Rising Technologies, Investment and Discount Rates

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Abstract

This paper examines the recent compositional shift in corporate capital and its impact on investment's sensitivity to funding costs. I show that the rising share of intangibles in U.S firms' assets significantly dampens the stimulus effect of interest rate shocks. For a given surprise change to the fed funds rate, a one standard deviation above the mean in intangible capital intensity mutes investment's response by more than 30%. These results hold in robust specifications, when isolating the pure interest rate effect, and controlling for other known factors such as leverage and firm growth.

A number of characteristics of intangible capital can potentially explain the heterogeneous responses: collateral value, adjustment costs, project duration and depreciation rates. I propose a structural interpretation of the empirical findings in a quantitative general equilibrium model of heterogeneous firms. Under a reasonable calibration, the model's insights indicate that the higher depreciation tax shield from intangible capital investment quantitatively plays the main role in driving the results. I present further empirical evidence for this channel by focusing on negative profit firms.

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1 Introduction

What are the aggregate consequences of the compositional shift in production factors from traditional PPE to a higher share of intangible assets? An increasing gap between the aggregate investment by U.S firms and fundamentals of corporate profits and future returns has puzzled academics and policy makers since the early 2000s. The so-called secular stagnation in investment has persisted after the global financial crisis, despite consistently low interest rates in the past decade, for reasons that are yet to explain.

More recently, an emerging empirical literature offers a hint by providing evidence on concurrent underlying dynamics of deep structural changes. The composition of corporate investment has been shifting away from traditional brick and mortar type capital, easily identifiable on the firms' balance sheet where it is capitalized and recorded as property, plant and equipment, and towards a rising share of expenditures in non-physical production factors. This includes investments in intellectual property, research and development, brand and advertising, and innovation in economic processes, among other assets (Corrado et al., 2006, Alexander and Eberly, 2018). The share of these new production factors, collectively known as intangible capital, in the firms' total assets has been consistently rising since the early 1960s and accelerated dramatically since the 1990s. It currently represents nearly half of total assets owned by the U.S corporate sector (see figure (1) below).

As a major target in both fiscal and monetary policy's objective functions, aggregate investment is a well scrutinized measure. However, studies evaluating transmission channels of interest rates to the real economy focus exclusively on investment in physical assets, ignoring a good part of the capital stock that is in the form of intangibles. Moreover, little is known about the consequences of the recent shift in investment composition, and its implications on the optimal policy action.

This paper fills the gap by addressing these two issues in detail. In doing so, this work relates to at least three strands of the existing literature. First, I contribute to the literature that studies monetary policy transmission to investment at the firm level (for example Ottonello and Winberry, 2018., Gorodnichenko and Weber, 2016). I provide evidence that the intangible capital intensity is a determinant factor for its effectiveness at the firm level, and study how it explains the cross section of heterogeneous responses through fundamental financial channels. I show that firms with a high share of intangible capital react less to interest rate stimulus and compare the relative contributions of various potential channels in a quantitative model of firm dynamics in general equilibrium. I find that the higher depreciation tax shield of intangible capital and its shorter duration play a crucial role in explaining the heterogeneity in investment sensitivity. To support this claim, I provide empirical evidence that the effect is concentrated among firms with positive profits, and less strong among firms with no depreciation tax shield due to negative profits. Moreover, an innovation of this paper is to consider the effect of interest rate shocks not only on physical capital investment but on total investments, including intangible assets.

Second, this paper also contributes to the nascent literature on intangible capital (Haskel and Westlake, 2017., Alexander and Eberly, 2018., Crouzet and Eberly, 2018), by providing evidence that the rising intangible share has economically significant aggregate effects on monetary policy effectiveness. Finally, this paper contributes to the literature of structural models of firm dynamics with financial constraints (Gourio and Miao, 2010., Bazdreschet al, 2017., Catherine et al, 2019), by studying firm dynamics in equilibrium and quantitatively assessing the role of depreciation, capital adjustment costs, and financing constraints in dampening the investment sensitivity to interest rate shocks.

The shift in production assets' composition towards intangibles is at the heart of the explanation to the recent puzzling trends in corporate factor allocations and investment. For example, Koh et al. (2016) find that intellectual property products capital accounts entirely for the observed decline of the US labor share (Autor et al. 2017). Crouzet and Eberly (2018) argue that omitted intangible factors can partly explain the investment gap both at the industry and firm level, and that intangible intensity is correlated with the rise of industry concentration through increasing productivity and market power. Corrado et al. (2007) compute that intangibles account for at least as much as physical assets as a source of growth, and Peters and Taylor (2017) point out that accounting for intangible capital significantly strengthens the investment-q relation in the data at the firm level.

Fixed intangible assets differ from physical capital in many dimensions that have fundamental implications on the firm's dynamic optimization problem. From a financial perspective, intangible capital is relatively illiquid, with essentially no resale market value in some cases. Intangibles also tend to have a high depreciation rate, and investment costs are expensed when incurred, which gives rise to a higher present value of depreciation over the lifetime of the asset. Finally, R&D expenditures for example can have a high rate of failure, which depends on the industry. These characteristics imply a low pledgeability value as collateral for external financing, a high depreciation tax shield, and relatively higher adjustment costs. From a market structure point of view, intangibles by their innovative nature also tend to increase the firm's productivity and command market power (for example in the case of patents), both of which increase market shares and industry concentration. Disentangling the contribution of each of these characteristics is key in explaining the effect of intangible capital on monetary policy transmission at the firm level. I tackle this question with a quantitative model and show that project duration and the higher depreciation tax shield of intangible capital is key in explaining the dampened effect of interest rate shocks on investment in intangibles.

The rest of the paper is organized as follows. Section 2 introduces the data and stylized facts about the rise of intangible capital, section 3 discusses the empirical methodology and presents the main results, and section 4 provides robustness analysis. Section 5 interprets the empirical findings in the context of a quantitative model of firms in general equilibrium, and section 6 contains concluding remarks.

2 Data and Salient Facts on U.S Investment

The main source of firm level information is the Compustat quarterly panel data on U.S publicly listed firms. This dataset provides high frequency data on the relevant balance sheet and income statement variables at the firm level over a long enough sample period to study cross-sectional as well as the within firm time series of sensitivity to surprises in monetary policy. A well known issue with this dataset is that it does not contain information about privately held firms. However, missing this subsample of firms is unlikely to systematically bias the results since most intangible capital is held by sizable companies who tend to be industry leaders with high market shares and high markups (Crouzet and Eberly, 2018). Moreover, there is a large enough heterogeneity in intangible capital stocks in the sample of publicly traded firms to study cross-sectional variations (see figure (2) below). Compustat provides rich information on firm balance sheet in the sample period between 1990 and 2016, at the quarterly level, which is a high enough frequency to study investment reactions to monetary policy shocks. The main variables of interest from this source are the gross stock of physical capital (ppegt), capital stock net of depreciation (ppent), sales growth, total assets, and the leverage ratio constructed from short term and long term debt over total assets. Table (2) below presents summary statistics of the main firm level variables used.

Compustat quarterly also provides data on balance sheet intangible capital held by firms in the sample. However, this balance sheet measure of reported intangible assets mostly arises from past acquisitions[1] and is subject to biases from firm mis-valuations at the time of acquisition. Further, this mis-valuation is likely to correlate with other firm fundamental measures and therefore bias the results. Thus, I use the Peters-Taylor (2017) approach for the data on intangible capital. The construction of this data proceeds by capitalizing past R&D and sales, general and administrative (SG&A) expenses using a perpetual inventory method from 1950 onwards. It uses industry specific rates from the BEA to depreciate R&D capital following Li and Hall (2016). This approach of capital stock data construction is similar to the one used in Cooper and Haltiwanger (2006) for physical capital stocks in manufacturing firms. The result is a yearly stock of own account intangible capital at the firm level. Crucially, this data is not subject to the mis-valuation bias that is likely to be present in the Compustat balance sheet intangibles information. To match this data to my other variables' frequency, I construct the quarterly level stocks using the intra-year break down of R&D and SG&A expenses by firms, and the same approach as for the yearly level data construction.

The main variable capturing investment is the log change in the total stock of capital $\Delta \log k_{j,t+1}^{total}$, computed at the quarterly level. The innovation in this measure is that it contains not only tangible capital, given by PPE (variables *ppegt* and *ppent* in Compustat) but also intangible capital. As a robustness check, I verify that the main results also hold when only considering investment in tangible capital, which has been the focus of the literature so far, as for example in Ottonello and Winberry (2018).

I proxy for monetary policy surprises by following the long literature on monetary policy transmission and taking the change in the 3-month futures' price on the fed funds rate in a short time window[2] around press releases following FOMC meetings[3].

[1] Exceptions are software development for leasing and sale, and exploratory expenses in the Oil sector.

[2] I use the change between 10 minutes before and 20 minutes after the FOMC meetings announcements about interest rate changes.

