Monetary Policy and Intangible Investment

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Abstract

The investment and stock prices of firms with relatively more intangible assets respond less to monetary policy. 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

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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. The literature documents that firms with relatively 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, 2021), and intangible assets depreciate faster than physical capital (Ewens et al., 2019). These 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, comprehensive empirical evidence investigating this link is lacking.

We analyze the relationship between intangible capital and monetary policy transmission among publicly-listed U.S. firms 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 adjustment of firm 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 narrow time window around FOMC announcements (as in Bernanke and Kuttner, 2005), thus offering a tight high-frequency specification. The investment response analysis, in turn, uses these high-frequency shocks to instrument the monetary policy stance (following Gertler and Karadi, 2015), thus mirroring the stock market results in a low-frequency dynamic environment.

These two empirical approaches yield consistent results documenting that the stock prices and investment of firms with relatively 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 firm characteristics with the monetary policy stance and with GDP growth, firm fixed effects, and granular time-by-industry fixed effects. These controls ensure that the results are not driven by differences in cyclicality or other observable differences between tangible and intangible firms, time-invariant unobservable firm characteristics, nor by economy-wide or industry-specific trends.

The effects of intangible capital on monetary policy transmission are statistically and economically significant. Whereas tangible investment declines by 3% to 6% after 12 quarters in response to a 25bps monetary tightening, intangible investment declines by less than 1%. In the cross-section of firms, a one standard deviation increase in the intangible-to-total capital ratio is associated with a one-tenth smaller stock price decline and one-seventh smaller investment decline in response to monetary tightening.

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. Monetary policy affects firm investment not only through the cost of capital, but also through the collateral value of firm assets and therefore firm financial constraints. However, intangible assets are not a good source of collateral, and consequently firms with relatively more intangible assets use less debt to begin with (Brown et al., 2009; Falato et al., 2020). Therefore, the marginal effect of monetary policy on collateral-based borrowing is smaller for firms with relatively more intangible assets. A testable prediction of the credit channel is that intangible assets weaken the transmission of monetary policy particularly among firms that are more reliant on collateral for their marginal borrowing and investment. Consistent with this prediction, the difference in the investment and stock price responses between tangible and intangible firms is more pronounced among more financially constrained firms, as proxied by young age and small size, high cash holdings, or tighter constraints according to the textual analyis-based *Delaycon* measure of Hoberg and Maksimovic (2015). Corroborating evidence also shows the net debt issuance in firms with relatively more intangible assets responds less to monetary policy, especially among more constrained firms.

The second economic channel relates to the fact that intangible assets have higher depreciation rates.[1] When the deprecation rate is higher, the elasticity of the user cost of capital (i.e., the sum of the interest rate and the depreciation rate) to interest rates is smaller (Crouzet and Eberly, 2019). Therefore, investment may respond less to changes in interest rates when depreciation rates are higher. Consistent with this channel, the weaker stock price and investment responses to monetary policy in firms with relatively more intangible assets are more pronounced among firms with a wider gap between tangible and intangible asset depreciation rates. However, some of these results have modest statistical and economic significance, indicating that 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 due to higher adjustment costs. Higher adjustment costs may be driven by the fact that firm-specific intangible assets need to be built over a period of time and are not easily redeployable across firms. Moreover, the creation of intangible assets requires skilled human capital that is costly to hire and fire (Eisfeldt and Papanikolaou, 2013). However, using different adjustment cost proxies, we find that tangible and intangible investment by firms with higher adjustment costs respond *more* to monetary policy.[2] The extrapolation of this finding to the comparison of tangible and intangible investment suggests that higher adjustment

[1] For example, the BEA and Ewens et al. (2019) estimate intangible asset depreciation rates of between 10%–46%, while most tangible asset depreciation rates are below 10% (Li, 2012).

[2] 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 (Bloom, 2009).

costs unlikely contribute to the weaker response of intangible investment to monetary policy.

Our empirical strategy hinges on resolving a number of methodological challenges. The first challenge is measuring intangible capital. Firm financial statements 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. Following Peters and Taylor (2017), in firm-level Compustat data we define intangible investment as expenditures on R&D and organizational capital. 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. The results are robust to using alternative measures of firm-level intangible capital from Ewens et al. (2019), and to using the perpetual inventory method to measure the tangible capital stock as well. We also confirm that the weaker response of intangible investment to monetary policy holds in aggregate data sourced from the U.S. Bureau of Economic Analysis (BEA). This is reassuring given the BEA data cover all U.S. establishments rather than just public firms, and uses a different definition of intangible investment based on expenses on R&D, software, and artistic originals.

The second methodological challenge is to identify the effects of monetary policy on stock prices and investment. We identify monetary policy shocks from the change in the 3-months ahead Fed Funds futures prices in the 30 minutes around an Federal Open Markets Committee (FOMC) announcement, following Bernanke and Kuttner (2005) and Gurkaynak et al. (2005). We use these monetary policy shocks to directly estimate the high-frequency stock price response and also show that the results are robust to separating out central bank information shocks (Jarocinski and Karadi, 2020). The investment response analysis captures the monetary policy stance by the 1-year Treasury rate level (as in Cloyne et al., 2018), which is instrumented using the cumulative high-frequency monetary policy shocks (similar to Bu et al., 2021).

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, usually related 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), or composite indexes (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 relatively more tangible and relatively more intangible assets, and between tangible and intangible investment. Crucially, our analysis controls for other firm balance sheet characteristics, including traditional proxies of financial constraints, and for the interaction of those characteristics with monetary policy. This ensures that the effect of intangible capital on monetary policy transmission is distinct from the effects of financial constraints on monetary policy transmission.

The second strand of related literature focuses on the secular rise of corporate intangible capital (Corrado and Hulten, 2010; Corrado et al., 2018) and its implications for firm productivity, financing, and investment (Brown et al., 2009; Bianchi et al., 2019; Crouzet and Eberly, 2019; Falato et al., 2020). Our analysis documents how these established features of intangible capital affect monetary policy transmission. Caggese and Pérez-Orive (2021) 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 effect of monetary policy on intangible firms.

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

Firm-level asset and investment data are sourced from quarterly financial statements of public firms in Compustat. Tangible investment and capital stock are reported in firm financial statements as capital expenditure (CAPX) and net property, plant, and equipment (PPENT), respectively.[3] 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) expense and 30% of selling, general and administrative (SG&A) expense. R&D expense captures investment in knowledge capital, whereas a share of SG&A expense reflects investment in brand and organizational capital.[4] We also consider R&D and SG&A investments separately to verify the results are not driven by the pro rata share of SG&A expenditure, which cannot isolate intangible spending from other expenditures in SG&A when using intangible investment as dependent variable.

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 annual measure directly from Peters and Taylor (2017) through Wharton Research Data Services (WRDS), and interpolate it to obtain a quarterly measure.

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,

[3] In U.S. GAAP, net property, plant, and equipment is defined as "the cost, less accumulated depreciation, of tangible fixed property used in the production of revenue". Therefore, the tangible capital stock measure is similar to our intangible capital stock measure in that it is derived from applying the perpetual inventory method on tangible fixed investment (using accounting-based depreciation rates).

[4] 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.

R&D, or SG&A expenditure, and very small firms with physical capital under $5 million. The final sample contains 9,863 unique firms and 327,431 firm-quarter observations between 1991 and 2016. We deflate all data using the CPI into real 1990 U.S. dollars, and map firm fiscal quarters to calendar quarters using information on a firm's fiscal year end (see Online Appendix Section AI.3).

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.[5] We use NIPA data in robustness exercises and to illustrate the aggregate dynamics of tangible and intangible investment in different data sources.

2.1.1 Dynamics of Tangible and Intangible Investment

Figure 1 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, a hypothesis that we explore rigorously in the remainder of the paper. The similarity between the firm-level and aggregate intangible investment series is reassuring, given the difficulty in measuring intangible investment. Panel D further decomposes Compustat intangible investment into its

[5] NIPA Table 5.3.3 - Real Private Fixed Investment by Type. 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. We show in the Online Appendix that the firm-level and aggregate data exhibit a similar upward trend in intangible investment and capital stock.

R&D and SG&A components. Although R&D investment appears somewhat more volatile, it is still substantially less cyclical than physical investment.

2.2 Other Variables

Firm-level control variables are sourced from Compustat and include firm age, Tobin's Q, leverage, cash holdings, cashflow, firm size, and a dummy for whether a firm pays a dividend (see Online Appendix Tables A1 and A2 for variable definitions). Daily stock returns data from CRSP are merged with Compustat using the linking table from WRDS. Variables are winsorized at the 1% level to avoid outliers. Table 1 presents 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 relatively more intangible assets have more cash, lower leverage, and are less likely to pay a dividend (see Falato et al., 2020). Unsurprisingly, firms with relatively more intangible assets have relatively higher intangible investment. The ratio of tangible over intangible investment is 0.411 for the average intangible firm and 4.652 for the average tangible firm. Otherwise, the two groups are comparable in terms of firm age, total assets, and profitability.

The macroeconomic variables 1-year Treasury rate, consumer price index (CPI), industrial production, real GDP growth, and the employment ratio are sourced from the Federal Reserve Economic Data, and the excess bond premium is taken from Gilchrist and Zakrajšek (2012) to control for financial conditions.

3 Main Results

This section consists of two parts. The first part examines how the stock prices of firms with relatively more intangible assets respond to monetary policy shocks. The second part considers how intangible investment responds to monetary policy compared to tangible investment, and how the total investment in firms with relatively 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 Bernanke and Kuttner (2005) and Gurkaynak et al. (2005). The identifying assumption is that this narrow window contains no other news that affect interest rate expectations. The data cover all FOMC meetings from 1991 to 2016.[6] We assess a firms' stock price response to monetary policy shocks using the regression specification:

$$RET_{it} = \beta_1 \cdot IR_{it} + \beta_2 \cdot \Delta FF4_t \times IR_{it} + \gamma_1' \cdot X_{it}^f + \gamma_2' \cdot \Delta FF4_t \times X_{it}^f + \eta_{jt} + \mu_i + \psi_{fq} + \varepsilon_{it}, \quad (1)$$

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. IR_{it} is a firm's *intangible ratio*, defined as the ratio of intangible-to-total capital at the end of the previous quarter. The key coefficient of interest β_2 captures whether the stock prices of firms with relatively more intangible assets react differently to monetary policy surprises. The vector X_{it}^f contains time-varying firm-level controls Tobin's Q, age, cash holdings, leverage, size, cashflows, and a dummy for whether the firm pays a dividend. We control for the level of these firm characteristics and for their interaction with the FF4 shock, to ensure that any differences in the stock price response between tangible and intangible firms is not driven by other observable firm characteristics. Firm size is measured as book assets (which include tangible capital) plus off-balance sheet

[6] 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.

intangible capital, following Peters and Taylor (2017). The regressions thus include both the intangible-to-total capital ratio (as the main variable of interest), and the control variable for firm *total* assets, and therefore capture the *size* and the *composition* of a firm's capital stock.

The model is saturated with 4-digit NAICS industry × event-date fixed effects η_{jt} 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 absorb all time-invariant, unobserved firm heterogeneity. Firm fixed effects offer a within-estimation of the effects of intangible capital on monetary policy response, which uses solely the time variation of the variables within each firm (equivalent to a de-meaning of all variables, see Wooldridge, 2019, ch. 14). All regression include fiscal-quarter fixed effects ψ_{fq} to control for seasonality (fiscal quarters may differ from calendar quarters, see Online Appendix Section AI.3). Standard errors are clustered at the industry and 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 −4.35% to a 1% unexpected increase in the Fed Funds rate (in line with −4.68% in Bernanke 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 1.25 and 1.33 across the specifications and consistently significant at the 5% level. This implies that a one standard deviation increase in the intangible-to-total capital ratio (by 0.29) is associated with a 36bps–

38bps smaller stock price decline in response to a 1% unexpected increase in the Fed Funds rate.

These results demonstrate that the market value of firms with relatively more intangible assets responds less to monetary policy shocks. This finding is robust in specifications that use abnormal stock price returns (columns 4 and 5), which 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.[7] Online Appendix Table A4 further verifies that these results are driven by monetary policy shocks rather than communication of the central bank's views about the state of the economy (Jarocinski and Karadi, 2020), and that the results are robust to using an alternative measure of firm intangible capital from Ewens et al. (2019), an alternative firm-level tangible capital measure based on applying the perpetual inventory method to capital expenditures, and a within-firm de-meaned intangible ratio.

3.2 Investment Response

This section analyzes the tangible, intangible, and total (tangible plus intangible) investment response to monetary policy in quarterly firm-level data.

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 dynamic response of investment to monetary policy instrumented by the

[7] For example, a potential concern may be that intangible firms' stock returns react more to any unanticipated shock to the aggregate economy because they have riskier business models. 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 and others a dampening effect of firm financial constraint measures on stock price response to monetary policy (Ozdagli, 2018; Chava and Hsu, 2020).

high-frequency FF4 shocks (similar to Cloyne et al., 2018; Bu et al., 2021).

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. 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 Romer and Romer, 2004; Coibion, 2012; Bu et al., 2021), while controlling for key lagged macroeconomic variables.[8] The Online Appendix (Section AII) verifies that this approach yields the monetary policy responses of key macroeconomic variables consistent with the extant literature, and that the cumulative FF4 shocks are a strong instrument for the 1-year Treasury rate.

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

$$y_{it+h} - y_{it-1} = \beta_1^h \cdot \hat{R}_t + \gamma_1^{h\prime} \cdot X_{t-1}^m + \gamma_2^{h\prime} \cdot X_{it-1}^f + \mu_i + \psi_{fq} + \varepsilon_{it}, \tag{2}$$

where the outcome variable y_{it} is a measure of investment, and $\hat{R}_t$ is the instrumented 1-year Treasury rate. X_{t-1}^m contains lagged macroeconomic control variables (log CPI, log industrial production, the excess bond premium, real GDP growth, 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 the same firm-level controls X_{it-1}^f as in the stock returns regression, including a firm's intangible-to-total capital ratio. Note that we cannot include time fixed effects in Eq. (2), because they would absorb all time-series variation that identifies the coefficient of interest β_1^h. However, can include time fixed effects in further specifications that

[8]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 is a strong instrument for the 1-year Treasury rate as compared to contemporaneous FF4 shocks, which have little explanatory power.

examine the interaction between monetary policy and firm characteristics (see Eq. 3 below), and confirm there that including time fixed effects does not affect the results.

3.2.2 Results from Local Projections

The investment analysis considers as outcome variables the log of tangible, intangible, and total investment rates, defined as the respective investment divided by the lagged capital stock.[9] Figure 2, Panel A, documents an average decline of the firm total investment rate by almost 3% after 8-12 quarters in response to a 25bps monetary tightening in the full sample of firms. Panel B splits the sample and documents that the response of total investment is substantially weaker among firms with relatively more intangible capital. In response to a 25bps higher 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 intangible ratio reduce their total investment by around 1%. This pattern is consistent with the high-frequency results showing a weaker stock price response to monetary policy shocks in intangible firms (see Table 2).

Panels C and D decompose the total investment response by comparing the effects of monetary policy on a firm's tangible and intangible investment. The vast majority of the total investment response comes from tangible investment, which declines by about 5-6% after 12 quarters in response to a 25bps higher Treasury rate. By contrast, intangible investment declines by less than 1%.

To test whether the difference in the response of tangible and intangible investment is statistically significant, panel E plots the response of the log ratio of a firm's tangible over intangible investment, that is, the percentage point difference between the response of tangible and intangible investment. This ratio's decline by up to 4% is statistically different from zero. Panel F repeats this exercise using the log ratio of tangible investment to R&D.

