Firm-Level Uncertainty and the Transmission of Monetary Policy*

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Abstract

We show that firms which face higher uncertainty adjust their investment less in response to monetary policy shocks. We find corroborating evidence of this differential effect from firm-level stock returns on FOMC announcement days. Our results are explained by a real options or "wait-and-see" channel whereby higher uncertainty dampens the response to changes in business conditions. Consistent with this mechanism the dampening effect is stronger for firms that face higher reversibility costs of investment.

Keywords: Monetary policy transmission, firm level uncertainty

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1 Introduction

Since the global financial crisis of 2007-09, there has been an increasing interest in studying the effects of uncertainty on the economy. But as discussed in the survey by Bloom (2014), it has been difficult to empirically disentangle the direct effects of uncertainty since uncertainty tends to move concurrently with changes in business cycle conditions (especially around recessions).[1] In this paper, we instead estimate the indirect effect of uncertainty by investigating how it affects the transmission of shocks. Specifically, we study whether ex-ante firm-level uncertainty matters for the transmission of monetary policy shocks to investment decisions. In doing so we also contribute to the growing literature on the importance of firm heterogeneity for monetary transmission.

Our measure of firm-level uncertainty is constructed from options on individual firm's stock prices. Specifically, it is the expected volatility of the firm's stock price, which is a forward looking measure that encapsulates a broad notion of uncertainty. We combine this with quarterly firm-level balance sheet data and monetary policy shocks constructed from high-frequency futures rates around Federal Open Market Committee (FOMC) announcements. Using a Jordà (2005) local projection framework on this firm-level data, we study how uncertainty affects the response of investment decisions to monetary policy.

Our main result is that a firm adjusts its physical capital investment less in response to monetary policy shocks if it is facing higher uncertainty. In terms of magnitude, in response to a one standard deviation expansionary monetary policy shock, the physical capital stock rises by 1.4% after 2 years for a low uncertainty firm (firm at the 30th percentile of uncertainty). On the other hand, for a high uncertainty firm (70th percentile) the investment response is close to zero. The difference between the low and high uncertainty firm's investment response is strongly statistically significant. This result holds across a variety of robustness checks, including using alternative measures of monetary policy shocks, dropping unscheduled meetings

[1] See Baker et al. (2020) for a recent example that attempts to address this problem.

and using time and time-by-sector fixed effects. As we discuss in detail below, there is a growing literature which finds that various firm characteristics (e.g. leverage and liquidity) matter for monetary transmission. We show that our results are not driven by these characteristics; our results are unchanged when we control for these characteristics and their interaction with the monetary policy shock.

We provide corroborating evidence for our investment results using firm-level stock prices by conducting an event-study analysis around the announcements of the FOMC. Specifically, we study how the stock price of a firm with high or low uncertainty responds differentially to the surprise component of the FOMC's announcement. As with the investment analysis, we control for a wide variety of firm characteristics (and their interactions with the monetary shocks) to isolate the role of uncertainty. For a low uncertainty firm, a one standard-deviation expansionary monetary policy shock raises stock prices by around 0.4% on the day of the FOMC meeting. But for a firm with high uncertainty the response of the stock price is essentially zero. Again, the difference between the response of a high and low uncertainty firm is statistically significant.

What explains the dampening effect of uncertainty? Our results are consistent with the real options (or "wait-and-see") channel of uncertainty transmission, see for example Bernanke (1983) and Dixit et al. (1994). According to this channel when uncertainty is high, firms delay their investment decisions if they face (partial) irreversibility in their investment decisions. We provide empirical evidence for two main predictions of this theory.

First, if costs associated with reversibility are important, then the implication is that firms with higher reversibility costs should display higher dampening effects. To test this implication we use a measure of asset redeployability (constructed by Kim and Kung (2017)) as a proxy for reversibility costs. A firm's redeployability score is higher when other firms in the economy are more likely to use the assets owned by the firm. Kim and Kung (2017) show that redeployability is positively related to recovery rates and more active transcations in the used asset market. Consistent with theoretical predictions we find that the dampening effect of uncertainty is stronger for firms that have a lower redeployability score (i.e. higher reversibility costs).

Second, under the real options framework we should observe the dampening effect of higher uncertainty not just for monetary policy shocks but for demand shocks more broadly. We study the effect of uncertainty as captured by our options based measure in relation to two demand shocks: sales growth shocks and tax shocks. We follow the approach of Bloom et al. (2007) to identify sales growth shocks. For tax shocks we use the measures of Romer and Romer (2010) and Leeper et al. (2012). For both types of shocks we find that firms with higher uncertainty adjust their investment by less, consistent with our monetary policy shock results.

While the literature on monetary transmission to investment has focused primarily on physical capital (or tangible) investment,[2] there has been a substantial increase in the importance of intangible capital in recent years, see for example Corrado and Hulten (2010). For R&D capital– an important component of intangible capital–there is a long history of thinking about the adjustment costs as being of a different nature (e.g. Bloom (2007)) and there is also corresponding empirical evidence that uncertainty transmits differently to R&D (e.g. Stein and Stone (2013)). Motivated by this we investigate how intangible capital investment more broadly is affected by the interaction of uncertainty and monetary policy. We adapt the approach of Peters and Taylor (2017) to construct quarterly measures of "knowledge capital" and "organization capital". The knowledge capital variable is intended to capture the "stock" of R&D capital for the firm, while the organization capital variable is intended to capture intangible capital such as human capital, brand loyalty, customer relationships and distribution systems. We find that the dampening effect of uncertainty is present for organization capital but not for knowledge capital. We show this both for the baseline results and for the strengthening of the dampening effect for firms with lower values of asset redeployability.