[3] Prior to 1994, there were no press releases, and surprises to the fed funds rate are measured on the

This methodology assumes that the time window is short enough so that only the central bank announcement systematically affects real activity, including investment, and asset prices during this period. Under this assumption, changes on the futures' rate, which are traded on the Chicago Board of Exchange and reflect the market's expectations about future rates, provide a proxy measure for the unexpected component of the monetary policy announcement, or the surprise change in the short term interest rate. I aggregate those surprise changes at the quarterly level by computing the weighted average over the quarter, where each policy shock is weighted by the number of days until the end of the quarter, to reflect the time that firms had to react to each individual shock. In robustness checks, I also use the simple sum of monetary policy shocks across the quarter, and compute the sensitivity of investment to the isolated interest rate shock, stripped from the simultaneous information shock, proposed in Jarocinski and Karadi (2018). The authors decompose monetary policy shocks into a pure shock component on interest rates and a concurrent central bank information shock by studying the high-frequency correlation between interest rates and stock returns around the FOMC meetings announcements[4].

Finally, all aggregate-level control variables of GDP growth, inflation, VIX, and unemployment rate are downloaded from FRED.

3 Empirical Methodology and Results

3.1 Reduced Form Evidence

To measure the effect of monetary policy on corporate investment, one needs to isolate the causal effect of a change in interest rates from other factors that the monetary

following day when the Fed begins open market operations from which the market infers the policy change.

[4] I thank Peter Karadi for sharing his data on monetary policy shocks and its decomposition between pure interest rate and information shocks.

policy endogenously responds to, and which can also drive investment themselves. For that, I follow the literature on monetary policy transmission and use a high-frequency event study approach and the change in the fed funds futures' contract price around central bank policy announcements to assess the impact on real activity. Examples of this approach include Gurkaynak, Sack and Swanson (2005), Nakamura and Steinsson, 2013., Gertler and Karadi, 2015., Gorodnichenko and Weber, 2016., and Winberry and Ottonello, 2018 among others. The surprise component in the interest rate change according to this approach is computed as follows:

$$\xi_t = w(t) \times (ffr_{t+\Delta_t} - ffr_{t-\Delta_t}) \tag{1}$$

where ξ_t is the quarterly level aggregated monetary policy surprise, w(t) is the weight on individual surprises, corresponding to the number of days left in the quarter following the announcement, and $(ffr_{t+\Delta_t} - ffr_{t-\Delta_t})$ is the change in the fed fund futures' price around the monetary policy announcement.

I start by presenting reduced form evidence on the effect of rising intangible capital on the transmission of monetary policy shocks to firms' investment. The main empirical specification is as follows:

$$\Delta \log k_{i,t+1} = \alpha_i + \alpha_{s,t} + \beta \xi_t \times \Gamma_{i,t} + \mu Z_{i,t} + \epsilon_t \tag{2}$$

where $\Delta \log k_{i,t+1}$ is the log change in total capital stock, including intangibles and physical capital, between end of quarter t and end of quarter $t+1$. α_i represents firm i fixed effects and controls for time invariant firm level unobservables, and $\alpha_{s,t}$ is industry s times year t fixed effect that controls for time varying industry characteristics. The surprise change in the interest rate is captured by ξ_t, which is an aggregated measure of the shocks on interest rates that occurred during quarter t, using a weighted average of the numbers of days from announcement until the end of the quarter. $\Gamma_{i,t}$ is the share of intangibles in total capital of the firm at the end of quarter t, constructed using the perpetual inventory method and capitalizing the past firm expenses on research and development and a fraction of SG&A (Peters and Taylor, 2017). $Z_{i,t}$ is a firm level vector of control variables including the intangible capital intensity, total assets, leverage and sales growth.

To help with interpretation, I standardize the intangible intensity variable so that units of the right hand side variable are in standard deviations away from the sample mean. Results of the reduced form empirical analysis are presented for the sample period of 1990-2007 to focus on conventional monetary policy shocks[5].

I start by running the regression specification (2) on total investment in physical and intangible capital. The results are reported in table (3) below.

The monetary policy shock variable is constructed from changes to the 3-month futures on the fed funds rate, so that a negative change corresponds to an expansionary monetary policy shock. Therefore, according to standard new Keynesian models of investment, we should expect a positive reaction of corporate investment and negatively signed regression coefficient on investment. I find instead that the interaction coefficient between monetary policy and intangible intensity is positive significant in all regression specifications. In particular, columns (3) and (4) estimate the full specification with firm and year fixed effects, and industry $\times$ year fixed effects. Column (4) further controls for firm level balance sheet and income statement information that are likely to explain investment behavior. All standard errors presented are robust and clustered at the industry level throughout.

These strongly significant results across robust specifications show that intangible capital significantly dampens the firms' reaction to a given monetary policy shock, in terms of total investment including property, plant and equipment as well as intangibles. In particular, a one standard deviation increase in intangible capital share,

[5] I also run the regressions and find qualitatively similar results including the following period of zero lower bound and unconventional monetary policy shocks.

relative to the mean, decreases investment response by more than 3 basis points.

To have a more precise understanding of the economic magnitudes, I compare these effects with the average effect of a monetary policy shock on total investment. Table (4) shows the results of a regression specification similar to that in equation (2) but where the surprise component on interest rates is added. Formally, I test the following:

$$\Delta \log k_{i,t+1} = \alpha_i + \alpha_{s,t} + \beta \xi_t \times \Gamma_{i,t} + \gamma \xi_t + \mu Z_{i,t} + \epsilon_{it} \tag{3}$$

As expected, and consistent with the standard theory models of investment, I find a significant negative coefficient indicating that a one standard deviation surprise decrease in the fed funds rate leads to a 8 to 9 basis points increase in investment at the firm level. These results are broadly in line with the existing literature. Looking at the interaction term between the monetary shock and the intangible intensity of capital, we see that the coefficient is positively significant in all specifications. Thus, intangible capital intensity dampens the stimulus effect of monetary policy, reducing it by about 3 basis points, or a third of the average total effect. Overall, these results show that firms' intangible intensity drives the heterogeneous responses of investment to interest rates shocks. They shed new light on the consequences of the recent compositional shift in the nature of firms' production capital by providing evidence that it significantly affects the effectiveness of monetary policy transmission in the corporate sector.

3.2 Sensitivity of Investment in Physical and Intangible Capital

The above analysis unveiled the firm level heterogeneity in the sensitivity of total investment in capital to shocks in the short term rates. In this section, I investigate the different sensitivities of investments in physical and intangible capital separately. According to the findings above, we should expect to see that investment in intangibles react less to a given shock on the short term rates. To answer this question empirically, I isolate investments in physical and intangibles in the LHS of the previous regression specification. The results are reported in table (5) below.

I find that the coefficient on the monetary policy shock is more than twice stronger for investment in physical capital. This is consistent with the evidence above and helps further understand the heterogeneity of investment responses at the firm level. The reduction in interest rates helps disproportionately more firms that have a higher share of tangible/physical capital, and that are further investing in their PPE. On the other hand, firms with a high share of intangibles react less to the stimulus. Finally, investment in intangible capital on its own is also less sensitive to changes in the short term funding cost when compared to investment in physical capital.

A number of characteristics of intangible capital can explain this result. Intangibles tend to have a lower duration, i.e higher depreciation rate compared to physical capital, they are also less valuable as collateral to raise external financing, and require higher adjustment costs. I tackle the question of which channel is quantitatively dominant in a general equilibrium model of the firm in section (5) below. I show that short duration and the higher depreciation tax shield play a crucial role.

3.3 Dynamics of the Heterogeneous Responses

To study the dynamics of firms' investment responses to interest rate shocks over time, I compute the impulse response functions using the local projection method proposed by Jorda (2005). More specifically, I test and present the results of the following regression specification:

$$\log k_{i,t+1+h} - \log k_{i,t} = \alpha_{i,h} + \alpha_{tsh} + \beta_h \xi_t \times \Gamma_{i,t} + \mu_h Z_{i,t} + \epsilon_{iht} \qquad (4)$$

where h is the number of lagged-ahead quarters in the future (between 0 and 6), $\alpha_{i,h}$ is the firm fixed effect, α_{tsh} represents the year, industry and year×industry fixed effects. ξ_t is the quarter-level aggregated monetary policy surprise at quarter t, $\Gamma_{i,t}$ is the share of intangibles in the firm's assets and $Z_{i,t}$ is a firm level vector of control variables including sales growth, total assets and the leverage ratio. Results for total capital investment are reported in figure (5) below. The blue line presents the β_h coefficients, the light gray area represents the 95% confidence interval, and the dark gray area represents the 90% confidence interval.

