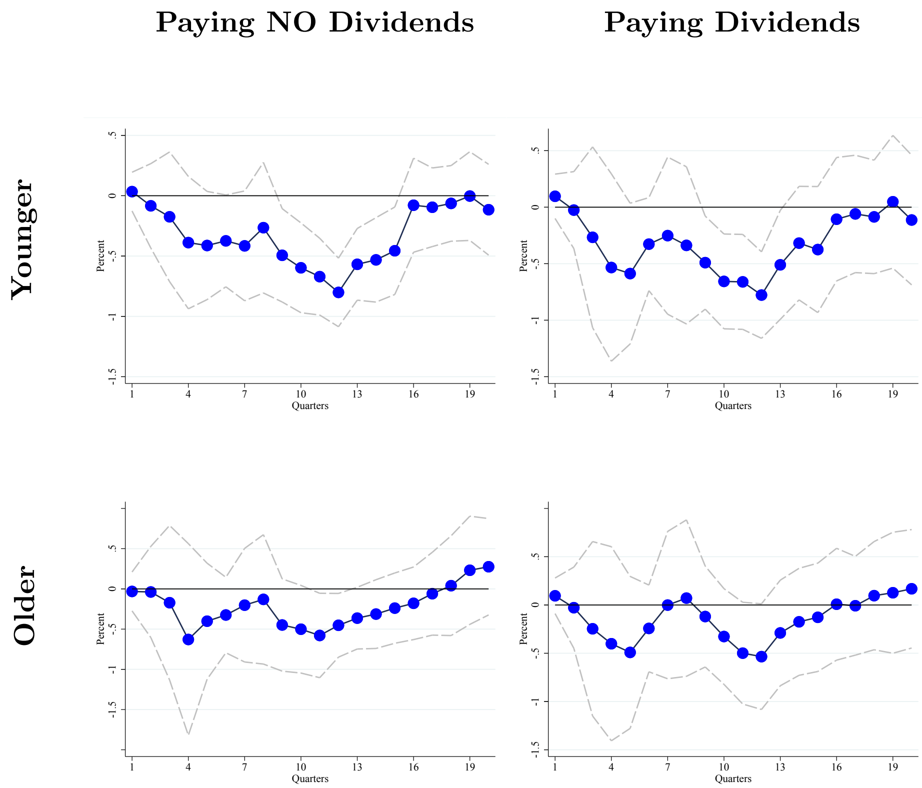

Notes: This figure shows the IRFs for the response of real total debt growth (annualized) following a 25bps increase in the one year interest rate. The interest rate is interacted with binary indicators based on age and dividend status. Younger refers to $<$ 15 years since incorporation and older refers to $>$ 15 years since incorporation. No dividends means the firm did not pay cash dividends in the previous year. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

Figure I.2: **Response of Nominal Interest Payments**



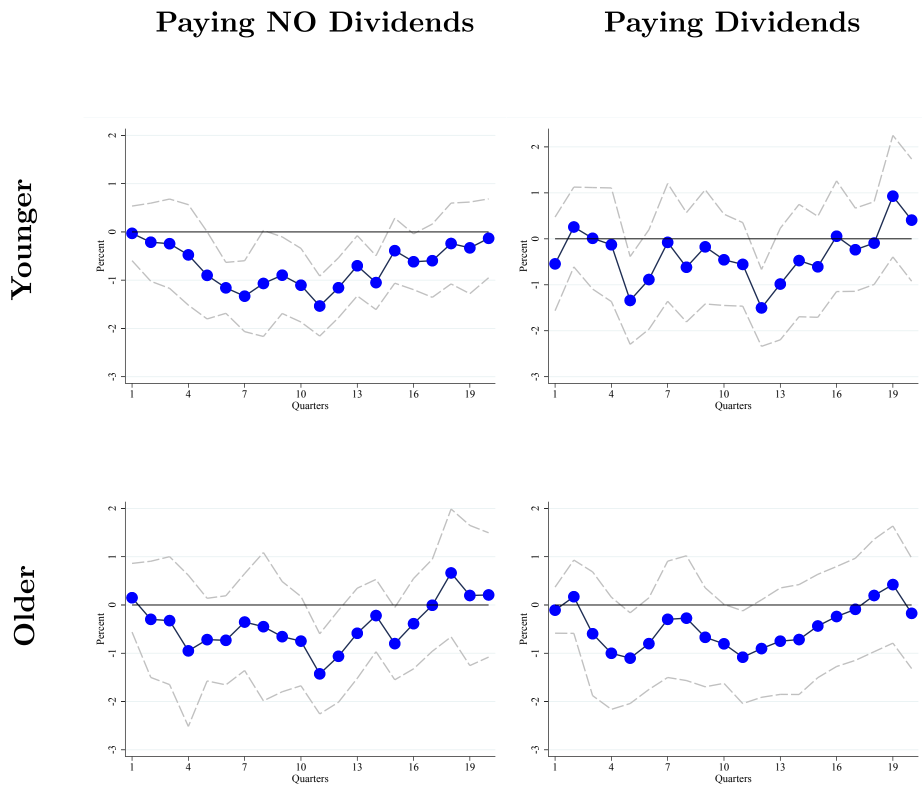

Notes: This figure shows the IRFs for the response of log interest expenditures ($\times 100$) following a 25bps increase in the one year interest rate. The interest rate is interacted with binary indicators based on age and dividend status. Younger refers to $< 15$ years since incorporation and older refers to $> 15$ years since incorporation. No dividends means the firm did not pay cash dividends in the previous year. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