[9] See the Online Appendix Section AI for detailed variable definitions. These quarterly investment rates are winsorized at the 1% level, and their summary statistics are in line with the annual investment rates in Peters and Taylor (2017) (see Table 1).

This narrower measure of intangible investment omits SG&A expenditure, and verifies that the weaker response of intangible investment is not driven by its SG&A component.[10]

3.2.3 Results from Interaction Term Estimates

To ensure that the weaker total investment response in firms with relatively more intangible assets, documented in panel B of Figure 2, 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 Specification (2) with interaction terms between the 1-year Treasury rate and firm characteristics:

$$\begin{aligned} y_{it+h} - y_{it-1} = \beta_1^h \cdot IR_{it-1} + \beta_2^h \cdot \hat{R}_t \times IR_{it-1} + \beta_3^h \cdot \Delta Y_{t-1} \times IR_{it-1} \\ + \gamma_1^{h\prime} \cdot X_{it-1}^f + \gamma_2^{h\prime} \cdot \hat{R}_t \times X_{it-1}^f + \mu_i + \eta_t + \psi_{fq} + \varepsilon_{it}. \end{aligned} \tag{3}$$

This specification mirrors the stock returns Specification (1). The coefficient β_2^h captures whether firms with a higher intangible-to-total capital ratio respond differently to monetary policy, while controlling for the interaction of monetary policy with other firm characteristics X_{t-1}^f. Additionally, Specification (3) controls for the interaction of a firm's intangible ratio and GDP growth, $\Delta Y_{t-1} \times IR_{it-1}$, to ensure that the heterogenous effects of monetary policy on investment are not driven by differences in the cyclicality of the investment by tangible and intangible firms (for example, due to heterogeneity in firm financing patterns over the business cycle, see Covas and Den Haan, 2011). Since the main coefficient of interest is the interaction term coefficient β_2^h, we can include time fixed effects η_t, or industry-by-time fixed effects η_{jt}, to control for time-varying unobserved macroeconomic conditions that influence all firms, or all firms within a given industry, respectively. These fixed effects also ensure

[10] Figure A5 in the Online Appendix compares the response of the knowledge and organizational components of intangible investment to monetary policy. R&D and SG&A expenditures respond similarly to monetary policy and the total investment of firms with above-median knowledge or organizational capital respond less to monetary policy than those of firms below the medians. This verifies that our results are not driven by the fact that the investment in organizational capital is measured based on a pro rata 30% share of SG&A expenditure (consistent with the literature), which implies that changes in organizational investment cannot be isolated from other expenditures recorded in SG&A.

that the results are not driven by long-run economy-wide or industry-specific trends.[11]

Table 3 documents the results from estimating Eq. (3) for horizons of $h = 8$ and $h = 12$ quarters (at which the impulse response functions of Figure 2 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-by-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 25bps increase in the 1-year Treasury rate by between 36bps and 44bps, corresponding to around one-seventh of the average investment response of 3%. This strong attenuating effect is consistent with the previous results from the sample splits in Figure 2, panel B, and confirms that the weaker investment response by intangible firms is not driven by other firm characteristics.[12]

Robustness The Online Appendix (Section AIII) verifies that the results are robust to using monetary policy shocks separated from central bank information shocks from Jarocinski and Karadi (2020) as the instrument (see Figure A4). The results in Table 3 are also robust to using the alternative firm-level intangible capital estimate from Ewens et al. (2019), and an alternative firm-level tangible capital measure based on applying the perpetual inventory method to capital expenditures (see Table A5). The results are also robust to de-meaning the intangible ratio within firms, which indicates that the results are not confounded by unobserved, time-invariant, and proportionate to the average intangible-to-total capital ratio differences in firm monetary policy response (see Ottonello and Winberry, 2020, Online Appendix A.1). Another robustness exercise complements the firm-level analysis based on public firms with an analysis based on national accounts data from the BEA that cover all

[11] In a robustness test (not reported) we confirm that the main results from estimating Specification (3) are very similar with and without time fixed effects. This indicates that unobserved time-varying macroeconomic conditions have a limited effect on our results and offers credibility to the results from estimating Specification (2) that cannot include time fixed effects.

[12] Note that the results on the weaker total investment response in firms with relatively more intangible assets and on the weaker intangible investment compared to tangible investment response mirror each other, as firms with relatively more intangible capital do more of intangible investment. The pooled correlation between firms' tangible-to-total capital and tangible-to-total investment ratios is 76.25%.

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.

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, and that the total investment in firms with relatively more intangible assets responds less to monetary policy. These results are consistent with those obtained in the tightly-identified high-frequency stock price analysis that documents a weaker response of the market value of firms with relatively more intangible capital to monetary policy shocks (see Section 3.1). This is reassuring given the complexity of accounting for the endogeneity of monetary policy when estimating the dynamic response of investment (Nakamura and Steinsson, 2018). Overall, we therefor document a set of consistent findings based on different methodologies and data sources that all confirm that intangible capital attenuates the effectiveness of monetary policy transmission. The remainder of the paper explores several economic channels that may explain these findings.

4 Why Does Intangible Capital Weaken Monetary Policy Transmission?

This section discusses and tests three economic mechanisms that may explain why intangible capital weakens monetary policy transmission to firm stock prices and investment.

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 (or pledgeable value) of firm assets and thus on firm financial constraints (Kiyotaki and Moore, 1997).[13] However, intangible assets have lower collateral value compared to tangible assets, so firms with relatively more intangible assets use less debt to begin with.[14]

Formally, consider a profit-maximizing firm that chooses its investment at date t. The firm has an initial capital stock K_t and internal funds (cash) A_t. It decides how much debt D_t to raise in order to make an investment $I_t = A_t + D_t$, resulting in a 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:

$$D_t \leq (1-\mu)Q_t(r_t)K_t, \tag{4}$$

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.

The Online Appendix (Section AIV) shows that solving this optimization problem gives rise to two solution regions, depending on whether the collateral constraint (4) binds. An *unconstrained firm* matches the marginal product of capital to its opportunity cost r_t and

[13] The literature often uses the term "collateral constraints" without distinguishing between secured and unsecured debt. Whereas much corporate debt is de-jure unsecured (Lian and Ma, 2021), Rampini and Viswanathan (2022) articulate the importance of pledgeable value even for unsecured debt, which is implicitly backed by unencumbered collateral in case of default. In this paper, we use the term "collateral" to refer not only to de-jure collateral behind secured debt, but also to the liquidation value of firm assets that serves as implicit collateral for most unsecured debt.

[14] The reason is that intangible assets are often firm-specific and harder to value and liquidate than tangible assets. For example, the value of a partially-developed technology is often linked to the human capital of the researchers who work on it, making it difficult to transfer ownership of such an asset without a substantial loss of value. Another reason for the low collateral value of intangible assets is that the structure of a debt contract is not well-suited for R&D-intensive firms due to uncertain and volatile returns, adverse selection problems, and the ease of risk-shifting (see Brown et al., 2009, p. 157). Accordingly, empirical studies confirm that firms finance intangible assets primarily through equity or internal funds (Bates et al., 2009; Brown et al., 2009; Hall and Lerner, 2010; Brown et al., 2013; Falato et al., 2020). Consistent with this, the median leverage of intangible firms is 18.1%, but 27.5% for tangible firms. While some intangible assets, notably patents, can be used as collateral (Mann, 2018), patents do not fully ameliorate external finance frictions caused by the low collateral value of intangible assets (Dell'Ariccia et al., 2020).

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. The share of intangible assets, μ, does not affect investment because collateral values are irrelevant in a financially unconstrained firm.

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

$$\frac{dI_t}{dr_t} = (1-\mu)Q_t'(r_t)K_t. \tag{5}$$

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, the investment of firms with a higher share of intangible assets μ declines *less* when interest rates increase because such firms use less debt funding. Intuitively, fluctuations in asset values have little effect on financial constraints if a firm cannot pledge these assets anyway.

This stylized model 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.* Accordingly, whereas our baseline results confirm that firms with relatively 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 firms that rely on collateral for their marginal borrowing. If collateral constraints were measured perfectly and explained 100% of the weaker monetary policy response by intangible firms, then we should expect a large difference in the monetary policy response between financially constrained tangible and financially constrained intangible firms, but no difference in the monetary policy response between financially unconstrained tangible and financially unconstrained intangible firms

It is useful to contrast our posited economic channel with the existing literature. Much of the literature compares financially constrained to unconstrained firms and finds that financial constraints may either amplify or weaken monetary policy transmission (Ozdagli, 2018; Cloyne et al., 2018; Ottonello and Winberry, 2020; Chava and Hsu, 2020). By contrast, we posit an *interactive* effect of financial constraints and intangible capital, where the difference in the monetary policy response between tangible and intangible firms is sharper for financially constrained firms.[15]

4.1.1 Measuring Financial Constraints

The literature uses several approaches to measure financial constraints based on firm characteristics. 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, 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 more cash, 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 Hoberg and Maksimovic (2015).[16] Either approach is potentially imperfect (Farre-Mensa and Ljungqvist, 2016). Therefore, we document the results using all the above approaches to measuring financial constraints and obtain consistent results.

[15]To fully understand the mechanism behind our hypothesis, note that both tangible and intangible firms *may or may not* be financially constrained. For example, Table 1 documents that the correlation between the intangible ratio and the measures of financial constraints is far away from one. Although relatively more intangible firms have more cash and lower leverage, these firms have similar age and appear, if anything, less constrained according to the *Delaycon* measure of Hoberg and Maksimovic (2015). Consequently, we do not consider asset intangibility and financial constraints as interchangeable categories. Rather, we measure both characteristics separately, and compare the effect of intangible assets on firms' monetary policy response between constrained and unconstrained firms.

[16]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.

4.1.2 Stock Price and Investment Response

To assess whether the weaker stock price and investment responses to monetary policy in firms with relatively more intangible assets are more pronounced among financially constrained firms, we re-run the baseline regressions as in Tables 2 and 3, while splitting the sample into more and less financially constrained firms. All regressions include the same controls and fixed effects as in the baseline.

Columns 1–4 in Table 4 re-estimate the coefficient on the interaction term ΔFF4 $\times$ Intangible Ratio in the stock price analysis (i.e., β_2 in Specification 1). Columns 5–8 document the coefficient estimates on the interaction term $\hat{R}$ $\times$ Intangible Ratio in the investment analysis at $h = 8$ and $h = 12$ quarter horizons (i.e., β_2^h in Specification 3).[17]

Panel A splits the sample into young firms (columns 1–2 and 5–6), defined as those with below-median age in a given quarter, and old firms with above-median age (columns 3–4 and 7–8). For young firms, the coefficient estimates are higher than the full-sample estimates (cf. Tables 2 and 3), and about twice the magnitude of the estimates for old firms. A potential shortcoming of using age as proxy of financial constraints is that some young firms may grow quickly and not be financially constrained. We address this in panel B by comparing estimates among firms of below-median age *and* size to firms of above-median age *and* size. In the stock return regressions, the coefficient estimates among firms that are young and small range between 1.93 and 2.46, while estimates among old and large firms are close to zero and statistically insignificant. The coefficient estimates for young and small firms imply that a one standard deviation increase in the intangible-to-total capital ratio leads to a 56bps–0.71bps smaller stock price decline in response to a 1% unanticipated increase in the Fed Funds rate, compared to a 36bps smaller decline in the full sample.

Similarly, for firm investment the coefficient estimates on the interaction between the instrumented 1 year Treasury rate and the intangible ratio range from 0.091 to 0.10 for firms

[17] Figure A9 in the Online Appendix plots the estimates of the interaction term of the 1-year Treasury rate and the intangible ratio for the different sub-samples for all quarterly horizons $h = 1$ to $h = 20$.

that are young and small, while estimates among old and large firms are economically small and only marginally statistically significant. The coefficient estimates for young and small firms imply that a one standard deviation increase in the intangible-to-total capital ratio is associated with a 66bps–73bps smaller decrease of total investment in response to a 25bps monetary policy tightening for these firms, compared to a 36bps–44bps smaller decrease in the full sample.

Panel C splits the sample into firms with high and low cash holdings, defined as, respectively, firms in the top tercile and bottom two terciles of the cash-to-assets ratio distribution in a given quarter.[18] Panel D splits the sample by the median for the textual analysis-based *Delaycon* measure of Hoberg and Maksimovic (2015) in each quarter. The results consistently reveal that the coefficient estimates on the interaction of the intangible ratio with the FF4 shocks or the instrumented 1-year Treasury rate are larger for constrained firms compared to unconstrained firms, and that coefficient estimates for unconstrained tangible and intangible firms are economically smaller and have lower to no statistical significance.

Overall, the results based on multiple measures of firm financial constraints confirm that the weaker stock price and investment response to monetary policy in firms with relatively more intangible assets is more pronounced among financially constrained firms, consistent with the credit channel predictions. As the credit channel might not explain 100% of the weaker monetary policy response by intangible firms, and given that all proxies of financial constraints remain imperfect, we observe some effects of a weaker monetary policy response by more intangible firms also among financially unconstrained firms – although the differences are smaller in magnitude and often not statistically significant.

[18] 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, see Denis and Sibilkov (2010).

4.1.3 Borrowing Response

The results from the previous subsection document a weaker credit channel of monetary policy for intangible firms based on differences in firm investment responses. Yet the credit channel is fundamentally a liability-side mechanism. If the credit channel is at work, one should expect that firms with relatively more intangible assets adjust not only their investment, but also their borrowing less in response to monetary policy. Accordingly, we extend our analysis and document how firms adjust their borrowing in response to monetary policy.

Figure 3 documents that firms with relatively more intangible capital reduce their debt growth by less in response to monetary policy, consistent with a weaker credit channel.[19] Panel A documents that debt growth declines by 0.5–0.7 percentage points 8–12 quarters after a 25bps monetary policy tightening in the full sample (compared to the mean debt growth of 6.5%). Panel B shows that the decline in debt growth is smaller at around 0.3–0.5 percentage points for firms with above-median intangible-to-total capital ratio and larger at more than 0.8 percentage points for firms with a below-median intangible ratio.

Table 5 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 4). In panel A, the full-sample estimates imply that a one standard deviation higher intangible ratio is associated with a 7bps weaker response in debt growth. Consistent with the credit channel predictions, these coefficient estimates are larger among young and small firms (panels B and C), and among firms with an above-median *Delaycon* financial constraints measure (panel D).[20] For example, the estimates in panel C imply that, among young and small firms, a one standard deviation increase in the intangible-to-total capital ratio is associated with a 22bps smaller

[19] 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.

[20] 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.

reduction in debt growth 8 quarters after a 25bps monetary policy tightening. By contrast, coefficient estimates are not statistically different from zero and economically smaller than in the full sample among old and large firms.

Firms might also respond to monetary policy shocks by issuing equity. This effect, if present, might be more pronounced for intangible firms because their investment relies on equity financing and responds to equity financing shocks (Brown et al., 2009; Hall and Lerner, 2010). To test for this effect, we consider how monetary policy affects the growth of firm book equity, which captures net changes in equity stemming from new issuance, payouts, and retained earnings.[21] Figure 3 documents in panels C and D that book equity growth does not respond to monetary policy, neither in more tangible nor in more intangible firms. This lack of response is consistent with frictions and costs in public equity issuance, and with the fact that accumulating internal equity from retained earnings takes time.