Following the monetary policy shock, I find that firms with a relatively higher intangible capital intensity react less in their total investment, as evidenced by the positively significant beta coefficient on the interaction term. Moreover, this effect decreases over time and gradually disappears (becomes statistically insignificant) after two quarters following the initial shock, although remaining positive for the whole projection period. I conclude that the heterogeneous effect in investment reactions is strongest at impact of the monetary shock, it then gradually declines in significance within 2 to 4 quarters following the initial shock.

Together with the findings of the previous section, the results of the firm level empirical analysis show a statistically significant and economically strong heterogeneity in firms' investment responses to monetary policy stimulus.

3.4 Aggregate-Level Evidence

To further explore the cross sectional heterogeneity of the sensitivity of total corporate investment to monetary policy chocks, I follow in this section the aggregate-level approach used by Ottonello and Winberry (2018) for leverage, in the case of intangible capital. I sort firms in deciles according to the average intangible capital intensity over the sample period of 1990-2016, and sum up the total firm level capital stock per quarter for every decile. I then regress the log change in the total stock of capital on the quarter-level aggregated monetary policy surprise, for each decile of the intangible intensity distribution, and controlling for other aggregate variables that are likely to affect firm investment decisions. More precisely, the empirical specification estimated in this section is the following:

$$\Delta \log K_{d,t+1} = \alpha_d + \beta_d \xi_t + \gamma_d \Gamma_t + \epsilon_t \tag{5}$$

where $\Delta \log K_{d,t+1}$ is the log change in the aggregate stock of capital for decile d, α_d is group fixed effect, ξ_t is the quarter-level aggregated monetary policy surprise, and Γ_t is a vector of aggregate control variables including GDP growth, unemployment, inflation and the VIX volatility index.

For each decile of the distribution of intangible intensity, I plot the β_d coefficients (blue line) and the standard errors obtained for regression (5) in figure (7) below. The light gray bands show the 95% confidence interval while the darker gray bands denote confidence intervals at the 90% level.

The pattern that emerges is clear and consistent with the firm level evidence presented above. The sensitivity of total capital investment to monetary policy stimulus is significant and negative for the lowest deciles, i.e the firms at the left tail of the intangible intensity distribution. These mainly include firms in the manufacturing sector where production relies heavily on tangible capital in the form of machinery and heavy physical equipment. As discussed in the model section below, these firms react to monetary policy stimulus as their user cost of capital is more sensitive to interest rate changes due to a lower present value of future depreciation tax shield. On the other hand, the aggregate investment response is more muted and mostly insignificant for firms in the highest deciles in terms of intangible intensity. These typically include firms in high tech industries, retail and pharmaceuticals (Alexander and Eberly, 2018). Furthermore, the cross section of beta coefficients exhibits a weakly monotonically decreasing pattern of investment response across firms sorted by intangible intensity (in absolute terms and significance).

The evidence presented here, consistent with the firm level findings, brings aggregate level support to the heterogeneity of investment sensitivity to monetary policy shocks driven by the level of intangible capital intensity. This effect survives aggregation and therefore has significant economy-wide level implications on the optimal policy action.

4 Robustness to Other Potential Channels

In this section, I test the robustness of the contribution of intangible capital intensity to the heterogeneity in investment responses when controlling for other potential channels and accounting for other known factors that have been found to drive the firm level sensitivity to monetary policy shocks. The objective is to understand whether the intangible intensity factor still predicts the cross section of sensitivities after we account for the other competing explanations provided in the literature. In particular, we investigate the robustness to including the degree of firm leverage, whether the firm makes positive profits during the period, and when using the pure interest rate shock net of the information content in the monetary policy announcement.

4.1 The Leverage Effect

In this section, I disentangle the effect of the degree of firm leverage from intangible capital intensity in explaining the heterogeneous responses of investment to shocks in the funding costs. To do so, I start by adding to the previous regression specification, on top of the leverage level as a control variable, the interaction term between leverage and the monetary policy shock. The level of leverage was found in recent evidence to affect the investment sensitivity of firms to changes in the interest rates (Ottonello and Winberry, 2018). Moreover, leverage and intangible intensity are negatively correlated in the data as shown in figure (3) below. This intuitive correlation is consistent with the characteristics of intangible capital as illiquid and with low collateral value, which explains why high intangible firms rely less on debt financing. Therefore, it is important to account for the leverage effect and show the net contribution of the intangible capital intensity factor. The regression specification tested in this section is the following:

$$\log k_{i,t+1+h} - \log k_{i,t} = \alpha_{i,h} + \alpha_{tsh} + \beta_h \xi_t \times \Gamma_{i,t} + \beta_l \xi_t \times \mathcal{L}_{i,t} + \mu_h Z_{i,t} + \epsilon_{iht} \tag{6}$$

The results of this regressions including the leverage interaction effect are presented in table (6) below. We see that the coefficient on intangible intensity is robust to the inclusion of leverage both as a control and as an interaction terms with the interest rate shock. Consistent with previous results, the intensity of intangible capital is strongly positive significant in all specifications. This evidence shows that the intangible intensity effect is significant and drives the results above and beyond the degree of firm leverage. Moreover, including both interaction terms renders the leverage interaction effect insignificant.

4.2 Negative Profit Firms

We showed above that the intangible capital intensity at the firm level plays a significant role in explaining the sensitivity of investment to interest rate stimulus. In the model section (5) below, I interpret this finding by comparing different channels that can potentially drive the result, based on the characteristics of intangible capital. In particular, I argue that the higher net present value of depreciation tax shield related to intangibles makes its user cost of capital, and therefore investment, less sensitive to the interest rate or cost of debt. To verify this claim, I restrict the sample of firms to those with negative net income during the period of the monetary policy action. These firms do not have a tax shield since their net income is negative for the year, and I therefore expect to find no significant difference in responses in the cross section sorted on intangible intensity. The regression specification is the same as in equation (2), only the sample of firms is more restricted. The results are reported in table (7).

As expected, I find that intangible intensity does not significantly explain any differences in investment sensitivities among firms who have no tax shield, and therefore do not benefit from the accelerated depreciation of this type of capital. This evidence is consistent with the depreciation tax shield playing a major role in explaining the heterogenous investment sensitivity in the cross section of firms.

4.3 Isolating the Pure Interest Rate Effect

In the analysis so far, I estimated the sensitivity of firm investment decisions to monetary policy surprises as proxied by changes to the fed funds futures' rate following FMOC meeting announcements. The surprise component was captured by measuring the change in the 3-month futures contract price in a narrow window before and after the announcement. However, every time such an event takes place, the Fed also conveys information about its own expectations and assessment of the economic outlook when releasing its policy statement. Therefore, the market reacts to the change in the short term interest rate simultaneously to the information shock regarding the Fed's new expectations. This concurrence of shocks at the same time may bias the sensitivity results if only looking at the overall surprise change to the short term rate. To disentangle the pure effect of changes in the interest rate on investment in the cross section of intangible capital intensity, I use the monetary policy shock decomposition data created by Jarocinski and Karadi (2018), where they use a Bayesian structural vector autoregression (VAR) and high-frequency co-movements of interest rates with stock prices to identify the information shock from the monetary effect. An interest rate hike by the Fed decreases stock prices, while the contemporaneous information shock about an improved economic outlook raises them. It is this discrepancy between the two effects on stock prices that allows the decomposition of the overall monetary policy shock.

In these robustness checks, I revisit the main empirical specification above, this time interacting the share of intangible capital with the pure isolated interest rate shock. The regression specification is as follows:

$$\Delta \log k_{i,t+1} = \alpha_i + \alpha_{s,t} + \beta \xi_t^{pure} \times \Gamma_{i,t} + \mu Z_{i,t} + \epsilon_t \tag{7}$$

with the same fixed effects and control variables but with the pure interest rate component of the monetary policy shock. I report results of this specification with and without the control for the shock itself in table (8) below.

Similar to the findings above, the analysis confirms that the intangible intensity of firm's capital significantly dampens the investment sensitivity to shocks on the short term rate. This result is again robust to the inclusion of firm controls, and stringent firm and time fixed effects. The effect of intangible capital is also economically significant: a one standard deviation increase above the mean in intangible intensity reduces sensitivity of investment in total capital by about 30% to 40%.

Finally, I report the results of the Jorda (2005) style local projections for the case where the pure interest rate shock is used for the impulse function. The results confirm the analysis above and are reported in figure (6) below. The intangible intensity affects the sensitivity of total investment to monetary policy in the short run, i.e in the first quarter, then the heterogeneity explained by capital type gradually becomes less significant.

5 Model

I introduce a model to interpret the empirical findings structurally by analyzing firm dynamics in general equilibrium. More precisely, the objective is to simulate a shock on interest rates and quantitatively assess the contributions of different potential channels in driving the lower sensitivity of investment with a high intangible intensity of capital. For that, I simulate an economy with heterogeneous firms in general equilibrium for different calibrations of parameter values. For each model calibration, I then vary the corporate debt interest rate over a grid of values and examine the reaction of investment and other aggregate quantities. Comparing the investment sensitivity for different calibrations of parameter values then allows a determination of which channel is quantitatively the most important in driving the results.