Figure I.3: **Response of Real Sales Growth**




Notes: This figure shows the impulse response functions for the response of real sales growth (year on year growth) following a 25bps increase in the one year interest rate. The interest rate is interacted with binary indicators based on age and dividend status. Younger refers to $<$ 15 years since incorporation and older refers to $>$ 15 years since incorporation. No dividends means the firm did not pay cash dividends in the previous year. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

Figure I.4: **Response of Earnings Growth (EBITDA)**

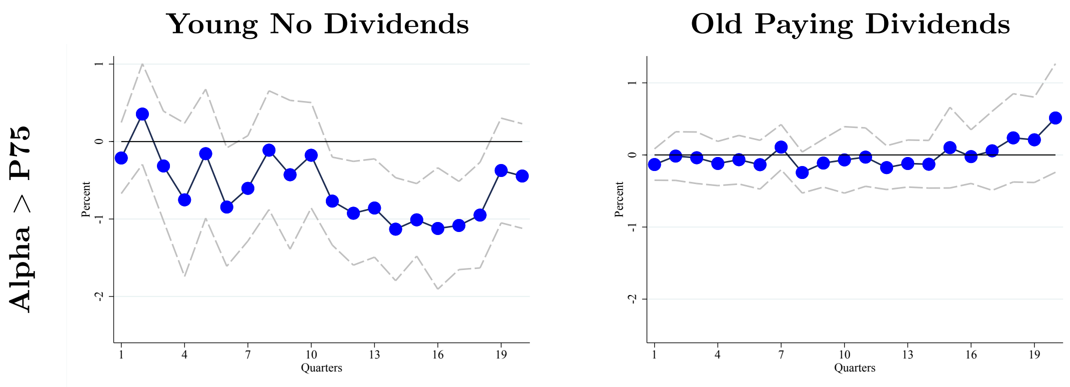



Notes: This figure shows the impulse response functions for the response of real EBITDA (year on year growth) following a 25bps increase in the one year interest rate. The interest rate is interacted with binary indicators based on age and dividend status. Younger refers to $<$ 15 years since incorporation and older refers to $>$ 15 years since incorporation. No dividends means the firm did not pay cash dividends in the previous year. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

# J Controlling for Alpha, Beta and Volatility

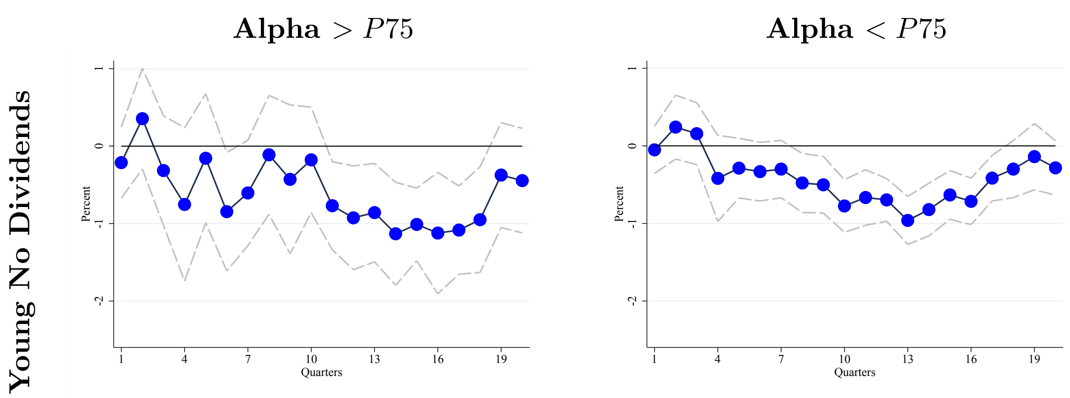
## J.1 Effects by age, dividend status and Alpha

Figure J.1: **Response of Investment Controlling for Alpha**




Notes: This figure shows the IRFs for the investment rate following a 25bps increase in the one year interest rate. The interest rate is interacted with binary indicators based of age, dividend status and quartiles of the Alpha distribution. The panels condition on high Alpha (top quartile). The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