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 R&D capital depreciation rate between of 30% and 46%. 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 AIV.3 verifies that higher depreciation

[21] Book equity growth is defined as the growth in book equity scaled by lagged book equity stock, analogous to our definition of debt growth. Online Appendix, Figure A10, furthermore confirms that 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, leading to a somewhat counter-intuitive *increase* in net equity issuance in response to monetary tightening. Furthermore, cash flows decline (not reported), explaining the altogether flat response of book equity growth in Figure 3.

rates make investment less interest rate-sensitive whenever the marginal product of capital is decreasing and convex. This condition holds for a range of production functions, including Cobb-Douglas.[22]

The depreciation channel predicts that *investment in assets with higher depreciation rates responds less to monetary policy.* A corollary is that *firms with relatively 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 the industry level from the BEA Fixed Assets Tables 3.3 and 3.6, and for intangible assets from Ewens et al. (2019).[23]

We first consider the effect of depreciation rates on the response of investment to monetary policy. Figure 4, panel A, plots the response of intangible investment to a 25bps 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 initially responds less for firms with low depreciation rates, although this difference disappears after 8 quarters. Panel B documents that tangible investment with high depreciation rates also responds less to monetary policy compared to that with low depreciation rates, but the difference between the two is relatively small.

We then proceed to test whether depreciation rates can explain the weaker monetary policy response in firms with relatively 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 6 documents the impact of the depreciation gap on the difference in monetary policy response between tangible and intangible firms by splitting the sample into firms with above- and below-median depreciation gap in a given quarter.

[22]Online Appendix Section AIV.3 verifies that higher depreciation rates also 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.

[23]Ewens et al. (2019) assume a fixed depreciation rate of 20%, so that there is no variation in intangible depreciation estimates among firms that have only organizational but no knowledge capital. For that reason, we exclude firms with zero or missing knowledge capital in sample splits based on intangible depreciation rates.

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 between 2.46 and 2.59 (almost twice the full-sample estimates) for high depreciation gap firms and statistically insignificant for low depreciation gap firms. Panel B documents the total investment response to monetary policy at 8 and 12 quarters horizons (as in Table 3) on the respective subsamples. 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 compared to low depreciation gap firms, but they remain close to the the full-sample estimates (cf. Table 3).

Overall, the evidence on the role of the depreciation channel in explaining the weaker response of intangible investment to monetary policy is thus mixed. Depreciation rates help explain the weaker stock price response for firms with relatively more intangible assets. Yet the depreciation channel offers statistically less significant and short-lived results in explaining the heterogeneous response of tangible and intangible investment to monetary policy, and the weaker total investment response for firms with more intangible-to-total 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 Channels Related to Adjustment Costs

Another potential reason for a weaker response of intangible investment to monetary policy may be that intangible investment is harder to scale up and down. We refer to a range of economic mechanisms behind this channel as 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). Several features of intangible capital may contribute to its higher adjustment costs. First, intangible assets often have to be built rather than purchased, and liquidated rather than sold, because intangible assets are firm-specific and therefore not easily redeployable across firms. Second, intangible investment relies on highly skilled human capital as a key production factor (Eisfeldt and Papanikolaou, 2013; Döttling et al., 2020), and hiring and firing talent is costly and takes time. Consistent with these arguments, Peters and Taylor (2017) document that "compared with physical capital, intangible capital adjusts more slowly to changes in investment opportunities."[24]

Existing data does not permit comparing adjustment costs between tangible and intangible assets. Therefore, we analyze the effect of adjustment costs on the tangible and intangible investment response separately, and extrapolate our findings to the comparison between tangible and intangible investment.[25] To capture the effect of adjustment costs on the tangible investment response to monetary policy, we use two proxies of adjustment costs. The first proxy is the Hall (2004) measure of capital adjustment costs, obtained from a structural model of investment estimated on industry-level data. The second proxy is the Kim and Kung (2017) firm-level measure of asset redeployability. The intuition is that redeployable assets can be purchased and sold more easily, and consequently have lower capital adjustment costs. Figure 4 documents that firms with higher tangible adjustment costs, as captured by below-median asset redeployability (panel C) or above-median Hall (2004) capital adjustment costs (panel D), respond, if anything, *more* to monetary policy. A potential explanation for this finding is that investment with high adjustment costs responds negatively to uncertainty (because uncertainty increases the risk that irreversible investment will not pay off, see Bloom, 2009), and uncertainty responds positively to interest rate shocks (Bekaert et al., 2013). The results also mirror findings in Kim and Kung (2017) that firms with less redeployable assets respond more to uncertainty shocks.

[24]For example, Eisfeldt and Papanikolaou (2013) document that organizationally complex firms often list the loss of talent as a risk in their annual reports. Also see further discussions on high adjustment costs of intangible investment in Brown et al. (2009), p. 160.

[25]Higher 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 shock. For this reason, we focus this analysis on the effect of monetary policy on investment only.

We similarly consider the effect of adjustment costs on the response of intangible investment to monetary policy. To do so, we consider the high-skill labor share in a firm, which we interpret as leading to higher adjustment costs because skilled labor is costly to hire and fire. We measure a firm's reliance on high-skill labor using data on the high-skill labor share of income from the NBER-CES Manufacturing Industry Database. These data report value added, total payroll, and the production workers' payroll for manufacturing industries at the 6-digit NAICS industry level. Following Pierce and Schott (2016), we compute the income share of high-skill labor as the total payroll net of production workers' wages, scaled by value added. As an alternative measure of a firm's reliance on high-skill human capital, we use the amount of employee stock compensation paid by a firm, motivated by the fact that many high-skill employees are rewarded with stock compensation (Eisfeldt et al., 2021).[26] Consistent with the earlier findings for tangible capital adjustment costs, in Figure 4 firms with above-median high-skill labor share and above-median stock compensation, which face higher intangible capital adjustment costs, respond more to monetary policy (panels E and F).

Extrapolating these results 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. Taken at face value, this indirect inference does not support the notion that higher adjustment costs contribute to the weaker response of intangible investment to monetary policy.

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

[26]Stock compensation is measured as stock compensation expense (Compustat variable STKCO) scaled by a firm's market value. This measure is averaged over 2006–2016, as this is the period over which data is consistently available.

relatively more intangible assets respond less to monetary policy, and intangible investment responds less to monetary policy compared to tangible investment. In the cross-section, the attenuating effect of intangible assets is most pronounced among firms that rely most on collateral, 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.

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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, and firms with missing or negative assets or sales, negative CAPX, R&D, or SG&A expenditure, very small firms with physical capital under $5 million. The *Intangible Ratio* is a firm's intangible-to-total capital, *total Q* is a firm's market value of total assets divided by the book value of total assets, *cash* is cash divided by book assets, *leverage* is long-term and short-term debt divided by book assets, *age* is measured as quarters since the first observation in Compustat, *book assets* are all assets reported on a firm's balance sheet, *total assets* are book assets plus off-balance sheet intangible capital, *Delaycon* is a textual analysis-based financial constraints measure taken from Hoberg and Maksimovic (2015), *dividend paid* is a dummy whether a firm paid a dividend in a given fiscal year, *debt growth* is the change in long-term and short-term debt relative to its lagged level, *equity growth* is the change in book equity relative to its lagged level, the *tangible investment rate* is CAPX divided by lagged property, plant and equipment, the *intangible investment rate* is intangible investment defined as R&D expenditures and 30% of SG&A expenditures divided by lagged intangible capital, and the *total investment rate* is the sum of tangible and intangible investment divided by lagged total capital. For more details on how the variables are constructed, see Table A1 in the Online Appendix.

	All			Intangible Firms			Tangible Firms		
	mean	p50	sd	mean	p50	sd	mean	p50	sd
Intangible Ratio	0.577	0.653	0.290	0.815	0.824	0.0964	0.347	0.359	0.217
Total Q	1.621	1.357	0.845	1.680	1.406	0.872	1.557	1.315	0.798
Cash	0.130	0.0596	0.163	0.171	0.0948	0.186	0.0961	0.0476	0.122
Leverage	0.288	0.248	0.252	0.219	0.181	0.215	0.300	0.275	0.230
Age	63.00	50	48.27	69.63	57	48.57	67.55	54	49.43
Book Assets	1.903	0.280	8.197	1.772	0.298	6.436	2.297	0.322	9.534
Total Assets	2.558	0.415	10.42	2.488	0.454	8.827	2.673	0.381	11.01
Delaycon	-0.0147	-0.0211	0.0886	-0.0208	-0.0270	0.0888	-0.0115	-0.0167	0.0873
Dividend Paid	0.429	0	0.495	0.399	0	0.490	0.483	0	0.500
Debt Growth	0.0650	-0.00908	0.549	0.0686	-0.0114	0.606	0.0682	-0.00766	0.513
Equity Growth	0.0172	0.0114	0.279	0.0186	0.0132	0.252	0.0207	0.0118	0.276
Total Inv. Rate	0.0550	0.0448	0.0405	0.0551	0.0470	0.0357	0.0552	0.0427	0.0443
Tangible Inv. Rate	0.0664	0.0462	0.0668	0.0763	0.0564	0.0676	0.0581	0.0397	0.0618
Intan Inv. Rate	0.0554	0.0476	0.0379	0.0525	0.0458	0.0345	0.0585	0.0500	0.0400
CAPX / Intan Inv.	2.432	0.504	6.192	0.411	0.256	0.758	4.625	1.462	8.419
CAPX / R&D	1.741	0.539	4.008	0.785	0.385	1.758	4.232	1.857	6.346
Observations	327431			125775			125825		

Table 2: Stock Returns Around FOMC Meetings

This table presents coefficient estimates from estimating Eq. (1). 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 Online Appendix 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 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	-4.35**				
	(1.74)				
ΔFF4 × Intangible Ratio		1.31**	1.29**	1.33**	1.25**
		(0.62)	(0.64)	(0.57)	(0.59)
ΔFF4 × Log Age		0.75***	0.76***	0.13	0.14
		(0.26)	(0.26)	(0.26)	(0.26)
ΔFF4 × Total Q		-0.42	-0.43	0.050	0.043
		(0.48)	(0.47)	(0.31)	(0.31)
ΔFF4 × Cash		-4.01*	-4.33*	-0.052	-0.18
		(2.24)	(2.22)	(1.06)	(1.07)
ΔFF4 × Leverage		-0.16	-0.18	-0.91	-0.97
		(1.15)	(1.12)	(1.00)	(0.97)
ΔFF4 × Cashflows		3.73	3.86	-3.54	-3.84
		(8.15)	(8.63)	(4.56)	(4.87)
ΔFF4 × Log Size		-0.63**	-0.66**	-0.064	-0.076
		(0.28)	(0.27)	(0.11)	(0.11)
ΔFF4 × Dividend Paid		0.33	0.27	-0.23	-0.29
		(0.35)	(0.36)	(0.21)	(0.23)
Observations	463130	454678	454599	454678	454599
R-squared	0.030	0.239	0.258	0.140	0.160
Industry × Event-Date FE	No	Yes	Yes	Yes	Yes
Firm FE	Yes	No	Yes	No	Yes
Quarter FE	Yes	Yes	Yes	Yes	Yes
Firm-Level Controls	Yes	Yes	Yes	Yes	Yes

Table 3: Investment Response

This table presents coefficient estimates from estimating Eq. (3). 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 Online Appendix 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)	(2)	(3)	(4)	(5)	(6)
	ΔI_t^{tot}	ΔI_t^{tot}	ΔI_t^{tot}	ΔI_t^{tot}	ΔI_t^{tot}	ΔI_t^{tot}
$\hat{R}$	-0.10***			-0.12***		
	(0.017)			(0.024)		
$\hat{R}$ × Intangible Ratio		0.055**	0.049***		0.060**	0.059***
		(0.021)	(0.014)		(0.025)	(0.017)
ΔGDP × Intangible Ratio		-0.072	-0.057*		-0.041	-0.052*
		(0.044)	(0.032)		(0.038)	(0.027)
$\hat{R}$ × Log Age		0.0095***	0.0099***		0.0063*	0.0095***
		(0.0033)	(0.0022)		(0.0036)	(0.0023)
$\hat{R}$ × Total Q		-0.0073***	-0.0022		-0.0052**	-0.00018
		(0.0026)	(0.0023)		(0.0026)	(0.0023)
$\hat{R}$ × Cash		0.020**	0.0050		0.018**	0.0014
		(0.0080)	(0.0068)		(0.0074)	(0.0075)
$\hat{R}$ × Leverage		-0.00018	-0.0046		-0.016**	-0.016*
		(0.0060)	(0.0073)		(0.0072)	(0.0080)
$\hat{R}$ × Cashflows		0.017	-0.053		0.016	-0.083+
		(0.044)	(0.038)		(0.056)	(0.053)
$\hat{R}$ × Log Size		0.00027	-0.00060		0.0019**	0.00087
		(0.00088)	(0.00070)		(0.00095)	(0.00076)
$\hat{R}$ × Dividend Paid		0.0013	0.00015		-0.0019	-0.0022
		(0.0031)	(0.0030)		(0.0035)	(0.0039)
Observations	160437	159789	154437	142792	142123	137119
R-squared	0.077	0.049	0.039	0.101	0.067	0.055
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
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
Firm Controls	Yes	Yes	Yes	Yes	Yes	Yes
Macro Controls	Yes	No	No	Yes	No	No

Table 4: Sample Splits Credit Channel

For different sub-samples of firms, this table replicates the stock returns regressions from Table 2 in columns 1–4, and the investment regressions from Table 3 in columns 5-8. 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 D, more (less) constrained firms have an above-median (below-median) textual analysis-based *delaycon* financial constraints measure of Hoberg and Maksimovic (2015). Columns 1–4 report estimates from firm-event date level regressions. The dependent variables are raw or abnormal stock returns on FOMC announcement days, and the reported coefficient estimates are β_2 in Eq. (1), i.e., the interaction term between ΔFF4 (the change in the 3-month ahead Fed Futures rate in the 30 minutes around the FOMC announcement), and a firm's *Intangible Ratio* (intangible-to-total capital). All regressions in columns 1–4 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 reported in Table 2. Standard errors in parentheses are clustered by event date and industry. Columns 5-8 report estimates from firm-quarter level regressions. The dependent variable is the h-quarter change in the log total investment rate, and the reported coefficient estimates are β_2^h in Eq. (3), i.e., the interaction term between $\hat{R}$ (the 1-year Treasury rate, instrumented by cumulative high-frequency monetary policy shocks), and a firm's *Intangible Ratio*. All regressions in columns 5–8 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 reported in Table 3. In parentheses we report Driscoll-Kraay heteroscedasticity and autocorrelation robust standard errors. 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. ***, **, *, indicate significance levels of 1%, 5%, 10%, respectively.