5.1 Set-up

The basic model set-up follows Bazdresch et al. (2017). Consider a firm with Cobb-Douglas technology facing a collateral constraint, convex capital adjustment costs and linear equity issuance costs. The firm uses labor and capital to produce under the following technology:

$$y = F(k, l) = e^{z}(k^{\alpha} l^{1-\alpha})^{\theta} \tag{8}$$

The firm's cash flow function then writes:

$$\Pi^{\star}(z, K, D, K', D') = (1-\tau)\Big(e^{z}(k^{\alpha} l^{1-\alpha})^{\theta} - rD\Big) + \tau\delta K + (D' - D) - c(I) \tag{9}$$

where primed letters denote next period quantities. τ is the corporate income tax rate, r the interest rate on corporate debt, z the productivity, K, D and K', D' the stocks of capital and debt in the current and next period, respectively. The firm's investment is:

$$I = K' - (1-\delta)K \tag{10}$$

assume further that every dollar of capital invested also incurs the firm a convex adjustment cost following the following quadratic form:

$$c(I) = I + \frac{\gamma}{2}\Big(\frac{I}{K}\Big)^{2} \tag{11}$$

Log productivity z follows an $AR(1)$ process:

$$\begin{cases} z' = \rho_z z + \epsilon \\ \epsilon \sim \mathcal{N}(0, \sigma^2) \end{cases} \tag{12}$$

The firm is subject to two financing constraints: the first constraint imposed is a collateral constraint on external debt issuance. i.e the firm can only issue a fraction of its capital stock in debt:

$$D' < \xi K' \tag{13}$$

In addition, the firm faces a linear cost on equity issuance. Cash flow is distributed as dividends when positive. Hence, the shareholder's cash flow is:

$$\begin{cases} E = \Pi^\star, \quad \text{if } \Pi^\star > 0 \\ E = (1+\lambda)\Pi^\star \quad \text{if } \Pi^\star \leq 0 \end{cases} \tag{14}$$

The value function of this problem has the following dynamics

$$V_t(z, K, D) = \max_{K', D'} \left\{ E(z, K, D, K', D') + \frac{1}{1+r} \mathbb{E} V_{t+1}(z, K', D') \right\} \tag{15}$$

where $\frac{1}{1+r}$ is the discount factor of shareholders.

The model parameter values calibration follows standard estimations in the relevant literature and is presented in table (9) below. In particular, I use two sets of parameter values, one for an economy with tangible capital, characterized by high collateral value, low depreciation, and low adjustment costs, and one for an economy with high intangible intensity, where pledgeability of capital is low, and adjustment costs and depreciation rates are high.

To simplify the model solution, I further assume perfect competition between firms and substitute l for k in the production technology function as follows:

$$y = F(k, l) = e^z (k^\alpha l^{1-\alpha})^\theta \tag{16}$$

The FOC on labor gives

$$wl = (1-\alpha)\theta y \implies \pi(k,z) = y - wl = (1-(1-\alpha)\theta)y \tag{17}$$

$$y = e^z k^{\alpha\theta}\left(\frac{(1-\alpha)\theta}{w}y\right)^{\theta(1-\alpha)} \tag{18}$$

Substituting l with its expression back in the production function, we have:

$$y = e^{\frac{z}{1-\theta(1-\alpha)}} k^{\frac{\alpha\theta}{1-\theta(1-\alpha)}} \left(\frac{(1-\alpha)\theta}{w}\right)^{\frac{\theta(1-\alpha)}{1-\theta(1-\alpha)}} \tag{19}$$

$$\pi(k,z) = \left[(1-(1-\alpha)\theta)\left(\frac{(1-\alpha)\theta}{w}\right)^{\frac{\theta(1-\alpha)}{1-\theta(1-\alpha)}}\right] e^{\frac{z}{1-\theta(1-\alpha)}} k^{\frac{\alpha\theta}{1-\theta(1-\alpha)}} \tag{20}$$

Let:

$$A = \left[(1-(1-\alpha)\theta)\left(\frac{(1-\alpha)\theta}{w}\right)^{\frac{\theta(1-\alpha)}{1-\theta(1-\alpha)}}\right] \tag{21}$$

$$\nu = \frac{z}{1-\theta(1-\alpha)} \tag{22}$$

$$\Phi = \frac{\alpha\theta}{1-\theta(1-\alpha)} \tag{23}$$

So that the maximization problem of the firm can be written equivalently as

$$\pi(k) = Ae^{\nu}k^{\Phi} \tag{24}$$

5.2 Interest Rates and Asset Composition

I study the interaction between asset composition and the cost of debt by comparing the firm dynamics in general equilibrium following a shock to interest rates. More precisely, I start from two baseline economies in which the interest rate on corporate debt changes: an economy with only physical capital which has a depreciation rate of 10% per period and a collateralization rate of 40%[6], and an economy were production capital is all intangible, i.e I assume that capital has a lower collateral value of only 10% and a higher depreciation rate per period of 40%. These assumptions are consistent with Li and Hall (2016), who argue that intangible capital provides less value in

[6] i.e the firm can borrow a maximum of 40% of its stock of capital at any given time.

the production function over time, mainly because of competition and obsolescence, which moreover tend to be industry specific. On the other hand, PPE type of capital is subject to physical decay as the main source of value loss. They estimate that depreciation rates for R&D capital range from 37% for software to 49% for computer system design and 73% for motor vehicles and parts. Using a forward looking profit model, they find that depreciation rates are significantly higher for intangibles than physical capital. Capital adjustment costs are calibrated to 40% for tangible capital, consistent with Haltiwanger and Cooper (2006) who estimate this parameter at 45%. They are set to 70% for intangibles to reflect the higher failure rate in intangible formation and the more costly process of replacing knowledge based capital.

I simulate the model in both economies until the steady state is reached, and then vary the interest rate on corporate debt, and analyze the dynamics of aggregate variables including investment, output, consumption, and a measure of productivity dispersion. To compare the contributions of the three potential channels, I repeat this exercise for each economy with alternative sets of parameter values. I successively change the collateral constraint (ξ), the adjustment cost (γ), and the capital depreciation rate (δ). The results are reported in figures (8) to (13) below.

The first quantitative result of the model, which is consistent with the empirical findings above, is that firms with a higher intangible asset intensity have a lower response to monetary policy stimulus. At least three characteristics of intangible capital can potentially drive this result. The first one is related to the lower pledgeability of intangible capital. Because this capital is less liquid and has higher reversibility costs, firms can raise less debt for a dollar of intangible capital compared with PPE. Therefore, they are less able to lever up and invest in response to lower interest rates. The second channel is related to the higher depreciation rates of intangibles. Because the firm expenses a greater part of this capital cost, its user cost is less sensitive to the interest rate due to a higher present value of future depreciation. This intuition is discussed in further details below. Finally, because R&D typically has higher failure rates, capital adjustment costs are higher. The higher cost of adjusting its capital stock in turn lowers the firm's response to interest rate incentives.

To quantitatively assess the role of each potential channel, I compare the investment sensitivities to interest rates at the steady state general equilibrium for each of the baseline economies described above and for counterfactual economies where one of the channels is muted. For the tangible capital economy, I compute the sensitivity of interest rates in the counterfactual cases where the depreciation rate and adjustment cost are higher, and when the collateral constrain is tighter. For the intangible intense economy, I compute the equilibrium sensitivity of investment with lower depreciation rates and adjustment costs, and a looser collateral constraint. In other words, I quantitatively assess the second derivative of investment with respect to these three parameters by varying the intensity of each capital type's characteristics and analyzing the impact on investment sensitivity to the same shock in interest rates.

The results, plotted in figures (8) to (13) below, show that changing the depreciation rates[7] of capital has a quantitatively stronger effect on investment sensitivity, as compared with the other channels. In other words, the higher expensing rates of intangible capital explains more of the difference in investment sensitivity than the difference in collateralization and capital adjustment costs. These results shed light on the optimal policy action, and indicate for example that accelerated depreciation alters monetary policy transmission significantly more than a tightening of the overall corporate credit conditions.

[7] Or equivalently project duration.

5.3 Intuition: The User Cost of Capital

The dynamics of the user cost of capital were first proposed by Jorgenson (1963), Hall and Jorgenson (1967), and used in Corrado et al. (2007) and Crouzet and Eberly (2018). This formulation gives an intuition of the result above in a simple setting. It states that the cost of capital increases with its price, the discount and depreciation rates, and decreases with capital gains:

$$c = q(r + \delta) - \dot{q} \tag{25}$$

In their model, the corporate income tax rate affects the user cost of capital as follows:

$$c = q(r + \delta)\frac{(1 - k)(1 - uz)}{(1 - u)} \tag{26}$$

Where k is the investment tax credit, u is the corporate income tax rate, and z is the present value of the depreciation deduction on one dollar's investment. The elasticity of the user cost of capital with respect to the interest rate is then given by:

$$\frac{\partial c}{\partial r} = \frac{c}{r + \delta} \tag{27}$$

In this simplified set up, we can see that when the depreciation rate δ of capital is high, the sensitivity of the user cost to changes in the interest rate becomes low. This intuition is consistent with our empirical and structural model findings, since depreciation of intangible assets are higher than that of tangible capital.

