Monetary Policy and Intangible Investment

Robin Döttling[1] and Lev Ratnovski[2]

[1]Erasmus University Rotterdam

[2]European Central Bank

January 2021

Abstract

We document that the stock prices and investment of firms with more intangible assets respond less to monetary policy shocks. Similarly, intangible investment responds less to monetary policy compared to tangible investment. These effects are most pronounced among financially constrained firms, indicating that corporate intangible capital weakens the credit channel of monetary policy transmission. The evidence that higher depreciation rates or higher adjustment costs of intangible assets explain these effects is mixed, suggesting a smaller role for these channels.

Keywords. Intangible Investment, Monetary Policy, Credit Channel, Stock Returns, Heterogeneity.

JEL classifications. E22, E52, G31, G32

Contact: doettling@rsm.nl and lev.ratnovski@ecb.int. We are grateful to Dalida Kadyrzhanova and Camelia Minoiu for substantial contribution in the early stages of this project. We thank for helpful comments and suggestions Stijn Claessens, Romain Duval, Michael Ehrmann, Peter Hoffmann, Albert-Jan Hummel, Marek Jarocinski, Peter Karadi, Luc Laeven, Alberto Martin, Roberto Steri, Felix Ward, as well as seminar participants at the European Central Bank, the Bank of Portugal, Erasmus University Rotterdam, Tinbergen Institute Macro Research Day, the 6th IWH FIN-FIRE Workshop, the 2020 EEA Virtual Congress, and De Nederlandsche Bank. Francesca Caucci and Anna Stelzer provided excellent research assistance. The views expressed in the paper are those of the authors and do not represent those of the ECB.

1 Introduction

Technological progress and the transition to a service economy have increased the importance of corporate intangible assets such as the knowledge derived from R&D, intellectual property, organizational structure, business strategy, and brand equity. Intangible investment was under half of tangible investment in the 1970s, and now exceeds tangible investment (Corrado and Hulten, 2010). This technological transition is associated with changes in corporate financing and investment patterns. For example, the literature documents that firms with more intangible assets use less debt and invest mostly from internal funds, due to the lower collateral value of intangible assets (Brown et al., 2009; Bates et al., 2009; Falato et al., 2020). On the asset side, intangible investment responds less than tangible investment to changes in corporate valuation (Peters and Taylor, 2017; Crouzet and Eberly, 2020), and intangible assets depreciate faster than physical capital (Ewens et al., 2019).

These changes in corporate financing and investment patterns raise the question of how corporate intangible capital affects monetary policy transmission. While the relation between the rise of intangible capital and monetary policy transmission has been recognized in the academic and policy debate (e.g., see the Crouzet and Eberly (2019) address to the Jackson Hole economic policy symposium),[1] comprehensive empirical evidence investigating this link is lacking.

We analyze the relationship between intangible capital and monetary policy transmission using two empirical approaches. The first approach examines the heterogeneity in firm stock price responses to monetary policy announcements, to elicit the market's perception of how monetary policy affects firms depending on their intangible capital stock. The second approach uses instrumental variable local projections to directly estimate the slow-moving

[1] Also see a recent speech by Haskel (2020) at the Bank of England.

adjustment of investment in response to monetary policy over horizons of multiple quarters (Jordà, 2005). The two approaches are complementary in their identification strategy. The stock price analysis identifies monetary policy shocks from changes in Fed Funds futures prices in a 30-minute window around FOMC announcements, as in Bernanke and Kuttner (2005). Local projections, in turn, use these shocks to instrument the monetary policy stance following Gertler and Karadi (2015).

These two empirical approaches yield consistent results. We document that the stock prices and investment of firms with more intangible capital respond less to monetary policy. Similarly, intangible investment responds less to monetary policy compared to tangible investment. These findings are present across alternative measures of intangible capital and monetary policy shocks, and robust to controlling for a rich set of time-varying firm characteristics, the interactions of those firm characteristics with the monetary policy stance, firm fixed effects, and time $\times$ NAICS-4 industry fixed effects. These controls ensure that our results are not driven by other observable differences between tangible and intangible firms, by unobservable differences across firms, nor by economy-wide or industry-specific trends.

The effects of intangible capital on monetary policy transmission are statistically and economically significant. In our most demanding specification a one standard deviation increase in the intangible-to-total capital ratio is associated with an 11bp smaller stock price decline in response to a 25bp unexpected increase in the Fed Funds rate, compared to an average stock price decline of 1.09%. Similarly, a one standard deviation increase in the intangible-to-total capital ratio is associated with a 41bp smaller investment decline in response to a 25bp increase in the instrumented 1-year Treasury rate, compared to an average decline of 3% after 12 quarters. Moreover, whereas a 25bp increase in the instrumented 1-year Treasury rate is associated with a tangible investment decline of 3% to 6% after 12 quarters (in firm-level and aggregate data, respectively), intangible investment declines by less than

1%.[2,3]

We test three economic channels that may explain why intangible assets mute monetary policy transmission. The first channel is a weaker credit channel of monetary policy. The credit channel is an amplification mechanism by which monetary policy affects firm investment not only through the cost of capital, but also through the collateral value of firm assets and firm financial constraints. However, intangible assets are not a good source of collateral, and consequently firms with more intangible assets use less debt to begin with (Brown et al., 2009; Rampini and Viswanathan, 2013; Falato et al., 2020). Therefore, the effect of monetary policy on asset collateral values is less pertinent for firms with more intangible assets. We confirm this intuition in a formal model of the credit channel of monetary policy that incorporates intangible assets with low collateral values. A testable prediction from the model is that intangible assets weaken the transmission of monetary policy to investment particularly among financially constrained firms, which are more reliant on asset collateral values for their marginal borrowing and investment.

We confirm this prediction in the data. A one standard deviation increase in the intangible-to-total capital ratio is associated with a 26bp weaker stock price response to a 25bp monetary policy shock among financially constrained firms, but only a 5bp weaker response among unconstrained firms. Similarly, a one standard deviation increase in the intangible-to-total capital ratio is associated with an up to 73bp weaker total investment response to a 25bp change in the instrumented 1-year Treasury rate among financially constrained firms, but only a 29bp weaker investment response among unconstrained firms. These results hold

[2] All data cover 1991-2016, see Section 2.

[3] The results on the total investment response and on the intangible-*vs.*-tangible investment response to monetary policy mirror each other. Firms with more intangible capital do more of intangible investment: the pooled correlation between firms' tangible-to-total capital and tangible-to-total investment ratios is 78.4%. Therefore, economic channels that explain a weaker investment response to monetary policy in firms with more intangible capital also help understand the weaker intangible investment response.

across multiple measures of firm financial constraints: young firm age, small size, high cash holdings, and the *delaycon* measure of Hoberg and Maksimovic (2015) that is based on the textual analysis of firm financial statements. While no single measure of firm financial constraints is perfect (Farre-Mensa and Ljungqvist, 2016), the robustness of the results across the measures is reassuring. We corroborate our evidence by documenting that also the debt growth in firms with intangible assets responds less to monetary policy, especially among financially constrained firms. Taken together, these findings offer consistent evidence that a weaker credit channel contributes to the muted monetary policy response in firms with intangible assets.[4]

The second economic channel relates to the fact that intangible assets have higher depreciation rates. For example, the BEA and Ewens et al. (2019) estimate intangible asset depreciation rates of between 10-40%, while most tangible asset depreciation rates are below 10% (Li, 2012). In a neoclassical production model, optimal investment equates the marginal product of capital with its user cost, i.e., the sum of the interest rate (the cost of funding) and the depreciation rate. When the deprecation rate is higher, the elasticity of the user cost of capital to interest rates is smaller (Crouzet and Eberly, 2019). Accordingly, investment may respond less to changes in interest rates when depreciation rates are higher.[5] Consistent with this channel, we document that intangible investment responds less to monetary policy in firms with higher intangible asset depreciation rates. Furthermore, the weaker stock price and investment response to monetary policy in firms with more intangible assets is more pronounced among firms with a wider gap between tangible and intangible asset deprecia-

[4]We also examine the effects of monetary policy on firm equity financing, which may be particularly important for intangible investment (Brown et al., 2009; Hall and Lerner, 2010). We find that neither intangible nor tangible firms adjust their external equity issuance in response to monetary policy, consistent with significant frictions and costs in external equity financing.

[5]We formally confirm that this holds in a Neoclassical production model as long as in the production function the marginal product of capital is declining and convex (e.g., as in the Cobb-Douglas production function).

tion rates. However, some of these results have modest statistical and economic significance. Therefore, the depreciation channel appears to play a smaller role in explaining our headline findings compared to the credit channel.

In the third economic channel, intangible investment may respond less to monetary policy because of its higher adjustment costs.[6] Unfortunately, we cannot test for this channel directly, as there are no systematic estimates of adjustment costs for intangible capital. Instead, we test for this channel indirectly, using tangible investment adjustment cost estimates from Hall (2004) and a measure of the redeployability of tangible assets from Kim and Kung (2017).[7] Our analysis reveals that tangible investment with higher adjustment costs responds *more* to monetary policy. A possible mechanism behind this result is that interest rates are positively associated with uncertainty (Bekaert et al., 2013), and uncertainty discourages investment with high adjustment costs (Majd and Pindyck, 1987; Bloom, 2009). The extrapolation of this finding to the comparison of tangible and intangible investment suggests that the higher adjustment costs of intangible investment unlikely contribute to its weaker response to monetary policy.

Our empirical strategy hinges on resolving a number of methodological challenges. The first challenge is measuring intangible capital. Firm financial statements directly report tangible investment and capital stock. By contrast, most intangible investment is expensed, and most intangible capital is not recorded on a firm's balance sheet. Consequently, the literature designates certain expenditure streams as intangible investment, and capitalizes them to measure the intangible capital stock (see Peters and Taylor, 2017; Falato et al., 2020). This

[6]Higher investment adjustment costs may be driven by the fact that firm-specific intangible assets cannot be purchased but need to be built over a period of time, and cannot be sold but need to be liquidated. Moreover, the creation of intangible assets uses skilled human capital that is costly to hire and fire. Consistent with this notion, Peters and Taylor (2017) find that intangible investment adjusts slower than tangible investment to changes in investment opportunities.

[7]Redeployable assets have lower investment adjustment costs because they can be bought rather than built, and sold rather than liquidated.

leaves some flexibility as to which expenditure streams to treat as intangible investment. Accordingly, we ensure that our results are robust across various intangible investment and capital stock estimates. Aggregate intangible investment is sourced from the National Income and Product Accounts (NIPA) Tables of the U.S. Bureau of Economic Analysis (BEA). The BEA defines intangible investment as expenses on research and development (R&D), software, and artistic originals; these data cover all U.S. establishments. Firm-level data for US public firms are sourced from Compustat. Following Peters and Taylor (2017), we define intangible investment as expenditures on R&D and organizational capital.[8] These expenditures are capitalized and supplemented with on-balance sheet intangible assets (externally acquired patents, software, and post-merger goodwill) to obtain an estimate of a firm's intangible capital stock.[9] Figure 1 plots the evolution of the intangible-to-total capital and investment ratios in the aggregate and firm-level data. These ratios are higher in firm-level data, consistent with its broader definition of intangible assets that includes organizational capital, and its focus on public firms that are often more technological and complex than smaller private establishments. Reassuringly, the aggregate and firm-level measures display a similar upward trend. This suggests that the growth of intangible capital in the U.S. economy is a broad-based phenomenon that can be captured for various types of firms and under alternative definitions of intangible capital.

The second methodological challenge is to identify monetary policy shocks. The Fed-

[8] Investment in organizational capital is measured as a share of selling, general, and administrative expenses (SG&A). Organization capital is a prominent component of overall intangible capital (Eisfeldt and Papanikolaou, 2013). We confirm the robustness of our results to using an alternative measure of intangible capital from Ewens et al. (2019) that features other estimates of the SG&A share in intangible capital and of intangible asset depreciation rates.

[9] An alternative approach to capture intangible capital in firms is to focus on on-balance sheet intangibles only. On-balance sheet intangibles are a subset of intangible assets, and on average account for 16% of total intangible assets. The correlation between on-balance sheet intangible asset growth and off-balance sheet intangible asset growth is low, under 5%. Accordingly, on-balance sheet intangibles may respond to monetary policy or other shocks differently than the total intangible investment (cf. Duval et al., 2020; Haskel, 2020).

eral Reserve communicates the changes to its monetary policy stance through the Federal Open Markets Committee (FOMC) announcements. We identify the unexpected component of these announcements as the change in the 3-months ahead Fed Funds futures prices in the 30 minutes around an announcement, following Kuttner (2001), Bernanke and Kuttner (2005), and Gurkaynak et al. (2005). Intuitively, the price of Fed Funds futures before an FOMC announcement incorporates the market's expectations about that announcement, so that the change in futures prices around an announcement reflects its unexpected component. The identifying assumption is that during the 30 minutes window around the FOMC announcement no other news significantly affects interest rate expectations. We use this measure of monetary policy shocks in our stock price response analysis. In the local projections analysis, we use these high-frequency monetary policy shocks to instrument the monetary policy stance, following Gertler and Karadi (2015). This allows us to capture the contribution of unexpected shocks to the monetary policy stance, while also controlling for lagged macroeconomic variables to account for the endogeneity of the monetary policy stance to macroeconomic conditions.

This paper brings together two growing strands of literature. The first strand is the literature on the heterogeneity in firm investment and stock price response to monetary policy. The key dimension of heterogeneity explored in the extant literature is that according to firm financial constraints. The literature employs various proxies of financial constraints, including firm size (Kashyap et al., 1994; Gertler and Gilchrist, 1994), age (Cloyne et al., 2018), cash and leverage (Jeenas, 2018), distance to default (Ottonello and Winberry, 2020), as well as composite indexes of financial constraints (Ozdagli, 2018; Chava and Hsu, 2020). We contribute to this literature by comprehensively documenting a novel source of heterogeneity in monetary policy transmission, namely that between firms with more tangible and more intangible assets, and between tangible and intangible investment. Crucially, our analysis controls for other firm balance sheet characteristics, including those that traditionally serve as proxies of financial constraints, and for the interaction of those characteristics with monetary policy measures. This ensures that the effect of intangible capital on monetary policy transmission that we identify is distinct from the effects of financial constraints on monetary policy transmission.[10]

The second strand of related literature focuses on the secular rise of corporate intangible capital over the last five decades (Corrado et al., 2009; Corrado and Hulten, 2010; Corrado et al., 2018) and its implications for firm productivity, financing, and investment (Brown et al., 2009; Corrado et al., 2017; Bianchi et al., 2019; Crouzet and Eberly, 2019; Falato et al., 2020). Our analysis brings together these established implications, as we document how the lower collateral value and higher depreciation rates of intangible assets affect monetary policy transmission. Caggese and Pérez-Orive (2020) develop a model in which lower interest rates reduce the income on corporate savings, disadvantaging firms with intangible assets that invest primarily from internal funds. This dynamic effect can further weaken the credit channel of monetary policy for intangible firms, consistent with our empirical results.

This paper proceeds as follows. Section 2 describes the data, Section 3 documents the main results, Section 4 presents evidence on the economic channels, and Section 5 concludes.

2 Data

2.1 Measuring Intangible Investment and Capital

We source firm-level asset and investment data from quarterly financial statements of public firms in Compustat. Tangible investment and capital stock are reported in firm financial

[10]Our paper shares with the above-cited literature the focus on firm heterogeneity in the transmission of monetary policy. Complementary literature considers the role of bank heterogeneity in the transmission of monetary policy; see Jiménez et al. (2014) and Chakraborty et al. (2020), among others.

statements as capital expenditure (CAPX) and net property, plant, and equipment (PPENT), respectively. Measuring intangible investment and capital is more challenging. Most intangible investment is expensed, so most of intangible capital is not on a firm's balance sheet. We follow Peters and Taylor (2017) and define intangible investment as the sum of research and development (R&D) expenses and 30% of selling, general and administrative (SG&A) expenses. R&D expenses capture investment in knowledge capital, whereas a share of SG&A expenses reflects investment in brand and organizational capital.[11]

A firm's intangible capital stock is measured by capitalizing intangible investment using depreciation rate estimates from Li (2012) and adding on-balance sheet intangibles (mostly goodwill). We take this measure directly from Peters and Taylor (2017) through Wharton Research Data Services. Their measure is annual, so we interpolate it linearly to obtain a quarterly measure. In robustness, we use an alternative intangible capital stock estimate from Ewens et al. (2019), who use acquisition prices to estimate industry-level depreciation rates and SG&A expenditure shares that contribute to intangible capital formation, and obtain very similar results.

Following sampling procedures standard in the corporate finance literature, we exclude financial firms (SIC 4900–4999), utilities (SIC 6000–6999), and government (SIC 9000 and above). We also exclude firms with missing or negative assets or sales, negative CAPX, R&D, or SG&A expenditure, and very small firms with physical capital under $5 million. This leaves us with 8938 unique firms and 318305 firm-quarter observations between 1991 and 2016 (the period for which the monetary policy shocks data are available). We deflate all data using the CPI into real 1990 U.S. dollars.

[11] The share of SG&A expenditure attributed to organizational capital varies in the literature from 20% to 30% (see Falato et al., 2020). Ewens et al. (2019) estimate an average share of 28%. Compustat often adds R&D expenditure to SG&A expenditure. Therefore, we follow the procedure of Peters and Taylor (2017), Appendix B, and subtract R&D investment from SG&A expenditure whenever reported SG&A expenditure exceeds reported R&D investment.

Next to firm-level data, we source aggregate corporate asset and investment data from the BEA's National Income and Product Accounts (NIPA) at quarterly frequency. Total investment is defined as total non-residential fixed investment. This can be split into tangible investment in structures and equipment, and intangible investment in intellectual property products (IPP) that include R&D, software, and artistic originals.[12]

2.2 Dynamics of Tangible and Intangible Investment

Compared to the firm-level Compustat-based measure, the BEA employs a narrower definition of intangible investment that excludes organizational capital. At the same time, BEA data cover all U.S. establishments, while Compustat only covers public firms. Figure 1 plots the evolution of intangible-to-total capital (panel A) and investment (panel B) ratios in both datasets. Compustat data show higher intangible-to-total capital and investment ratios, consistent with its focus on more technological and complex public firms, and a broader definition of intangible capital. Despite this level difference, firm-level and aggregate data exhibit a similar upward trend in intangible investment and capital stock.

Figure 2 depicts aggregate investment growth rates. Panel A documents a strong similarity in the growth rates of total investment (tangible + intangible) in Compustat and BEA data. Panels B and C decompose BEA and Compustat investment into their tangible and intangible components. In both datasets intangible investment is procyclical but less volatile than physical investment (see Fatas, 2000; Barlevy, 2007; Aghion et al., 2012, for a discussion of the cyclicality of R&D investment). The lower cyclicality of intangible investment is consistent with the notion that it may respond less to monetary policy shocks (or other shocks more broadly), a hypothesis that we explore rigorously in the remainder of the paper. The similarity between the firm-level an aggregate intangible investment series is reassuring,

[12] NIPA Table 5.3.3 - Real Private Fixed Investment by Type.

given the difficulty in measuring intangible investment. Panel D further decomposes Compustat intangible investment into its R&D and SG&A components. Although R&D investment appears somewhat more volatile than SG&A expenditure, it is still substantially less cyclical than physical investment. Nevertheless, we ensure that our results are not driven by the features of SG&A expenditure by confirming their robustness to measuring intangible investment using its R&D component only.