	Stock Returns				Investment			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Raw	Abn.	Raw	Abn.	$h = 8$	$h = 12$	$h = 8$	$h = 12$
Panel A: Split by Age								
	Young		Old		Young		Old	
MP × Intangible Ratio	1.87*	1.56*	0.94	0.92	0.087***	0.092***	0.045**	0.051*
	(1.02)	(0.79)	(0.86)	(0.82)	(0.021)	(0.023)	(0.022)	(0.027)
Observations	228751	228751	209537	209537	76848	67242	79341	71606
Panel B: Split by Age & Size								
	Young & Small		Old & Large		Young & Small		Old & Large	
MP × Intangible Ratio	2.46***	1.93***	0.15	-0.027	0.10***	0.091***	0.036	0.045*
	(0.92)	(0.67)	(1.03)	(1.12)	(0.029)	(0.027)	(0.022)	(0.025)
Observations	128994	128994	127151	127151	43072	37088	51570	47354
Panel C: Split by Cash Holdings								
	High Cash		Low Cash		High Cash		Low Cash	
MP × Intangible Ratio	2.90**	2.64***	0.30	0.47	0.100***	0.096***	0.041*	0.049*
	(1.19)	(0.96)	(0.92)	(0.95)	(0.018)	(0.024)	(0.023)	(0.025)
Observations	144799	144799	295785	295785	50614	44805	105124	93637
Panel D: Split by Delaycon								
	More Constrained		Less Constrained		More Constrained		Less Constrained	
MP × Intangible Ratio	2.69*	2.69**	1.43	0.15	0.093***	0.098***	0.047**	0.043*
	(1.54)	(1.25)	(1.75)	(1.40)	(0.024)	(0.028)	(0.023)	(0.023)
Observations	123909	123909	127779	127779	48268	42761	50684	45206

Table 5: 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 C, 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. 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. ***, **, * 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: Full Sample				
$\hat{R}$ × Intangible Ratio	0.0086	0.0095*		
	(0.0059)	(0.0052)		
Observations	155945	138003		
Panel B: Split by Age				
	Young		Old	
$\hat{R}$ × Intangible Ratio	0.015*	0.013*	0.0094	0.0095
	(0.0075)	(0.0075)	(0.0079)	(0.0072)
Observations	72507	62832	78914	71104
Panel C: Split by Age & Size				
	Young & Small		Old & Large	
$\hat{R}$ × Intangible Ratio	0.030***	0.030**	0.0015	0.002
	(0.011)	(0.014)	(0.007)	(0.0073)
Observations	38909	33070	53801	49415
Panel D: Split by Delaycon				
	More Constrained		Less Constrained	
$\hat{R}$ × Intangible Ratio	0.031***	0.028***	0.016**	0.008
	(0.0078)	(0.0067)	(0.0072)	(0.0076)
Observations	45295	39811	46922	41491

Table 6: Sample Splits by Depreciation Gap

This table replicates the baseline investment and stock price results for firms with an 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. 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. 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	2.59***	2.46***	-0.45	-0.47
	(0.83)	(0.69)	(1.30)	(1.27)
Observations	112472	112472	106197	106197

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	0.042**	0.049**	0.023	0.042
	(0.021)	(0.026)	(0.024)	(0.027)
Observations	39579	35162	41627	37339

Figure 1: 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).

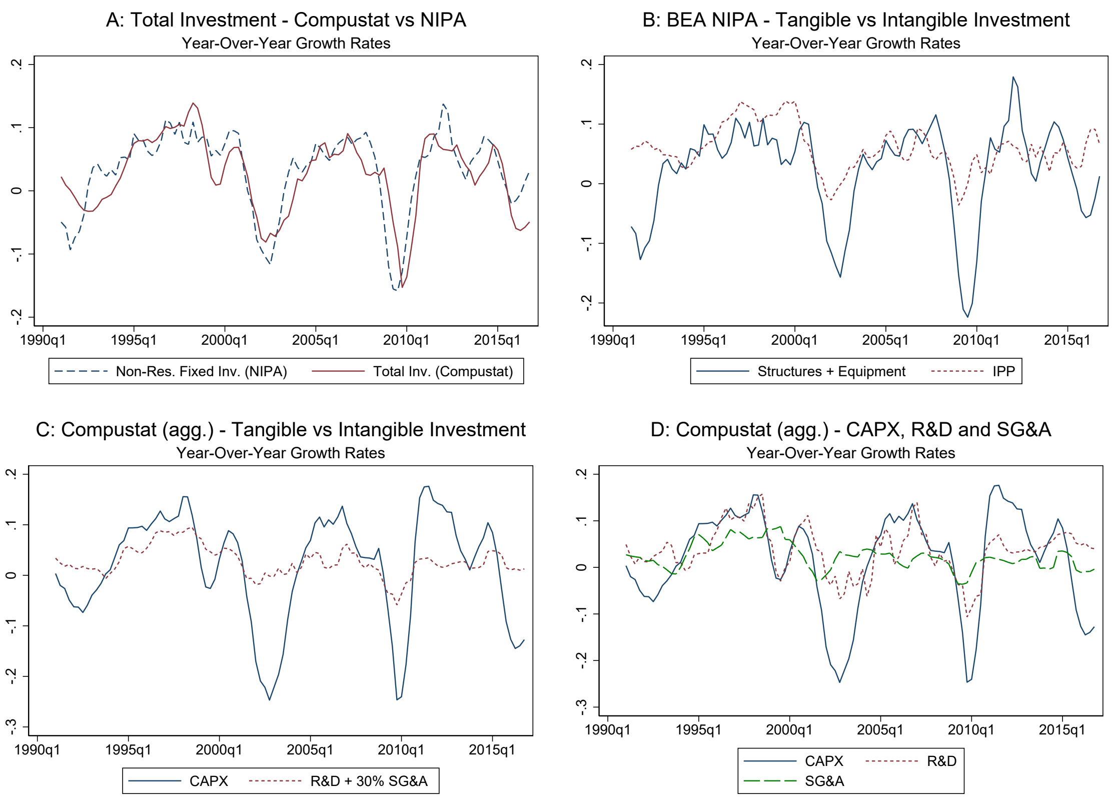


Figure 2: Firm-level Investment Response

This figure plots the dynamic response of investment to a 25bps higher 1-year Treasury rate, estimated using Eq. (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 and 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.

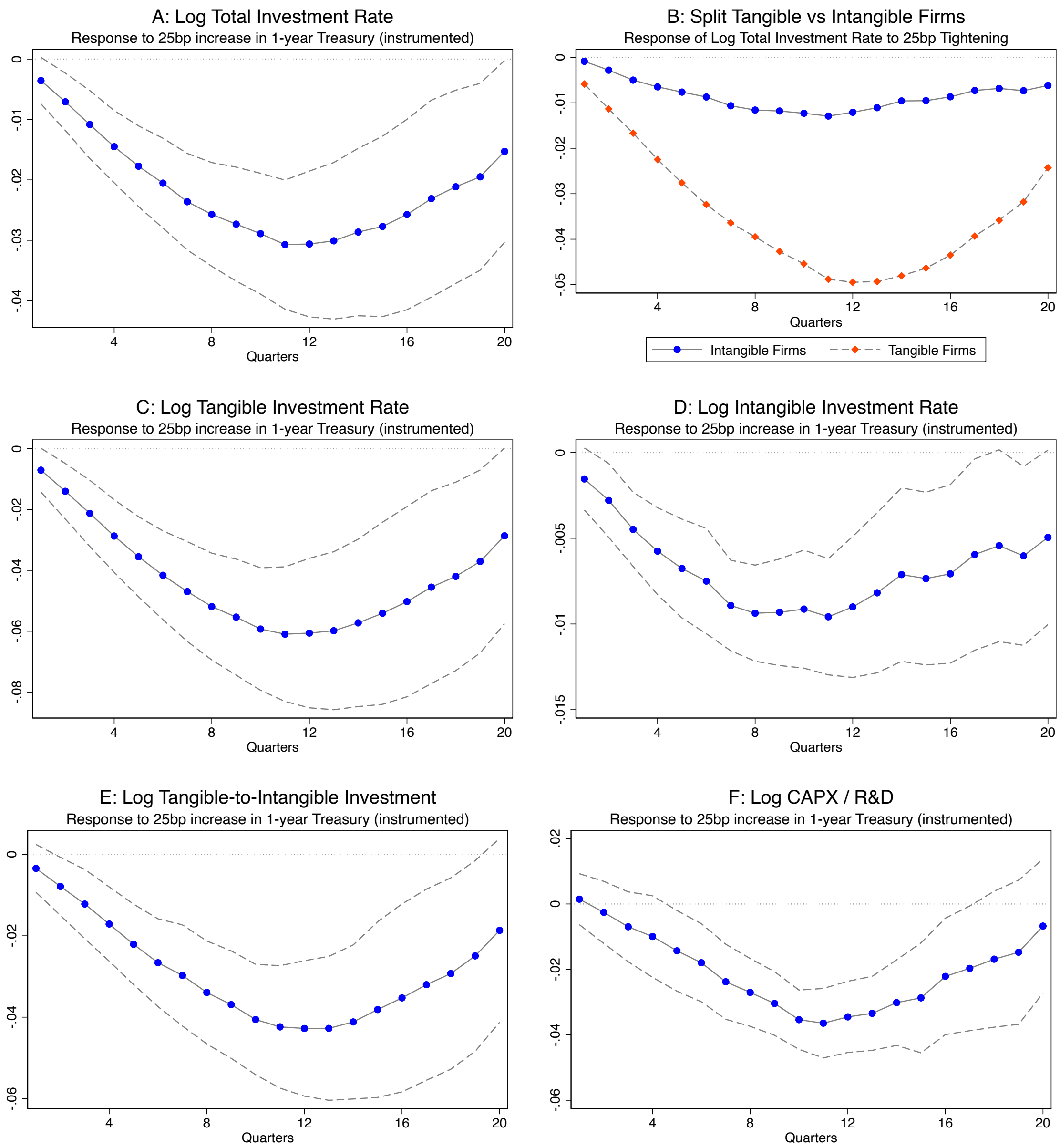


Figure 3: Firm-level Borrowing Response

This figure plots the dynamic response of borrowing to a 25bps higher 1-year Treasury rate, estimated using Eq. (2). 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 and 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.

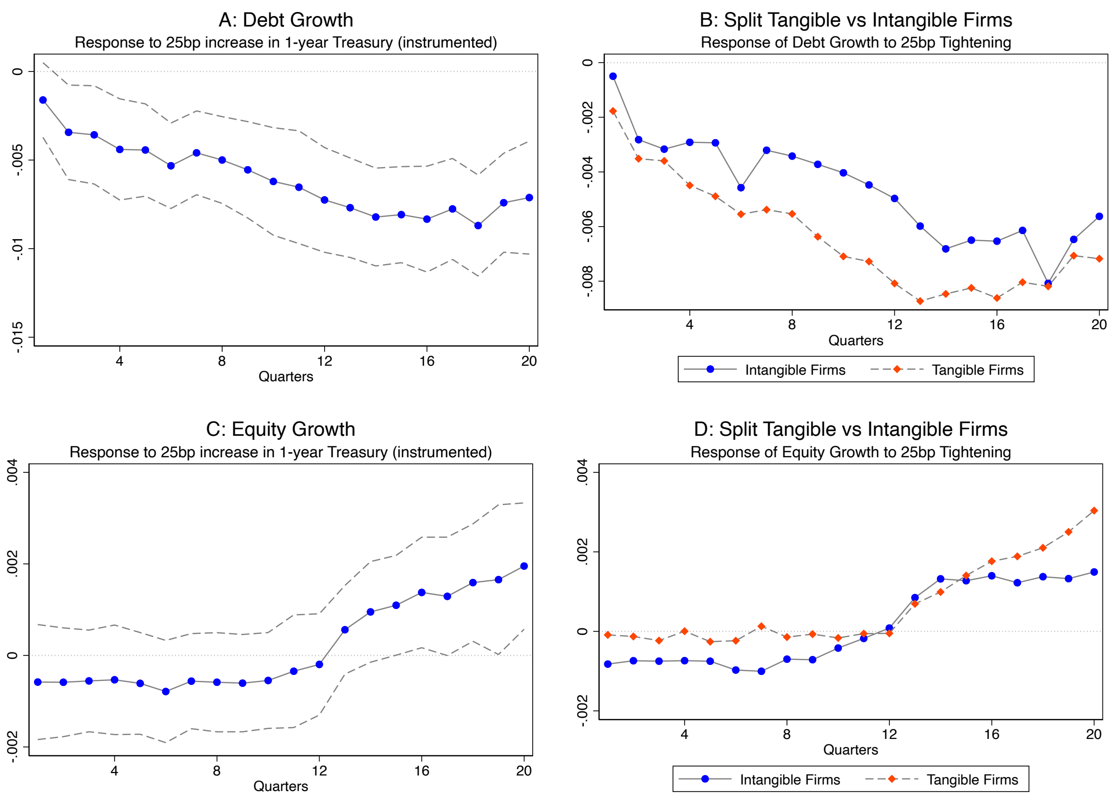
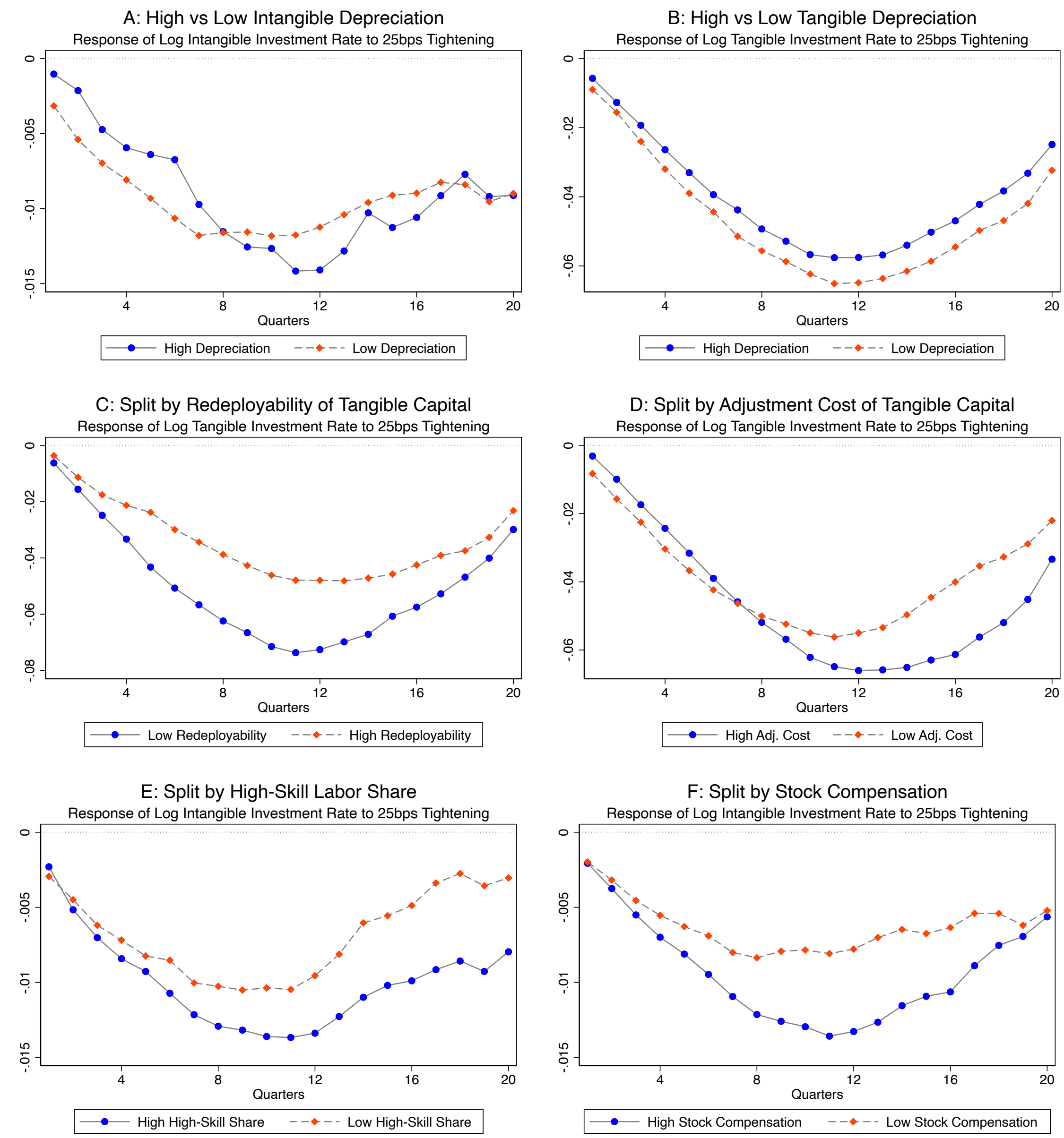


Figure 4: Investment Response - Sample Splits by Depreciation Rates and Adjustment Costs

This figure plots the dynamic response of firm investment rates to a 25bps higher 1-year Treasury rate on different sub-samples on different sub-samples. High vs low splits split firms above- vs below-median based on depreciation rates, redeployability estimates from Kim and Kung (2017), adjustment cost estimates from Hall (2004), income share of non-production labor according to the NBER-CES Manufacturing Industry Database, or employee stock compensation according to Compustat. 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 and fiscal quarter fixed effects.