6 Conclusion

Corporate investment is a major channel through which interest rate policies affect the real economy. It is a driver of growth that is of crucial importance to both policy makers and academics. This paper studies an implication of the compositional shift in firms' investments from traditional PPE towards a rising share of intangible capital.

These types of assets include R&D, intellectual property, economic processes, brand and advertising, and customer capital among other non-physical production factors.

I show that this shift in asset type has significantly dampened the transmission of monetary policy in the corporate sector. More precisely, firms with a one standard deviation above the mean in intangible intensity exhibit a sensitivity to changes in the short term interest rate that is more than 30% lower.

Compared to traditional PPE, intangible assets are relatively illiquid and have a lower collateral value, as well as higher adjustment costs and depreciation rates.

I compare the relative contributions of these three characteristics of intangible capital in explaining the empirical results using a quantitative structural model of heterogeneous firm dynamics in general equilibrium. I find that the higher depreciation tax shield of intangible capital is the main driver of the lower sensitivity of investment to changes in the discount rate.

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Table 1: Summary Statistics - Monetary Policy Surprise Quarterly Variables

	Observations	Mean	Standard Deviation	Min	Max
Fed funds rate surprise	108	-0.0144	(0.0456)	-0.2192	0.0767
Pure monetary shock	108	-0.0088	(0.0369)	-0.1742	0.0864
Pure information shock	108	-0.0055	(0.0245)	-0.0983	0.0856

Table 2: Summary Statistics - Compustat Firm Quarterly Variables

	Observations	Mean	Standard Deviation
Sales/Turnover (Net)	451746	449.913	(2385.313)
Assets - Total	452863	2057.278	(9697.234)
Debt in Current Liabilities	452864	78.975	(536.511)
Long-Term Debt - Total	452864	513.188	(2304.254)
Leverage Ratio	452863	0.251	(0.317)
Own account intangible K - Total	452864	910.654	(5366.402)
Own account intangible K - Share	330936	0.515	(0.295)
Balance sheet intangible K - Total	234599	728.939	(4466.663)
Balance sheet intangible K - Share	154704	0.164	(0.505)

Table 3: Total Investment Sensitivity and Intangible Capital Intensity

	Total Capital Investment			
	(1)	(2)	(3)	(4)
MP shock × Intangible share	0.0291**	0.0287**	0.0386**	0.0378**
	(3.09)	(2.93)	(2.65)	(2.66)
Intangible share	-0.0776***	-0.0677***	-0.0722***	-0.0610***
	(-11.52)	(-11.70)	(-9.47)	(-9.93)
Assets - Total		0.000000551***		0.000000888***
		(3.38)		(6.31)
Leverage		-0.0000444*		-0.0000339
		(-1.82)		(-1.42)
Sales growth		0.0359***		0.0353***
		(4.60)		(4.54)
Constant	0.0368***	0.0316***	0.0375***	0.0343***
	(149.16)	(50.86)	(31.26)	(20.69)
Firm FE	Yes	Yes	Yes	Yes
Year FE	No	No	Yes	Yes
Year x industry FE	No	No	Yes	Yes
Obs	346653	327341	346653	327341
R-squared	0.130	0.157	0.136	0.165

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Table (3) presents the results of the estimation of the interaction effect between intangible intensity and monetary policy shocks on firm level investment. The regression specification with total quarterly investment in capital on the LHS is $\Delta \log k_{i,t+1} = \alpha_i + \alpha_{s,t} + \beta\xi_t \times \Gamma_{i,t} + \mu Z_{i,t} + \epsilon_t$. Column (2) adds firm FE, column (3) adds year and industry × year FE, and column (4) adds firm level control variables. MP shocks are computed from the surprise changes to the fed funds rate following FOMC meetings. Therefore, a *negative* change corresponds to an *expansionary* policy. The strongly positive significant coefficient on MP shock × intangible share indicates a lower sensitivity of high intangible intensity firms to a given monetary policy shocks. t statistics in parentheses. Robust standard errors are clustered at the industry level in all regressions.

Table 4: Total Investment Sensitivity and Intangible Capital Intensity

	Total Capital Investment			
	(1)	(2)	(3)	(4)
MP shock × Intangible share	0.0346***	0.0353***	0.0343***	0.0314***
	(3.49)	(3.57)	(3.41)	(4.00)
MP shock	-0.0891***	-0.0892***	-0.0907***	-0.0911***
	(-6.73)	(-6.70)	(-7.34)	(-8.61)
Intangible share	-0.0722***	-0.0724***	-0.0722***	-0.0611***
	(-9.39)	(-9.43)	(-9.66)	(-9.95)
Assets - Total		0.000000972***	0.000000973***	0.000000888***
		(6.91)	(6.91)	(6.30)
Leverage			-0.0000146	-0.0000338
			(-0.86)	(-1.41)
Sales growth				0.0354***
				(4.54)
Constant	0.0367***	0.0340***	0.0341***	0.0338***
	(32.00)	(29.10)	(25.32)	(20.68)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Year x industry FE	Yes	Yes	Yes	Yes
Obs	346653	346653	345677	327341
R-squared	0.136	0.136	0.137	0.165

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Table (4) presents the results of the estimation of the direct effect of the monetary shock as well as the interaction effect between intangible intensity and monetary policy shocks on firm level investment. The regression specification with total quarterly investment in capital on the LHS is $\Delta \log k_{i,t+1} = \alpha_i + \alpha_{s,t} + \beta^{inter}\xi_t \times \Gamma_{i,t} + \beta^{direct}\xi_t + \mu Z_{i,t} + \epsilon_t$. Column (2) adds firm FE, column (3) adds year and industry × year FE, and column (4) adds firm level control variables. MP shocks are computed from the surprise changes to the fed funds rate following FOMC meetings. Therefore, a *negative* change corresponds to an *expansionary* policy. The strongly positive significant coefficient on MP shock × intangible share indicates a lower sensitivity of high intangible intensity firms to a given monetary policy shocks. t statistics in parentheses. Robust standard errors are clustered at the industry level in all regressions.

Table 5: Capital Type and Investment Sensitivity to Monetary Policy Shocks

	Tangible Investment		Intangible Investment	
	(1)	(2)	(3)	(4)
MP shock	-0.0942**	-0.116***	-0.0418***	-0.0370***
	(-3.07)	(-3.37)	(-4.23)	(-4.22)
Intangible share	0.0490***	0.0397***	-0.0479***	-0.0545***
	(8.66)	(8.12)	(-7.68)	(-9.08)
Assets - Total		0.000000976**		0.000000485***
		(2.70)		(3.30)
Sales growth		0.101***		0.00904***
		(6.04)		(5.14)
Leverage		-0.0120***		-0.0000131
		(-11.25)		(-0.81)
Constant	-0.0165***	0.0222***	0.0453***	0.0419***
	(-9.66)	(10.74)	(26.81)	(25.15)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Year x industry FE	Yes	Yes	Yes	Yes
Obs	306472	294175	306714	290492
R-squared	0.0543	0.0818	0.162	0.179

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Table (5) presents the results of a comparison between the average total effect of monetary policy on investment in physical capital (columns (1) and (2)) and investment in intangible capital (columns (3) and (4)). The following quarterly regression specification applies to each type of capital successively: $\Delta \log k_{i,t+1} = \alpha_i + \alpha_{s,t} + \gamma\xi_t + \mu Z_{i,t} + \epsilon_{it}$. All regressions include firm, year and year and industry × year fixed effects. Columns (1)-(2) have Physical investment as dependent variable, whereas columns (3)-(4) have intangible investment as the dependent variable. Columns (2) and (4) add firm level controls. MP shocks are computed from the surprise changes to the fed funds rate following FOMC meetings. Therefore, a *negative* change corresponds to an *expansionary* policy. The strongly positive significant coefficient on MP shock × intangible share indicates a lower sensitivity of high intangible intensity firms to interest rate shocks. t statistics in parentheses. Robust standard errors are clustered at the industry level in all regressions.