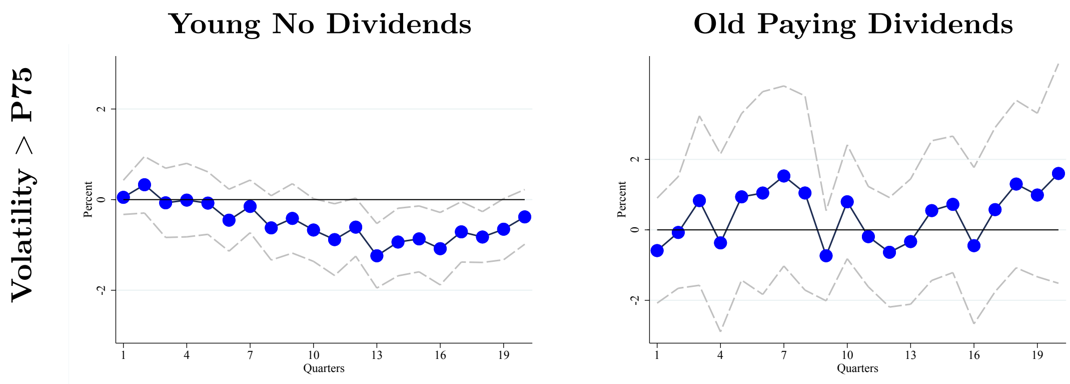
Figure J.2: **Response of Investment Controlling for Young No Dividends**




Notes: This figure shows the IRFs for the investment rate following a 25bps increase in the one year interest rate. The interest rate is interacted with binary indicators based of age, dividend status and quartiles of the Alpha distribution. The figure presents results conditional on being a young firm paying no dividends. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

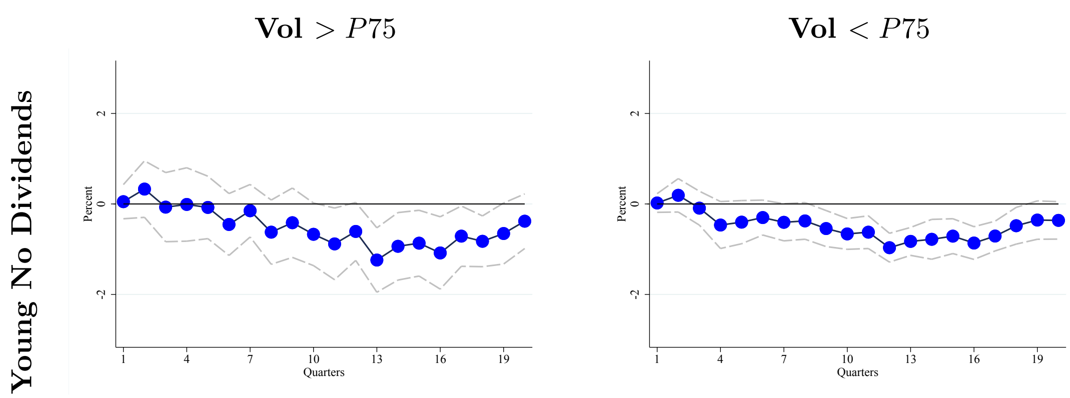
## J.2 Effects by age, dividend status and Volatility

Figure J.3: **Response of Investment Controlling for Volatility**




Notes: This figure shows the IRFs for the investment rate following a 25bps increase in the one year interest rate. The interest rate is interacted with binary indicators based of age, dividend status and quartiles of the volatility distribution. These panels condition on high volatility (top quartile) The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

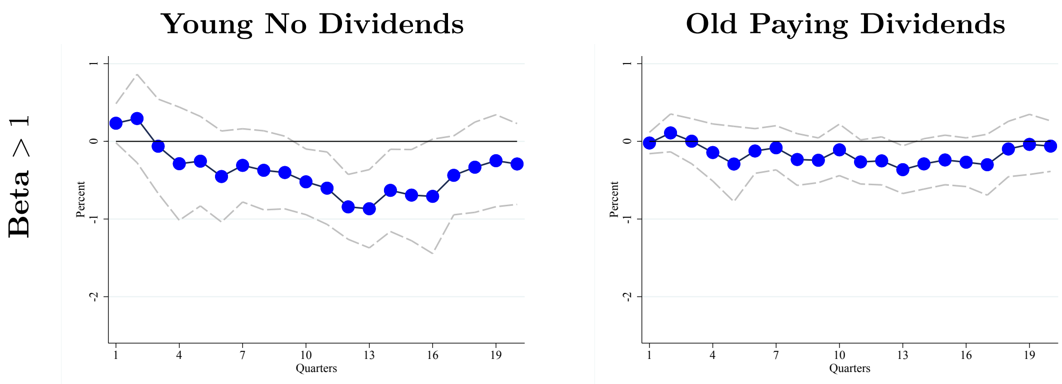
Figure J.4: **Response of Investment Controlling for Young No Dividends**




Notes: This figure shows the IRFs for the investment rate following a 25bps increase in the one year interest rates. The interest rate is interacted with binary indicators based of age, dividend status and quartiles the volatility distribution. The results are show conditional on being a young firm paying no dividends. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