Online Appendix for "Monetary Policy and Intangible Investment"

by Robin Döttling and Lev Ratnovski

This online appendix is organized as follows. Section AI provides details on the data construction. Section AII discusses the identification of the monetary policy stance and verifies it produces macroeconomic responses consistent with those in the extant literature. Section AIII presents several robustness tests of the main results as well as additional results. Section AIV provides details on the theoretical underpinning of the credit channel and depreciation channel.

AI Details on Data Construction

AI.1 Variable Definitions

Section 2 in the main paper discusses the sampling procedure and key variables. Table A1 lists the definitions of variables in firm-level Compustat data, where capitalized abbreviations refer to the item names in Compustat. Table A2 lists definitions and data sources of aggregate variables.

Note that firm size is computed as a measure of a firm's *total* assets, which is the sum of book assets (Compustat item AT, which includes tangible capital) plus off-balance sheet intangible capital. The regressions include the intangible-to-total capital ratio as the main variable of interest and the control variable for firm total assets, and therefore capture the *size* and the *composition* of a firm's capital stock. Similarly, Tobin's Q is computed using the measure of total assets as well. This is important because Peters and Taylor (2017) show that this measure, which they refer to as "Total Q", does better at predicting intangible investment.

Investment rates In the investment regressions the key dependent variables are investment rates defined as the respective investment divided by the lagged capital stock, i.e.,

$$I_{it}^{tan} = \frac{CAPX_{it}}{PPE_{it-1}},$$

$$I_{it}^{int} = \frac{R\&D_{it} + 0.3 \times SG\&A_{it}}{K_{it-1}^{int}},$$

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

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. We winsorize investment rates at the 1% level. The summary statistics of these quarterly investment rates are presented in Table 1 in the main paper and are in line with the annual investment rates in Peters and Taylor (2017).

AI.2 Comparison of Aggregate and Firm-Level Data

Compared to the firm-level Compustat-based measure, the BEA employs a narrower definition of intangible investment that only includes expenditures on R&D, software, and artistic originals. At the same time, BEA data cover all U.S. establishments, while Compustat only covers public firms. Figure A1 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 a broader definition of intangible capital and with large public firms being more technological and organizationally complex. Despite this level difference, firm-level and aggregate data exhibit a similar upward trend in intangible investment and capital stock.

AI.3 Mapping Fiscal Dates to Calendar Dates

We account for differences in fiscal and calendar quarters in Compustat data by mapping fiscal dates to calendar dates using information on when a firm's fiscal year ends (Compustat item $FYRC$: Fiscal year end). For example, if a firm's fiscal quarter ends in March, then we can use this information to map its fiscal Q4 to calendar Q1. To map fiscal years to calendar years, the description of the Compustat fiscal year variable states that "fiscal years ending January 1 through May 31 are treated as ending in the prior calendar year. Thus, data for a fiscal year beginning on June 1, 2000, and ending on May 31, 2001 is reported as data year 2000. A fiscal year beginning on July 1, 2000 and ending on June 30, 2001, is reported as data year 2001." This implies that, for firms with a fiscal year ending between January and March, fiscal year t is mapped to calendar year t in Q1–Q3 and to calendar year $t+1$ in Q4. For firms with a fiscal year ending between March and May, fiscal year t is mapped to calendar year t in Q1–Q2 and to calendar year $t+1$ in Q3–Q4. For firms with a fiscal year ending in June, fiscal year t is mapped to calendar year $t-1$ in Q1–Q2 and to calendar year t in Q3–Q4. For firms with a fiscal year ending between July and September, fiscal year t is mapped to calendar year $t-1$ in Q1–Q3 and to calendar year t in Q4. For firms with a fiscal year ending between October and December, the fiscal year is equal to the calendar year.

AII Verifying the Estimation of the Investment Response to Monetary Policy

Estimating the effects of monetary policy on investment (and other slow-moving variables) is complex (Nakamura and Steinsson, 2018). First, monetary policy is endogenous to macroeconomic conditions. Second, the true structure of the relationship between macroeconomic variables is uncertain, so estimations rely on the structure of the macroeconomic model. Consequently, there is no universal approach to such estimations and the methods used in the literature vary. As discussed in Section 3.2 in the main paper, we estimate the dynamic response of investment to the monetary policy stance captured by the 1-year Treasury level (as in Cloyne et al., 2018) instrumented using cumulative high-frequency monetary policy shocks (similar to Bu et al., 2021).[27]

Three observations support the validity of our approach. First, cumulative high-frequency shocks are a strong instrument for the level of the 1-year Treasury rate. This can be seen in the first-stage regression results reported in Table A3, which show that the coefficient estimates on the cumulative high-frequency shocks (denoted by FF4_tc) are a statistically significant and therefore a strong instrument for the 1-year Treasury rate. For illustration, Figure A2 plots the actual and the instrumented 1-year Treasury rate, along with the cumulative FF4 instrument.

Second, our approach yields the estimated responses to monetary policy of multiple macroeconomic variables that are in line with the existing literature, in both the magnitude and the timing of the impact. This is documented in Figure A3. In response to a 25bps higher 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 in line with estimates in Gertler and Karadi (2015) and Cloyne et al. (2018), both in magnitude and in the lag of the peak response (about 8-16 quarters).

As a third verification check, we note that all results on the effects of monetary policy on investment are mirrored by the results on the effects of monetary policy on firm stock prices, which are obtained from a tightly identified high-frequency setting.

[27] Romer and Romer (2004) and Elliott et al. (2019) also use cumulative high-frequency shocks, in a VAR model and directly in regression analysis, respectively. Other studies use alternative methods, e.g., Bernanke and Blinder (1992), Christiano et al. (1996) and Gertler and Karadi (2015) obtain exogenous variation in monetary policy levels from proxy VAR models, while Jeenas (2018) and Ottonello and Winberry (2020) use high-frequency shocks directly in local projections.

AIII Robustness Tests and Additional Results

AIII.1 Robustness of Baseline Stock Return Results

The baseline stock return results documented in Table 2 are robust to using alternative measures of monetary policy surprises and 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 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.[28] Table A4 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. Table A4, panel B, documents that the 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.

Third, Panel C of Table A4 uses an alternative firm-level tangible capital measure to compute the intangible-to-total capital ratio based on applying the perpetual inventory method (PIM) to capital expenditures. This measure replaces the accounting-based tangible capital

[28] 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.

measure Net Property Plant and Equipment (PPENT), which we use as the baseline measure in the paper. A potential concern with the accounting-based capital stock measure is that it may be distorted due to the use of accounting depreciation rates, which may differ from economic depreciation rates due to accounting conventions, such as accelerated depreciation, and other non-linearities in accounting depreciation rates. In the perpetual inventory method estimation for tangible assets, we use firm-level average depreciation rates, which can be thought of as depreciation rates that smoothen variation in accounting-based deprecation over the lifetime of a firm, and in this dimension potentially get closer to true economic depreciation rates in a firm. Note, however, that at the same time, averaged depreciation rates may, by construction, capture less well true changes in depreciation rates over the life cycle of the firm. Reassuringly, the results in panel C are very similar to the baseline results in Table 2, despite some drop in the number of observations for the perpetual inventory method (related to the fact that we need consecutive non-missing capital expenditures to apply the perpetual inventory method).

Finally, Panel D of Table A4 uses a within-firm de-meaned version of the baseline intangible-to-total capital ratio. Ottonello and Winberry (2020) demonstrate in their Online Appendix A.1 that, when unobserved, time-invariant differences in firm monetary policy response that are proportionate to some sample-average variable, not de-meaning this variable biases the estimates, as regression residuals would be correlated with the omitted interaction term between the variable and the monetary policy measure. In our setting, a similar problem could arise if a firm's sample-average intangible-to-total capital ratio interacted with the monetary policy measure were correlated with the residuals from our main regressions. Panel D documents that the baseline stock return results are robust to using a de-meaned intangible-to-total capital ratio, indicating that our results are not confounded by unobserved, permanent, and proportionate to the average intangible-to-total capital ratio differences in firm monetary policy response.

AIII.2 Robustness of Firm-Level Investment Results

Figure A4 documents the robustness of the results in Figure 2 to using cumulative "pure" monetary policy shocks (separated from central bank information shocks) from Jarocinski and Karadi (2020) as the instrument. The results are similar to those in the baseline.

Analogous to Table A4, Table A5 documents the robustness of the investment results to using different monetary policy and intangible capital measures. Panel A uses pure monetary policy shocks separated from central bank information shocks as instrument in the interaction term specification of Table 3. 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). Panel C uses an alternative firm-level tangible capital measure based on applying the perpetual inventory method to capital expenditures, and panel D uses a within-firm demeaned intangible-to-total capital ratio, as described in the previous sub-section. In all three exercises the interaction term of the instrumented 1-year Treasury and a firm's intangible ratio is similar in magnitude to that in the baseline. This confirms that the weaker investment response of firms with relatively more intangible capital is robust to using an alternative monetary policy instrument and alternative intangible capital measures.

Figure A5 presents another robustness check that decomposes the intangible investment response to monetary policy into the responses of its knowledge (RD) and organizational investment (SGA) components. In panels A-D, R&D and SG&A expenditures respond similarly to monetary policy, irrespective of whether we consider log expenditures or log investment rates. We also find that the total investment of firms with above-median knowledge or organizational capital respond less to monetary policy than those of firms below the medians (panels E and F). This verifies that our results are not contaminated by the method of measuring intangible investment that, following Peters and Taylor (2017) and Falato et al. (2020), assigns a fixed weight to the share of SGA expenditure associated with intangible investment.

AIII.3 Results from Aggregate Investment Data

The firm-level measure of intangible capital is sourced from Compustat and therefore only captures public firms. We can 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.

The regression specification for aggregate data only includes macro controls and calendar quarter fixed effects:

$$y_{t+h} - y_{t-1} = \alpha + \beta_1^h \hat{R}_t + \beta_2^h X_{t-1}^m + \psi_{cq} + \varepsilon_t. \tag{6}$$

As in the main text, we present the results in the form of impulse response functions (IRFs) that plot the coefficients β_1^h for quarterly horizons $h = 1 \dots 20$, along with 95% confidence intervals. These coefficients can be interpreted as the change in the dependent variable over h quarters given a 1% higher level of interest rates.

Figure A6 plots the monetary policy response of BEA NIPA investment data and documents that also in aggregate data intangible investment responds significantly less than tangible investment, similar to the patterns in the firm-level data in Figure 2. In response to an instrumented 25bps higher 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.

AIII.4 Additional Results on the Credit Channel

Table 4 reports estimates of the coefficient on the interaction between the instrumented 1-year Treasury rate and the intangible ratio (i.e., β_2^h in Specification 3) among more and less constrained firms for horizons $h = 8$ and $h = 12$ quarters. Figure A9 plots the coefficient estimates of this interaction term for each quarterly horizon from $h = 1$ to $h = 20$ quarters. Panel A reports the estimates for sample splits based on firm age, panel B for age and size, panel C for cash holdings, and panel D for the *Delaycon* financial constraint measure from Hoberg and Maksimovic (2015). In all samples splits, the difference in the coefficient estimates between more and less constrained firms is most pronounced around horizons of $h = 8$ to $h = 12$ quarters.

Figure A10 decomposes the response of equity growth reported in Figure 3 in the main paper into gross equity issuance, net equity issuance, and payouts. Gross equity issuance does not respond to monetary policy (see panel A). At the same time, payouts to shareholders (dividends and share repurchases) decrease in response to monetary tightening (see panels C and D), leading to a somewhat counter-intuitive *increase* in net equity issuance in response to monetary tightening (see panel D). At the same time, cash flows decline (not reported), explaining the altogether flat response of book equity growth in Figure 3.

AIII.5 Implications of a Weaker Credit Channel for Aggregate Investment

Because firms with more intangible capital make more of intangible investment,[29] firm financial constraints should also affect the aggregate tangible and intangible investment response to monetary policy. To test this aggregate implication, we analyze the response of the log

[29]The average tangible over intangible investment ratio is 0.411 among firms with above-median intangible-to-total capital stock, compared to 4.625 among tangible firms below median, see Table 1.

tangible-to-intangible investment ratio to monetary policy (i.e., the difference in the tangible and intangible investment response, similar to panel D of Figure 2) where tangible and intangible investment are aggregated separately across financially constrained and financially unconstrained firms. As before, we capture financial constraints by age, 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. As in the sample splits in Table 4, for cash holdings we 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.

Figure A7 plots the results from sample splits (for full-sample aggregate responses, see Figure A8). Panel A distinguishes young and old firms, and documents that the difference in the response of tangible and intangible investment to monetary policy reaches 5 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 is 5 percentage points and statistically significant at 10 quarters and widens further thereafter. Panels C and D report similar results for the split based cash holdings, and panels E and F 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 constrained and unconstrained firms inform both the weaker monetary policy response in firms with relatively more intangible capital and the weaker intangible (compared to tangible) investment response to monetary policy in the aggregate.

AIV Details on the Credit and Depreciation Channel

AIV.1 Solving the Firm's Problem in the Credit Channel Model

This subsection solves the firm's optimization problem in the model derived in Section 4.1 in the main paper. The problem is given by:

$$\begin{aligned} \max_{I_t, D_t} \quad & F(K_{t+1}) - I_t r_t \\ s.t. \quad & K_{t+1} = K_t + I_t, \\ & I_t = A_t + D_t, \\ & D_t \leq (1-\mu) Q_t(r_t) K_t. \end{aligned} \tag{7}$$

Eliminating I_t and K_{t+1}, this problem can be written as the following Lagrangian,

$$\max_{D_t} \mathcal{L} = F(K_t + A_t + D_t) - (A_t + D_t) r_t + \lambda [D_t - (1-\mu) Q_t(r_t) K_t]$$

in which choose the optimal debt level D_t, investment follows as the residual $I_t = A_t + D_t$, and λ is the Lagrange multiplier on the collateral constraint (4). The first order condition with respect to D_t is given by

$$F'(K_{t+1}) = r_t + \lambda.$$

Thus, there are two solution regions, depending on whether the collateral constraint (4) binds. For an *unconstrained firm*, $\lambda = 0$, and accordingly the 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. In this case, 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, for a constrained firm $\lambda = 0$, and D_t follows from the collateral constraint

(4) and the fact that $I_t = A_t + D_t$:

$$I_t = A_t + (1-\mu)Q_t(r_t)K_t,$$

Differentiating with respect to r_t yields condition (5) in the paper:

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

Here, investment is limited by the collateral value of firm assets, which declines in the interest rate since $Q_t'(r_t) \leq 0$. As discussed in Section 4.1 in the paper, this condition shows that the investment of firms with a higher share of intangible assets μ declines *less* when interest rates increase because such firms use less debt funding.