Table 6: Robustness - Leverage

	Total Capital Investment			
	(1)	(2)	(3)	(4)
MP shock × Intangible share	0.0256***	0.0271**	0.0373**	0.0373**
	(2.60)	(2.80)	(2.47)	(2.74)
MP shock × Leverage	0.0391	0.0310	0.0325	0.189
	(1.10)	(1.01)	(1.04)	(1.72)
Leverage	-0.000959*	-0.000473	-0.000374	-0.00150**
	(-1.70)	(-1.09)	(-0.85)	(-2.82)
Intangible share	-0.0428***	-0.0775***	-0.0721***	-0.0610***
	(-10.22)	(-11.66)	(-9.70)	(-9.94)
Assets - Total				0.000000888***
				(6.30)
Sales growth				0.0353***
				(4.54)
Constant	0.0517***	0.0365***	0.0353***	0.0342***
	(4.75)	(136.12)	(26.29)	(20.81)
Firm FE	No	Yes	Yes	Yes
Year FE	No	No	Yes	Yes
Year x industry FE	No	No	Yes	Yes
Obs	345677	345677	345677	327341
R-squared	0.025	0.131	0.137	0.165

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Table (6) presents the results of the robustness check estimation of the interaction effect between intangible intensity and monetary policy shocks along with the interaction between leverage and monetary policy shock. on firm level quarterly investment. The regression specification is $\Delta \log k_{i,t+1} = \alpha_i + \alpha_{s,t} + \beta^{Intangible}\xi_{\times}\Gamma_{i,t} + \beta^{Leverage}\xi_{\times}\mathcal{L}_{i,t} + \mu Z_{i,t} + \epsilon_t$. Column (2) adds firm FE, column (3) adds year and industry × year FE, and column (4) adds additional firm level control variables. MP shocks are computed from the surprise changes to the fed funds rate following FOMC meetings. Therefore, a *negative* change corresponds to an *expansionary* policy. The strongly positive significant coefficient on MP shock × intangible share indicates a lower sensitivity of high intangible intensity firms. t statistics in parentheses. Robust standard errors are clustered at the industry level in all regressions.

Table 7: Robustness - Negative Profit Firms

	Total Capital Investment			
	(1)	(2)	(3)	(4)
MP shock × Intangible share	-0.000111	0.00686	-0.0203	-0.0150
	(-0.01)	(0.30)	(-1.34)	(-0.76)
Intangible share	-0.0953***	-0.0864***	-0.0881***	-0.0767***
	(-10.54)	(-11.46)	(-7.39)	(-7.78)
Assets - Total		0.00000103**		0.00000174***
		(2.25)		(3.36)
Leverage		-0.0000265		-0.0000105
		(-1.06)		(-0.43)
Sales growth		0.0264***		0.0257***
		(4.01)		(3.97)
Constant	0.0615***	0.0504***	0.0953***	0.0683***
	(29.30)	(42.24)	(116.81)	(52.47)
Firm FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Year x Industry FE	Yes	Yes	Yes	Yes
Obs	127447	112589	127447	112589
R-squared	0.169	0.209	0.179	0.223

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Table (7) presents the results of the robustness check estimation of the interaction effect between intangible intensity and monetary policy shocks for the restricted sample of negative profit firms. The quarterly regression specification is $\Delta \log k_{i,t+1} = \alpha_i + \alpha_{s,t} + \beta^{Intangible} \xi_{\times} \Gamma_{i,t} + \mu Z_{i,t} + \epsilon_t$. All regressions include firm, year and year and industry × year fixed effects. All regressions have total quarterly capital investment as the dependent variable. Columns (2) and (4) add firm level controls. MP shocks are computed from the surprise changes to the fed funds rate following FOMC meetings. Therefore, a *negative* change corresponds to an *expansionary* policy. The strongly positive significant coefficient on MP shock × intangible share indicates a lower sensitivity of high intangible intensity firms. t statistics in parentheses. Robust standard errors are clustered at the industry level in all regressions.

Table 8: Robustness - Investment Sensitivity to Pure Monetary Shock

	Total Capital Investment			
	(1)	(2)	(3)	(4)
IRshock × Intangible share	0.0286**	0.0232*	0.0404***	0.0319**
	(2.82)	(1.98)	(3.82)	(2.96)
IR shock	-0.0263**	-0.0349***	-0.102***	-0.101***
	(-3.00)	(-4.79)	(-6.31)	(-7.42)
Intangible share	-0.0777***	-0.0678***	-0.0725***	-0.0613***
	(-11.55)	(-11.77)	(-9.48)	(-10.01)
Assets - Total		0.000000552***		0.000000887***
		(3.36)		(6.28)
Leverage		-0.0000441*		-0.0000334
		(-1.80)		(-1.39)
Sales growth		0.0360***		0.0353***
		(4.61)		(4.55)
Constant	0.0366***	0.0313***	0.0370***	0.0340***
	(137.66)	(49.62)	(30.98)	(20.61)
Firm FE	Yes	Yes	Yes	Yes
Year FE	No	No	Yes	Yes
Year x industry FE	No	No	Yes	Yes
Obs	346653	327341	346653	327341
R-squared	0.130	0.157	0.136	0.165

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Note: Table (8) presents the results of the robustness check estimation of the interaction effect between intangible intensity and monetary policy shocks on firm level quarterly investment using the isolated shock on interest rates as the impulse function. The regression specification is $\Delta \log k_{i,t+1} = \alpha_i + \alpha_{s,t} + \beta \xi_t^{pure} \times \Gamma_{i,t} + \beta^{direct} \xi_t^{pure} + \mu Z_{i,t} + \epsilon_t$. All regressions have total capital quarterly investment as the dependent variable. Columns (2) and (4) add additional firm level controls. Columns (3) and (4) add year and year × industry fixed effects. MP shocks are computed from the surprise changes to the fed funds rate following FOMC meetings. Therefore, a *negative* change corresponds to an *expansionary* policy. The strongly positive significant coefficient on MP shock × intangible share indicates a lower sensitivity of high intangible intensity firms. t statistics in parentheses. Robust standard errors are clustered at the industry level in all regressions.

Table 9: Model Parameter Values Calibration

ρ_z	Persistence of productivity process	.85
σ_z	Volatility of productivity process	.15
θ	Returns to scale	.85
α	Capital share	.85
r	Debt interest rate	.02
δ_{phy}	PPE depreciation rate	.10
δ_{int}	Intangible capital depreciation rate	.40
ξ_{phy}	Collateral constraint on PPE	.40
ξ_{int}	Collateral constraint on intangible capital	.10
τ	Corporate tax rate	.33
λ	Equity issuance cost	.10
γ_{phy}	PPE capital adjustment costs	.40
γ_{int}	intangible capital adjustment costs	.70

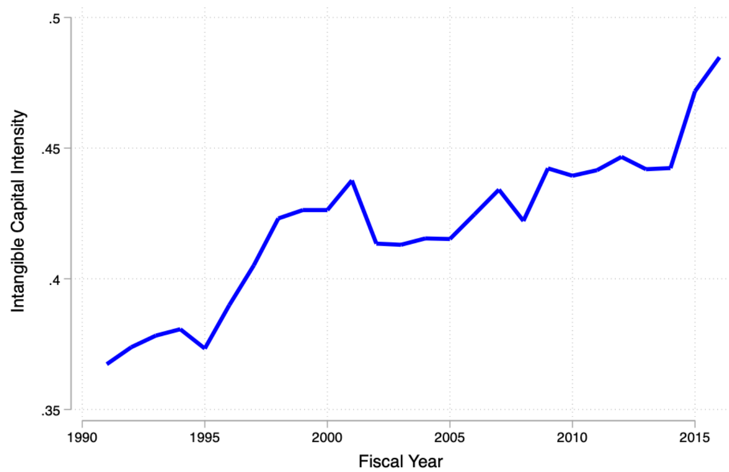

Figure 1: Intangible Capital Intensity - Aggregate Weighted Average

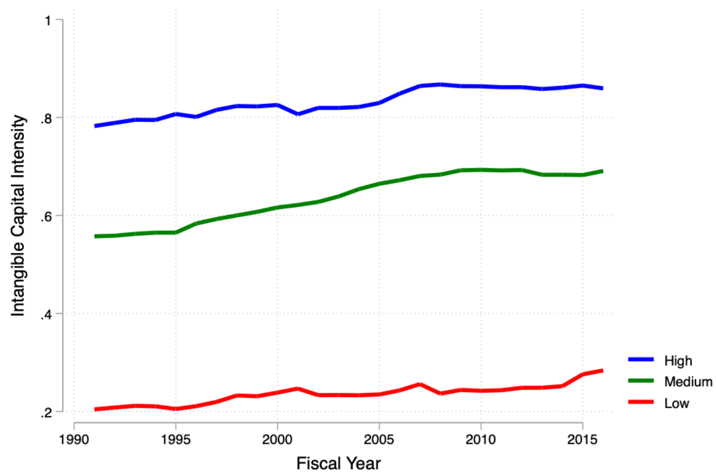

Figure 2: Intangible Capital Intensity - by Tercile

Figure (1) presents the yearly time series of aggregate weighted average by sales of the share of intangible assets in the total capital stock at the firm level. Figure (2) presents this measure broken down by tercile group of firms sorted on their intangible intensity. The aggregate evidence indicates a sharp rise of intangible intensity in the U.S corporate sector since 1990, along with a growing dispersion across firms. The blue line in figure (2) includes firms in high tech, retail and pharmaceutical industries, while the red line mostly contains firms in manufacturing.