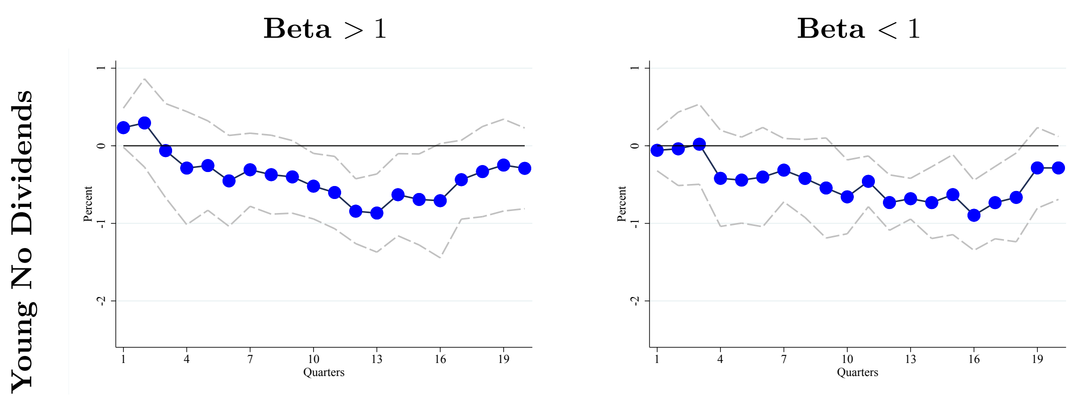
## J.3 Effects by age, dividend status and Beta

Figure J.5: **Response of Investment Controlling for Beta**




Notes: This figure shows the IRFs for the investment rate following a 25bps increase in the one year interest rate. The interest rate is interacted with binary indicators based on age, dividend status and whether Beta is above or below 1. The panels shows the results conditioning on a Beta larger than 1. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

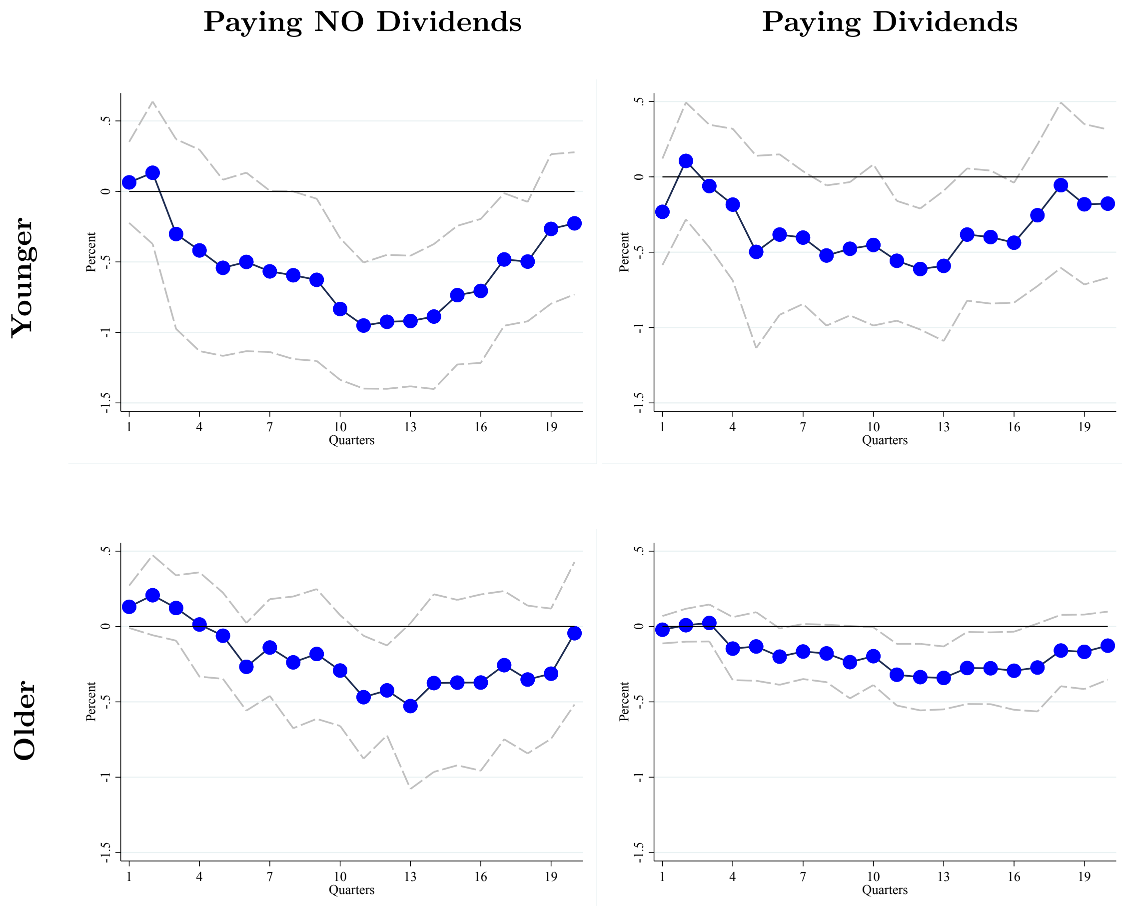
Figure J.6: **Response of Investment Controlling for Young No Dividends**




Notes: This figure shows the IRFs for the investment rate following a 25bps increase in the one year interest rate. The interest rate is interacted with binary indicators based on age, dividend status and whether Beta is above or below 1. The results are show conditional on being a young firm paying no dividends. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