2.3 Other Variables

Firm-level control variables are sourced from Compustat and include firm age, Tobin's Q, leverage, cash holdings, cashflows, firm size, and a dummy for whether a firm pays a dividend. Daily stock returns data from CRSP are merged with Compustat using the linking table from Wharton Research Data Services. Variables are winsorized at the 1% level to avoid outliers. Table 1 presents data summary statistics for all firms, and separately for firms with above- and below-median intangible-to-total capital ratios. Consistent with the literature, firms with more intangible assets have a higher Tobin's Q, more cash, lower leverage, and are less likely to pay a dividend, which likely reflects tighter financial constraints (Falato et al., 2020). Unsurprisingly, firms with more intangible assets have higher intangible investment, while those with more tangible assets have higher physical investment. The ratio of tangible over intangible investment is 0.426 for the average intangible firm and 4.652 for the average tangible firm. Beyond this, the two groups are comparable in terms of firm age, size, and profitability.

We obtain the macroeconomic variables 1-year Treasury rate, consumer price index (CPI), industrial production, and the employment ratio from the Federal Reserve Economic Data, and use the Gilchrist and Zakrajšek (2012) excess bond premium to control for financial conditions.[13]

3 Main Results

This section consists of two parts. First, we examine how the stock prices of firms with more intangible assets respond to unexpected monetary policy shocks. Second, we consider how intangible investment responds to monetary policy compared to tangible investment, and how the total investment in firms with more intangible assets responds to monetary policy.

3.1 Stock Price Response to Monetary Policy Shocks

The Federal Reserve communicates changes to its monetary policy stance through Federal Open Market Committee (FOMC) announcements. We identify monetary policy shocks using high-frequency movements in Fed Funds futures prices in the 30 minutes window around an FOMC announcement, following Kuttner (2001), Bernanke and Kuttner (2005), and Gurkaynak et al. (2005). The identifying assumption is that this narrow window contains no other news that affects interest rate expectations. The data cover all FOMC meetings from 1991 to 2016.[14]

We assess a firms' stock price response to monetary policy shocks using the following regression specification:

$$RET_{it} = \beta_1 \times \Delta FF4_t + \beta_2 \times X_{it} + \beta_3 \times \Delta FF4_t \times X_{it} + \eta_{jt} + \mu_i + \psi_{fq} + \varepsilon_{it}, \qquad (1)$$

[13] Online Appendix Table A1 lists all firm-level variable definitions. Online Appendix Table A2 lists all aggregate variables, definitions, and data sources.

[14] As common in the literature, we exclude the FOMC meeting on September 17, 2001, which coincided with the market opening following the September 11 terrorist attacks. We thank Peter Karadi for kindly sharing the data.

where RET_{it} is the stock return of firm i on the day of the FOMC meeting, and $\Delta FF4_t$ is the change in the 3-month ahead Fed Funds futures rate in the 30 minutes around the FOMC announcement on event-date t. X_{it} are firm characteristics at the end of the previous quarter. These include a firm's *intangible ratio*, defined as the ratio of intangible-to-total capital. The coefficient on the interaction of the intangible ratio with $\Delta FF4_t$ is the key parameter of interest. It captures whether the stock prices of firms with more intangible assets react differently to monetary policy surprises. Other firm-level controls in X_{it} are Tobin's Q, age, cash holdings, leverage, size, cashflows, and a dummy for whether the firm pays a dividend.

The model is saturated with 4-digit NAICS industry $\times$ event-date fixed effects $\eta_{j,t}$ that absorb any differences across narrowly-defined industries on each announcement date. Furthermore, we report results with and without firm fixed effects μ_i that control for all time-invariant firm characteristics. All regression include fiscal-quarter fixed effects ψ_{fq} to control for seasonality.[15] Standard errors are clustered at the industry and the event-date levels.

In measuring stock returns RET_{it} we consider both raw and abnormal returns. Abnormal returns are estimated from a basic capital asset pricing model over 100 days prior to the FOMC meeting, using the CRSP value-weighted index as market benchmark. Abnormal returns control for a firm's beta, which captures the volatility of a stock and its exposure to systematic risk.

3.1.1 Results

Table 2 documents the headline results. Column 1 reports an average stock price response of −4.36% to a 1% unexpected increase in the Fed Funds rate (in line with −4.68% in Bernanke

[15] Fiscal quarters vary across firms and do not necessarily coincide with calendar quarters, depending on a firm's reporting month.

and Kuttner, 2005). Columns 2 to 5 add the interactions of ΔFF4 with firm characteristics under different stock return measures and fixed effect combinations. The main explanatory variable of interest is the interaction between ΔFF4 and a firm's intangible ratio. The coefficient estimate for this interaction term is stable at between 1.42 and 1.53 across the specifications and consistently significant at the 5% level. This indicates that the stock prices of firms with a higher intangible-to-total capital ratio react less to monetary policy surprises. A one-standard deviation increase in the intangible ratio is associated with a 41bp–44bp smaller stock price decline in response to a 1% unexpected increase in the Fed Funds rate.

These results demonstrate that the market valuation of firms with more intangible assets responds less to monetary policy shocks, consistent with the notion that intangible assets attenuate the effects of monetary policy. This result is robust in specifications that use abnormal stock price returns to control for the difference in systematic risk across firms (columns 4 and 5). This verifies that the weaker response of intangible firms to monetary policy is not driven by their differential co-movement with the broader market and, by extension, by their exposure to systematic risk factors such as the macroeconomic cycle.[16]

3.1.2 Robustness

We verify the robustness of the baseline results documented in Table 2 to using alternative measures of monetary policy surprises and of intangible capital. First, we use the Jarocinski and Karadi (2020) decomposition of FF4 shocks into "pure" monetary policy shocks and "central bank information shocks". This decomposition accounts for the fact that FOMC announcements communicate not only the monetary policy stance, but also central bank

[16]Interestingly, in specifications with abnormal returns, the coefficients on the interactions between the monetary policy shock and all firm characteristics except the intangible ratio become statistically insignificant or only marginally significant. Such weak significance appears consistent, for example, with the fact that some papers establish an amplifying while others – a dampening effect of firm financial constraint measures on stock price response to monetary policy (Ozdagli, 2018; Chava and Hsu, 2020).

views about the state of the economy. For example, an interest rate cut may signal that the Federal Reserve is pessimistic about the economic outlook, leading to lower stock prices.[17] Online Appendix Table A3 documents the outcome of this decomposition in panel A. Column 1 confirms that pure monetary policy shocks affect stock prices negatively, while central bank information shocks affect stock prices positively, as expected. Columns 2 to 5 verify that the interaction of the intangible ratio with pure monetary policy shocks is positive, with point estimates slightly higher than those in the baseline. By contrast, the interaction of the intangible ratio with central bank information shocks is statistically insignificant, confirming that our results are driven by monetary policy shocks, rather than news about economic fundamentals.

Second, we replicate the baseline results using an alternative measure of firm intangible capital from Ewens et al. (2019). This measure uses acquisition prices to estimate industry-level intangible capital depreciation rates, and allows the share of SG&A expenditure counted towards intangible investment to vary by industry. Online Appendix Table A3 documents in Panel B that our results remain robust, with point estimates for the interaction between monetary policy surprises and this alternative measure of firm intangible ratio similar to those in the baseline.

3.2 Investment Response

We now turn to the analysis of the tangible and intangible investment response to monetary policy. We examine firm-level investment responses using Compustat data and aggregate investment response using national accounts data from the BEA.

[17] Jarocinski and Karadi (2020) identify a pure monetary policy shock from the negative co-movement of Fed Funds futures and stock prices, and a central bank information shock from the positive co-movement.

3.2.1 Empirical Strategy

The FF4 monetary policy shocks are appropriate for measuring their high-frequency impact on stock prices. However, the adjustment of investment is slow-moving, with long and uncertain lags, and measured at quarterly frequency. Therefore, as common in the literature, we estimate the adjustment of investment using local projections, where the monetary policy stance is instrumented using FF4 shocks.

We measure the monetary policy stance as the 1-year Treasury rate. Compared to the Fed Funds rate, the 1-year Treasury rate better captures interest rate variation in the unconventional monetary policy environment during the later part of our time sample, due to its longer maturity. Because monetary policy is endogenous to macroeconomic conditions, we instrument the Treasury rate using cumulative FF4 shocks as a *level* measure of monetary policy surprises (as in Coibion, 2012; Elliott et al., 2019), while controlling for key lagged macroeconomic variables (akin to the PVAR approach in Gertler and Karadi, 2015).[18] The first-stage regression results, reported in Online Appendix Table A4, confirm that the cumulative high-frequency shocks are a strong instrument for the 1-year Treasury rate. Figure 3 plots the actual and the instrumented 1-year Treasury rate, along with the cumulative FF4 instrument.

To trace out the dynamic impact of monetary policy on firm investment, we estimate instrumental-variable local projections (LP-IV, Jordà, 2005). That is, for each horizon h, we estimate the regression:

$$y_{t+h,i} - y_{t-1,i} = \beta_1^h \hat{R}_t + \beta_2^h X_{t-1}^m + \beta_3^h X_{t-1,i}^f + \mu_i + \psi_{fq} + \varepsilon_{t,i}, \tag{2}$$

[18] We follow Gertler and Karadi (2015), Footnote 11, and construct cumulative FF4 shocks by first creating a monthly series that accounts for the timing of FOMC announcements within a month. We then cumulate this monthly series to obtain a level measure, which we found to be a better instrument for the 1-year Treasury rate than contemporaneous FF4 shocks.

where the outcome variable $y_{t,i}$ is a measure of investment, and $\hat{R}_t$ is the instrumented 1-year Treasury rate. X^m_{t-1} are lagged macro control variables (log CPI, log industrial production, the excess bond premium, and the employment ratio). When estimating local projections on firm-level data, we include firm fixed effects μ_i, fiscal-quarter fixed effects ψ_{fq}, and all firm-level controls $X^f_{t-1,i}$ from the stock returns regression (1). The regression specification for aggregate data only includes macro controls and calendar quarter fixed effects:

$$y_{t+h} - y_{t-1} = \alpha + \beta^h_1 \hat{R}_t + \beta^h_2 X^m_{t-1} + \psi_{cq} + \varepsilon_t. \tag{3}$$

We present the results in the form of impulse response functions (IRFs) that plot the coefficients β^h_1 for quarterly horizons $h = 1 \ldots 20$, along with 95% confidence intervals.

Verification Online Appendix Figure A1 verifies that the response of standard macroeconomic variables to a monetary policy in our setup is in line with that documented in the literature. In response to a 25bp increase in the instrumented 1-year Treasury rate employment drops by 0.25%, the excess bond premium increases by just over 10bps, CPI drops by up to 0.4%, industrial production drops by up to 1%, and aggregate business investment drops by 3%. These responses are qualitatively and quantitatively in line with estimates in Gertler and Karadi (2015) and Cloyne et al. (2018).

3.2.2 Evidence from Firm-Level Data

Our firm-level analysis considers as outcome variables the tangible, intangible, and total investment rates, defined as, respectively:[19]

$$
\begin{aligned}
I_{it}^{tan} &= \frac{CAPX_{it}}{PPE_{it-1}}, \\
I_{it}^{int} &= \frac{R\&D_{it} + 0.3 \times SG\&A_{it}}{K_{it-1}^{int}}, \\
I_{it}^{tot} &= \frac{CAPX_{it} + R\&D_{it} + 0.3 \times SG\&A_{it}}{K_{it-1}^{int} + PPE_{it-1}},
\end{aligned}
$$

where K_{it}^{int} is the intangible capital stock estimate from Peters and Taylor (2017) and PPE_{it} is tangible capital measured as net property plant and equipment.

Figure 4 plots the response of log investment rates to an instrumented 25bp increase in the 1-year Treasury rate. Panel A documents that the firm-level total investment rate drops by almost 3% after 8-12 quarters, in line with the response of aggregate business investment (see Online Appendix Figure A1). We decompose this effect into the response of tangible and intangible investment along two dimensions. First, we consider the total investment response in firms with more tangible compared to more intangible assets. Second, we consider the tangible and intangible investment response within a firm.

Panel B documents the response of total investment to monetary policy for firms with below- and above-median intangible-to-total capital. The response of total investment is substantially weaker among firms with more intangible assets. In response to an instrumented 25bp increase in the Treasury rate, firms with a below-median intangible ratio reduce their total investment by almost 5% after 10-12 quarters. By contrast, firms with an above-median

[19] We winsorize investment rates at the 1% level. Their summary statistics presented in Table 1 are in line with the annual investment rates in Peters and Taylor (2017).

intangible ratio reduce their total investment by around 1%. The weaker investment response to monetary policy in intangible firms is consistent with the high-frequency results showing a weaker stock price response to monetary policy shocks in intangible firms (see Table 2), underlining the role of intangible assets in muting monetary policy transmission.

Panels C and D compare the effects of monetary policy on a firm's tangible and intangible investment by decomposing total investment into its tangible and intangible components. The vast majority of the total investment response comes from tangible investment, which declines by about 5-6% after 12 quarters in response to an instrumented 25bp increase in the Treasury rate. By contrast, intangible investment declines by less than 1%.

To test whether the difference in the response of tangible and intangible investment within firms is statistically significant, panel E plots the response of the log ratio of a firm's tangible over intangible investment (i.e., the percentage point difference between the response of tangible and intangible investment). A drop in this ratio indicates a stronger response of tangible compared to intangible investment. The ratio falls by up to 4% and this difference is statistically different from zero with 95% confidence. Panel F repeats this exercise using a narrower measure of intangible investment that omits SG&A expenditure. This makes the firm-level measure of intangible investment more comparable to the aggregate BEA measure that focuses on R&D investment. The log ratio of tangible investment (CAPX) to R&D exhibits a similar if a bit smaller decline of about 3% points, confirming that the result is robust to considering only the R&D component of intangible investment.

The sample split in panel B of Figure 4 documents a weaker total investment response in firms with more intangible assets. To ensure that this effect is not driven by other observable differences between tangible and intangible firms (for example, in leverage or cash holdings, see the summary statistics in Table 1), we enrich the local projections specification (2) with interaction terms between the 1-year Treasury rate and firm characteristics, $\hat{R}_t \times X^f_{it-1}$:

$$y_{t+h,i} - y_{t-1,i} = \beta_1^h \times \hat{R}_t + \beta_2^h \times X^m_{t-1} + \beta_3^h \times X^f_{it-1} + \beta_4^h \times \hat{R}_t \times X^f_{it-1} + \mu_i + \eta_t + \psi_{fq} + \varepsilon_{it}. \quad (4)$$

This specification mirrors the stock returns specification (1) of Section 3.1. The coefficients β_4^h capture how firm characteristics affect a firm's investment response to monetary policy. As in Section Section 3.1, the analysis focuses on identifying the interaction term between a firm's intangible ratio and monetary policy, while controlling for the interaction of all other firm characteristics with monetary policy. Since this specification focuses on identifying the interaction term, we can include time fixed effects η_t, or industry $\times$ time fixed effects η_{jt}, to control for time-varying macroeconomic conditions that influence all firms, or all firms within a given industry, respectively. These fixed effects ensure that the results are not driven by long-run economy-wide or industry-specific trends.

Table 3 documents the results from estimating Eq. (4) for horizons $h = 8$ and $h = 12$ quarters (at which the impulse response functions of of Figure 4 demonstrate the strongest investment response). The interaction term between the intangible ratio and the 1-year Treasury rate is positive and statistically significant (columns 2 and 5), also when including industry $\times$ time fixed effects (columns 3 and 6). A one standard deviation increase in the intangible-to-total capital ratio reduces a firm's total investment response to a 25bp increase in the 1-year Treasury rate by between 30bp and 45bp, corresponding to nearly one-sixth of the average investment response of 3%. This strong attenuating effect is consistent with the previous results from the sample splits in Figure 4 panel B.

Note that the results on the weaker total investment response in firms with more intangible assets and on the weaker intangible investment compared to tangible investment response mirror each other, as firms with more intangible capital do more of intangible investment. The pooled correlation between firms' tangible-to-total capital and tangible-to-total investment ratios is 78.4%. The availability of both sets of results is useful for a number of reasons. First, it allows us to verify the mutual consistency of these results, and verify the consistency of the investment results in firm-level and in aggregate data. Second, some candidate economic channels behind our headline results (which we discuss in Section 4) speak more directly to the results on total investment depending on a firms' intangible ratio, while others speak to the tangible- *vs.*-intangible investment response results. Therefore, economic channels that explain a weaker investment response to monetary policy in firms with more intangible capital also help understand the weaker intangible investment response.

Robustness Online Appendix Figure A2 documents the robustness of the sample split results in Figure 4 to using cumulative "pure" monetary policy shocks (separated from central bank information shocks) from Jarocinski and Karadi (2020) as instrument. The results are similar to those in the baseline. Furthermore, Online Appendix Table A5 panel A documents the robustness to using the pure monetary policy shocks as instrument in the interaction term specification of Table 3. Online Appendix Table A5 Panel B documents the robustness of the results in Table 3 to using the alternative firm-level intangible capital estimate from Ewens et al. (2019). In both exercises the interaction term of the instrumented 1-year Treasury and a firm's intangible ratio is statistically significant and similar in magnitude to that in the baseline. This confirms that the weaker investment response of firms with more intangible capital is robust to using alternative monetary policy shock and intangible capital measures.

3.2.3 Evidence from Aggregate Data

Our firm-level measure of intangible capital is sourced from Compustat and therefore only captures public firms. We therefore complement the firm-level analysis with an analysis based on national accounts data from the BEA that cover all establishments. The BEA also employs a different definition of intangible investment based on intellectual property products (IPP), which include R&D, software, and artistic originals, but exclude organizational capital. This allows us to verify the robustness of our results to an alternative measure of intangible investment.

Figure 5 plots the monetary policy response of log tangible investment in BEA NIPA data. In response to an instrumented 25bp increase in the 1-year Treasury rate, tangible investment (in structures and equipment) declines by about 3-4% after 12 quarters (panel A), somewhat less than the decline observed in firm-level data. Intangible investment (IPP) declines by around 1% (panel B), similar to the effect in firm-level data and substantially less compared to tangible investment. Total investment declines by just under 3% (panel C), in line with the firm-level results. Panel D documents that the log of the ratio of tangible over intangible investment declines by over 2%, indicating a statistically significant weaker monetary policy response of intangible compared to tangible investment.

Synthesis The investment results based on firm-level and aggregate data consistently document that intangible investment responds less to monetary policy compared to tangible investment. Likewise, in the cross-section, the total investment in firms with more intangible assets responds less to monetary policy. These investment results, which are based on instrumental variable local projections estimated on quarterly data, are also consistent with the high-frequency stock price results that indicate a weaker response of the market valuation of firms with more intangible capital to monetary policy shocks. Overall, we thus document a broad set of findings based on different methodologies and data sources that all confirm that intangible capital attenuates the effectiveness of monetary policy transmission. In the remainder of the paper we explore several economic channels that may explain these results.

4 Why Does Intangible Capital Weaken Monetary Policy Transmission?

Why may intangible capital weaken monetary policy transmission to firm stock prices and investment? This section discusses and tests three candidate economic mechanisms. The first mechanism is a "credit channel": firms with more intangible assets use less debt funding. Therefore, the standard amplification mechanism where monetary policy affects asset collateral values and firm financial constraints is muted for these firms. The second mechanism is a "depreciation channel": intangible assets have higher depreciation rates than tangible assets. Therefore, same interest changes may affect their user cost of capital proportionately less. The third mechanism is the "adjustment costs channel": intangible investment may be costlier to scale up and down compared to tangible investment. We find strong evidence consistent with the credit channel, weaker evidence for the depreciation channel, and, based on indirect tests, no evidence to support the adjustment costs channel.