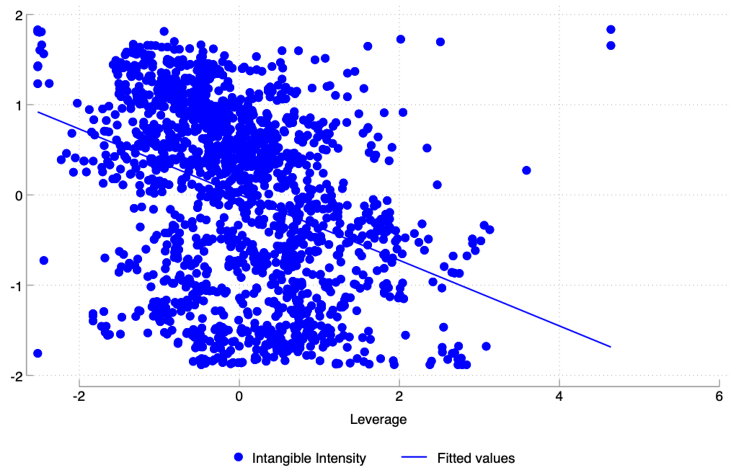

Figure 3: Intangible Capital Intensity - Leverage Correlation

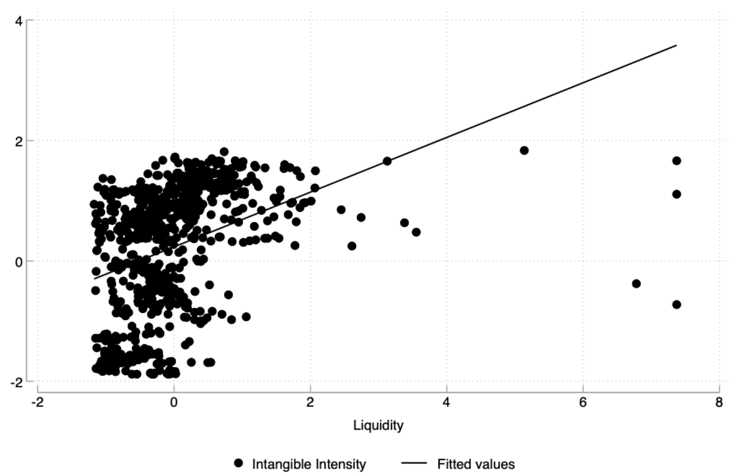

Figure 4: Intangible Capital Intensity - Liquidity Correlation

Note: these figures show scatter plots and the fitted lines between intangible intensity and leverage (figure 3) and intangible intensity and liquidity (figure 4) at the year-industry level. Averages are weighted by yearly firm sales. Leverage is defined as the sum of short-term and long-term debt divided by total assets. Liquidity is defined as cash divided by total assets. Both variables are winsorized at the 95% level and standardized.

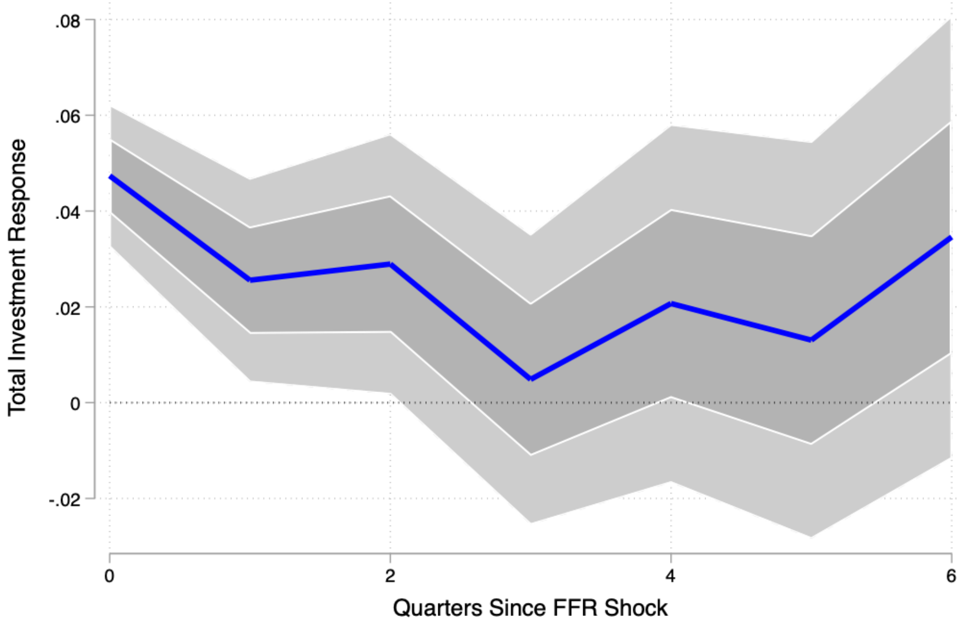

Figure 5: Dynamic Response of Total Investment

Figure (5) presents the Jorda (2005) local projection style impulse response functions of the interaction term β_h in the regression specification: $\log k_{i,t+1+h} - \log k_{i,t} = \alpha_{i,h} + \alpha_{tsh} + \beta_h \xi_t \times \Gamma_{i,t} + \mu_h Z_{i,t} + \epsilon_{iht}$ for h = 0, 1,... 6 quarters. The blue line plots the β_h coefficients for each number of quarter lag, the light gray bands show the 95% confidence interval while the darker gray bands denote confidence intervals at the 90% level. The positive coefficient indicates a lower reaction of investment to interest rate stimulus in high intangible firms.

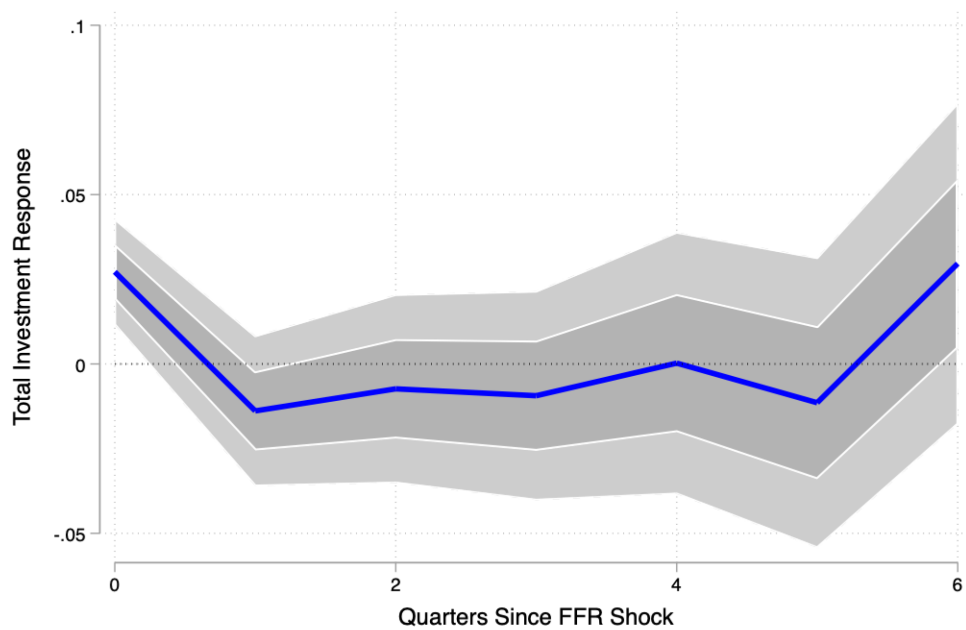

Figure 6: Dynamic Response of Total Investment - Pure IR shock

Figure (6) presents the Jorda (2005) local projection style impulse response functions of the interaction term β_h in the regression specification: $\log k_{i,t+1+h} - \log k_{i,t} = \alpha_{i,h} + \alpha_{tsh} + \beta_h \xi_t \times \Gamma_{i,t} + \mu_h Z_{i,t} + \epsilon_{iht}$ for h = 0, 1,... 6 quarters and where ξ_t denotes the pure interest rate shock. The blue line plots the β_h coefficients for each number of quarter lag, the light gray bands show the 95% confidence interval while the darker gray bands denote confidence intervals at the 90% level. The positive coefficient indicates a lower reaction of investment to interest rate stimulus in high intangible firms.