# K Results by Cohort and Dividend Status

Figure K.1: **Response of Investment by Cohort and Dividend Status**

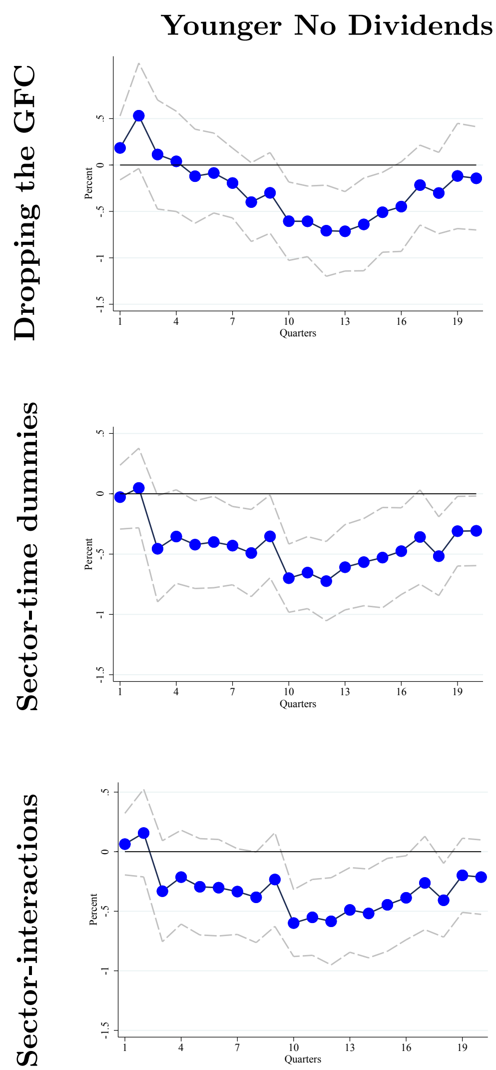



Notes: This figure shows the impulse response functions for the investment rate following a 25bps increase in the one year interest rate. The interest rate is interacted with binary indicators based on cohort and dividend status. Younger refers to firms incorporated after 1977 years since incorporation and older refers to firms incorporated before 1977. No dividends means the firm did not pay cash dividends in the previous year. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

# L Sensitivity Analysis

## L.1 Sub-samples and sectors

Figure L.1: **Excluding post-2007 and Controlling for Sectoral Effects**




Notes: This figure shows the IRFs for the investment rate following a 25bps increase in the one year interest rate. The first panel reports the effects for young non-dividend paying firms excluding the post-2007 period. The second row reports the response of younger non-dividend paying firms relative to old firms paying dividends including 2 digit sector-time fixed effects. The third row reports the response of younger non-dividend paying firms relative to old firms paying dividends controlling for 1 digit sector dummies interacted with the monetary policy shock. The IRFs are estimated using the local projection IV approach described in the text. Dotted lines are 90% standard error bands. Standard errors are computed using the Driscoll-Kraay method, clustering by firm and time, which is robust to very general forms of cross-sectional and temporal dependence.

# M Theoretical Framework

To illustrate the interaction of firm age, financial frictions and the channel we highlight in the data, this section presents a stylized financial accelerator model featuring a collateral constraint and where firms differ in their optimal scale. Heterogeneity in optimal scale is generated by heterogeneity in permanent TFP; in fact, in the model, there is a one-to-one map between distance to optimal scale and firm age. To fix ideas and keep the model as stylized as possible, we focus on the firm-side using a partial equilibrium set-up. We assume that the monetary authority controls the real interest rate.

## M.1 Basic set-up

Time is discrete and each firm, $i$, operates a decreasing-returns-to-scale (DRS) technology, which implies that there is an optimal scale conditional on a firm's idiosyncratic productivity:

$$y_{i,t} = z_i k_{i,t}^{\alpha} \quad , 0 < \alpha < 1 \tag{7}$$

where $y_{i,t}$ is output produced in period t, and $k_{i,t}$ is capital at the beginning of the period. We assume that the firms are heterogeneous in their level of TFP which, for simplicity in the example below, can be either Low or High: $z_{i,t} = z_i \in \{z_L, z_H\}$. Each firm makes decisions about production, capital, investment and financing, subject to both real and financial frictions: (i) investment adjustment costs and (ii) a borrowing constraint related to collateral (a fraction of the capital stock) and costs of issuing external equity.

The capital of the firm accumulates according to

$$k_{i,t+1} = (1 - \delta) k_{i,t} + I_{i,t} \tag{8}$$

where $I_{i,t}$ is gross investment, and $\delta$ is the depreciation rate. Firms face capital adjustment costs $AC(I, k)$ of the form

$$AC\left(I, k\right) = \frac{\theta_k}{2} \left( \frac{I_{i,t}}{k_{i,t}} - \delta \right)^2 k_{i,t} \tag{9}$$

Each firm is characterized by its idiosyncratic productivity $z$, its capital $k$ and debt (or savings) $b$. Denote the idiosyncratic state as $\boldsymbol{x} = (z, k, b)$.