4.1 Credit Channel

The credit channel of monetary policy is an amplification mechanism by which interest rates affect not only the price but also the quantity of credit available to firms, through their effect on the collateral value of firm assets and thus on firm financial constraints (Kiyotaki and Moore, 1997; Bernanke et al., 1999).[20] However, intangible assets have lower collateral value

[20]Here, the term 'collateral' refers not only to de-jure collateral for a specific loan, but also to the liquidation value of firm assets that serves as implicit collateral for most borrowing. While firms have some access to credit secured e.g. by their receivables, the collateral value of firm assets remains a major constraint on firm access to external finance. For example, the 2015 Bank of England survey reports that 90% of bank loans are secured by collateral (Haskel, 2020). Similarly, Rampini and Viswanathan (2013) document that U.S. firms' aggregate liabilities are lower than their tangible assets, and argue that therefore the vast majority of credit is explicitly or implicitly backed by collateral. Chaney et al. (2012) and Bahaj et al. (2020) document the importance of real estate collateral values for firm investment.

compared to tangible assets,[21] so firms with more intangible assets use less debt to begin with.[22] Consequently, monetary policy may have a smaller effect on the financial constraints (and hence the volume of credit and investment) for firms with more intangible assets.

Formally, consider a profit-maximizing firm that chooses its investment at date t. The firm has initial capital stock K_t and internal funds (cash) A_t. It decides how much debt D_t to raise in order to make investment $I_t = A_t + D_t$, resulting in capital stock $K_{t+1} = K_t + I_t$ at $t + 1$. Capital produces $F(K_{t+1})$, where $F'(K) \geq 0$ and $F''(K) \leq 0$. The firm's cost of borrowing (and the value of internal funds in alternative use) is the interest rate r_t.

Importantly, the firm is subject to a collateral constraint:

$$D_t \leq (1 - \mu) Q_t(r_t) K_t, \tag{5}$$

where $Q_t(r_t)$ is the collateral value of capital, which declines in the interest rate r_t, i.e., $Q_t'(r_t) \leq 0$. The parameter μ captures the share of the capital stock that is intangible and thus cannot be pledged as collateral. The empirical counterpart of μ in our analysis is the intangible-to-total capital ratio.

[21]The reason is that intangible assets are often more firm-specic and more difficult to value and liquidate than tangible assets. For example, the value of a partially-developed technology is likely to be intrinsically linked to the human capital of the researchers who work on it. It is difficult to transfer ownership of such an asset, or to seize it. A creditor who attempts to resell this asset would likely recoup only a fraction of its original value. Additional reasons for why intangible assets have low *implicit* collateral value are that the structure of a debt contract is not well-suited for RD-intensive firms due to uncertain and volatile returns, that adverse selection problems are more likely in high-tech industries due to the inherent riskiness of R&D, and that R&D intensive firms may find it easier to substitute high-risk for low-risk projects (see a discussion in Brown et al., 2009, p. 157). Accordingly, empirical studies find strong evidence that firms finance intangible assets primarily through equity or internal funds (Carpenter and Petersen, 2002; Hall, 2002; Bates et al., 2009; Brown et al., 2009; Hall and Lerner, 2010; Brown et al., 2013; Falato et al., 2020). While some intangible assets, notably patents, can be used as collateral (Loumioti, 2012; Mann, 2018), this practice is not prevalent. Dell'Ariccia et al. (2020) confirm that patents do not fully ameliorate external finance frictions caused by the low collateral value of intangible assets.

[22]Indeed, Table 1 documents median leverage of 23% for firms with above-median intangible-to-total capital ratio, but 31% for firms with below-median intangible ratio. Consistent with the difficulty in attracting debt finance, more intangible firms also maintain higher precautionary cash holdings: 16.8% in firms with above-median intangible-to-total capital ratio, but only 9.4% for below-median (see also Falato et al., 2020).

The firm's optimization program is:

$$
\begin{aligned}
\max_{I_t, D_t} \quad & F(K_{t+1}) - I_t r_t \\
s.t. \quad & K_{t+1} = K_t + I_t, \\
& I_t = A_t + D_t, \\
& D_t \leq (1-\mu) Q_t(r_t) K_t.
\end{aligned}
\tag{6}
$$

Solving the optimization problem gives two solution regions, depending on whether the collateral constraint (5) binds. An *unconstrained firm* matches the marginal product of capital to its opportunity cost r_t. It chooses investment I_t such that $F'(K_{t+1}) = r_t$. Investment declines in the interest rate because $F''(K_{t+1}) \leq 0$, representing the effect of monetary policy on the hurdle rate of investment. Note that the share of intangible assets in total capital μ does not affect the investment of a firm that is unconstrained by the collateral value of its assets.

By contrast, the investment of a *constrained firm* is given by $I_t = (1-\mu)Q_t(r_t)K_t + A_t$, with

$$
\frac{dI_t}{dr_t} = (1-\mu) Q_t'(r_t) K_t. \tag{7}
$$

Here, investment is limited by the collateral value of firm assets, which declines in the interest rate since $Q_t'(r_t) \leq 0$. Importantly, investment declines in the interest rate *less* for firms with a higher share of intangible assets in total capital μ, because such firms use less debt funding. Intuitively, fluctuations in collateral values have little effect on the financial constraints of firms that cannot pledge their assets as collateral anyway.[23]

[23]Note that our representation of the impact of intangible capital on the credit channel of monetary policy does not distinguish between firms that borrow from banks and from markets. This is consistent with the fact that, while firms with more intangible capital have lower leverage (see Table 1), the shares of bank and market debt in total debt are stable across the distribution of the intangible ratio: around 45% on average for firms with both above- and below-median intangible ratio, and similarly across all deciles of the firm

This stylized model of intangible assets and the credit channel of monetary policy thus yields the following testable prediction: *(1) firms with a higher intangible-to-total capital ratio adjust their investment less in response to monetary policy, (2) but only to the extent that such firms are financially constrained.* Whereas our baseline results confirm that firms with more intangible assets indeed respond less to monetary policy, the goal of this section is to analyze whether this muted reaction is driven primarily by financially constrained firms. To this end, we identify firms that are likely financially constrained according to common proxies used in the literature, and re-run our analysis on sub-samples of more and less constrained firms.

4.1.1 Measuring Financial Constraints

The literature uses a range of approaches to capture firm financial constraints. One approach uses firm characteristics that affect financial constraints. For example, young and small firms may face frictions in obtaining external financing because they have less well-established financial market relationships, are subject to greater asymmetric information problems, and have more uncertain returns. Therefore, young firm age (e.g., Hadlock and Pierce, 2010; Cloyne et al., 2018) and small firm size (e.g., Kashyap et al., 1994; Gertler and Gilchrist, 1994) are common proxies of financial constraints. Another approach uses firm characteristics that may be induced by financial constraints. For example, Cunha and Pollet (2019) document that financially constrained firms accumulate higher cash buffers than unconstrained firms, likely for precautionary reasons. Yet another approach identifies financial constraints from the textual analysis of firm financial statements, by assessing the frequency of language that indicates investment delays due to a lack of financing capacity, as in the *delaycon* measure of

intangible ratio (per Capital IQ data).

Hoberg and Maksimovic (2015).[24] Either approach is imperfect (Farre-Mensa and Ljungqvist, 2016), and the correlation between different measures of financial constraints is modest at about 0.12-0.16 (see Online Appendix Table A7). We therefore document the results using all the above approaches to measuring financial constraints and, reassuringly, obtain results that are consistent across these measures.

4.1.2 Stock Price Response

To assess whether the weaker stock price response to monetary policy in firms with more intangible assets is more pronounced among financially constrained firms, we re-run the baseline regressions as in Table 2, while splitting the sample into more and less financially constrained firms. All regressions include the same controls and fixed effects as in the baseline.

Table 4 documents the estimated coefficients on the interaction term ΔFF4 $\times$ Intangible Ratio. Panel A splits the sample into young firms, defined as those with below median age in a given quarter, and old firms (above median). Similarly, panel B splits the sample into firms of above- and below-median size. For young and for small firms (columns 1 and 2), the coefficient estimates are between 1.88 and 2.07, higher than the full-sample estimates (see Table 2) and about 2-4 times the estimates for old and for large firms (columns 3 and 4). A potential shortcoming of using age and size separately as proxies of financial constraints is that some successful young firms may grow quickly and not be financially constrained. We address this in panel C, by comparing estimates among firms of below-median age *and* size to firms of above-median age *and* size. The coefficient estimates among firms that are young and small range between 3.83 and 4.18, which is higher than the estimates for young or small firms individually, while estimates among old and large firms are close to zero and

[24] Hoberg and Maksimovic (2015) identify a set of constrained firms that discuss investment delays due to liquidity constraints in their annual reports. They then construct a continuous *delaycon* measure by scoring how proximate a firm's wording in the liquidity and capitalization section is to these constrained firms.

statistically insignificant. These estimates imply that, for firms that are young and small, a one standard deviation increase in the intangible-to-total capital ratio leads to a 1.1%-1.2% smaller stock price decline in response to a 1% unanticipated increase in the Fed Funds rate. This compares to a 0.45% smaller decline in the full sample and represents around a quarter of the average 4.36% stock price response.

Panel D splits the sample into firms with high and low cash holdings, defined as, respectively, firms in the top tercile and bottom two terciles by the cash-to-assets ratio in a given quarter. We pool the two lower cash holding terciles because the relation between cash and financial constraints is potentially not monotonic. While high cash holdings indicate precautionary cash hoarding in response to financial constraints, intermediate cash holdings are unlikely indicative of tighter financial constraints compared to low cash holdings. In fact, very low cash holdings may stem from a firm's poor performance, which tightens financial constraints. For firms with high cash holdings (columns 1 and 2), the coefficient estimates on the interaction term between ΔFF4 and a firm's intangible ratio are between 2.55 and 2.78. These are higher than the full-sample estimates and significant at the 1% level despite the smaller sample size. For firms with intermediate and low cash holdings (columns 3 and 4), the coefficient estimates are again smaller and statistically insignificant.

Panel E splits the sample using the textual analysis-based measure of firm financial constraints. We define financially constrained firms as those with an above-median *delaycon* measure of Hoberg and Maksimovic (2015) in a given quarter. Consistent with the age and cash results, the coefficient estimates on the interaction term between ΔFF4 and a firm's intangible ratio are between 2.25 and 2.66, larger than the full-sample estimates. The difference between constrained and unconstrained firms is the strongest for abnormal stock returns, with 9 times larger coefficient estimates for constrained firms. The difference is smaller for raw stock returns, owing to an imprecisely estimated coefficient for less constrained firms.[25]

To sum up, the results based on multiple measures of firm financial constraints confirm that the weaker stock price response to monetary policy in firms with more intangible assets is more pronounced among financially constrained firms, consistent with the credit channel predictions.

4.1.3 Investment Response

We now assess whether also the weaker investment response to monetary policy in firms with more intangible assets is more pronounced among financially constrained firms. To examine this, we re-run the investment local projection regressions as in Table 3, while again splitting the sample based on the measures of financial constraints. All regressions include the same control variables, interactions, and fixed effects as the baseline local projections.

Table 5 documents the investment response to monetary policy at 8 and 12 quarter horizons, for the splits based on different measures of financial constraints: age (panel A), size (panel B), the combination of age and size (panel C), cash holdings (panel D), and the textual analysis-based *delaycon* measure (panel E). The results consistently reveal that the coefficient estimates on the interaction of the intangible ratio with the instrumented 1-year Treasury rate are at least twice as high for constrained firms than for unconstrained firms. By contrast, coefficient estimates for unconstrained firms have lower or no statistical significance. Similar to the stock price results, the difference between constrained and unconstrained firms is starker when combining age and size as proxies of financial constraints (panel C) compared to using each proxy separately (panels A and B). Coefficient estimates on the interaction between the instrumented 1 year Treasury rate and the intangible ratio range from 0.095

[25]The sample size for the *delaycon* measure is smaller because this measure is available only over 1997-2015 and only for firms with a machine-readable capitalization and liquidity section of their financial report.

to 0.098 for firms that are young and small. These estimates imply that a one standard deviation increase in the intangible-to-total capital ratio is associated with a 69bp-71bp smaller decrease of total investment in response to a 25bp monetary policy tightening for these firms. This compares to a 30bp-45bp weaker response in the full sample (see Table 3), and represents around a quarter of the average 3% total investment response (see Figure 4).

These results confirm that, consistent with the stock price response, also the weaker investment response to monetary policy in firms with more intangible assets is more pronounced among financially constrained firms.

4.1.4 Borrowing Response

While we document the weaker credit channel of monetary policy in more intangible firms using predictions on the heterogeneity of firm investment depending on firm financial constraints, the credit channel is fundamentally a liability-side mechanism. If the credit channel is at work, one should expect that firms with more intangible assets adjust not only their investment, but also their borrowing less in response to monetary policy. To provide this consistency check, we extend our analysis and document how firms adjust their borrowing in response to monetary policy.

Figure 6 documents that firms with more intangible capital reduce their debt growth less in response to monetary policy, consistent with a weaker credit channel.[26] Panel A documents that debt growth declines by 0.4-0.6 percentage points 8-12 quarters after a 25bp monetary policy tightening in the full sample (compared to the mean debt growth of 3.8%). Panel B shows that the decline in debt growth is smaller at around 0.2-0.4 percentage point for firms with above-median intangible-to-total capital ratio and larger at up to 0.8 percentage point

[26] Debt growth is defined as the growth in total debt (the sum of short term debt and long term debt), scaled by lagged total debt outstanding. Thus, debt growth measures the net issuance of total debt relative to outstanding debt.

for firms with a below-median intangible ratio. Table 6 tabulates the coefficient estimates of an interaction term of the intangible ratio with the instrumented 1-year Treasury rate across the sample splits by firm financial constraints (analogous to the investment analysis in Table 5). The coefficient estimates are larger among young firms and small firms (panels A-C), and among firms with an above-median *delaycon* financial constraint measure (panel D).[27] For example, the estimates in panel C imply that for firms that are young and small a one standard deviation increase in the intangible-to-total capital ratio is associated with a 25bp smaller reduction in debt growth 8 quarters after a 25bp monetary policy tightening. By contrast, coefficient estimates are not statistically different from zero among firms that are old and large. Thus, the smaller adjustment to debt growth in firms with more intangible assets in response to monetary policy is more pronounced among financially constrained firms, consistent with a weaker credit channel of monetary policy for these firms.

Firms might also respond to monetary policy shocks by issuing equity. This channel, if present, might be more pronounced for firms with intangible assets, as their investment relies on equity financing and responds to equity financing shocks (Brown et al., 2009; Hall and Lerner, 2010). To test for these effects, we consider the effects of monetary policy on the growth of firm book equity, which captures net changes in equity stemming from new issuance, payouts, and retained cashflows. Figure 6 in panels C and D documents that book equity growth does not respond to monetary policy, neither in more tangible nor in more intangible firms.[28] This lack of response is consistent with frictions and costs in public equity

[27] We do not report the results for sample splits by cash holdings because cash holdings affect the need for external financing (and therefore adjustments to debt) also directly, and not only as a proxy for firm financial constraints.

[28] Book equity growth is defined as the growth in book equity scaled by lagged book equity stock, analogous to our definition of debt growth. Internet Appendix, Figure A4 furthermore confirms that also gross equity issuance does not respond to monetary policy. At the same time, payouts to shareholders (dividends and share repurchases) decrease in response to monetary tightening, while cash flows decline, leading altogether to the flat response of book equity growth in Figure 6.

issuance, and with the fact that accumulating internal equity using cashflows takes time.

4.1.5 Implications for Aggregate Investment

Because firms with more intangible capital make more of intangible investment,[29] firm credit constraints should also affect aggregate tangible and intangible investment response to monetary policy. To test for this effect, we analyze the response to monetary policy of the log tangible-to-intangible investment ratio (i.e., the difference in the tangible and intangible investment response, similar to panel D of Figure 4) where tangible and intangible investment are aggregated separately across financially constrained and financially unconstrained firms. As before, we capture financial constraints by age, size, cash holdings, and the *delaycon* measure. We compare the aggregate response by firms in the top and bottom terciles of the distribution by each financial constraints measure, to ensure a clear separation of more- and less-constrained firms.[30]

Figure 7 plots the results. Panel A distinguishes young and old firms, and documents that the difference in the response of tangible and intangible investment to monetary policy reaches 4 percentage points after 10 quarters among old firms, but peaks at over 10 percentage points among young firms. Panel B plots the difference in these differences, which reaches 7 percentage points and is statistically significant. Panels C and D report similar results for the split based on firm size, panels E and F for cash holdings, and panels G and H for the textual analysis-based *delaycon* measure of financial constraints. The result that intangible investment responds less to monetary policy especially among financially constrained firms is consistent throughout. This confirms that the cross-sectional differences between financially

[29] The average tangible over intangible investment ratio is 0.43 among firms with above-median intangible-to-total capital stock, compared to 4.65 among tangible firms below median, see Table 1.

[30] For cash holdings we still compare the top two terciles to the bottom tercile, due to potential non-linearity of cash holdings as a proxy of financial constraints, consistent with the splits used for this measure in the firm-level credit channel results.

constrained and unconstrained firms inform both the weaker monetary policy response in firms with more intangible capital and the weaker intangible (compared to tangible) investment response to monetary policy in the aggregate.

4.2 Depreciation Channel

Intangible assets depreciate faster than tangible assets. The BEA reports R&D capital depreciation rates of 10-40% depending on the industry (Li, 2012), and Ewens et al. (2019) estimate an average R&D capital depreciation rate of 32%. This contrasts with an average tangible capital depreciation rate of under 10% in the BEA data.

Crouzet and Eberly (2019) argue that higher depreciation rates make intangible investment less interest rate sensitive. To see this, consider a standard neoclassical production model. Firms scale up investment until the marginal product of capital equals the user cost of capital, defined as the sum of the interest rate r and the depreciation rate δ: $F'(K_t) = r_t + \delta$. When depreciation rates are high, the elasticity of the user cost of capital with respect to the interest rate is lower. Online Appendix Section A.1 verifies that higher depreciation rates make investment less sensitive to interest rates whenever the marginal product of capital is decreasing and convex. This condition holds for a range of production functions, including Cobb-Douglas.

The depreciation channel predicts that *investment in assets with higher depreciation rates responds less to monetary policy.* A corollary is that *firms with more intangible assets adjust their investment less in response to monetary policy particularly when the gap between tangible and intangible asset depreciation rates is wider.* We test these predictions in turn, using depreciation rate estimates for tangible assets at industry level from the BEA Fixed Assets Tables 3.3 and 3.6, and for intangible assets (R&D capital and organizational capital) from

Ewens et al. (2019).[31]

We first consider the effect of depreciation rates on the response of tangible and intangible investment to monetary policy. Figure 9, panel A, plots the response of intangible investment to a 25bp monetary tightening in firms with high (above-median) and low (below-median) intangible asset depreciation rates. Consistent with the depreciation channel predictions, intangible investment of firms with high depreciation rates responds about half as strong as that of firms with low depreciation rates. Panel B documents similar analysis for tangible investment. While tangible investment with high depreciation rates also responds less to monetary policy compared to that with low depreciation rates, the difference between the two is smaller in relative terms. A possible explanation for this smaller difference is that there is less variation in tangible asset depreciation rates (10.1% versus 7.8% on average for firms with above- and below-median depreciation rates, respectively) than in intangible asset depreciation rates (35.1% and 27.4%).