We note that the presence of "hard" financial constraints is a modeling simplification. In practice, firms may face a downward-sloping demand schedule. However, the price of debt can be convex in the quantity of debt (indicating rapidly onsetting financial constraints), as firms of lower credit quality tend to have sharply higher credit spreads, even after conditioning on expected losses (Berndt et al., 2018).

AIV.2 Credit Channel and Redeployability

In interpreting the results on asset redeployability in Section 4.3 in the main paper, it is important to consider carefully a possible interaction between asset redeployability and the credit channel of monetary policy. On the one hand, 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). On the other hand, the markets for more redeployable assets are deeper, so the price of these assets may respond less to interest rates, weakening the credit channel. Indeed, Kim and Kung (2017, Online Appendix Section 2) confirm that the markets for more redeployable assets are deeper and thus the prices of such assets 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. 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 (more subject to the credit channel) and unconstrained firms (see Table A6). This confirms that the effect of adjustment costs on the response of investment to monetary policy is distinct from the credit channel.

AIV.3 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 $MPK'(I) = F''(K) \leq 0$, investment decreases in interest rates, i.e., $\partial I(r, \delta)/\partial r \leq 0$.

This effect is illustrated in Figure A11, which plots investment against the user cost of capital. On the horizontal 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 with 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 smaller effect on the user cost of capital if depreciation rates are higher and the marginal product of capital is convex.

Furthermore, 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 A11, 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 profit $\pi = F(K) - (r+\delta)K$ can be expressed as:

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

The effect of a change in the interest rate from r to r' on profit 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 $r'+\delta$. Figure A11 illustrates 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 greater than that from the horizontal line to $MPK(I_{INT})$. Intuitively, if depreciation is the dominant part of user costs, changes in interest rates have a smaller effect on firm profits.

AIV.3.1 Depreciation Channel and Firm Cyclicality

The depreciation channel also implies that the investment of firms with higher depreciation rates should be less cyclical. This can be illustrated by considering a simple Cobb-Douglas production function $F(K) = AK^{\alpha}L^{1-\alpha}$ with labor, for simplicity, in fixed supply $L=1$. A firm that equates the marginal product of capital to the user cost of capital, $F'(K) = r+\delta$, invests up to the point where

$$K = \left(\frac{\alpha A}{r+\delta}\right)^{\frac{1}{1-\alpha}}.$$

The partial derivative with respect to productivity A is given by

$$\frac{\partial K}{\partial A} = \frac{\alpha}{(r+\delta)(1-\alpha)} \left(\frac{\alpha A}{r+\delta}\right)^{\frac{\alpha}{1-\alpha}},$$

which decreases in δ. Thus, the investment of firms with higher depreciation rates δ responds less to productivity shocks and is therefore less cyclical.

These considerations provide an additional verification exercise for the depreciation channel. To perform this check, we run regressions similar to the baseline Specification (3), in which we regress a firm's total investment on GDP growth ΔY_t and an interaction of GDP growth with depreciation rates δ_{it-1}:

$$y_{it+h} - y_{it-1} = \beta_1^h \cdot \Delta Y_t + \beta_2^h \cdot \Delta Y_t \times \delta_{it-1} + \gamma_1^{h\prime} \cdot X_{it-1}^f + \mu_i + \eta_t + \psi_{fq} + \varepsilon_{it}.$$

The results are presented in Table A7 and show that a negative coefficient estimate on the interaction of GDP growth and the depreciation rate, statistically significant at the 8-quarter horizon but not at the 12-quarter horizon. This shows that the investment of firms with higher depreciation rates is less cyclical, consistent with the depreciation channel. The mixed statistical significance is consistent with our findings in Section 4.2 that the depreciation channel appears to play a smaller role in explaining a weaker monetary policy transmission to intangible firms.

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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 × 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	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
GDP Growth	Change in Real Gross Domestic Product (GDPC1)	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: 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. F statistics are reported for all variables and the instrument, respectively.

	(1) *R*	(2) *R*
FF4_tc	2.62***	
	(0.37)	
MPShockSign_tc		3.57***
		(0.56)
Log CPI	14.8***	11.0*
	(4.63)	(6.45)
Log Industrial Production	-7.90**	-8.87*
	(3.71)	(5.17)
Log Employment Ratio	62.3***	63.1***
	(11.4)	(14.3)
Excess Bond Premium	-67.4***	-69.6***
	(18.0)	(23.4)
ΔGDP	0.55	13.3
	(11.1)	(12.3)
Observations	107	107
F stat all	117	165
F stat IV	50.8	41.3

Table A4: Stock Returns - Robustness to Decomposition into Monetary Policy and Central Bank Information Shocks from Jarocinski and Karadi (2020) and Different Intangible Ratio Measures

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). In Panel C, Intangible Ratio (DM) is the within-firm de-meaned Intangible Ratio. Panel D uses an intangible ratio measure in which the tangible capital stock is computed using capital expenditures in the perpetual inventory method (PIM). 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. 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.

	(1) Raw Return	(2) Raw Return	(3) Raw Return	(4) Abnormal Return	(5) Abnormal Return
Panel A: MP-CBI Decomposition					
MPshockSign	-7.57***				
	(1.71)				
CBIshockSign	6.19**				
	(2.85)				
MPshockSign × Intangible Ratio		1.50**	1.47**	1.49**	1.41**
		(0.67)	(0.68)	(0.58)	(0.60)
CBIshockSign × Intangible Ratio		0.90	0.92	0.92	0.82
		(1.35)	(1.39)	(1.37)	(1.40)
Observations	463130	454678	454599	454678	454599
Panel B: EPW Intangible Measure					
ΔFF4	-4.35**				
	(1.74)				
ΔFF4 × Intangible Ratio (EPW)		1.45**	1.44**	1.48***	1.42**
		(0.62)	(0.64)	(0.56)	(0.59)
Observations	463321	454867	454788	454867	454788
Panel C: Perpetual Inventory Method for Tangible Capital					
ΔFF4	-3.19**				
	(1.34)				
ΔFF4 × Intangible Ratio (PIM)		1.52***	1.55***	1.44**	1.40**
		(0.53)	(0.53)	(0.59)	(0.59)
Observations	265311	253147	253133	253147	253133
Panel D: Deviation-from-mean Intangible Measure					
ΔFF4	-4.35**				
	(1.74)				
ΔFF4 × Intangible Ratio (DM)		3.74**	3.93**	2.86**	2.86**
		(1.76)	(1.79)	(1.28)	(1.34)
Observations	463130	454678	454599	454678	454599
Industry X Event-Date FE	No	Yes	Yes	Yes	Yes
Firm FE	Yes	No	Yes	No	Yes
Fiscal Quarter FE	Yes	Yes	Yes	Yes	Yes

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. 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. In Panel C, Intangible Ratio (DM) is the within-firm de-meaned Intangible Ratio. Panel D uses an intangible ratio measure in which the tangible capital stock is computed using capital expenditures in the perpetual inventory method (PIM). 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.

	$h=8$			$h=12$		
	(1) $\Delta^h I_t^{tot}$	(2) $\Delta^h I_t^{tot}$	(3) $\Delta^h I_t^{tot}$	(4) $\Delta^h I_t^{tot}$	(5) $\Delta^h I_t^{tot}$	(6) $\Delta^h I_t^{tot}$
Panel A: MP-CBI Decomposition						
$\hat{R}(MPS)$	-0.065***			-0.099***		
	(0.020)			(0.023)		
$\hat{R}(MPS)$ × Intangible Ratio		0.035	0.037**		0.049*	0.049***
		(0.023)	(0.015)		(0.027)	(0.017)
Observations	160437	160437	155081	142792	142792	137787
Panel B: EPW Intangible Measure						
$\hat{R}$	-0.10***			-0.12***		
	(0.018)			(0.025)		
$\hat{R}$ × Intangible Ratio (EPW)		0.046**	0.042***		0.056**	0.053***
		(0.018)	(0.013)		(0.022)	(0.015)
Observations	160439	160439	155082	142796	142796	137790
Panel C: Perpetual Inventory Method for Tangible Capital						
$\hat{R}$	-0.12***			-0.16***		
	(0.021)			(0.029)		
$\hat{R}$ × Intangible Ratio (PIM)		0.051**	0.057***		0.037	0.056***
		(0.023)	(0.016)		(0.025)	(0.019)
Observations	49095	49095	44401	44700	44700	40292
Panel D: Deviation-from-mean Intangible Measure						
$\hat{R}$	-0.10***			-0.12***		
	(0.017)			(0.024)		
$\hat{R}$ × Intangible Ratio (DM)		0.060**	0.051**		0.024	0.022
		(0.029)	(0.024)		(0.037)	(0.027)
Observations	160437	160437	155081	142792	142792	137787
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	No	Yes	No	No	Yes	No
Industry X 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 12-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. The difference between high and low redeployability firms is computed from an interaction term between the instrumented 1-year Treasury rate and a dummy for whether a firm's asset redeployability is above median.

	High Redeployability	Low Redeployability	Difference
Old	-0.25***	-0.25***	0.013*
Young	-0.24958	-0.25***	0.00042
Low Delaycon	-0.2828***	-0.29***	0.0072
High Delaycon	-0.3153***	-0.32***	0.0047
High Cash	-0.2517***	-0.25***	-0.0017
Low Cash	-0.229***	-0.25***	0.021

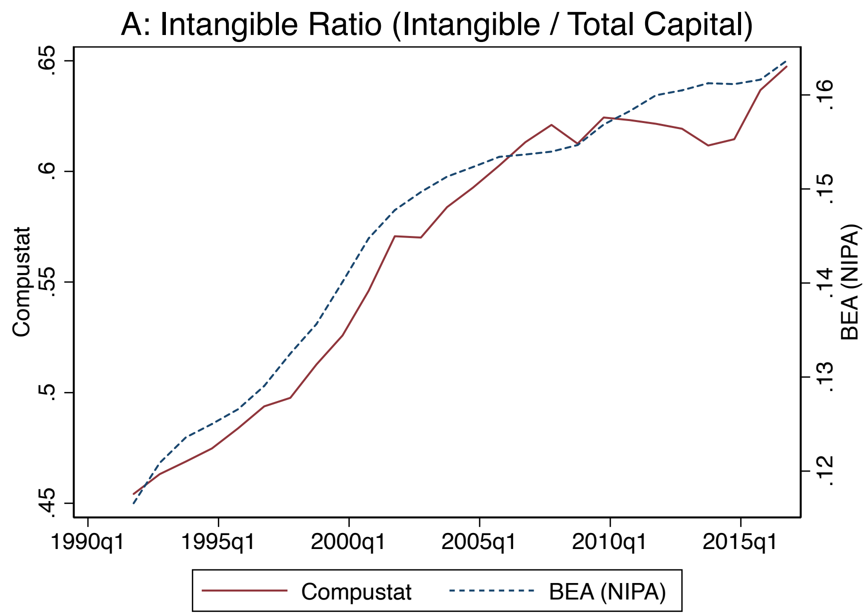
Table A7: Investment Cyclicality and Depreciation Rates

This table documents estimates from regressing log total investment rates on GDP growth interacted with total depreciation rates. The regressions controls for the same firm-level controls as in the baseline regressions reported in Table 3. The sample 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.

	$h = 8$		$h = 12$	
	(1) ΔI_t^{tot}	(2) ΔI_t^{tot}	(3) ΔI_t^{tot}	(4) ΔI_t^{tot}
ΔGDP	9.13**		4.92	
	(3.89)		(4.18)	
ΔGDP $\times$ Depreciation Rate	-29.5*	-30.8**	-17.4	-21.0
	(15.3)	(14.4)	(15.2)	(13.7)
Depreciation Rate	-4.08***	-3.99***	-5.04***	-4.83***
	(0.29)	(0.24)	(0.36)	(0.33)
Intangible Ratio	1.50***	1.48***	1.75***	1.71***
	(0.11)	(0.094)	(0.12)	(0.099)
Age	0.092***	0.14***	0.084***	0.16***
	(0.025)	(0.011)	(0.027)	(0.011)
Total Q	-0.11***	-0.078***	-0.14***	-0.11***
	(0.0096)	(0.0065)	(0.010)	(0.0067)
Cash	-0.015	-0.081**	-0.13***	-0.21***
	(0.037)	(0.036)	(0.043)	(0.039)
Leverage	0.15***	0.18***	0.27***	0.29***
	(0.027)	(0.019)	(0.033)	(0.020)
Cashflows	0.063	-0.066	-0.58***	-0.59***
	(0.14)	(0.13)	(0.16)	(0.14)
Size	-0.19***	-0.16***	-0.21***	-0.17***
	(0.016)	(0.016)	(0.014)	(0.014)
Dividend Paid	-0.017	-0.018*	-0.023**	-0.020**
	(0.011)	(0.0099)	(0.010)	(0.0085)
Observations	83365	83365	74499	74499
R-squared	0.072	0.060	0.099	0.084
Firm FE	Yes	Yes	Yes	Yes
Time FE	No	Yes	No	Yes
Fiscal Quarter FE	Yes	Yes	Yes	Yes

Figure A1: Intangible vs Physical Capital and Investment

This figure plots the evolution of the aggregate tangible-to-total capital and investment ratios in the 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).



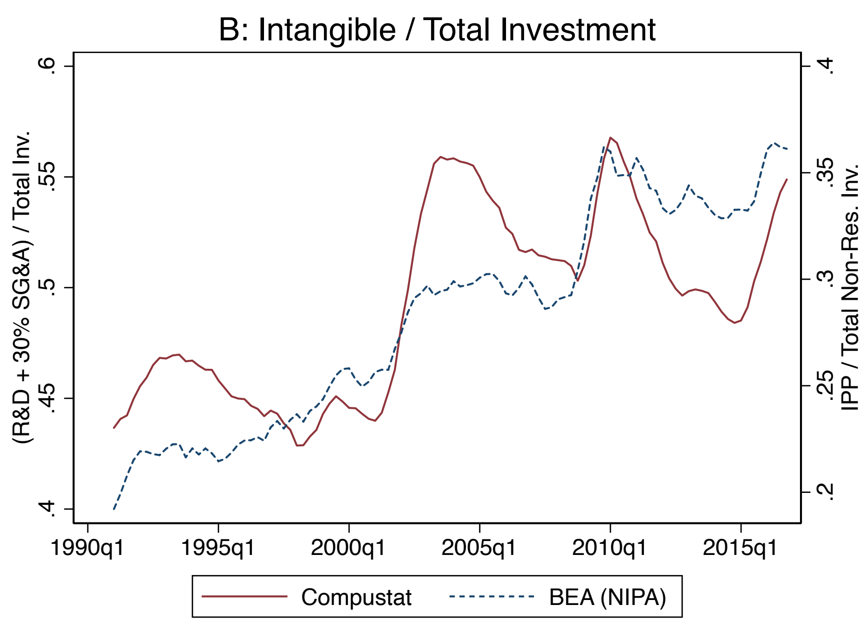


Figure A2: Monetary Policy Measures

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 A3).