## M.2 Financing and interest rates

Firms can finance their operations either using internal funds (savings) or by borrowing at an interest rate $r_t$. Firms cannot issuing external equity (i.e. we assume equity financing is infinitely costly), and we assume no costs of equity payout (i.e. dividends). Borrowing is subject to a standard collateral constraint of the form

$$b_{i,t+1} \leq m \times p_{c,t} k_{i,t+1} \tag{10}$$

where $m$ is maximum leverage, and $p_c$ is the collateral price of capital.[38]

In the exercise below, we assume that the only uncertainty comes from an exogenous processes for the real interest rate $r_t$, which is set by the monetary authority.[39]

$$r_{t+1} = \bar{r}(1 - \rho_r) + \rho_r r_t + \sigma_r \epsilon_{r,t+1} \tag{11}$$

where $\bar{r}$ is the unconditional mean for the real interest rate, $\rho_r$ is the auto-correlation coefficient, $\epsilon_{r,t+1} \sim \mathcal{N}(0,1)$. Since this is a partial equilibrium model there is no endogenous link between the real interest rate and the price of capital. To allow for an indirect effect via collateral values we allow the collateral price of capital $p_{c,t}$ to moves with the real interest rates.[40]

$$\log(p_{c,t}) = \log(\bar{p}_c) + \eta_{c,r}(r_t - \bar{r}) \tag{12}$$

where $\eta_{c,r}$ is the semi-elasticity of the collateral price of capital with respect to the interest rate.[41]

### M.3 Value of the firm

Dropping the time sub-index and denoting current and future values of a variable as $x, x'$ respectively, we can write the firm's problem recursively.

First note that equity payouts (i.e. dividends) are determined by the balance sheet constraint

$$d = y - I - AC(I,k) - \mathcal{T}(\tau,k) + \frac{1}{1 + r(1-\tau)} b' - b \tag{13}$$

where $\mathcal{T}(\tau,k) = \tau(y - \delta k)$ are corporate taxes paid. Note that, as is common in the firm dynamics literature, debt has a tax advantage over retained earnings.

An incumbent firm decides on investment and financing in order to maximize the present discounted value of equity payout:

$$\begin{aligned} V(k,b,r;z) \quad &= \quad \max_{I,b',d} \left\{ d + \frac{1}{1+r} E_{r'|r}\Big(V(k',b',r';z)\Big) \right\} \qquad (14) \\ s.t. \quad & \quad (8),\ (10),\ (11),\ (12),\ (13) \\ \text{and} \quad & \quad d \geq 0 \end{aligned}$$

Denote with $\lambda^k$, $\lambda^{BC}$, and $\lambda^d$ the lagrange multipliers on the capital accumulation equation (8), the borrowing constraint (10) and the non-negativity constraint on $d$. Then the optimality

[38] In principle, we allow it to be different from 1, which will allow us to talk about changes in the relative price of capital, either through *external* adjustment costs or general equilibrium effects not directly modelled here.

[39] Another way of thinking about this assumption is that monetary policy controls the nominal risk free rate but the aggregate price level is completely fixed.

[40] The purpose is simply to capture potential asset price feedback. This could be fully micro-founded in a standard general equilibrium but this would greatly complicate the model and the solution algorithm, as well as make the key mechanism less clear.

[41] In other words, when the interest rate changes by 1 *percentage point*, the price of capital changes $\eta_{k,r}$%.

conditions for the incumbent's problem are

$$\left(1+\lambda^{d}\right) AC_{I} = \lambda^{k} \tag{15}$$

$$\lambda^{BC} = \frac{1}{1+r(1-\tau)}\left(1+\lambda^{d}\right)+\frac{1}{1+r}E_{r'}\left(V_{b'}\right) \tag{16}$$

$$\lambda^{BC}\left(b'-mp_{c}k'\right) = 0 \tag{17}$$

$$\lambda^{d}d = 0 \tag{18}$$

where (17) and (18) are the complementary-slackness conditions. Optimality also requires a and a transversality condition (TVC) on the value of an extra unit of capital.

Note that $\lambda^k$ is the shadow value of an extra unit of capital, or the value for the firm of an extra unit of capital installed between the current and next period. An expression for this can be obtained by maximizing (14) w.r.t. $k'$. Using the Envelope conditions, iterating forward and imposing a transversality condition we can write

$$\begin{aligned}\left(1+\lambda_{t}^{d}\right) AC_{I,t} &= \lambda_{t}^{BC}mp_{c,t}+\\ &+ E_{t}\left\{\sum_{s=1}^{\infty}(1+r_{t+s-1})^{-s}\left[\left(1+\lambda_{t+s}^{d}\right)(1-\delta)^{s-1}\times\right.\right.\\ &\times \left.\left.\left((1-\tau)MPK_{t+s}+\tau\delta-AC_{k,t+s}\right)+(1-\delta)^{s}\lambda_{t+s}^{BC}mp_{k,t+s}\right]\right\}\end{aligned} \tag{19}$$

A firm will invest until the marginal cost of an additional investment unit (LHS), equals the present value of future benefits derived from the un-depreciated extra unit of capital (RHS). The latter includes the future increase in production, the tax rebates, the decrease in adjustment costs, as well as the relaxation of current and future borrowing constraints. This is the main component of *marginal Tobin's Q* in this environment. For a given capital level today, heterogeneity in Tobin's Q (and therefore in investment rates) will arise from the combination of two sources: (i) persistent idiosyncratic productivity, which affects the expected value of future $MPK$, and (ii) financial frictions, captured by the probability of future borrowing constraints will bind.