We then proceed to test whether depreciation rates can explain the weaker monetary policy response in firms with more intangible assets. To do so, we calculate for each firm the difference between its intangible and tangible asset depreciation rates, which we call a firm's "depreciation gap". Table 7 documents the impact of the depreciation gap on the monetary policy response in firms with more intangible assets by splitting the sample into firms with above- and below-median depreciation gap in a given quarter. Panel A reports the stock price response to monetary policy (as in Table 2) on the respective subsamples. The coefficient estimates for the interaction term between ΔFF4 and the firm's intangible ratio are almost twice as large for firms with a high depreciation gap compared to firms with a low depreciation gap. This indicates that the weaker stock price response to monetary policy

[31] In Online Appendix Section A.1 we also verify that higher depreciation rates make firm profits – and hence firm value – less sensitive to interest rates. This prediction underlies our analysis of the effects of monetary policy on stock prices depending on asset depreciation rates.

shocks in firms with more intangible assets is more pronounced in firms with a wider gap between tangible and intangible asset depreciation rates, consistent with the depreciation channel. Panel B documents the total investment response to monetary policy at 8 and 12 quarters horizons (as in Table 3) on the respective subsamples. While the coefficient estimates for the interaction between the instrumented 1-year Treasury rate and the firm's intangible ratio are larger for firms with a high depreciation gap at 8 quarters, there is no difference in the coefficient estimates at 12 quarters.

Overall, the evidence on the role of the depreciation channel in explaining the weaker response of intangible investment to monetary policy is thus mixed. We find that depreciation rates help explain the heterogeneous response of intangible investment across firms and the weaker stock price response for firms with more intangible assets. Yet the depreciation channel offers statistically less significant and short-lived results in explaining the heterogeneous response to monetary policy of tangible investment and the weaker total investment response for firms with more intangible assets. This mixed evidence suggests that, compared to the credit channel, the depreciation channel plays a smaller role in explaining the muted response of intangible investment to monetary policy.

4.3 Adjustment Costs

Another potential reason for a weaker response of intangible investment to monetary policy is its higher adjustment costs. Creating tangible and intangible capital takes planning and production time. This makes investment a forward-looking, not easily reversible, multi-period decision (Bernanke, 1983; Pindyck, 1991). While there is no systematic evidence on the relative adjustment costs of tangible and intangible investment, the literature identifies several features of intangible investment that may contribute to its higher adjustment costs. First, intangible investment is more irreversible because intangible assets often have to be built rather than purchased, and liquidated rather than sold. The reason for this is that intangible assets are firm-specific and therefore not easily redeployable across firms. Second, intangible investment is harder to scale up and down. The creation of intangible assets relies on highly skilled human capital as a key production factor (Döttling et al., 2020), and hiring and firing talent is difficult and costly. For example, Eisfeldt and Papanikolaou (2013) document that organizationally complex firms often list the loss of talent as a risk in their annual reports, and Roberts and Weitzman (1981) argue that R&D often requires sequential and irreversible investment outlays. Consistent with these arguments, Peters and Taylor (2017) document that "compared with physical capital, intangible capital adjusts more slowly to changes in investment opportunities."[32]

Interestingly, the effect of adjustment costs on the responsiveness of investment to monetary policy is ex ante ambiguous. On the one hand, mechanically, investment with high adjustment costs may respond less to monetary policy, especially over shorter time horizons. On the other hand, the literature documents that investment with high adjustment costs responds negatively to uncertainty (Majd and Pindyck, 1987; Bloom, 2009), because uncertainty increases the risk that irreversible investment will not pay off in the future. At the same time, uncertainty responds positively to interest rate shocks (Bekaert et al., 2013).[33] That is, contractionary monetary policy increases uncertainty, which dampens investment with high adjustment costs, while accommodative monetary policy reduces uncertainty, which fosters such investment. Due to this uncertainty effect, investment with high adjustment costs may respond more to monetary policy.[34]

[32]See further discussions on high adjustment costs of intangible investment in Bernstein and Nadiri (1989), Himmelberg and Petersen (1994), and Brown et al. (2009) p. 160.

[33]In our data, the correlation between interest rate shocks and VIX is 0.12 and significant at the 0.1% level.

[34]Note that higher investment adjustment costs may affect the stock price response to monetary policy differently from how they affect the investment response. For example, the market value of a firm with a more inflexible production schedule may respond more negatively to any unanticipated shocks. For this reason, we

Our analysis of the effect of investment adjustment costs on the relative dynamics of tangible and intangible investment is constrained by data availability. Ideally, we would use firm-level data on tangible and intangible investment adjustment costs. This would allow us to compute a firm's "adjustment costs gap" (the difference between adjustment costs of tangible and intangible investment, akin to the "depreciation gap" in Section 4.2) and assess how it affects the relative response of tangible and intangible firms to monetary policy. Unfortunately, the existing proxies of investment adjustment costs cover tangible assets only. Therefore, we cannot test directly whether adjustment costs contribute to the weaker response of intangible investment to monetary policy. Instead, we can shed light on the impact of adjustment costs indirectly, by establishing their effect on the response of tangible investment to monetary policy, and extrapolating this to the comparison between tangible and intangible investment. For this analysis, we use the Hall (2004) industry-level measure of investment adjustment costs and Kim and Kung (2017) firm-level estimates of asset redeployability (redeployable assets can be purchased and sold more easily, and consequently have lower investment adjustment costs).

Figure 8 documents that firms with higher tangible investment adjustment costs, as captured by below-median asset redeployability (panel A) or above-median Hall (2004) investment adjustment costs (panel B), respond, if anything, *more* to monetary policy. This finding is consistent with the effect of investment adjustment costs on monetary policy transmission that operates through the uncertainty channel, and mirrors findings in Kim and Kung (2017) that firms with less redeployable assets respond more to uncertainty shocks. Extrapolating this result to a comparison between tangible and intangible investment suggests that high adjustment costs should make intangible investment respond more to monetary policy, which is counterfactual. This indirect inference relies on the assumption that adjustment costs have

focus our analysis here on the effect of monetary policy on investment only.

similar economic effects for intangible as for tangible investment. Still, taken at face value, it does not support the notion that higher adjustment costs contribute to the weaker response of intangible investment to monetary policy.

A final observation relates to the interaction of investment adjustment costs and the credit channel of monetary policy. Redeployable assets are better collateral, so a firm with redeployable assets can use more debt and experience a stronger credit channel (Benmelech and Bergman, 2009). At the same time, the markets for more redeployable assets are deeper, so the prices of these assets may respond less to interest rates, weakening the credit channel.[35] Therefore, the link between asset redeployability and the intensity of the credit channel of monetary policy is a priori ambiguous. Consistent with this, we find no difference in the effect of asset redeployability on the monetary policy response of tangible investment between financially constrained firms (which are more subject to the credit channel) and unconstrained firms (see Online Appendix Table A6). This suggests that, empirically, the effect of adjustment costs on the response of investment to monetary policy is distinct from the credit channel.

5 Conclusion

Technological progress and the transition to a service economy increase the importance of corporate intangible assets. This paper sheds light on the implications of this transition for monetary policy. The key result is that monetary policy impacts investment less when more of corporate capital is intangible. The stock prices and investment of firms with more intangible assets respond less to monetary policy, and intangible investment responds less

[35] In Online Appendix Section 2, Kim and Kung (2017) highlight that the markets for more redeployable assets are deeper and therefore their prices respond less to shocks, consistent with Shleifer and Vishny (1992) and Zhang (2005). This effect can be represented as a lower Q'(r) in our model of the credit channel in Section 4.1.

to monetary policy compared to tangible investment. In the cross-section, the attenuating effect of intangible assets is most pronounced among credit constrained firms, consistent with intangible capital muting the credit channel of monetary policy. We also find somewhat weaker evidence that higher intangible capital depreciation rates contribute to these effects. Lastly, indirect evidence is not consistent with higher adjustment costs explaining the weaker responsiveness of intangible investment.

These findings have important economic policy implications. The result that the rise of intangible capital makes corporate investment less responsive to monetary policy helps shed light on why investment has responded only tepidly to substantial monetary easing during the last decade. Technological progress is likely to keep elevating the role of intangible capital, further weakening the investment channel of monetary policy in the future. Given these frictions in the transmission of monetary policy, intangible investment may best be encouraged not by traditional monetary policy, but by other means. These can include fiscal policies and structural reforms that support innovation and equity markets, and possibly expanding unconventional monetary policy tools to support equity financing of firms.

References

Aghion, P., P. Askenazy, N. Berman, G. Cette, and L. Eymard (2012). Credit constraints and the cyclicality of R&D investment: Evidence from France. *Journal of the European Economic Association 10*(5), 1001–1024.

Bahaj, S. A., A. Foulis, and G. Pinter (2020). Home values and firm behaviour. *American Economic Review 110*(7), 2225–70.

Barlevy, G. (2007). On the cyclicality of research and development. *American Economic Review 97*(4), 1131–1164.

Bates, T. W., K. M. Kahle, and R. M. Stulz (2009). Why do US firms hold so much more cash than they used to? *Journal of Finance 64*(5), 1985–2021.

Bekaert, G., M. Hoerova, and M. L. Duca (2013). Risk, uncertainty and monetary policy. *Journal of Monetary Economics 60*(7), 771–788.

Benmelech, E. and N. K. Bergman (2009). Collateral pricing. *Journal of Financial Economics 91*(3), 339–360.

Bernanke, B. S. (1983). Irreversibility, uncertainty, and cyclical investment. *Quarterly Journal of Economics 98*(1), 85–106.

Bernanke, B. S., M. Gertler, and S. Gilchrist (1999). The financial accelerator in a quantitative business cycle framework. *Handbook of Macroeconomics 1*, 1341–1393.

Bernanke, B. S. and K. N. Kuttner (2005). What explains the stock market's reaction to federal reserve policy? *Journal of Finance 60*(3), 1221–1257.

Bernstein, J. I. and M. I. Nadiri (1989). Rates of return on physical and R&D capital and structure of the production process: Cross section and time series evidence. In *Advances in Econometrics and Modelling*, pp. 169–187. Springer.

Bianchi, F., H. Kung, and G. Morales (2019). Growth, slowdowns, and recoveries. *Journal of Monetary Economics 101*, 47–63.

Bloom, N. (2009). The impact of uncertainty shocks. *Econometrica 77*(3), 623–685.

Brown, J. R., S. M. Fazzari, and B. C. Petersen (2009). Financing innovation and growth: Cash flow, external equity, and the 1990s R&D boom. *Journal of Finance 64*(1), 151–185.

Brown, J. R., G. Martinsson, and B. C. Petersen (2013). Law, stock markets, and innovation. *Journal of Finance 68*(4), 1517–1549.

Caggese, A. and A. Pérez-Orive (2020). How stimulative are low real interest rates for intangible capital?

Carpenter, R. E. and B. C. Petersen (2002). Is the growth of small firms constrained by internal finance? *Review of Economics and Statistics 84*(2), 298–309.

Chakraborty, I., I. Goldstein, and A. MacKinlay (2020). Monetary stimulus and bank lending. *Journal of Financial Economics 136*(1), 189–218.

Chaney, T., D. Sraer, and D. Thesmar (2012). The collateral channel: How real estate shocks affect corporate investment. *American Economic Review 102*(6), 2381–2409.

Chava, S. and A. Hsu (2020). Financial constraints, monetary policy shocks, and the cross-section of equity returns. *Review of Financial Studies 33*(9), 4367–4402.

Cloyne, J., C. Ferreira, M. Froemel, and P. Surico (2018). Monetary policy, corporate finance and investment. *NBER Working Paper 25366*.

Coibion, O. (2012). Are the effects of monetary policy shocks big or small? *American Economic Journal: Macroeconomics 4*(2), 1–32.

Corrado, C., J. Haskel, and C. Jona-Lasinio (2017). Knowledge spillovers, ICT and productivity growth. *Oxford Bulletin of Economics and Statistics 79*(4), 592–618.

Corrado, C., J. Haskel, C. Jona-Lasinio, and M. Iommi (2018). Intangible investment in the EU and US before and since the great recession and its contribution to productivity growth. *Journal of Infrastructure, Policy and Development 2*(1), 11–36.

Corrado, C., C. Hulten, and D. Sichel (2009). Intangible capital and us economic growth. *Review of Income and Wealth 55*(3), 661–685.

Corrado, C. A. and C. R. Hulten (2010). How do you measure a "technological revolution"? *American Economic Review 100*(2), 99–104.

Crouzet, N. and J. Eberly (2020). Rents and intangible capital: A q+ framework.

Crouzet, N. and J. C. Eberly (2019). Understanding weak capital investment: The role of market concentration and intangibles. *NBER Working Paper 25869*.

Cunha, I. and J. Pollet (2019, 11). Why Do Firms Hold Cash? Evidence from Demographic Demand Shifts. *Review of Financial Studies 33*(9), 4102–4138.

Dell'Ariccia, G., D. Kadyrzhanova, C. Minoiu, and L. Ratnovski (2020). Bank lending in the knowledge economy. *Review of Financial Studies forthcoming*.

Döttling, R., T. Ladika, and E. C. Perotti (2020). Creating intangible capital.

Duval, R., G. H. Hong, and Y. Timmer (2020). Financial frictions and the great productivity slowdown. *Review of Financial Studies 33*(2), 475–503.

Eisfeldt, A. L. and D. Papanikolaou (2013). Organization capital and the cross-section of expected returns. *Journal of Finance 68*(4), 1365–1406.

Elliott, D., R. R. Meisenzahl, J.-L. Peydró, and B. C. Turner (2019). Nonbanks, banks, and monetary policy: US loan-level evidence since the 1990s. *Available at SSRN 3475427*.

Ewens, M., R. Peters, and S. Wang (2019). Measuring intangible capital with market prices. *NBER*

Working Paper 25960.

Falato, A., D. Kadyrzhanova, J. Sim, and R. Steri (2020). Rising intangible capital, shrinking debt capacity, and the us corporate savings glut.

Farre-Mensa, J. and A. Ljungqvist (2016). Do measures of financial constraints measure financial constraints? *Review of Financial Studies 29*(2), 271–308.

Fatas, A. (2000). Do business cycles cast long shadows? Short-run persistence and economic growth. *Journal of Economic Growth 5*(2), 147–162.

Gertler, M. and S. Gilchrist (1994). Monetary policy, business cycles, and the behavior of small manufacturing firms. *Quarterly Journal of Economics 109*(2), 309–340.

Gertler, M. and P. Karadi (2015). Monetary policy surprises, credit costs, and economic activity. *American Economic Journal: Macroeconomics 7*(1), 44–76.

Gilchrist, S. and E. Zakrajšek (2012). Credit spreads and business cycle fluctuations. *American Economic Review 102*(4), 1692–1720.

Gurkaynak, R. S., B. P. Sack, and E. T. Swanson (2005). Do actions speak louder than words? The response of asset prices to monetary policy actions and statements. *International Journal of Central Banking 1*(1), 55–93.

Hadlock, C. J. and J. R. Pierce (2010). New evidence on measuring financial constraints: Moving beyond the KZ index. *Review of Financial Studies 23*(5), 1909–1940.

Hall, B. H. (2002). The financing of research and development. *Oxford Review of Economic Policy 18*(1), 35–51.

Hall, B. H. and J. Lerner (2010). The financing of R&D and innovation. In *Handbook of the Economics of Innovation*, Volume 1, pp. 609–639. Elsevier.

Hall, R. E. (2004). Measuring factor adjustment costs. *Quarterly Journal of Economics 119*(3), 899–927.

Haskel, J. (2020). Monetary policy in the intangible economy.

Himmelberg, C. P. and B. C. Petersen (1994). R&D and internal finance: A panel study of small firms in high-tech industries. *Review of Economics and Statistics*, 38–51.

Hoberg, G. and V. Maksimovic (2015). Redefining financial constraints: A text-based analysis. *Review of Financial Studies 28*(5), 1312–1352.

Jarocinski, M. and P. Karadi (2020). Deconstructing monetary policy surprises: The role of information shocks. *American Economic Journal: Macroeconomics 12*(2), 1–43.

Jeenas, P. (2018). Monetary policy shocks, financial structure, and firm activity: A panel approach.

Jiménez, G., S. Ongena, J.-L. Peydró, and J. Saurina (2014). Hazardous times for monetary policy: What do twenty-three million bank loans say about the effects of monetary policy on credit risk-taking? *Econometrica 82*(2), 463–505.

Jordà, Ò. (2005). Estimation and inference of impulse responses by local projections. *American Economic Review 95*(1), 161–182.

Kashyap, A. K., O. A. Lamont, and J. C. Stein (1994). Credit conditions and the cyclical behavior of inventories. *Quarterly Journal of Economics 109*(3), 565–592.

Kim, H. and H. Kung (2017). The asset redeployability channel: How uncertainty affects corporate investment. *Review of Financial Studies 30*(1), 245–280.

Kiyotaki, N. and J. Moore (1997). Credit cycles. *Journal of Political Economy 105*(2), 211–248.

Kuttner, K. N. (2001). Monetary policy surprises and interest rates: Evidence from the fed funds futures market. *Journal of Monetary Economics 47*(3), 523–544.

Li, W. C. (2012). Depreciation of business R&D capital. *Bureau of Economic Analysis/National Science Foundation R&D Satellite Account Paper*.

Loumioti, M. (2012). The use of intangible assets as loan collateral.

Majd, S. and R. S. Pindyck (1987). Time to build, option value, and investment decisions. *Journal of Financial Economics 18*(1), 7–27.

Mann, W. (2018). Creditor rights and innovation: Evidence from patent collateral. *Journal of Financial Economics 130*(1), 25–47.

Ottonello, P. and T. Winberry (2020). Financial heterogeneity and the investment channel of monetary policy. *Econometrica 88*(6), 2473–2502.

Ozdagli, A. K. (2018). Financial frictions and the stock price reaction to monetary policy. *Review of Financial Studies 31*(10), 3895–3936.

Peters, R. H. and L. A. Taylor (2017). Intangible capital and the investment-q relation. *Journal of Financial Economics 123*(2), 251–272.

Pindyck, R. S. (1991). Irreversibility, uncertainty, and investment. *Journal of Economic Literature 29*(3), 1110–1148.

Rampini, A. A. and S. Viswanathan (2013). Collateral and capital structure. *Journal of Financial Economics 109*(2), 466–492.

Roberts, K. and M. L. Weitzman (1981). Funding criteria for research, development, and exploration projects. *Econometrica*, 1261–1288.

Shleifer, A. and R. W. Vishny (1992). Liquidation values and debt capacity: A market equilibrium approach. *Journal of Finance 47*(4), 1343–1366.

Zhang, L. (2005). The value premium. *Journal of Finance 60*(1), 67–103.

Table 1: Summary Statistics of Compustat Variables

Summary statistics are reported for all firms, and for intangible and tangible firms separately. Intangible firms are defined as those with an above-median intangible ratio (intangible-to-total capital ratio) in a given quarter. Tangible firms are below the median. The sample runs from 1991-2016 and includes all firms in the matched CRSP-Compustat sample excluding financial firms, utilities and government. Variable definitions are in Table A1.