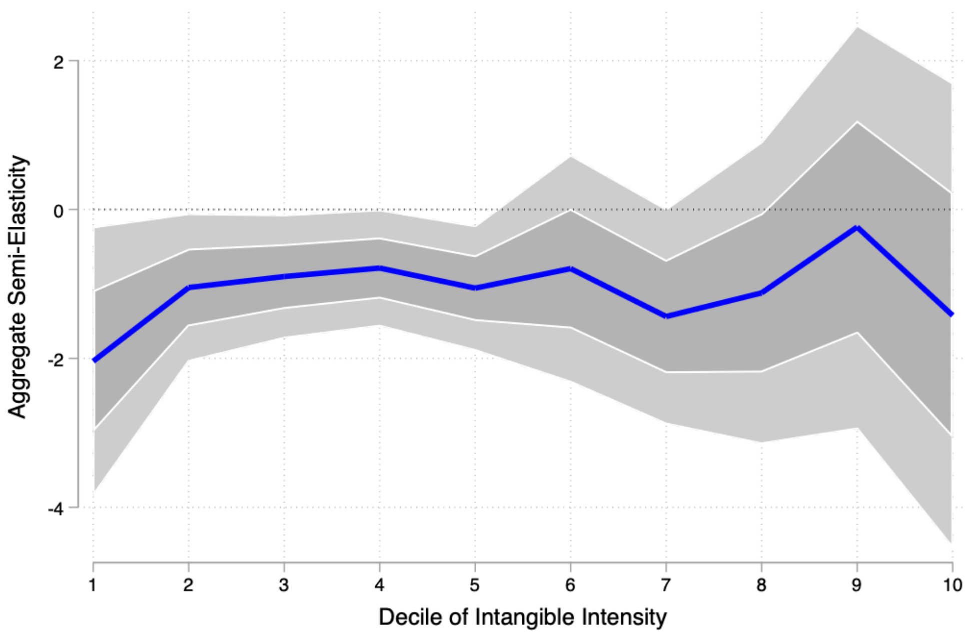

Figure 7: Total Investment Response by Decile of Intangible Intensity

This figure presents the sensitivity of investment to interest rates by decile of firms sorted on intangible intensity. The aggregate level estimation has the following specification: $\Delta \log K_{d,t+1} = \alpha_d + \beta_d \xi_t + \gamma_d \Gamma_t + \epsilon_t$ where $\Delta \log K_{d,t+1}$ is the log change in the aggregate stock of capital for decile d, α_d is group fixed effect, ξ_t is the quarter-level aggregated monetary policy surprise, and Γ_t is a vector of aggregate control variables including GDP growth, unemployment, inflation and the VIX volatility index. The blue line plots the β_d coefficients per decile, the light gray bands show the 95% confidence interval while the darker gray bands denote confidence intervals at the 90% level. The coefficient is negative significant for the lowest deciles (low intangible intensive firms, and gradually becomes insignificant for the highest deciles of firms.

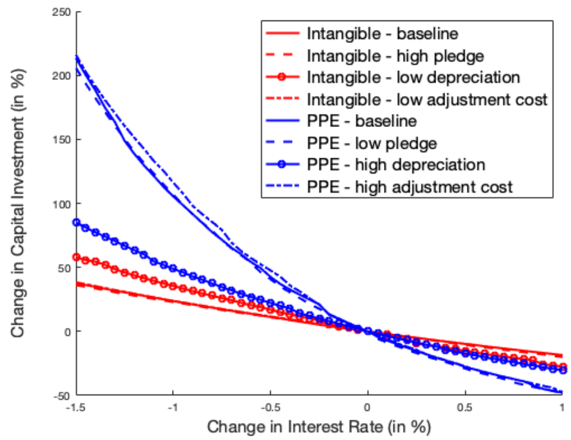

Figure 8: Investment

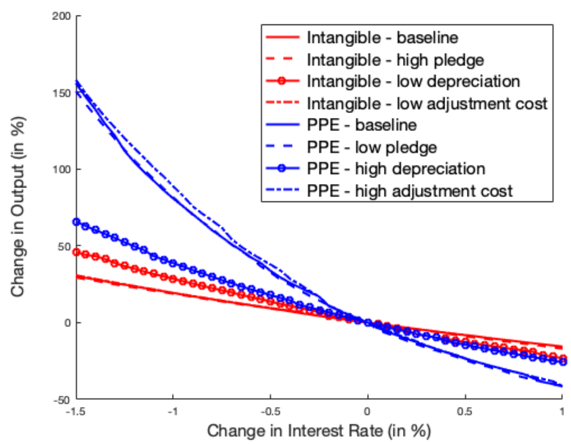

Figure 9: Output

Model investment (figure 8) and output (figure 9) sensitivity to changes in the interest rate. The blue (red) lines represent an economy with PPE (intangible) capital, and compare in general equilibrium the baseline calibration with counterfactuals of lower (higher) collateral value, higher (lower) depreciation rates, and higher (lower) adjustment costs. The quantitative results show that changing the depreciation rate of capital has the strongest effect on the sensitivity of investment and output to changes in the interest rates.

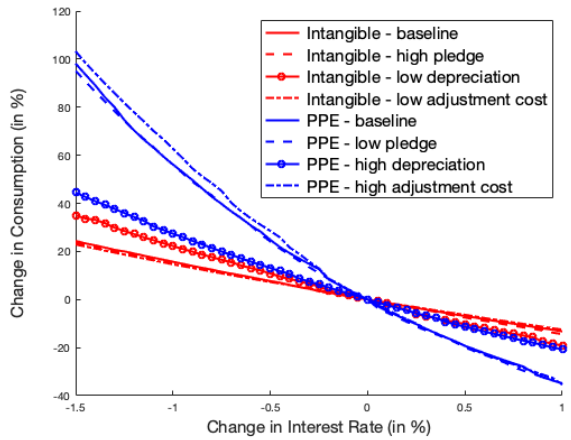

Figure 10: Consumption

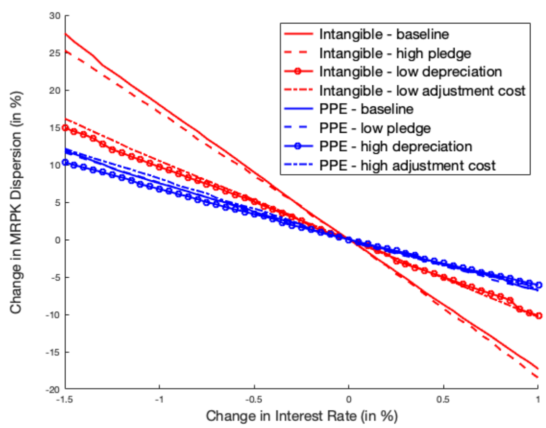

Figure 11: MRPK Dispersion

Model consumption (figure 10) and a measure of capital misallocation (figure 11) sensitivity to changes in the interest rate. The blue (red) lines represent an economy with PPE (intangible) capital, and compare in general equilibrium the baseline calibration with counterfactuals of lower (higher) collateral value, higher (lower) depreciation rates, and higher (lower) adjustment costs. The quantitative results show that changing the depreciation rate of capital has the strongest effect on the sensitivity of consumption and capital misallocation.

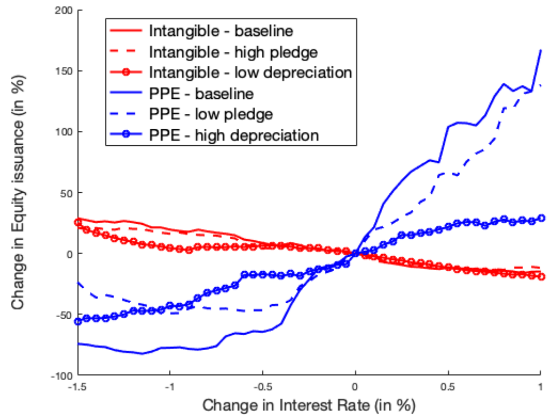

Figure 12: Equity Issuance

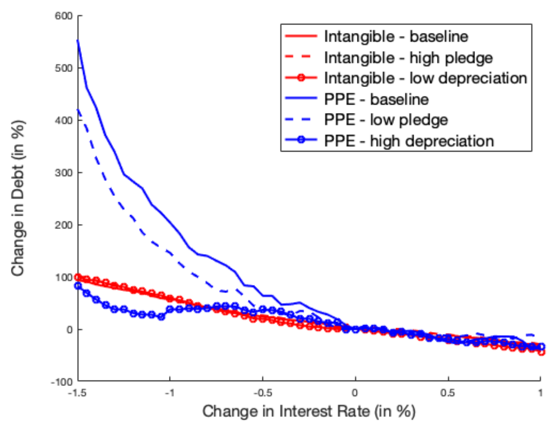

Figure 13: Debt Issuance

Model equity issuance (figure 12) and debt issuance (figure 13) sensitivity to changes in the interest rate. The blue (red) lines represent an economy with PPE (intangible) capital, and compare in general equilibrium the baseline calibration with counterfactuals of lower (higher) collateral value, higher (lower) depreciation rates, and higher (lower) adjustment costs. The quantitative results show that changing the depreciation rate of capital has the strongest effect on the sensitivity of equity and debt issuance to changes in the interest rates[8]

[8] Note: the irregular shape of the equity and debt plots is due to a computer memory limitation on the sparsity of the grid when solving the bellman optimization problem.