Note that the optimal scale $k^*$ of a firm will be determined by

$$MPK^{*} = \frac{1}{1-\tau}\left[AC_{I^{*}}(r+\delta)+AC_{k^{*}}-\tau\delta-mp_{c}(1+r)\frac{\lambda^{BC}}{1+\lambda^{d}}\right] \tag{20}$$

$$\frac{\tau r}{1+r(1-\tau)} = (1+r)\frac{\lambda^{BC}}{1+\lambda^{d}} \tag{21}$$

Eqs. (20) and (21) jointly determine the efficient level of capital (from the point of view of an individual firm). Importantly, given the permanent heterogeneity in productivity, firms will have different optimal scales.[42]

[42] In the special case where $\tau=0$ (no taxes) and $AC=0$, then the optimal level of capital is determined by the standard efficiency condition $MPK\left(k_{\tau=0}^{*}\right)=r+\delta$, the firm is indifferent between using internal and external (borrowing) funds, and therefore $\lambda_{ss}^{BC}=0$. When $\tau>0$, however, the borrowing constraint will bind in the case of

## M.4 Heterogeneity in the response to monetary policy

We now conduct the following simple exercise to highlight the relationship between age, financial friction and the effects of monetary policy. The exercise considers two firms who differ in their optimal scale. We will then examine how these firms respond to an increase in interest rates depending on how far these firms are from their optimal scale. As noted above, we regard distance from optimal scale as a measure of firm age in the model.

Figure M.1 plots the impulse response functions for capital and debt.[43] We consider two scenarios following a 25bps increase in the real interest rate. In Column 1 firms start with the same *absolute* level of the capital stock $k_0$, which we set at 60% of the optimal scale of the low-productivity firm ($k^*_L$). The firm in the blue line is therefore closer to their optimal scale (old) and the firm in the red line is further from their optimal scale (young). The "younger" firm would like to grow considerably but is constrained by the collateral constraint. When interest rates increase, the younger firm responds considerably more than the "older" firm. Note, both firms are both "small" but age/distance from optimal scale interacts with the financial frictions. In Column 2 we show that this sensitivity is not driven by higher productivity firm always being more responsive. Column 2 initializes each firm at the *same* distance from their *own* optimal scale. The firm in blue is now smaller in absolute size. The firm is red is still more productive. When both firms are closer to their own optimal scale, borrowing constraints are less severe for both firms and the responses are similar. Furthermore, when we vary the feedback from interest rates to collateral prices, captured by the parameter $\eta_{c,r}$ in the collateral price equation (12), the financial accelerator effect becomes larger, but only for the "younger" firms in red in Column 1.[44]