	All			Intangible Firms			Tangible Firms		
	mean	p50	sd	mean	p50	sd	mean	p50	sd
Intangible Ratio	0.580	0.657	0.289	0.815	0.824	0.0972	0.345	0.354	0.218
Tobin's Q	1.676	1.396	0.899	1.765	1.463	0.953	1.581	1.333	0.826
Cash	0.129	0.0596	0.162	0.168	0.0908	0.186	0.0940	0.0458	0.121
Leverage	0.287	0.247	0.251	0.230	0.188	0.226	0.310	0.281	0.239
Age	63.87	50	48.18	68.37	55	48.14	66.31	52	49.39
Book Assets	1.925	0.287	8.273	1.734	0.298	6.231	2.362	0.321	10.67
Total Assets	2.360	0.405	9.886	2.454	0.475	8.671	2.626	0.388	12.08
Cashflows	0.0311	0.0322	0.0366	0.0298	0.0314	0.0378	0.0343	0.0341	0.0338
Dividend Paid	0.433	0	0.496	0.400	0	0.490	0.482	0	0.500
Debt Growth	0.0382	-0.00860	0.340	0.0337	-0.0108	0.368	0.0454	-0.00717	0.325
Equity Growth	0.0148	0.0105	0.187	0.0158	0.0121	0.182	0.0172	0.0107	0.184
Delaycon	-0.0152	-0.0216	0.0884	-0.0205	-0.0273	0.0888	-0.0117	-0.0172	0.0871
Depreciation Gap	0.223	0.236	0.0565	0.224	0.234	0.0593	0.223	0.236	0.0527
Total Inv. Rate	0.0548	0.0448	0.0401	0.0549	0.0468	0.0357	0.0550	0.0424	0.0442
Tangible Inv. Rate	0.0663	0.0463	0.0663	0.0761	0.0562	0.0672	0.0580	0.0394	0.0623
Intan Inv. Rate	0.0552	0.0475	0.0375	0.0523	0.0456	0.0346	0.0582	0.0499	0.0399
CAPX / Intan Inv.	2.424	0.509	6.152	0.426	0.259	0.846	4.652	1.483	8.402
CAPX / R&D	1.733	0.546	3.968	0.790	0.388	1.746	4.243	1.857	6.339
Observations	318305			137863			137915		

Table 2: Stock Returns Around FOMC Meetings

The dependent variable is a firm's stock return on FOMC announcement days. Columns 1-3 consider raw returns, and columns 4 and 5 consider abnormal returns, with betas estimated over a 100-day window before the event date using the CRSP value-weighted index as market benchmark. ΔFF4 is the change in the 3-months ahead Fed Funds futures rate in the 30 minutes around the FOMC announcement. *Intangible Ratio* is a firm's intangible-to-total capital ratio. Other control variables are defined in Table A1. The sample includes all FOMC meetings over 1991-2016, except the meeting on September 17, 2001, and covers all firms in the matched CRSP-Compustat sample excluding financial firms, utilities and government. Industry fixed effects are based on 4-digit NAICS codes. Standard errors in parenthesis are clustered by event date and industry. ***, **, * indicate significance levels of 1%, 5%, and 10%, respectively.

	(1) Raw Return	(2) Raw Return	(3) Raw Return	(4) Abnormal Return	(5) Abnormal Return
ΔFF4	-4.36**				
	(1.76)				
ΔFF4 × Intangible Ratio		1.53**	1.45**	1.56**	1.42**
		(0.67)	(0.70)	(0.64)	(0.67)
ΔFF4 × Log Age		0.62**	0.65***	0.076	0.090
		(0.24)	(0.24)	(0.27)	(0.27)
ΔFF4 × Tobin's Q		-0.37	-0.41	0.15	0.13
		(0.49)	(0.49)	(0.31)	(0.31)
ΔFF4 × Cash		-3.78*	-3.90*	-0.11	-0.12
		(2.28)	(2.20)	(1.03)	(1.00)
ΔFF4 × Leverage		-0.33	-0.34	-1.08	-1.13
		(0.96)	(0.95)	(0.88)	(0.88)
ΔFF4 × Cashflows		-1.93	-1.17	-7.51*	-7.33
		(6.42)	(6.89)	(4.26)	(4.50)
ΔFF4 × Log Size		-0.59**	-0.61**	-0.027	-0.027
		(0.28)	(0.27)	(0.11)	(0.12)
ΔFF4 × Dividend Paid		0.43	0.38	-0.23	-0.27
		(0.37)	(0.38)	(0.21)	(0.22)
Observations	435218	426442	426391	426442	426391
R-squared	0.030	0.243	0.263	0.143	0.164
Industry × Event-Date FE	No	Yes	Yes	Yes	Yes
Firm FE	Yes	No	Yes	No	Yes
Fiscal Quarter FE	Yes	Yes	Yes	Yes	Yes
Firm-Level Controls	Yes	Yes	Yes	Yes	Yes

Table 3: Investment Response

The dependent variable is the h-quarter change in the log total investment rate. $\hat{R}$ is the 1-year Treasury rate, instrumented by cumulative high-frequency monetary policy shocks measured as changes in the 3-month ahead Fed Funds futures rate in the 30 minutes window around FOMC announcements. *Intangible Ratio* is a firm's intangible-to-total capital ratio. Other control variables are defined in Table A1. The sample covers all firms in the matched CRSP-Compustat sample excluding financial firms, utilities and government from 1991-2016. In parentheses we report Driscoll-Kraay heteroscedasticity and autocorrelation robust standard errors standard errors. ***, **, * indicate significance levels of 1%, 5%, and 10%, respectively. Non-interacted coefficients are omitted for brevity.

	$h=8$			$h=12$		
	(1) ΔI_t^{tot}	(2) ΔI_t^{tot}	(3) ΔI_t^{tot}	(4) ΔI_t^{tot}	(5) ΔI_t^{tot}	(6) ΔI_t^{tot}
$\hat{R}$	-0.10***			-0.12***		
	(0.016)			(0.023)		
$\hat{R}$ × Intangible Ratio		0.049**	0.041***		0.059**	0.056***
		(0.019)	(0.012)		(0.023)	(0.015)
$\hat{R}$ × Log Age		0.0095***	0.011***		0.0068*	0.0096***
		(0.0035)	(0.0025)		(0.0035)	(0.0023)
$\hat{R}$ × Tobin's Q		-0.0061*	-0.0028		-0.0041	-0.0018
		(0.0031)	(0.0028)		(0.0031)	(0.0028)
$\hat{R}$ × Cash		0.024***	0.012		0.026***	0.015**
		(0.0079)	(0.0074)		(0.0071)	(0.0059)
$\hat{R}$ × Leverage		-0.0051	-0.0073		-0.018***	-0.018**
		(0.0054)	(0.0064)		(0.0065)	(0.0078)
$\hat{R}$ × Cashflows		0.028	-0.033		0.029	-0.058
		(0.043)	(0.039)		(0.052)	(0.051)
$\hat{R}$ × Size		0.00056	-0.00084		0.0022**	0.00088
		(0.00076)	(0.00058)		(0.00089)	(0.00070)
$\hat{R}$ × Dividend Paid		0.0016	0.0021		-0.0016	-0.0012
		(0.0033)	(0.0033)		(0.0037)	(0.0043)
Observations	159027	159027	153742	141590	141590	136627
R-squared	0.080	0.055	0.046	0.105	0.075	0.063
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes	Yes	Yes	Yes
Macro Controls	Yes	No	No	Yes	No	No
Time FE	No	Yes	No	No	Yes	No
Industry × Time FE	No	No	Yes	No	No	Yes
Fiscal Quarter FE	Yes	Yes	Yes	Yes	Yes	Yes

Table 4: Stock Returns Around FOMC Meetings - Sample Splits Credit Channel

This table replicates the stock returns regressions from Table 2 for different sub-samples of firms. Age and size splits compare below-median to above median firms in the respective distribution. High cash firms are those in the top tercile of the cash-to-asset ratio distribution in a given quarter, and low cash are those in the bottom two terciles. In panel E, more (less) constrained firms have an above-median (below-median) textual analysis-based *delaycon* financial constraints measure of Hoberg and Maksimovic (2015). The dependent variables are raw or abnormal stock returns on FOMC announcement days. ΔFF4 is the change in the 3-month ahead Fed Futures rate in the 30 minutes around the FOMC announcement. *Intangible Ratio* is the firm's intangible-to-total capital ratio. The sample includes all FOMC meetings over 1991-2016, except the meeting on September 17, 2001, and covers all firms in the matched CRSP-Compustat sample excluding financial firms, utilities and government. All regressions include firm fixed effects, fiscal quarter fixed effects, and industry × event-date fixed effects based on 4-digit NAICS codes, as well as the same control variables and interaction terms as in the baseline regression (Table 2). Standard errors in parentheses are clustered by event date and industry. ***, **, *, §, indicate significance levels of 1%, 5%, 10%, and 15%, respectively.

	(1) Raw Return	(2) Abnormal Return	(3) Raw Return	(4) Abnormal Return
Panel A: Split by Age				
	Young		Old	
ΔFF4 × Intangible Ratio	2.07*	1.94**	1.32§	0.95
	(1.07)	(0.91)	(0.89)	(0.82)
Observations	201366	201366	208744	208744
Panel B: Split by Size				
	Small		Large	
ΔFF4 × Intangible Ratio	2.03*	1.88*	0.59	0.69
	(1.14)	(0.99)	(0.89)	(0.78)
Observations	196357	196357	214956	214956
Panel C: Split by Age & Size				
	Young & Small		Old & Large	
ΔFF4 × Intangible Ratio	4.18***	3.83***	-0.14	-0.24
	(0.90)	(0.67)	(1.09)	(1.18)
Observations	109334	109334	122746	122746
Panel D: Split by Cash Holdings				
	High Cash		Low Cash	
ΔFF4 × Intangible Ratio	2.78**	2.55***	0.47	0.66
	(1.13)	(0.97)	(1.01)	(1.02)
Observations	141777	141777	270370	270370
Panel E: Split by Delaycon				
	More Constrained		Less Constrained	
ΔFF4 × Intangible Ratio	2.25§	2.66***	1.51	0.31
	(1.51)	(0.96)	(1.84)	(1.36)
Observations	116378	116378	122967	122967

Table 5: Investment Response - Sample Splits Credit Channel

This table replicates the investment regressions from Table 3 on different sub-samples. Age and size splits compare below-median to above median firms in the respective distribution. High cash firms are those in the top tercile of the cash-to-asset ratio distribution in a given quarter, and low cash are those in the bottom two terciles. In panel E, more (less) constrained firms have an above-median (below-median) textual analysis-based *delaycon* financial constraints measure of Hoberg and Maksimovic (2015). The dependent variable is the h-quarter change in the log total investment rate. $\hat{R}$ is the 1-year Treasury rate, instrumented by cumulative high-frequency monetary policy shocks. *Intangible Ratio* is the firm's intangible-to-total capital ratio. All regressions include firm fixed effects, fiscal quarter fixed effects and time fixed effects, as well as the same control variables and interaction terms as in the baseline regressions (Table 3). In parentheses we report Driscoll-Kraay heteroscedasticity and autocorrelation robust standard errors standard errors. ***, **, * indicate significance levels of 1%, 5%, and 10%, respectively.

	(1) ΔI_t^{tot} $h = 8$	(2) ΔI_t^{tot} $h = 12$	(3) ΔI_t^{tot} $h = 8$	(4) ΔI_t^{tot} $h = 12$
Panel A: Split by Age				
	Young		Old	
$\hat{R} \times$ Intangible Ratio	0.081***	0.094***	0.040**	0.049**
	(0.022)	(0.024)	(0.019)	(0.023)
Observations	73515	64253	85398	77245
Panel B: Split by Size				
	Small		Large	
$\hat{R} \times$ Intangible Ratio	0.086***	0.085***	0.036**	0.049**
	(0.021)	(0.025)	(0.018)	(0.021)
Observations	70575	61129	88260	80279
Panel C: Split by Age & Size				
	Young & Small		Old & Large	
$\hat{R} \times$ Intangible Ratio	0.098***	0.095***	0.025	0.034
	(0.028)	(0.028)	(0.019)	(0.022)
Observations	39879	34314	54733	50440
Panel D: Split by Cash Holdings				
	High Cash		Low Cash	
$\hat{R} \times$ Intangible Ratio	0.092***	0.10***	0.036*	0.042*
	(0.019)	(0.025)	(0.021)	(0.022)
Observations	53136	47181	105270	93839
Panel E: Split by Delaycon				
	More Constrained		Less Constrained	
$\hat{R} \times$ Intangible Ratio	0.078***	0.088***	0.042**	0.040*
	(0.023)	(0.025)	(0.020)	(0.021)
Observations	48488	42951	52132	46566

Table 6: Debt Growth - Sample Splits Credit Channel

This table presents estimates of the firm borrowing response to monetary policy. The dependent variable is the h-quarter change in debt growth, defined as the growth rate of short-term and long-term debt. Age and size splits compare below-median to above median firms in the respective distribution. In panel D, more (less) constrained firms have an above-median (below-median) textual analysis-based *delaycon* financial constraints measure of Hoberg and Maksimovic (2015). $\hat{R}$ is the 1-year Treasury rate, instrumented by cumulative high-frequency monetary policy shocks measured as changes in the 3-month ahead Fed Funds futures rate in the 30 minutes window around FOMC announcements. *Intangible Ratio* is the firm's intangible-to-total capital ratio. Other control variables are defined in Table A1. The sample covers all firms in the matched CRSP-Compustat sample excluding financial firms, utilities and government from 1991-2016. All regressions include firm fixed effects, fiscal quarter fixed effects and time fixed effects, as well as the same control variables and interaction terms as in the baseline investment regressions (Table 3). In parentheses we report Driscoll-Kraay heteroscedasticity and autocorrelation robust standard errors standard errors. ***, **, * indicate significance levels of 1%, 5%, and 10%, respectively.

	(1) Δ Debt Growth $h = 8$	(2) Δ Debt Growth $h = 12$	(3) Δ Debt Growth $h = 8$	(4) Δ Debt Growth $h = 12$
Panel A: Split by Age				
	Young		Old	
$\hat{R}$ × Intangible Ratio	0.016***	0.011**	0.0077	0.0074
	(0.0047)	(0.0050)	(0.0049)	(0.0045)
Observations	65419	56452	79770	71790
Panel B: Split by Size				
	Small		Large	
$\hat{R}$ × Intangible Ratio	0.032***	0.031***	0.0013	-0.00091
	(0.0060)	(0.0062)	(0.0036)	(0.0036)
Observations	59156	50340	85923	77787
Panel C: Split by Age & Size				
	Young & Small		Old & Large	
$\hat{R}$ × Intangible Ratio	0.034***	0.018**	0.0011	-0.0011
	(0.0069)	(0.0082)	(0.0046)	(0.0043)
Observations	33052	27908	53693	49370
Panel D: Split by Delaycon				
	More Constrained		Less Constrained	
$\hat{R}$ × Intangible Ratio	0.021***	0.019***	0.012**	0.0072
	(0.0062)	(0.0048)	(0.0061)	(0.0053)
Observations	43343	37960	46074	40657

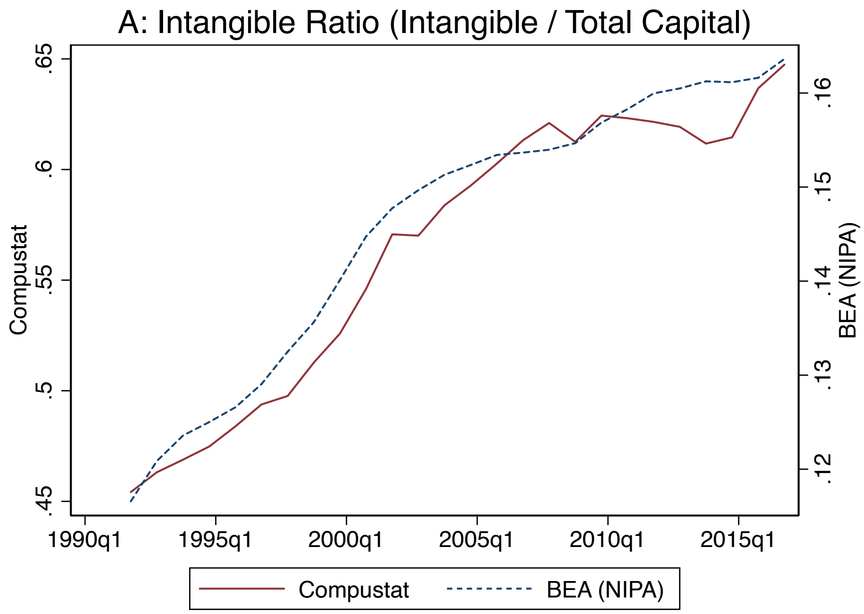
Table 7: Sample Splits by Depreciation Gap

This table replicates the baseline investment and stock price results for firms with above- and below-median *depreciation gap*, defined as the difference between a firm's intangible and tangible asset depreciation rates in a given quarter. Panel A replicates the stock returns regressions from Table 2 and the dependent variables are raw or abnormal stock returns on FOMC announcement days. $\Delta FF4$ is the change in the 3-month ahead Fed Futures rate in the 30 minutes around the FOMC announcement. Panel B replicates the investment regressions from Table 3 and the dependent variable is the h-quarter change in the log total investment rate. $\hat{R}$ is the 1-year Treasury rate, instrumented by cumulative high-frequency monetary policy shocks measured as changes in the 3-month ahead Fed Funds futures rate in the 30 minutes window around FOMC announcements. *Intangible Ratio* is the firm's intangible-to-total capital ratio. Other control variables are defined in Table A1. The sample includes all FOMC meetings over 1991-2016, except the meeting on September 17, 2001, and covers all firms in the matched CRSP-Compustat sample excluding financial firms, utilities and government. All regressions include the same fixed effects and control variables as in the baseline regressions from Tables 2 and 3, respectively. Standard errors are in parentheses. ***, **, * indicate significance levels of 1%, 5%, and 10%, respectively.

Panel A: Stock Returns				
	High Depreciation Gap		Low Depreciation Gap	
	(1) Raw Return	(2) Abnormal Return	(3) Raw Return	(4) Abnormal Return
ΔFF4 × Intangible Ratio	2.20*	1.90*	1.18	1.38
	(1.11)	(1.12)	(1.00)	(0.96)
Observations	198490	198490	212553	212553
Panel B: Investment				
	High Depreciation Gap		Low Depreciation Gap	
	ΔI_t^{tot} $h=8$	ΔI_t^{tot} $h=12$	ΔI_t^{tot} $h=8$	ΔI_t^{tot} $h=12$
$\hat{R}$ × Intangible Ratio	0.058**	0.061*	0.042***	0.062***
	(0.025)	(0.031)	(0.015)	(0.017)
Observations	75065	66224	82374	74000

Figure 1: Intangible vs Physical Capital and Investment

This figure plots the evolution of the aggregate tangible-to-total capital and investment ratios in Compustat and BEA data. The aggregated Compustat data is based on public firms and defines intangible investment as investment in research and development (R&D) and organizational capital (measured as a portion of SG&A expenditures). The BEA data is based on all establishments and defines intangible investment as that in intellectual property products (IPP).



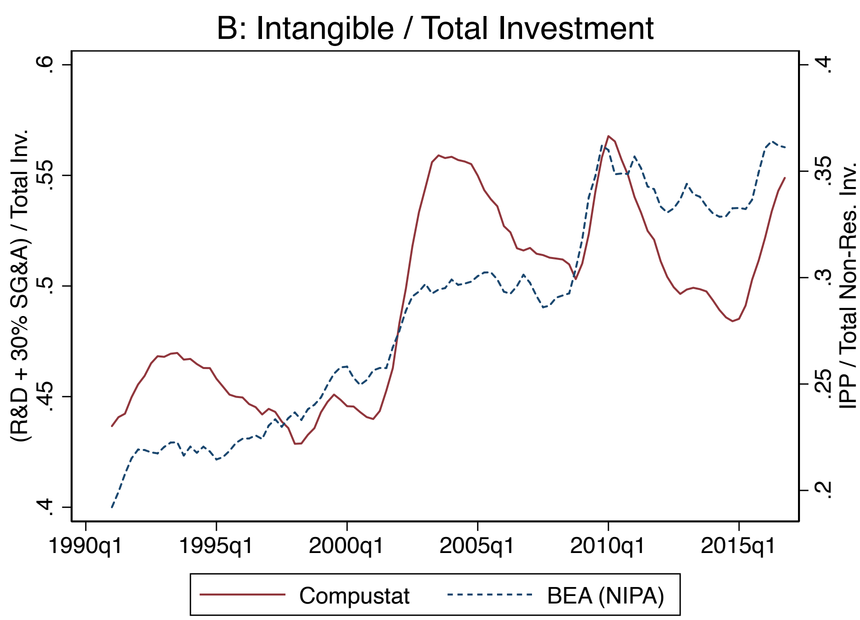


Figure 2: Decomposing Investment Growth

This figure plots the growth rates of investment ratios in Compustat and BEA data. The aggregated Compustat data is based on public firms and defines intangible investment as investment in research and development (R&D) and organizational capital (measured as a portion of SG&A expenditures). The BEA data is based on all establishments and defines intangible investment as that in intellectual property products (IPP).