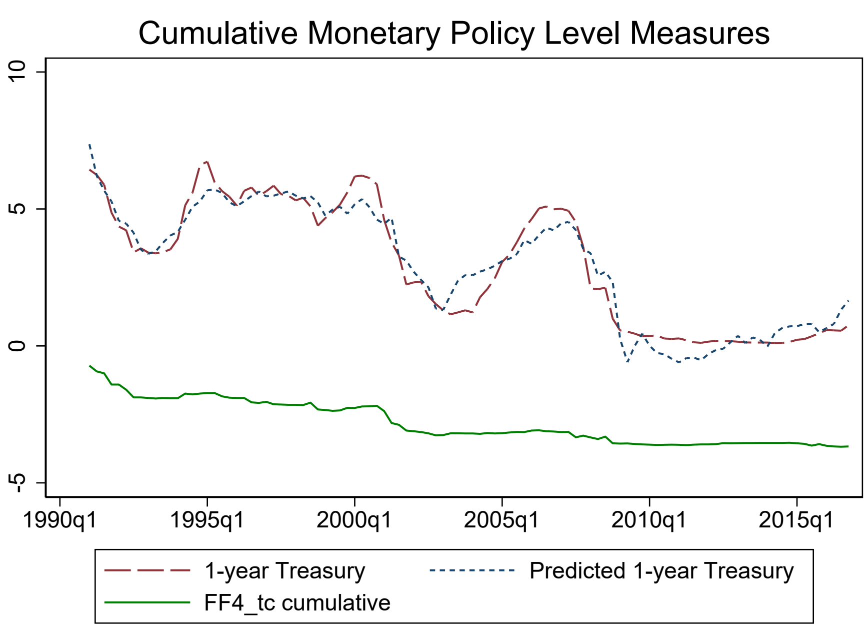


Figure A3: Response of Other Macro Variables

This figure plots the dynamic response of a number of macroeconomic variables to a 25bps higher 1-year Treasury rate, estimated using Eq. (6). 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, GDP growth, and the log of the employment ratio (excluding the respective dependent variable). The dashed line represents 95% confidence intervals using Newey-West standard errors.

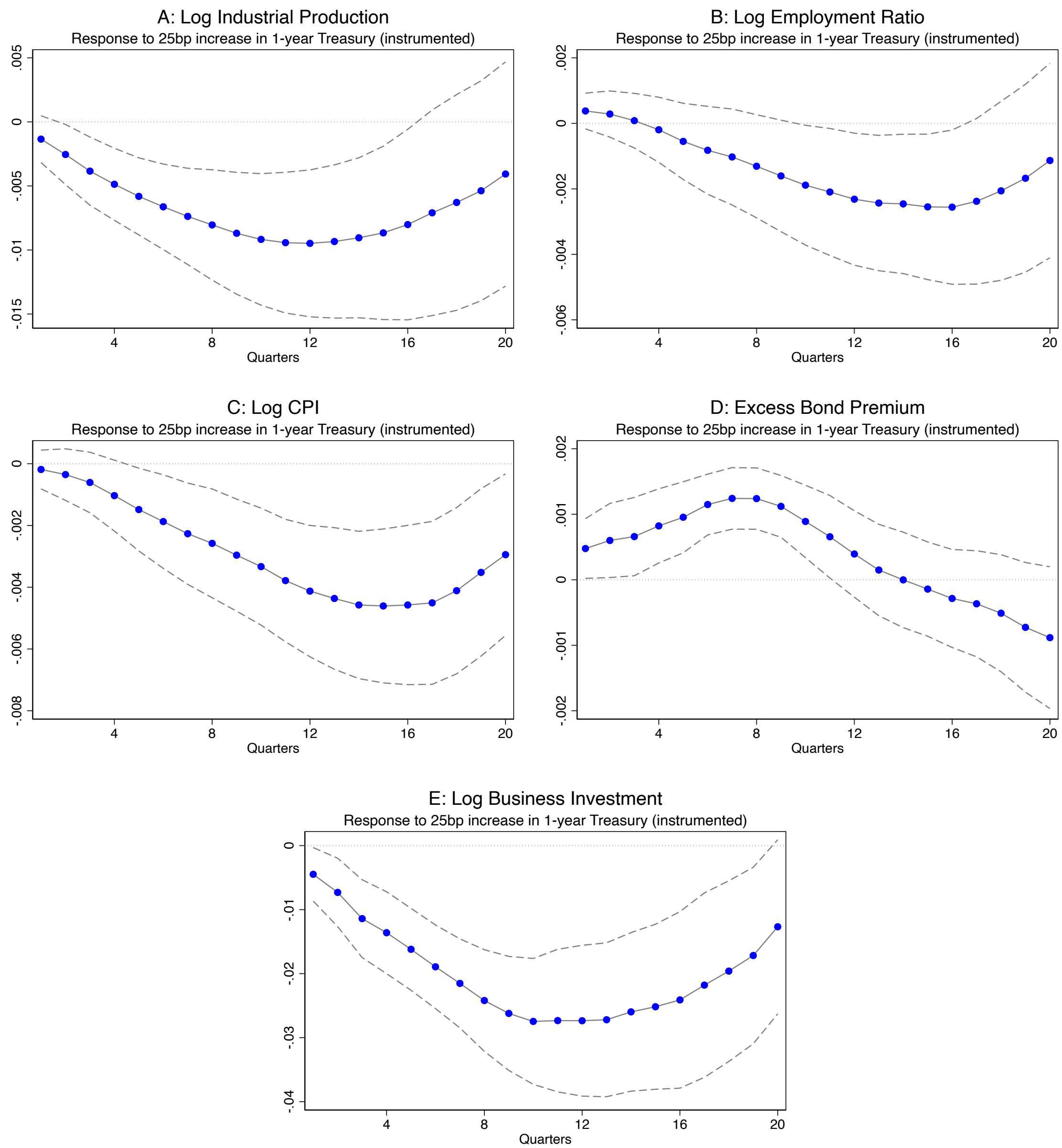


Figure A4: Firm-level Investment Response - Robustness to Monetary Policy Shock and Central Bank Information Decomposition from Jarocinski and Karadi (2020)

This figure presents robustness of Figure 2 using monetary policy shocks from Jarocinski and Karadi (2020) as instrument. The figure plots the dynamic response of investment to a 25bps higher 1-year Treasury rate, estimated using Eq. (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 and 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.

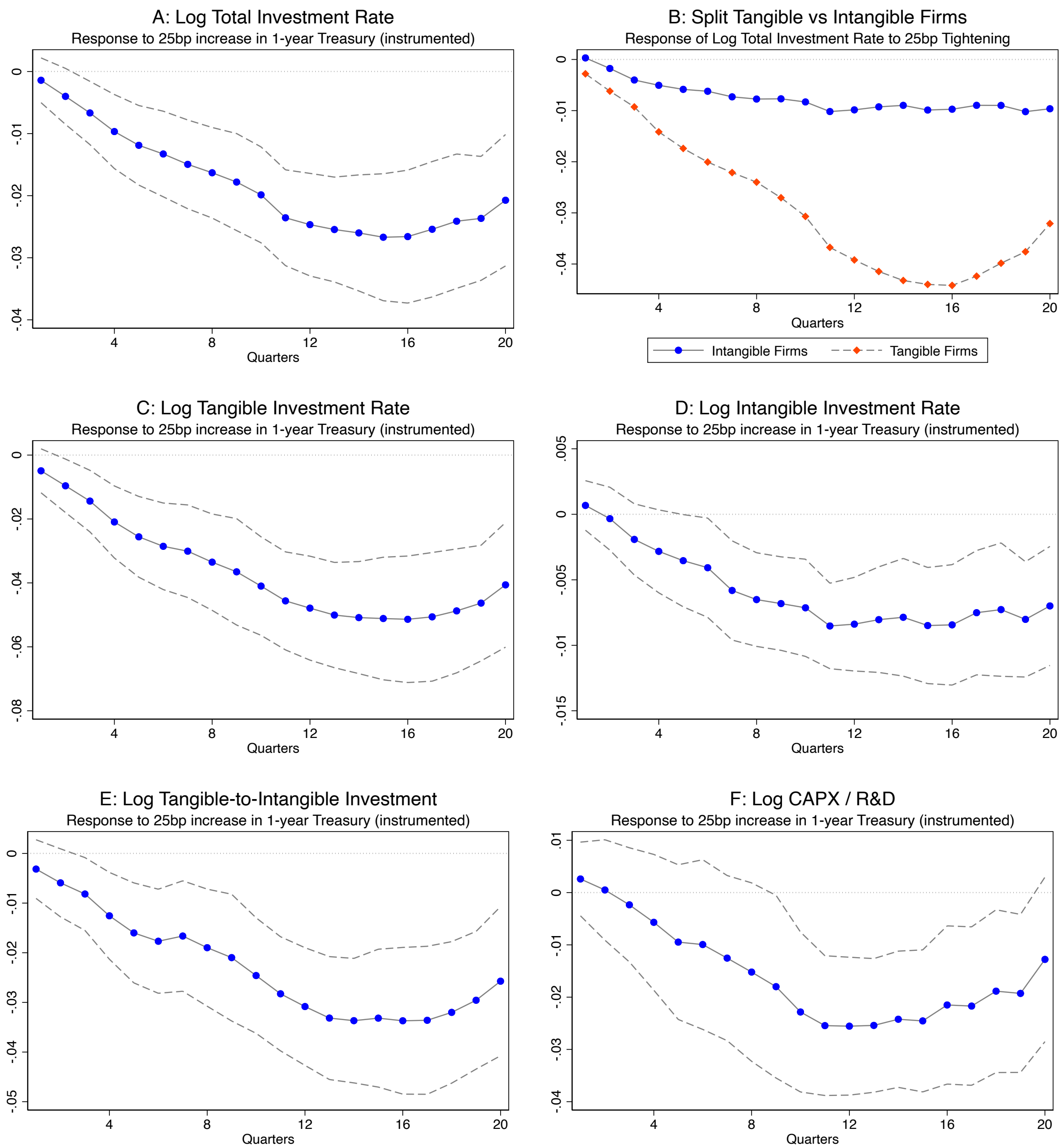


Figure A5: Firm-level Investment Response - Decomposition Knowledge and Organizational Investment

This figure plots the dynamic response of investment to a 25bps higher 1-year Treasury rate, estimating Eq. (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 the instrumented the 1-year Treasury rate (β_1^h in Eq. (2)). The tangible, R&D and SG&A investment rates are defined as, respectively, CAPX divided by lagged net property plant and equipment, R&D divided by lagged knowledge capital, and SG&A divided by lagged organizational capital. All regressions include firm and macro controls, as well as firm and fiscal quarter fixed effects. The dashed line represents 95% confidence intervals using heteroscedasticity and autocorrelation robust Driscoll-Kraay standard errors.

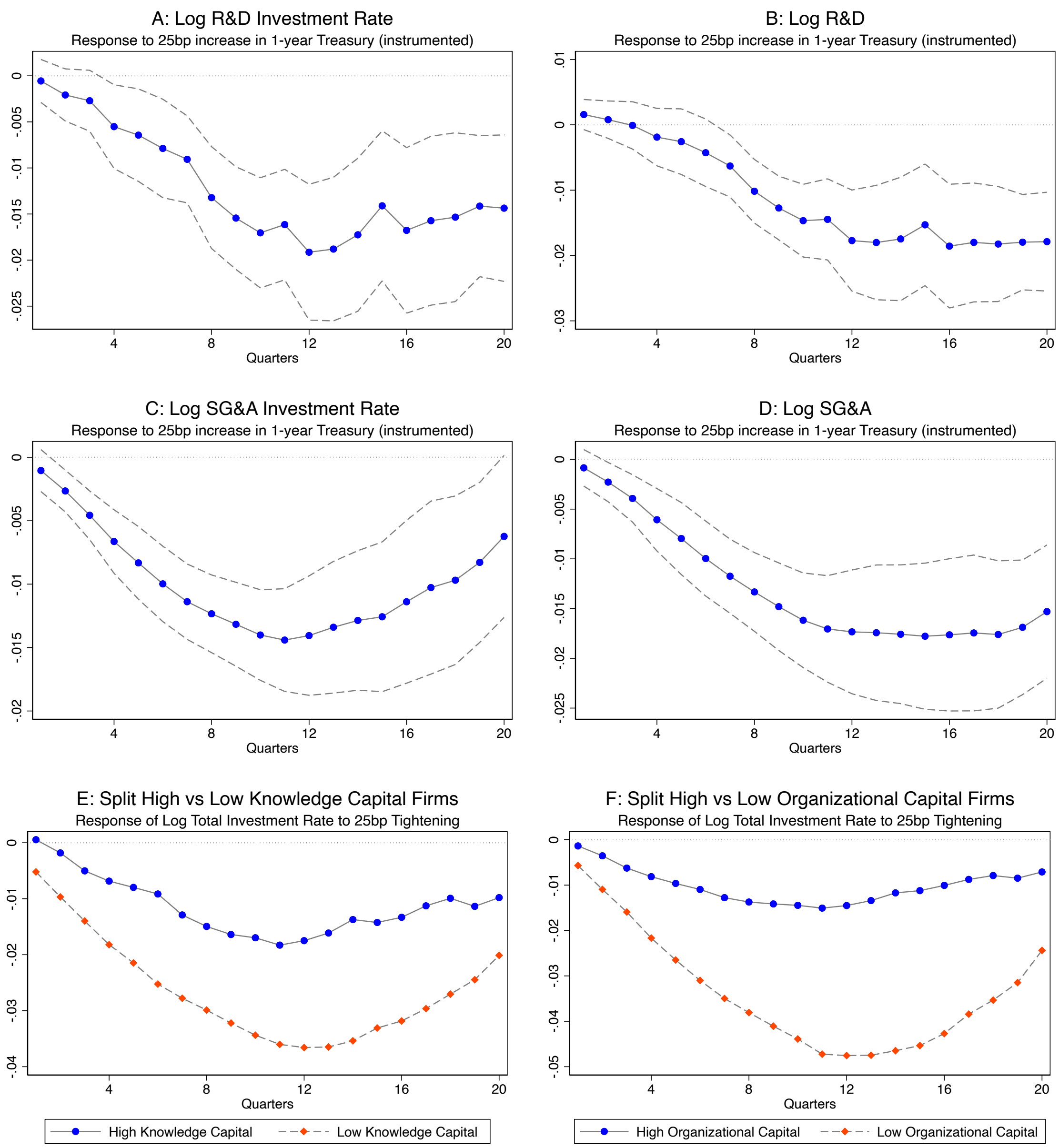


Figure A6: Aggregate Investment Response (NIPA)

This figure plots the dynamic response of investment to a 25bps higher 1-year Treasury rate, estimated using Eq. (6). 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, GDP growth, and the log of the employment ratio. The dashed line represents 95% confidence intervals using Newey-West standard errors.