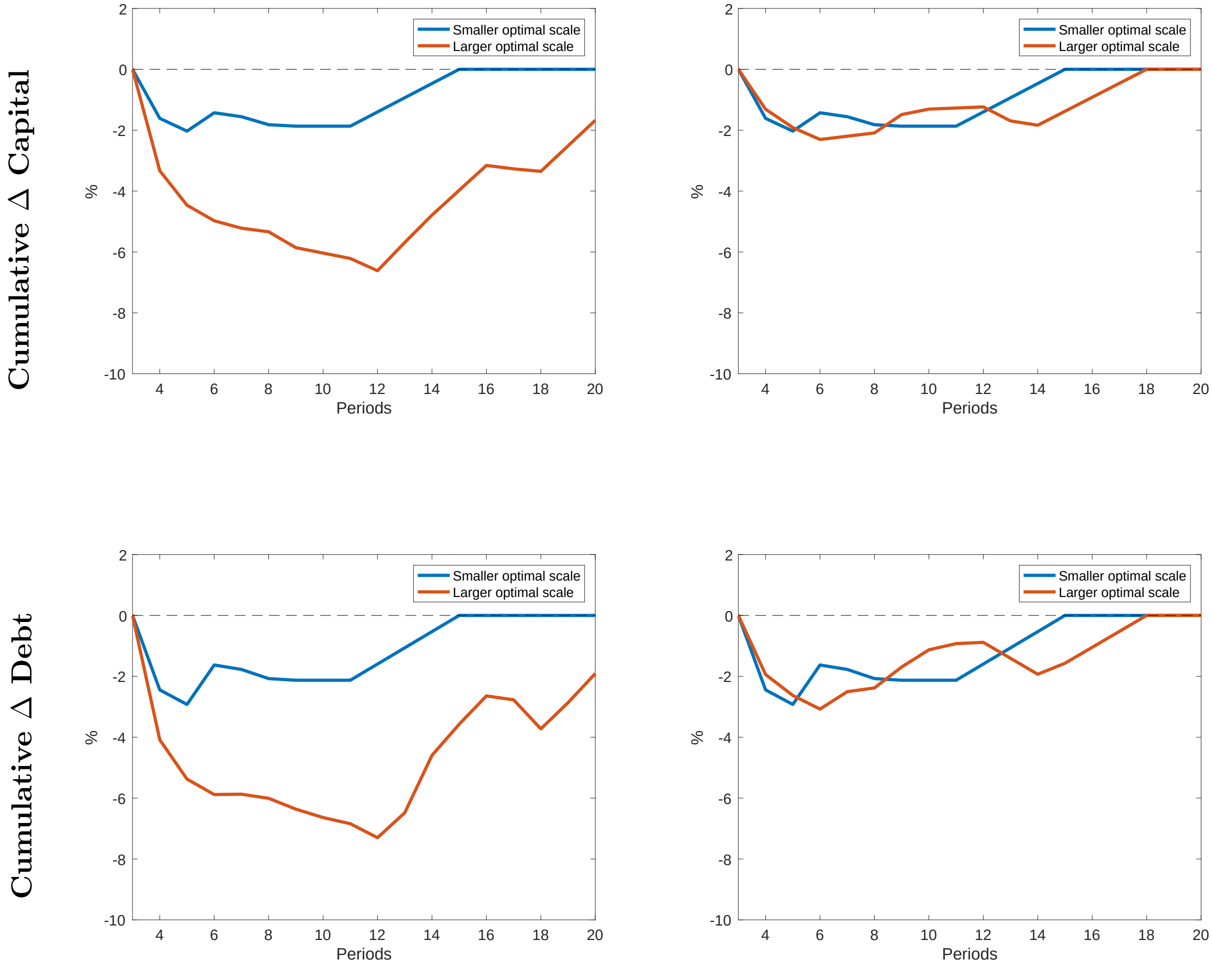
no uncertainty, and the optimal level of capital will satisfy $k^*_{\tau>0} < k^*_{\tau=0}$.

[43]This is a highly non-linear model. Impulse response functions are computed as follows. Denote with $\mathcal{F}_{i,t-1}$ the information set and characteristics of firm $i$ at period $t-1$ before the shock. Then, the fully non-linear model-implied IRF of variable $X_{i,t}$ to a $\Delta$ bp interest rate shock at horizon $h$ is then defined as $IRF_h(X) = E_t\left(X_{i,t+h}\middle|\epsilon_{r,t} = \Delta, \mathcal{F}_{i,t-1}\right) - E_t\left(X_{i,t+h}\middle|\epsilon_{r,t} = 0, \mathcal{F}_{i,t-1}\right)$ where the expectation is taken with respect to the distribution of future interest rates and collateral prices, given that there is no other source of uncertainty. Note that the interest rate shock at period $t$ implies an interest rate path for $t+1$, $t+2$,...,$t+h$ given by the process (11) and a collateral price path given by the process (12). The first term in the RHS is the average of the life-cycle paths under the simulated shock, while the second term is the average of the benchmark life-cycle paths *without* a shock.

[44]For the remaining model parameters, we use calibrated values informed by the literature and our results in the main part of the paper. The curvature of the production function is set to $\alpha = 0.65$. The permanent productivity can take two values $z_L, z_H$; these are calibrated in such a way that the optimal scale of the firm with $z_H$ is approximately double that of the firm with $z_L$. Capital and dividend adjustment costs parameters are set to $\theta_k = 0.3$, which implies small costs. The depreciation rate is set to $\delta = 0.025$. The corporate tax rate is set to $\tau_c = 21\%$, while the maximum leverage $\frac{b'}{/p_c k'}$ is $m = 0.8$. The parameters in (11)-(12) are $\bar{r} = r_{ss} = 2\%$, $\rho_r = 0.7$, $\sigma_r = 0.002$; we normalize $\bar{p}_c = 1$, and set the semi-elasticity $\eta_{c,r} = -4$, similar to estimates from the data.

Figure M.1: **Response of Capital and Debt to an Interest Rate Increase**

| **Same absolute size/level of initial capital:** $k_{0,L} = k_{0,H} \propto k_L^*$ | **Same relative distance from own optimal scale:** $k_{0,L} \propto k_L^*$ **;** $k_{0,H} \propto k_H^*$ |
| --- | --- |




Notes: The figure shows the response of capital and debt to a 25bps increase in the real interest rate. The red line corresponds to a firm with a (permanent) high level of TFP and a large optimal scale. The blue line refers to a firm with a (permanent) low level of TFP and a smaller optimal scale. Column 1 conducts an experiment where both firms have the same absolute size when monetary policy changes. Both firms are initially at 60% of the optimal scale (for $k$) of the low TFP firm. We interpret the blue firm as "old" (close to optimal scale) and the red firm as "young" (far from optimal scale). Column 2 repeats the exercise but each firm starts with a level of capital that is 60% of their *own* optimal scale. In this experiment the firms differ in absolute size but have the same "age"/relative size.