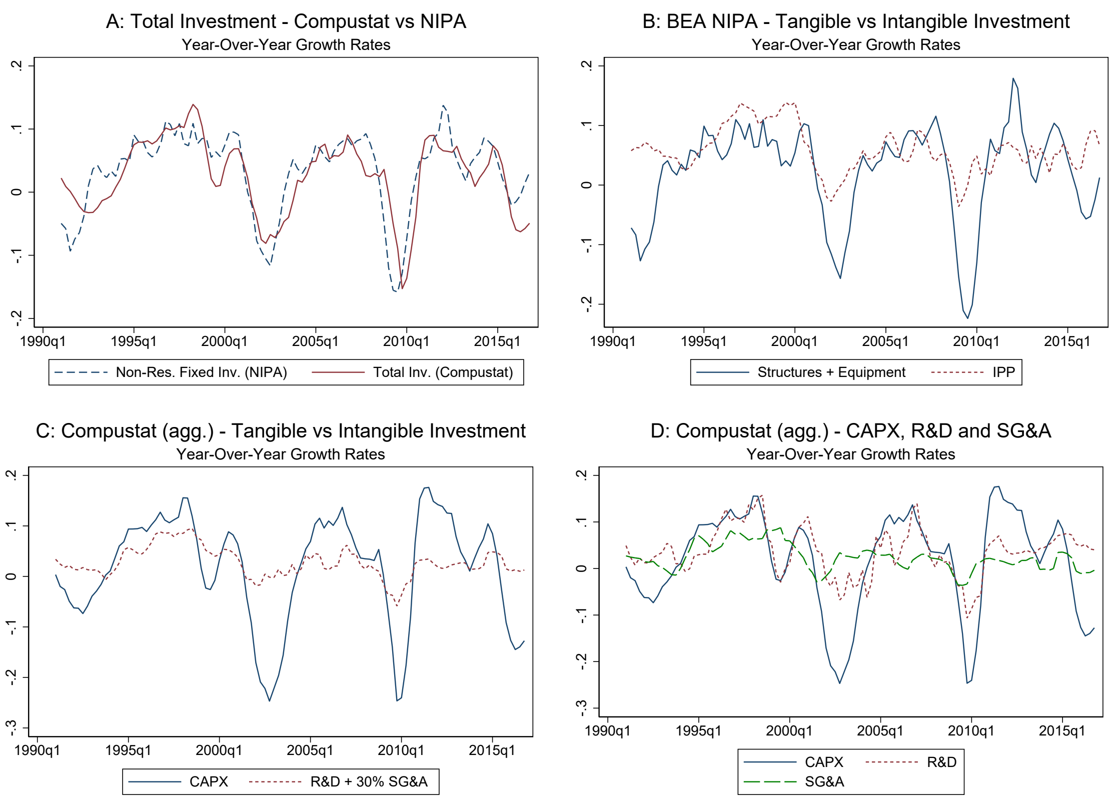


Figure 3: Monetary Policy Measures

This figure plots the 1-year Treasury rate along the cumulative high-frequency FF4 shocks that are identified from movements in Fed Funds futures rates around FOMC meetings. The predicted 1-year Treasury rate is the predicted rate from the first-stage regression with cumulative FF4 shocks and macroeconomic control variables (see Online Appendix Table A4).

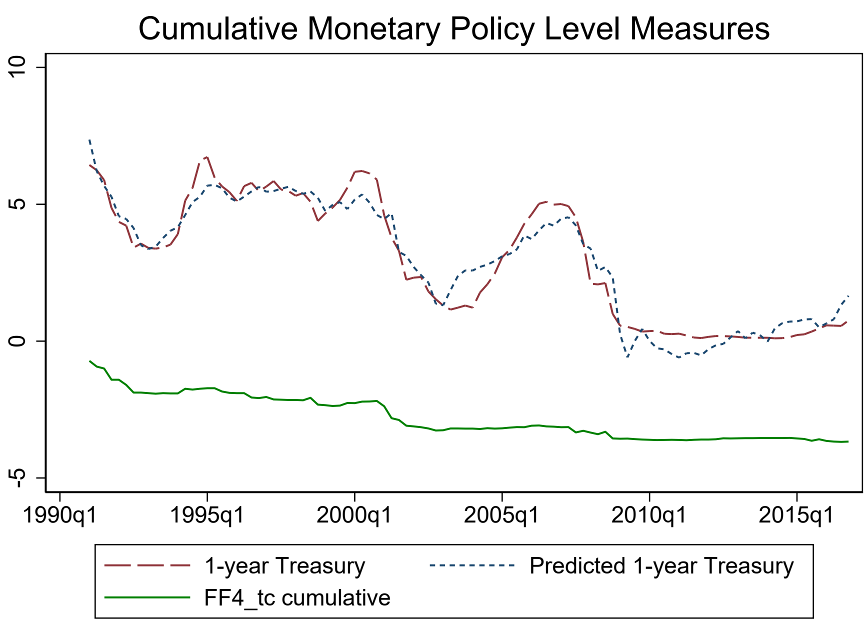


Figure 4: Firm-level Investment Response

The figure plots impulse responses to a 25bp increase in the 1-year Treasury rate, estimated using the instrumental-variable local projections specification (2). The 1-year Treasury rate is instrumented by cumulative high-frequency monetary policy shocks measured as changes in the 3-month ahead Fed Funds futures rate in the 30 minutes window around FOMC announcements. The sample covers all firms in the matched CRSP-Compustat sample excluding financial firms, utilities and government from 1991-2016. Each point represents the point estimate of the coefficient of instrumented the 1-year Treasury rate (β_1^h in Eq. (2)). All regressions include firm and macro controls, as well as firm $\times$ fiscal quarter fixed effects. The dashed line represents 95% confidence intervals using heteroscedasticity and autocorrelation robust Driscoll-Kraay standard errors. Intangible firms (tangible firms) are firms with an above-median (below-median) intangible-to-total capital ratio in a given quarter.

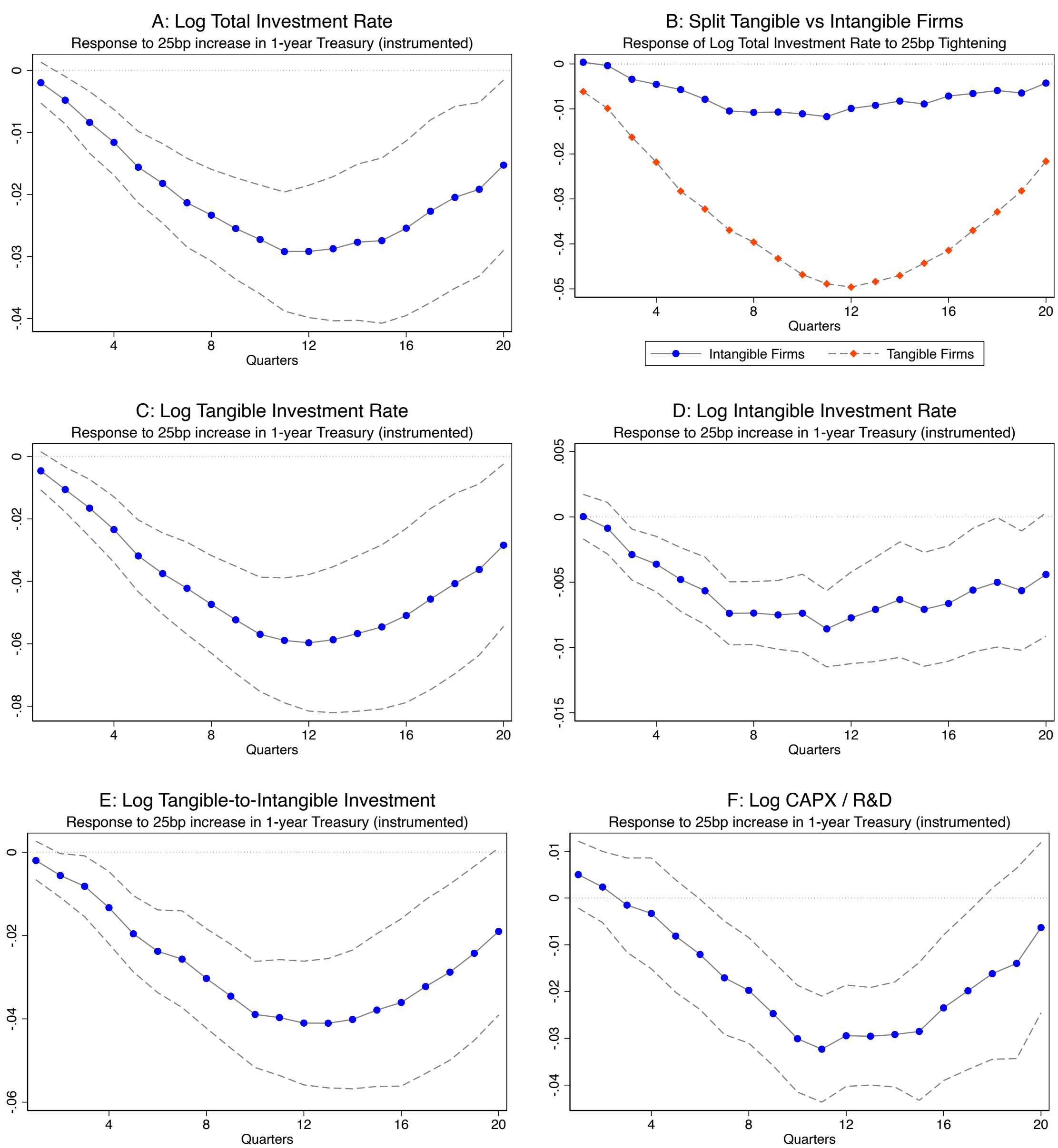


Figure 5: Aggregate Investment Response (NIPA)

This figure plots impulse responses to a 25bp increase in the 1-year Treasury rate, estimated using the instrumental-variable local projection specification (3). The 1-year Treasury rate is instrumented by cumulative high-frequency monetary policy shocks measured as changes in the 3-month ahead Fed Funds futures rate in the 30 minutes window around FOMC announcements. The sample covers 1991-2016. Each point represents the point estimate of the coefficient of the instrumented 1-year Treasury rate. All regressions include macro controls log CPI, log industrial production, excess bond premium, and the log of the employment ratio. The dashed line represents 95% confidence intervals using Newey-West standard errors.

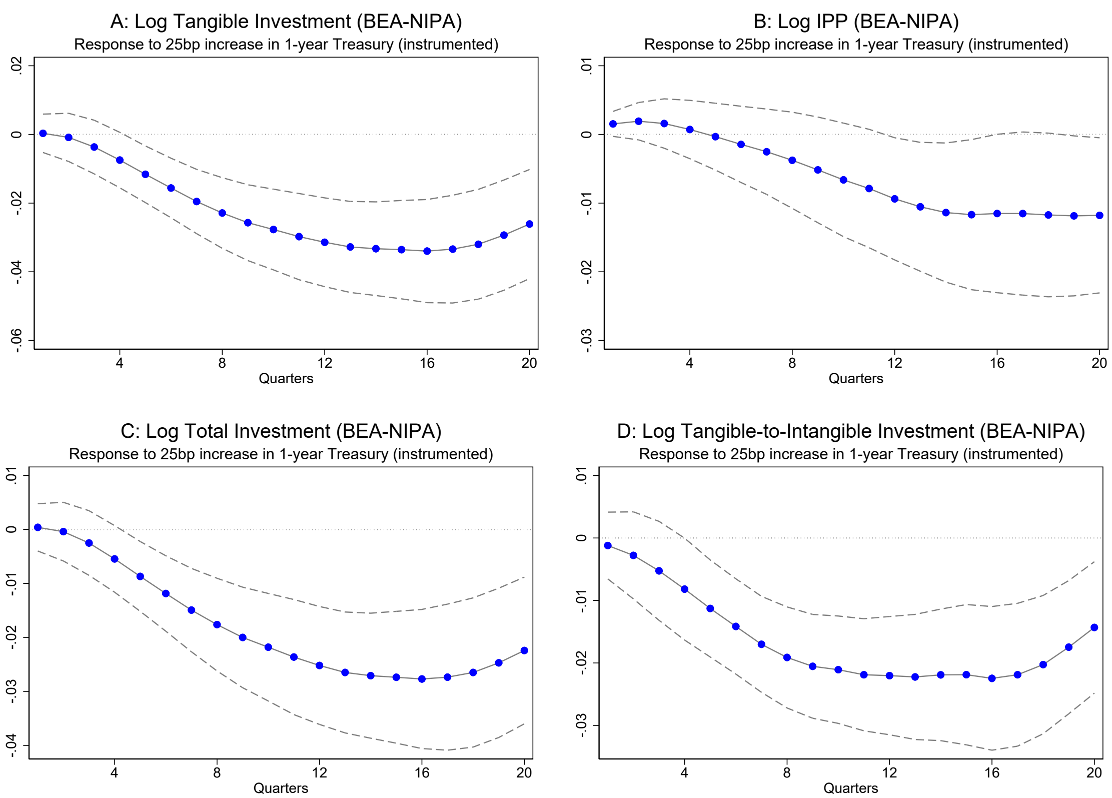


Figure 6: Firm-level Borrowing Response

This figure plots impulse responses to a 25bp increase in the 1-year Treasury rate, estimated using instrumental-variable local projections. Debt growth is defined as the growth rate of short-term and long-term debt (i.e., net debt issuance). Equity growth is defined as the growth rate of book equity (i.e., net increase in shareholder capital). The 1-year Treasury rate is instrumented by cumulative high-frequency monetary policy shocks measured as changes in the 3-month ahead Fed Funds futures rate in the 30 minutes window around FOMC announcements. The sample covers all firms in the matched CRSP-Compustat sample excluding financial firms, utilities and government from 1991-2016. Each point represents the point estimate of the coefficient of instrumented the 1-year Treasury rate (β_1^h in Eq. (2)). All regressions include firm and macro controls, as well as firm $\times$ fiscal quarter fixed effects. The dashed line represents 95% confidence intervals using heteroscedasticity and autocorrelation robust Driscoll-Kraay standard errors. Intangible firms (tangible firms) are firms with an above-median (below-median) intangible-to-total capital ratio in a given quarter.

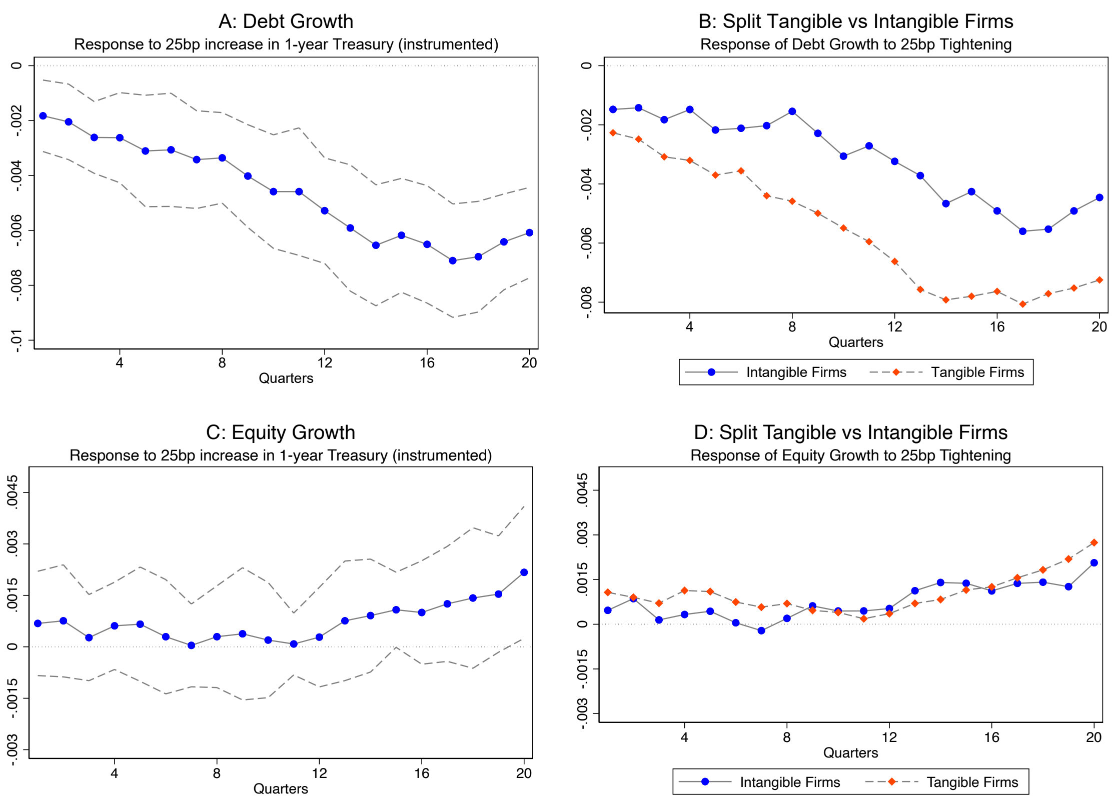


Figure 7: Response of Aggregate Compustat Tangible-to-Intangible Investment - Credit Channel

This figure plots impulse responses of the aggregate log tangible-to-intangible investment rate to a 25bp increase in the instrumented 1-year Treasury rate. Each panel represents aggregations within different sub-sets of firms. Young (old) firms and small (large) firms are those in the lowest (highest) tercile of the age and size distribution in a given quarter, respectively. High cash firms are those in the top tercile in the cash-to-assets distribution in a given quarter, and low cash firms are those in the bottom two terciles. High (low) *delaycon* firms are in the highest (lowest) tercile of the distribution of the textual analysis-based delaycon measure of financial constraints of Hoberg and Maksimovic (2015). All regressions include macro controls log CPI, log industrial production, excess bond premium and the log of the employment ratio. The dashed line represents 95% confidence intervals using Newey-West standard errors.