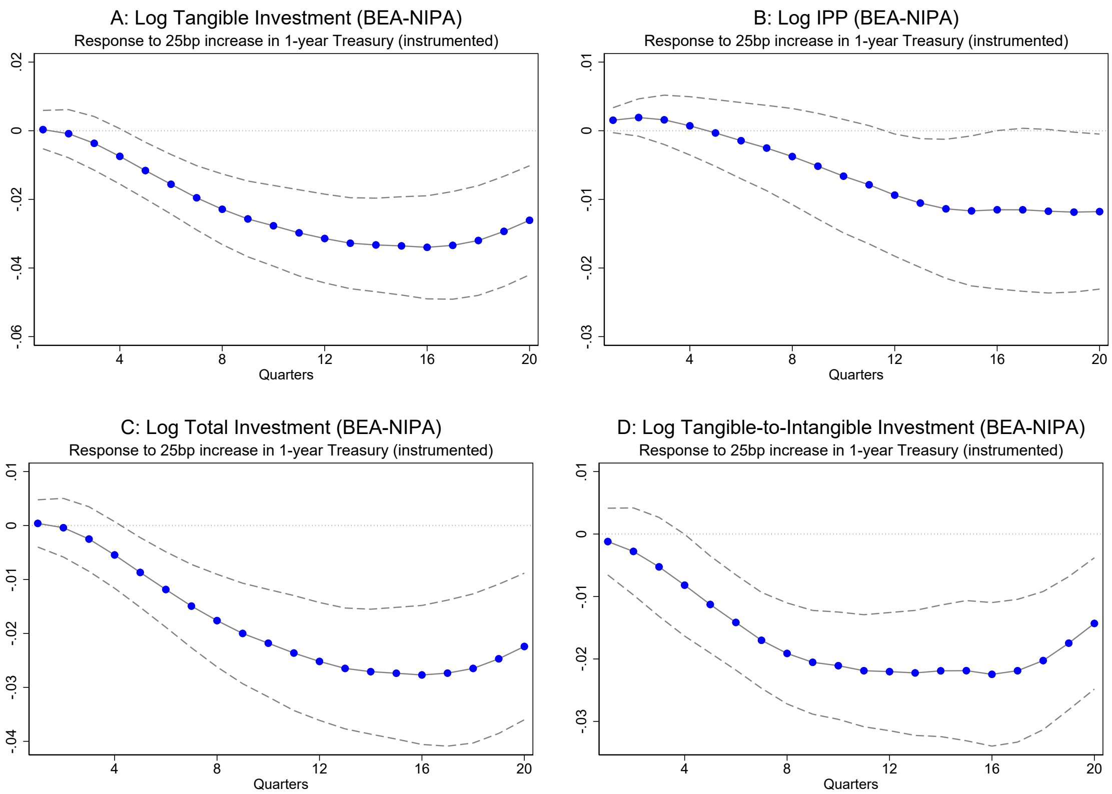


Figure A7: Response of Aggregate Compustat Tangible-to-Intangible Investment - Credit Channel

This figure plots the dynamic response of the aggregate log tangible-to-intangible investment ratio to a 25bps higher 1-year Treasury rate. Each panel represents aggregations within different sub-sets of firms. Young (old) firms are those in the lowest (highest) tercile of the age distribution in a given quarter. 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, GDP growth and the log of the employment ratio. The dashed line represents 95% confidence intervals using Newey-West standard errors.

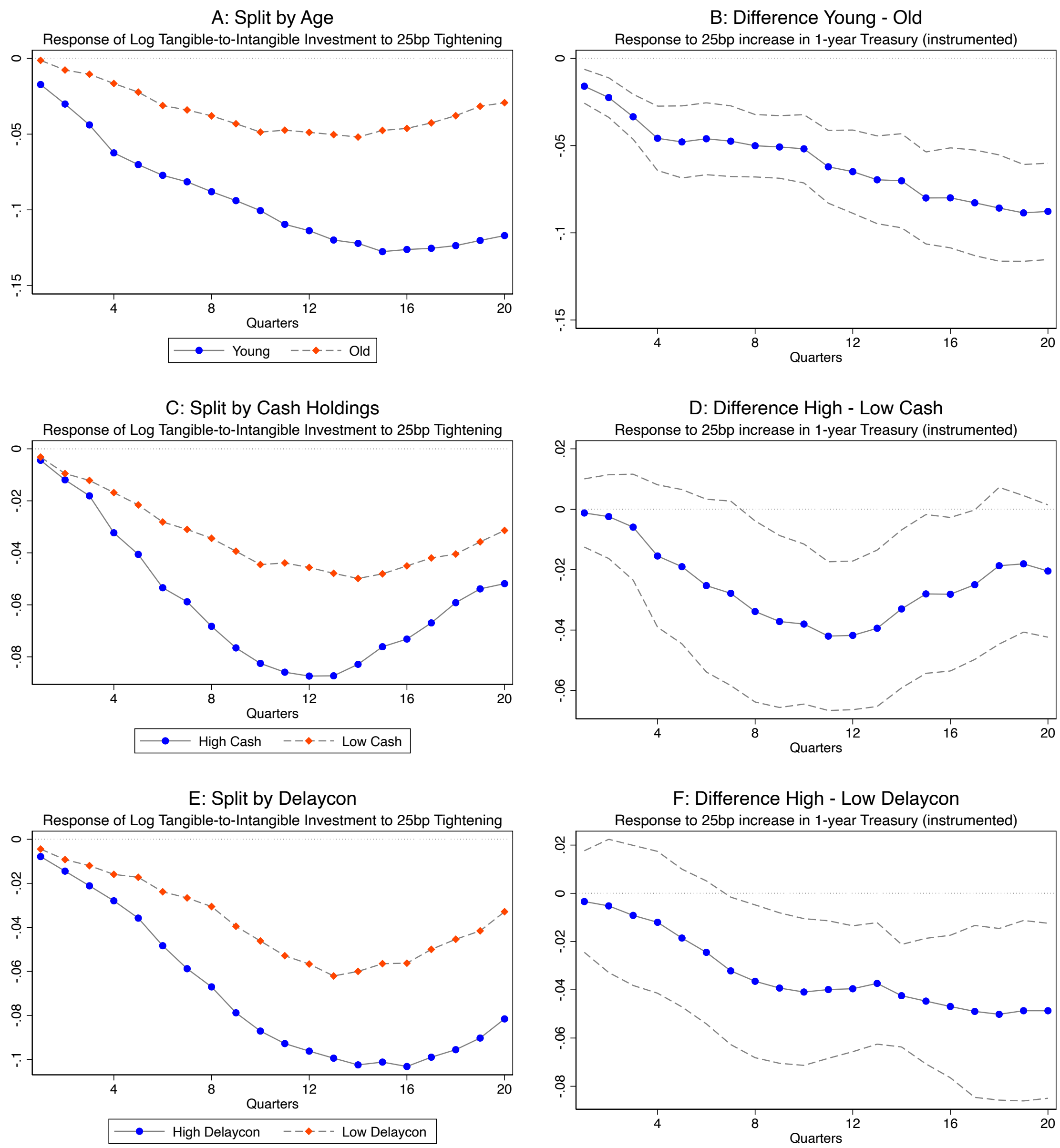


Figure A8: Aggregate Investment Response calculated from Compustat Firm-Level Data

This figure plots the dynamic response of a aggregate Compustat investment to a 25bps higher 1-year Treasury rate, estimated using Eq. (6). 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 (β_1^h in Eq. 2). 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, GDP growth, and the log of the employment ratio (excluding the respective dependent variable). The dashed line represents 95% confidence intervals using Newey-West standard errors.

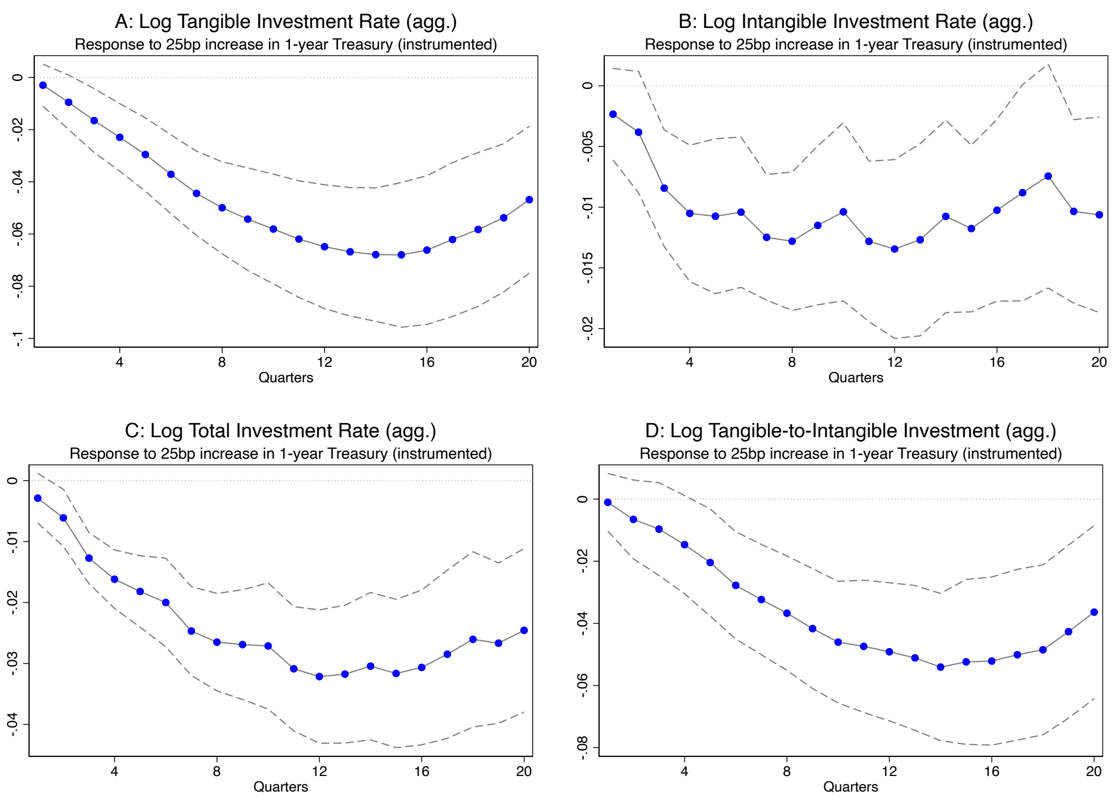


Figure A9: Firm-level Investment Response - Credit Channel Interactions with Monetary Policy

This figure plots the dynamic response of the interaction between $\hat{R}$ (the 1-year Treasury rate, instrumented by cumulative high-frequency monetary policy shocks) and a firm's intangible-to-total capital. Each dot represents a point estimate of the coefficient β_2^h in Eq. (3) 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 D, more (less) constrained firms have an above-median (below-median) textual analysis-based *delaycon* financial constraints measure of Hoberg and Maksimovic (2015). The sample covers all firms in the matched CRSP-Compustat sample excluding financial firms, utilities and government from 1991–2016. All regressions include firm and macro controls, as well as firm, time, and fiscal quarter fixed effects.

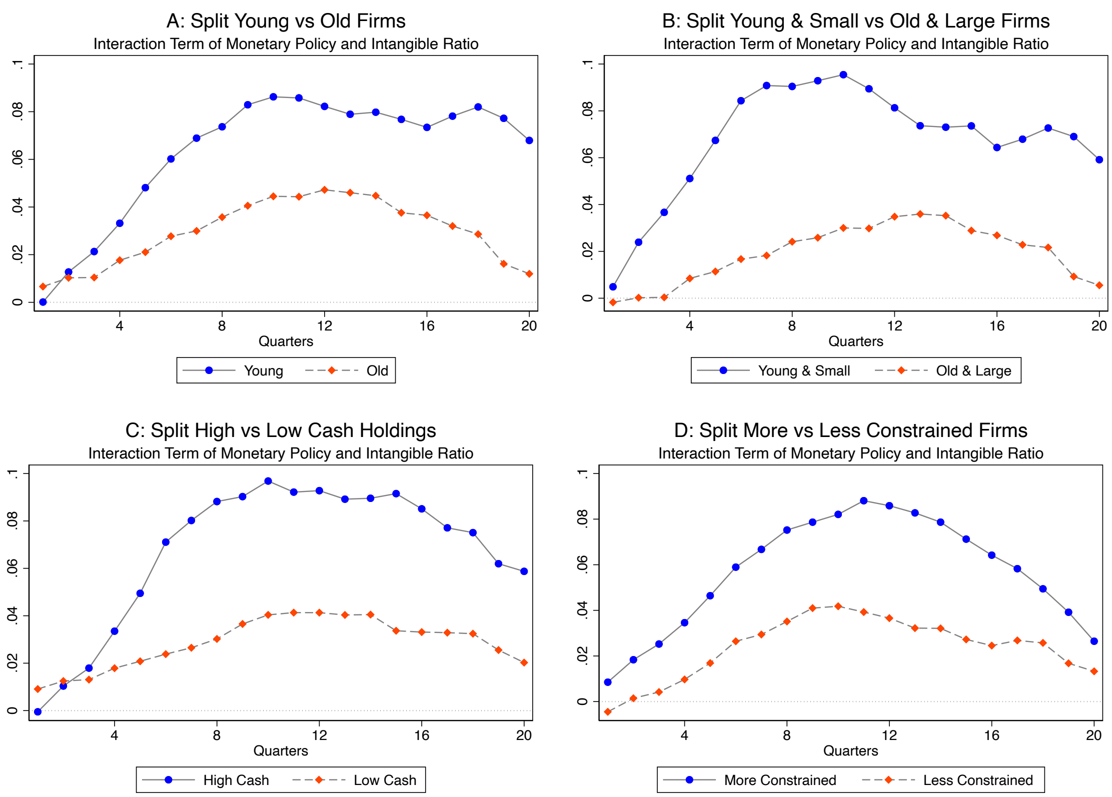


Figure A10: Response of Equity Issuance and Payouts

This figure plots the dynamic responses of equity issuance and payouts to a 25bps increase in the 1-year Treasury rate, estimated using Eq. (2). 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.

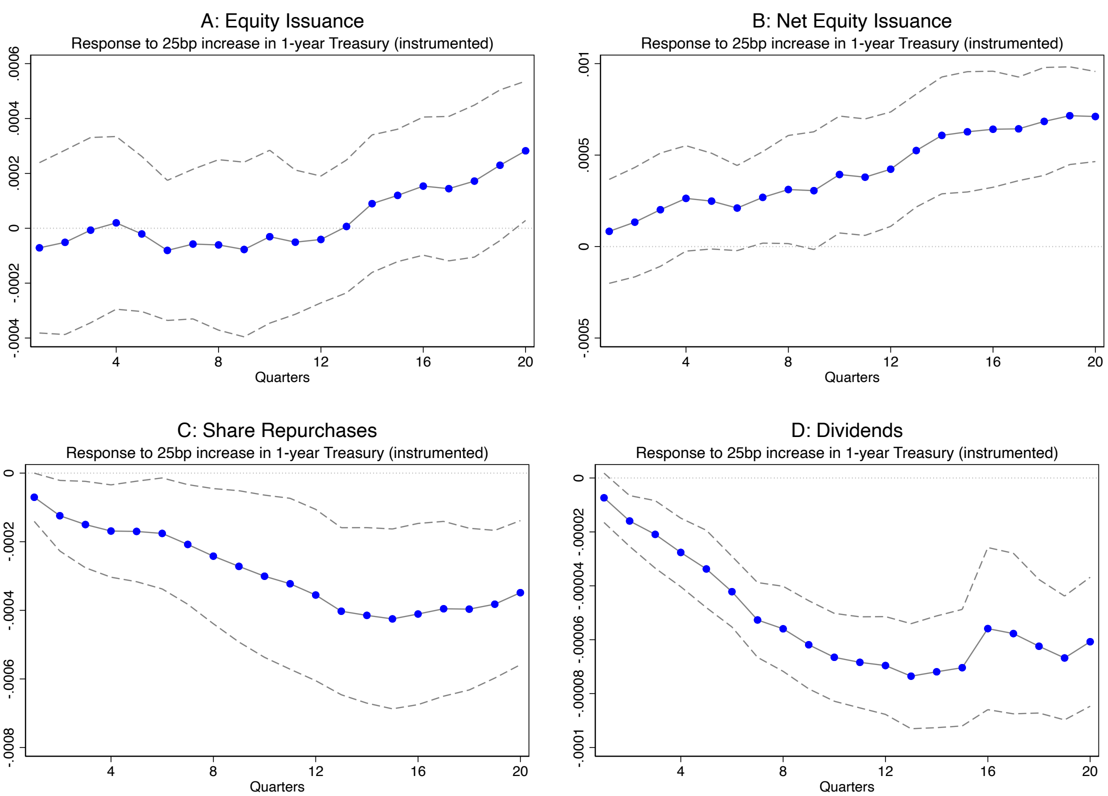


Figure A11: Depreciation Channel: The Effect of a Change in Interest Rates on Investment