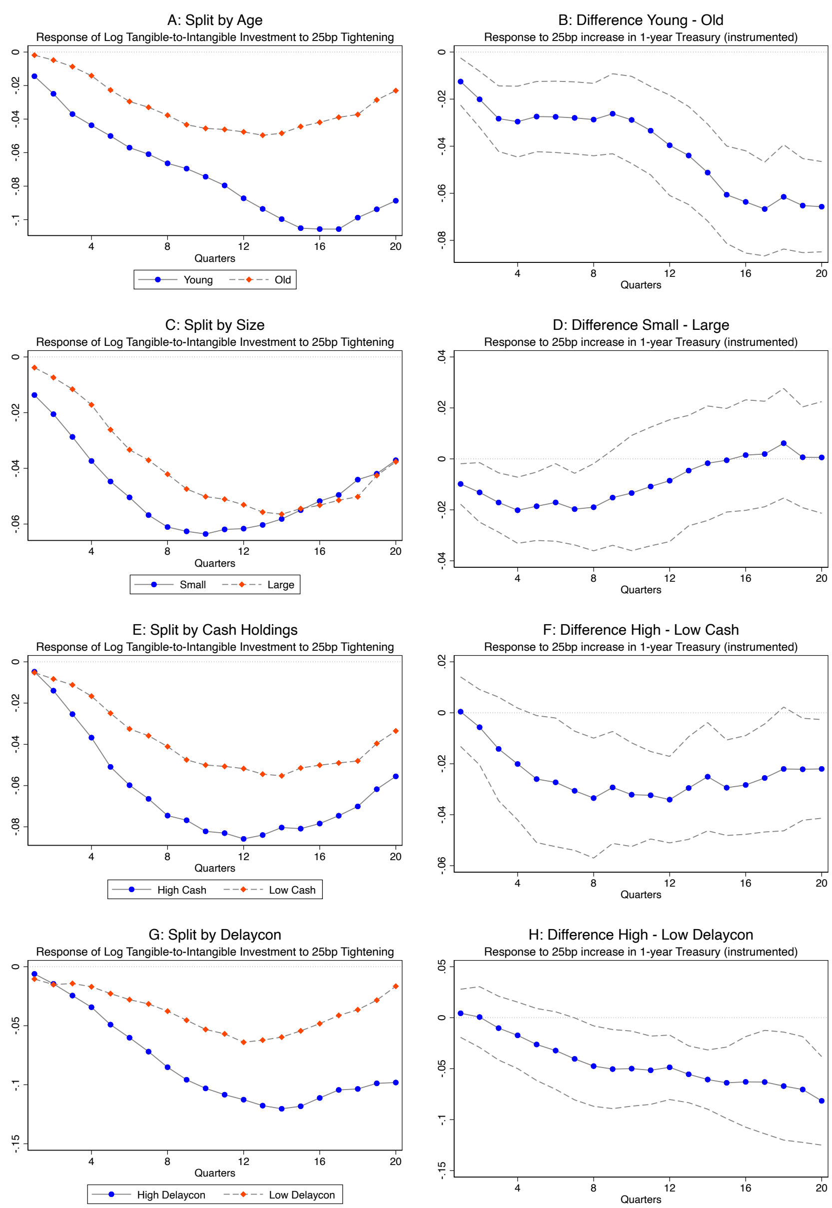


Figure 8: Tangible and Intangible Investment Response - Sample Splits by Depreciation Rates

This figure plots impulse responses of tangible investment rate and intangible investment rate to a 25bp increase in the 1-year Treasury rate on different sub-samples. High (low) depreciation firms have a tangible or intangible depreciation rate above (below) the median in a given quarter. The 1-year Treasury rate is instrumented by cumulative high-frequency monetary policy shocks measured as changes in the 3-month ahead Fed Funds futures rate in the 30 minutes window around FOMC announcements. The sample covers all firms in the matched CRSP-Compustat sample excluding financial firms, utilities and government from 1991-2016. Each point represents the point estimate of the coefficient of instrumented the 1-year Treasury rate (β_1^h in Eq. (2)). All regressions include firm and macro controls, as well as firm $\times$ fiscal quarter fixed effects.

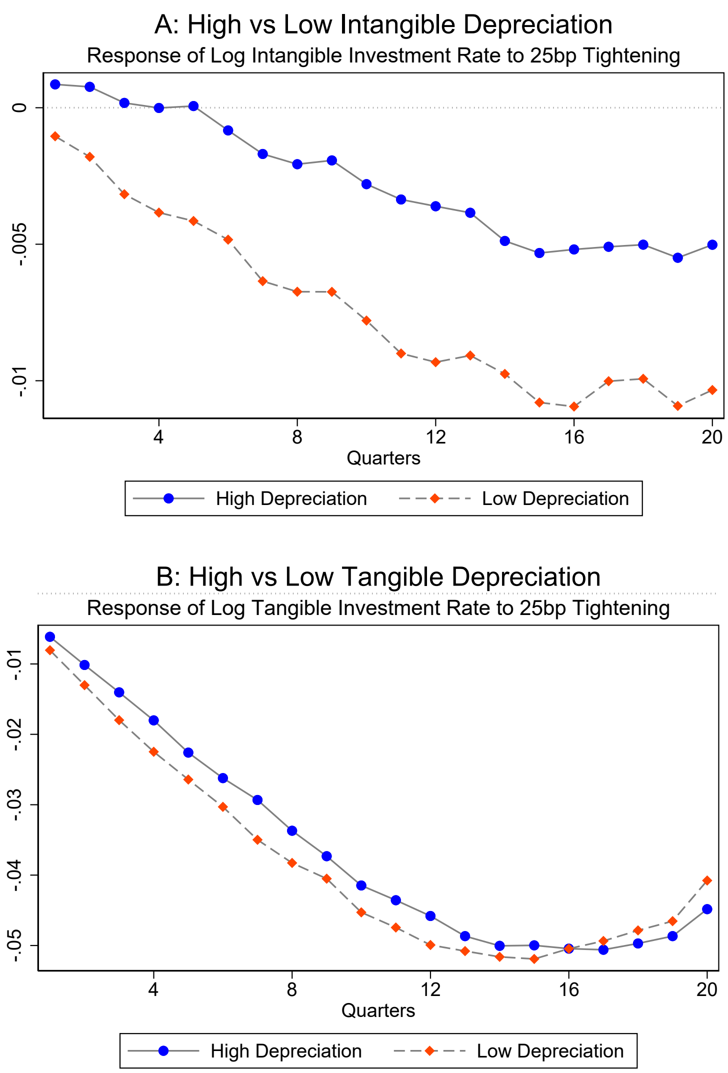
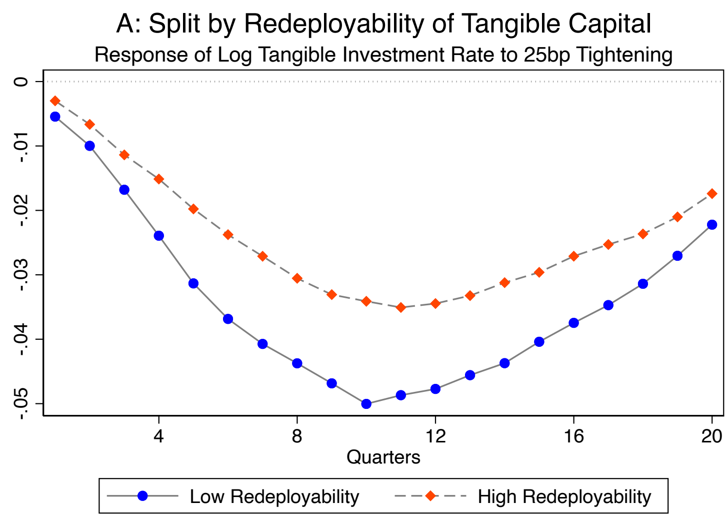
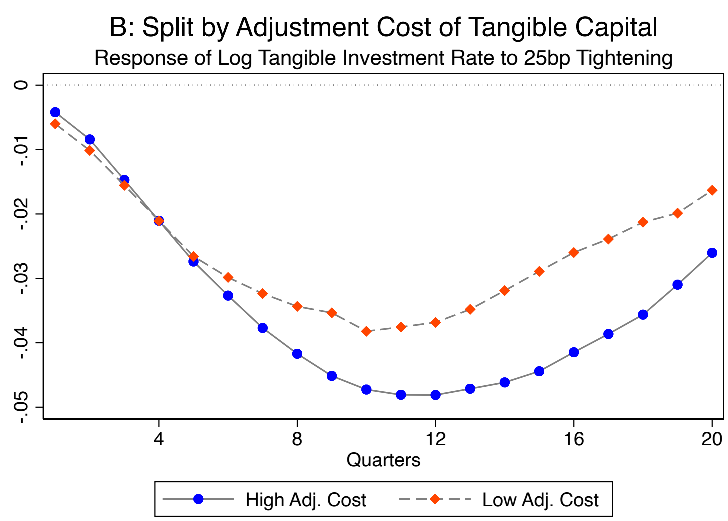


Figure 9: Tangible Investment Response - Sample Splits by Redeployability and Adjustment Cost

This figure plots impulse responses of tangible investment rate to a 25bp increase in the 1-year Treasury rate on different sub-samples, estimated using instrumental-variable local projections. High (low) redeployability firms have an asset redeployability estimate from Kim and Kung (2017) above (below) the median in a given quarter. High (low) adjustment cost firms have an investment adjustment cost estimate from Hall (2004) above (below) the median in a given quarter. The 1-year Treasury rate is instrumented by cumulative high-frequency monetary policy shocks measured as changes in the 3-month ahead Fed Funds futures rate in the 30 minutes window around FOMC announcements. The sample covers all firms in the matched CRSP-Compustat sample excluding financial firms, utilities and government from 1991-2016. Each point represents the point estimate of the coefficient of instrumented the 1-year Treasury rate (β_1^h in Eq. (2)). All regressions include firm and macro controls, as well as firm $\times$ fiscal quarter fixed effects.





Online Appendix

Table A1: Definitions of Compustat Variables

Variable	Definition
Physical Capital	PPENT
Intangible Capital	Off-balance sheet intangibles from Peters and Taylor (2017) + Compustat item INTAN
Total Capital	Physical Capital + Intangible Capital
Intangible Ratio	Intangible Capital / Total Capital
Intangible Investment	XRD + 0.3 $\times$ XSGA
Total Investment	CAPX + Intangible Investment
Intangible Investment Rate	Intangible Investment / Lagged Intangible Capital
Physical Investment Rate	CAPX / Lagged PPENT
Total Investment Rate	Total Investment / Lagged Total Capital
Tobin's Q	(CSHO * PRCC + Total Assets - CE) / Total Assets
Cash	CHE / AT
Leverage	(DLTT + DLC) / AT
Age	Quarters since first observation in Compustat
Delaycon	Financial constraint measure from Hoberg and Maksimovic (2015), based on textual analysis of annual reports
Total Assets	AT + Off-balance sheet intangibles
Size	Log of Total Assets
Cashflows	OIBDP / Lagged AT
Dividend Paid	Dummy whether DVT > 0 in a given fiscal year
Debt Growth	Change in (DLTT + DLC) / Lagged (DLTT + DLC)
Equity Growth	Change in CEQ / Lagged CEQ

Table A2: Definitions of Aggregate Variables

Variable	Definition	Data Source
Physical Investment	Non-residential investment in structures and equipment	BEA Fixed Asset Table 2.3
Intangible Investment	Investment in Intellectual Property Products (IPP)	BEA Fixed Asset Table 2.3
Total Investment	Physical + Intangible Investment	BEA Fixed Asset Table 2.3
1-year Treasury	Interest Rate on 1-year U.S. Treasuries (GS1)	FRED
CPI	Consumer Price Index (CPALTT01USM661S)	FRED
Employment Ratio	Employment-Population Ratio (EMRATIO)	FRED
Industrial Production	Industrial Production Index (INDPRO)	FRED
Business Investment	Gross private domestic investment: Domestic business (W987RC1Q027SBEA)	FRED
Excess Bond Premium	Excess bond premium of Gilchrist and Zakrajšek (2012)	Authors' website

Table A3: Stock Returns - Robustness to Decomposition into Monetary Policy and Central Bank Information Shocks from Jarocinski and Karadi (2020) and Intangible Capital Measure from Ewens et al. (2019)

This table documents robustness tests for the baseline Table 2. Panel A decomposes changes in the Fed Funds futures into interest rate shocks (MPshockSign) and central bank information shocks (CBIshockSign), as in Jarocinski and Karadi (2020). Panel B uses the intangible capital stock measure from Ewens et al. (2019) (EPW). The dependent variables are raw or abnormal stock returns on FOMC announcement days. Abnormal returns betas are estimated over a 100-day window before the event date, using CRSP value-weighted index as market benchmark. ΔFF4 is the change in the 3-month ahead Fed Futures rate in the 30 minutes around the FOMC announcement. *Intangible Ratio* is the firm's intangible-to-total capital ratio. Other control variables are defined in Table A1. The sample includes all FOMC meetings over 1991-2016, except the meeting on September 17, 2001, and covers all firms in the matched CRSP-Compustat sample excluding financial firms, utilities and government. Industry fixed effects are based on 4-digit NAICS codes. Standard errors in parentheses clustered by event date and industry. ***, **, * indicate significance levels of 1%, 5%, and 10%, respectively. Non-interacted coefficients are omitted for brevity.

	(1) Raw Return	(2) Raw Return	(3) Raw Return	(4) Abnormal Return	(5) Abnormal Return
Panel A: MP-CBI Decomposition					
MPshockSign	-7.50***				
	(1.75)				
CBIshockSign	6.05**				
	(2.90)				
MPshockSign × Intangible Ratio		1.77**	1.67*	1.78**	1.61**
		(0.87)	(0.87)	(0.78)	(0.79)
CBIshockSign × Intangible Ratio		1.03	1.00	0.97	0.88
		(1.24)	(1.30)	(1.32)	(1.36)
Observations	435218	426442	426391	426442	426391
R-squared	0.030	0.243	0.263	0.143	0.164
Panel B: EPW Intangible Measure					
ΔFF4	-4.36**				
	(1.77)				
ΔFF4 × Intangible Ratio (EPW)		1.44**	1.31*	1.28**	1.08*
		(0.68)	(0.69)	(0.61)	(0.63)
Observations	451394	442081	442027	442081	442027
R-squared	0.030	0.240	0.259	0.142	0.162
Industry × Event-Date FE	No	Yes	Yes	Yes	Yes
Firm FE	Yes	No	Yes	No	Yes
Fiscal Quarter FE	Yes	Yes	Yes	Yes	Yes
(Interacted) Firm-Level Controls	Yes	Yes	Yes	Yes	Yes

Table A4: First Stage Regression

This table reports the results from the first-stage regression. The dependent variable is the 1-year Treasury rate and the instrument is the cumulative high-frequency FF4 shocks (FF4_tc), lagged by one quarter. Column 2 uses the monetary policy shocks from the decomposition by Jarocinski and Karadi (2020). Regressions include lagged macro controls. Newey-West standard errors are reported in parentheses.

	(1) R	(2) R
FF4_tc	2.29***	
	(0.32)	
MPShockSign_tc		3.29***
		(0.43)
Log CPI	13.8***	10.2*
	(4.78)	(5.78)
Log Industrial Production	-8.07**	-8.40*
	(4.01)	(4.96)
Excess Bond Premium	-0.81***	-0.87***
	(0.16)	(0.16)
Log Employment Ratio	62.6***	63.2***
	(11.6)	(13.1)
Observations	107	107
F stat	135	184
Adj R2	0.93	0.92

Table A5: Investment Response - Robustness to Using Pure Monetary Policy Shocks from Jarocinski and Karadi (2020) and Intangible Capital Measure from Ewens et al. (2019)

This table documents robustness tests for the baseline Table 3 investment results. The dependent variable is the h-quarter change in the log total investment rate. $\hat{R}$ is the 1-year Treasury rate, instrumented by cumulative high-frequency shocks, each measured as a change in the 3-month ahead Fed Funds futures rate in the 30 minutes window around FOMC announcements. *Intangible Ratio* is the firm's intangible-to-total capital ratio. Other control variables are defined in Table A1. Panel A uses as instrument pure monetary policy shocks $\hat{R}$ (MPS) from the decomposition by Jarocinski and Karadi (2020). Panel B uses the intangible capital stock measure from Ewens et al. (2019) (EPW) to measure the intangible capital stock and investment. The sample includes all FOMC meetings over 1991-2016, except the meeting on September 17, 2001, and covers all firms in the matched CRSP-Compustat sample excluding financial firms, utilities and government. In parentheses we report Driscoll-Kraay heteroscedasticity and autocorrelation robust standard errors standard errors. ***, **, * indicate significance levels of 1%, 5%, and 10%, respectively. Non-interacted coefficients are omitted for brevity.

	$h=8$			$h=12$		
	(1)	(2)	(3)	(4)	(5)	(6)
	ΔI_t^{tot}	ΔI_t^{tot}	ΔI_t^{tot}	ΔI_t^{tot}	ΔI_t^{tot}	ΔI_t^{tot}
Panel A: MP-CBI Decomposition						
$\hat{R}$ (MPS)	-0.070***			-0.10***		
	(0.018)			(0.021)		
$\hat{R}$ (MPS) × Intangible Ratio		0.039*	0.035**		0.056**	0.053***
		(0.022)	(0.014)		(0.026)	(0.016)
Observations	159027	159027	153742	141590	141590	136627
R-squared	0.075	0.054	0.046	0.101	0.075	0.063
Panel B: EPW Intangible Measure						
$\hat{R}$	-0.11***			-0.13***		
	(0.022)			(0.027)		
$\hat{R}$ × Intangible Ratio (EPW)		0.045**	0.030**		0.050*	0.035**
		(0.020)	(0.014)		(0.025)	(0.017)
Observations	158741	158741	153455	141321	141321	136356
R-squared	0.095	0.055	0.044	0.125	0.075	0.060
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm Controls	Yes	Yes	Yes	Yes	Yes	Yes
Macro Controls	Yes	No	No	Yes	No	No
Time FE	No	Yes	No	No	Yes	No
Industry × Time FE	No	No	Yes	No	No	Yes
Fiscal Quarter FE	Yes	Yes	Yes	Yes	Yes	Yes

Table A6: Response of Tangible Investment to Monetary Policy by Tangible Asset Redeployability and Financial Constraints

This table presents estimates of the coefficient on the instrumented 1-year Treasury rate at 12 quarters (β_1^{12}) from estimating Eq. (2) on different sub-samples. The dependent variable is the h-quarter change in the log total investment rate. Age and size splits compare below-median to above median firms in the respective distribution. High cash firms are those in the top tercile of the cash-to-asset ratio distribution in a given quarter, and low cash are those in the bottom two terciles. High (low) delaycon firms have an above-median (below-median) textual analysis-based *delaycon* financial constraints measure of Hoberg and Maksimovic (2015). The sample includes all firms in the matched CRSP-Compustat sample from 1991-2016, excluding financial firms, utilities and government. In parentheses we report Driscoll-Kraay heteroscedasticity and autocorrelation robust standard errors standard errors. ***, **, * indicate significance levels of 1%, 5%, and 10%, respectively.

	High Redeployability	Low Redeployability	Difference
Old	-0.18***	-0.1736***	0.0064
Young	-0.18***	-0.1841***	-0.0041
Large	-0.18***	-0.162***	0.018
Small	-0.20***	-0.22***	-0.020
Low Delaycon	-0.17***	-0.1629***	0.0071
High Delaycon	-0.22***	-0.2122***	0.0078
High Cash	-0.19***	-0.19***	0.000042
Low Cash	-0.19***	-0.162***	0.028

Table A7: Correlation Table

This table reports correlations between selected variables in the quarterly firm-level data. The sample includes all firms in the matched CRSP-Compustat sample except financial firms, utilities and government. Variable definitions are given in Table A1.

	Age	Size	Cash	Delaycon	Depr. Gap	Redeployability
Age	1.000					
Size	0.4115	1.000				
Cash	-0.122	-0.139	1.000			
Delaycon	-0.157	0.016	0.145	1.000		
Depreciation Gap	-0.021	-0.033	-0.082	-0.067	1.000	
Redeployability	-0.092	0.018	-0.070	0.012	-0.243	1.000
Adjustment Costs	0.007	-0.024	0.037	0.008	0.031	-0.056

Figure A1: Response of Other Macro Variables

This figure plots impulse responses of a number of macroeconomic variables to a 25bp increase in the 1-year Treasury rate, estimated using the instrumental-variable local projections specification (2). The 1-year Treasury rate is instrumented by cumulative high-frequency monetary policy shocks measured as changes in the 3-month ahead Fed Funds futures rate in the 30 minutes window around FOMC announcements. The sample covers 1991-2016. Each point represents the point estimate of the coefficient of instrumented the 1-year Treasury rate. All regressions include macro controls log CPI, log industrial production, the excess bond premium, and the log of the employment ratio (excluding the respective dependent variable). The dashed line represents 95% confidence intervals using Newey-West standard errors.

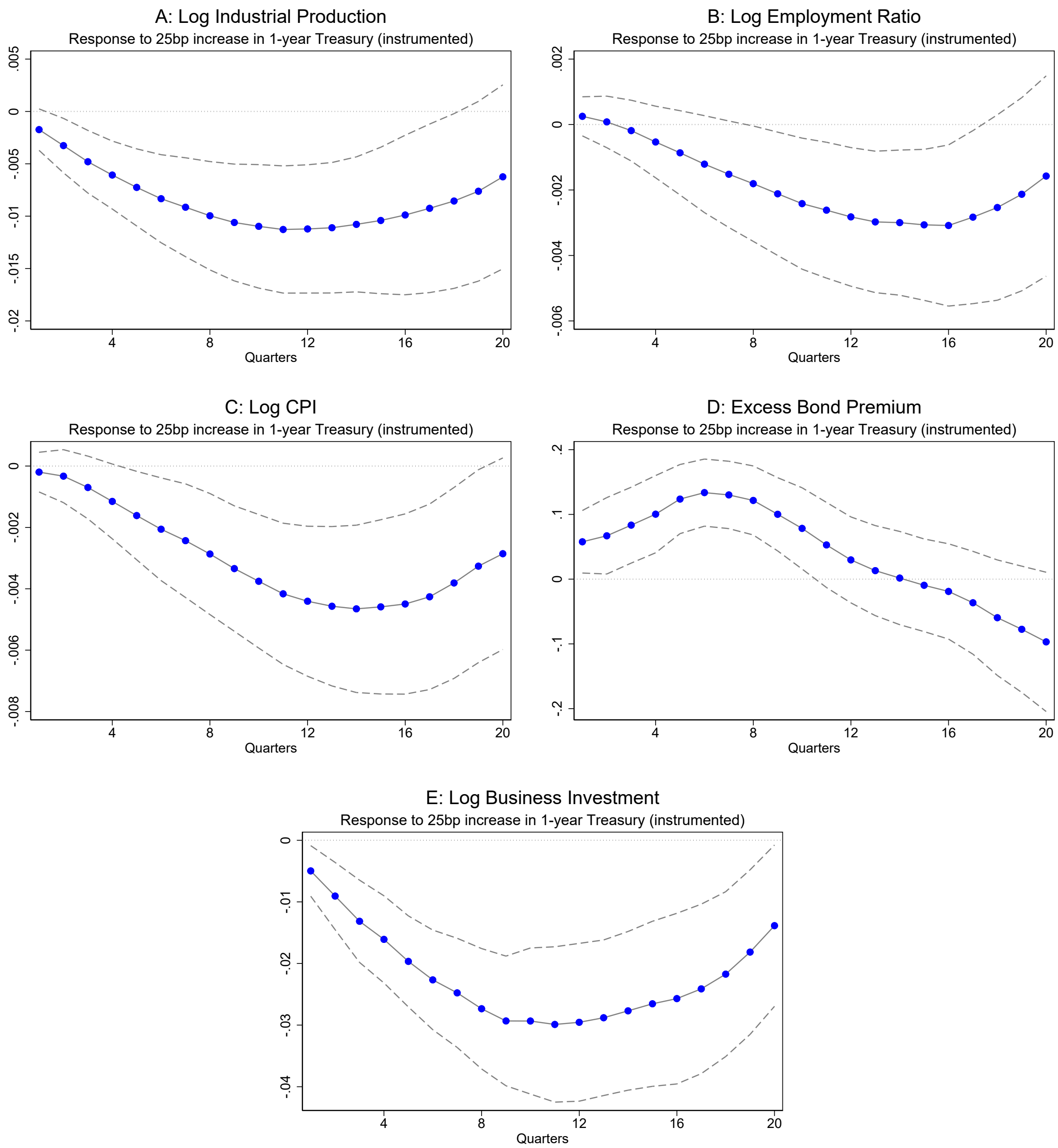


Figure A2: Firm-level Investment Response - Robustness to Monetary Policy Shock and Central Bank Information Decomposition from Jarocinski and Karadi (2020)

This figure presents robustness of Figure 4 using monetary policy shocks from Jarocinski and Karadi (2020) as instrument. The figure plots impulse responses to a 25bp increase in the 1-year Treasury rate, estimated using the instrumental-variable local projections specification (2). The sample covers all firms in the matched CRSP-Compustat sample excluding financial firms, utilities and government from 1991-2016. Each point represents the point estimate of the coefficient of the instrumented 1-year Treasury (β_1^h in Eq. 2). All regressions include firm and macro controls, as well as firm $\times$ fiscal quarter fixed effects. Intangible firms (tangible firms) are firms with an above-median (below-median) intangible-to-total capital ratio in a given quarter. The dashed line represents 95% confidence intervals using heteroscedasticity and autocorrelation robust Driscoll-Kraay standard errors.

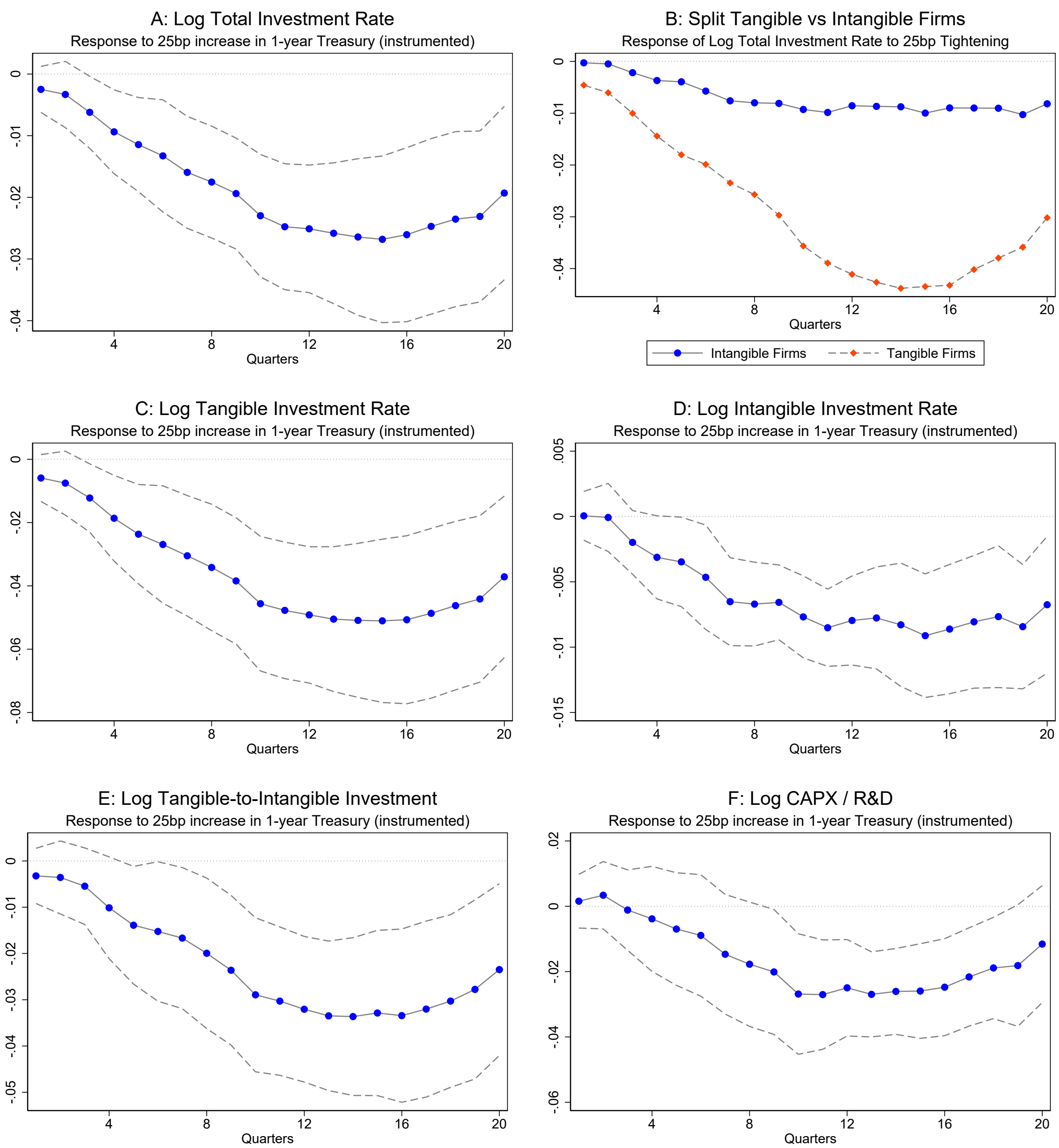


Figure A3: Aggregate Investment Response calculated from Compustat Firm-Level Data

This figure plots impulse responses of a number of macroeconomic variables to a 25bp increase in the 1-year Treasury rate, estimated using the instrumental-variable local projections specification (2). The 1-year Treasury rate is instrumented by cumulative high-frequency monetary policy shocks measured as changes in the 3-month ahead Fed Funds futures rate in the 30 minutes window around FOMC announcements. The sample covers 1991-2016. Each point represents the point estimate of the coefficient of instrumented the 1-year Treasury rate. The sample covers all firms in the matched CRSP-Compustat sample excluding financial firms, utilities and government from 1991-2016. All regressions include macro controls log CPI, log industrial production, the excess bond premium, and the log of the employment ratio (excluding the respective dependent variable). The dashed line represents 95% confidence intervals using Newey-West standard errors.

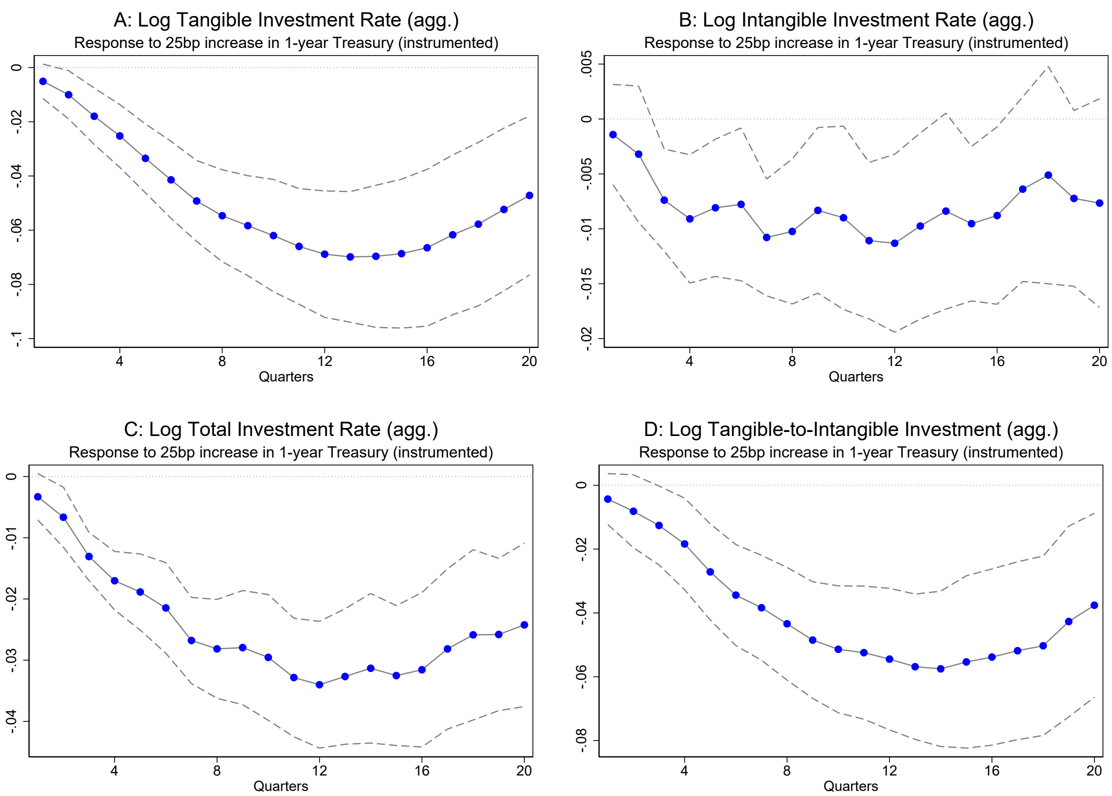
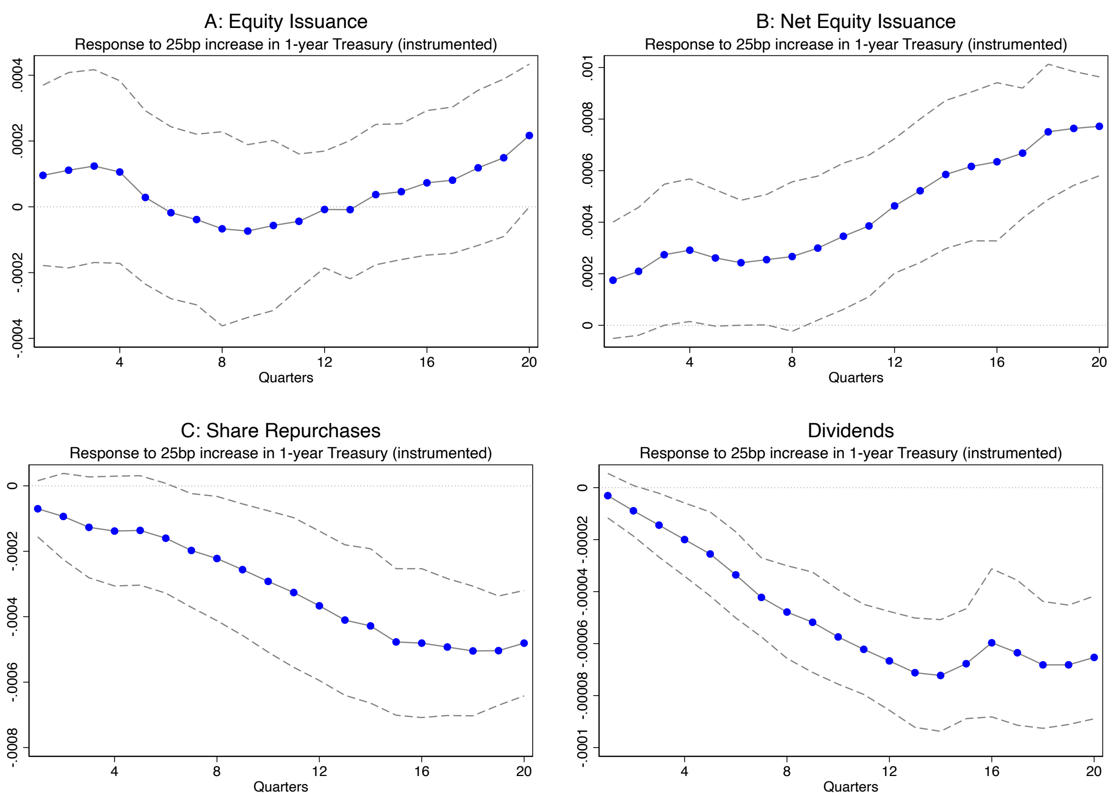


Figure A4: Response of Equity Issuance

This figure plots impulse responses to a 25bp increase in the 1-year Treasury rate, estimated using instrumental-variable local projections. Equity issuance is the funding raised through external equity issuance, scaled by previous period book assets. Net equity issuance subtracts dividends and share repurchases from equity issuance, all scaled by previous period book assets. The 1-year Treasury rate is instrumented by cumulative high-frequency monetary policy shocks measured as changes in the 3-month ahead Fed Funds futures rate in the 30 minutes window around FOMC announcements. The sample covers all firms in the matched CRSP-Compustat sample excluding financial firms, utilities and government from 1991-2016. Each point represents the point estimate of the coefficient of instrumented the 1-year Treasury rate (β_1^h in Eq. (2)). All regressions include firm and macro controls, as well as firm $\times$ fiscal quarter fixed effects. The dashed line represents 95% confidence intervals using heteroscedasticity and autocorrelation robust Driscoll-Kraay standard errors. Intangible firms (tangible firms) are firms with an above-median (below-median) intangible-to-total capital ratio in a given quarter.



A.1 Theoretical Background of the Depreciation Channel

This appendix illustrates why a given change in interest rates has a smaller effect on investment if asset depreciation rates are higher. Consider a standard Neoclassical production framework with a concave production function $F(K)$ with $F'(K) \geq 0$ and $F''(K) \leq 0$. Firms scale up investment I up to the point where the the marginal product of capital, $MPK(I) = F'(K)$ is equal to the user cost of capital, which is the sum of the interest rate r and the depreciation rate δ:

$$MPK(I) = r + \delta$$

This condition implicitly defines a function $I(r, \delta)$. Since $MPK'(I) = F''(K) \leq 0$, an increase in interest rates decreases investment, i.e. $\partial I(r, \delta)/\partial r \leq 0$.

This is illustrated in Figure A5, which plots investment on the x-axis against the user cost of capital on the y-axis. On the x-axis, the points I_{TAN} and I_{INT} mark the investment level under the interest rate level r and, respectively, depreciation rates δ_{TAN} and δ_{INT} with $\delta_{TAN} > \delta_{INT}$. Since MPK is decreasing, an increase from r to $r' > r$ results in a reduction in investment from I_{TAN} to I'_{TAN} and from I_{INT} to I'_{INT}.

At the same time, the figure also highlights that the investment reduction from I_{TAN} to I'_{TAN} is larger than that from I_{INT} to I'_{INT} because $\delta_{TAN} > \delta_{INT}$. This result holds under any production function that implies a convex MPK, i.e. $F'''(K) \leq 0$, which holds for standard production functions such as Cobb-Douglas. Thus, a given increase in interest rates has a relatively smaller effect on the user cost of capital if depreciation rates are higher and the marginal product of capital is convex.

Note also that for any investment function with decreasing $MPK(I)$ higher depreciation rate δ implies a lower effect of an interest rate increase on firm profits. This can be seen in Figure A5, where firm profits are represented by the area bounded by the vertical axis, the $MPK(I)$ function, and the horizontal line at the user cost of capital $r + \delta$. To see this, note that profits $\pi = F(K) - (r + \delta)K$

can be expressed as

$$\pi(I) = \int_0^K \left[MPK(k) - (r + \delta)\right] dk$$

The effect of a change in interest rates from r to r' on profits is therefore given by $\pi(I') - \pi(I)$, which is the area bounded by the vertical axis, the $MPK(I)$ function, the horizontal line at the user cost of capital $r + \delta$, and the horizontal line at the user cost of capital $r' + \delta$. From Figure A5 it is clear that this area is smaller for a higher level of the depreciation rate $\delta_{INT} > \delta_{TAN}$ because the height is the same $(r' - r)$, while the width of the area from the horizontal line to $MPK(I_{TAN})$ is wider than that from the horizontal line to $MPK(I_{INT})$. Intuitively, if depreciation rates are the dominant part of user costs, changes in interest rates have a smaller effect on firm profits.

Figure A5: The Effect of a Change in Interest Rates on Investment