In addition to the large literature on uncertainty (surveyed for example in Bloom (2014)

[2]Recent exceptions that study monetary policy and intangible capital include Döttling and Ratnovski (2021) and Howes et al. (2022)

and Cascaldi-Garcia et al. (2020)), our paper is related to a few different strands of the literature. One strand studies monetary policy and firm heterogeneity. There are various dimensions of firm heterogeneity that have been shown to matter for monetary transmission: leverage (Ottonello and Winberry (2020) and Lakdawala and Moreland (2021)), liquidity (Jeenas (2019)), age (Cloyne et al. (2018)), source and composition of debt (Darmouni et al. (2020), Gürkaynak et al. (2019) and Ippolito et al. (2018)) and tax treatment (Kurt (2022)). Our results show that uncertainty at the firm level is another important factor that matters for monetary transmission.

Our paper is related to two recent papers that also study the role of uncertainty in monetary transmission. Kroner (2021) focuses on forward guidance shocks to find a role for pessimism in driving investment responses and then builds a New Keynesian model with ambiguity aversion to explain the results. Fang (2020) explores the aggregate investment response to monetary policy shocks and builds a structural model with lumpy investment and non-convex adjustment costs. Our empirical firm-level results with investment, stock price and redepoyability data complement these papers to highlight the importance of uncertainty for monetary transmission.

The other strand of the literature that our paper is related to studies the role of uncertainty in affecting firm-level outcomes (see Leahy and Whited (1996), Bloom (2007), Bloom (2009), Bachmann et al. (2013), Christiano et al. (2014), Bloom et al. (2018), Ilut et al. (2018), Dew-Becker and Giglio (2020), Chang et al. (2022) and Handley and Li (2020) for some examples). While the main focus in this literature has typically been on investigating the direct effects of change in uncertainty on economic outcomes, our approach focuses on how uncertainty matters for the transmission of shocks, specifically monetary policy shocks.

2 Data

This section lays out details on the data used in our empirical analysis. For the investment results our sample runs from 1996:Q1 through 2008:Q2. For the stock price results on FOMC announcement days our sample runs from January 1996 to June 2008. We use this sample to focus on the effects of conventional monetary policy.

2.1 Firm-level uncertainty from options data

Our measure of firm-level uncertainty comes from the OptionMetrics dataset. OptionMetrics reports a daily implied volatility for each option traded. Since a firm's equity can have more than one associated option contract, we aggregate to the firm level by weighting each option contract (that expires within 15 to 45 days) by its trading volume on a given day. We use this volume-weighted average of implied volatilities as our baseline measure. Then, for our quarterly local projections, we aggregate to the quarterly level by averaging the firm's implied volatility measure across trading days in the quarter. On average, a quarter in our sample contains 1,216 Compustat firms with a non-missing implied volatility measure.[3] Within a quarter, the average firm has 35 trading days with a non-missing implied volatility.

Figure A.1 displays a quarterly time series of the 30th percentile ("low" uncertainty firm), median and 70th percentile ("high" uncertainty firm) values for our baseline implied volatility measure. The figure also shows the VIX which is the implied volatility for the S&P 500 index. While our firm-level measure is correlated with the VIX, as expected, our empirical specification exploits the variation across firms to study the effects of firm-level uncertainty in determining the differential response to monetary policy shocks. We also show that our results are unchanged when we control for the VIX (and its interaction with monetary policy shock) in our analysis.

[3] In 1996, the first year that implied volatility is available, there is an average of 800 firms per quarter. The average is above 1,000 firms in each subsequent year.

2.2 Monetary policy shock

For monetary policy surprises our baseline measure is FF4, which is the daily change in the three-month-ahead fed funds futures contract on FOMC announcement days. The futures data is from Chicago Mercantile Exchange (CME). This is the measure commonly used in the literature, for example see Gertler and Karadi (2015) for a prominent example. In the appendix, we show that using alternative measures that i)use higher frequency intra-day data, ii)use longer horizon futures rates, iii)combine short and long horizon futures or iv)account for the information effect in monetary surprises gives very similar results. We also confirm our results with the monetary policy shocks measure of Romer and Romer (2004), as updated in Wieland and Yang (2020). For our investment results, we aggregate the shock to the quarterly level by summing up all the shocks within the quarter. We confirm that our results are robust to an alternative aggregation that takes into account when the FOMC meeting happens within the quarter.

2.3 Firm-level investment, stock prices and other characteristics

Our three measures of capital stock (i.e. physical, knowledge and organization) are constructed using the standard perpetual inventory method using data from Compustat. Specifically, for physical capital stock, firm i's initial capital stock is the firm's first reported value of gross capital stock (*ppegtq*). Then, for each subsequent quarter, a firm's capital stock is updated by the change in its net capital stock (*ppentq*). For quarters with a missing value of net capital stock, it is filled using linear interpolation of the directly adjacent quarters. Where interpolation is not possible, we set the capital stock to the current value of gross capital stock, if not missing, and continue the perpetual inventory method. All results are robust to alternatively using the net capital stock measure (*ppentq*) as directly reported in Compustat.

For knowledge and organization capital, we follow the methodology as described in Peters and Taylor (2017); however, we apply this to the quarterly Compustat data, rather than the annual dataset. For knowledge capital, we assume that each firm begins with an initial capital stock of zero in its first observation in the Compustat database.[4] Then, in each subsequent quarter, we update the knowledge capital stock by first depreciating the previous quarter's capital stock by 15% and then adding the Compustat R&D spending variable (*xrdq*). For quarters where *xrdq* is missing, we linearly interpolate between the nearest two quarters. Organization capital follows an analogous methodology with two differences. First, the depreciation rate is 20%. Second, R&D spending is replaced by 30% of the value of Selling, General and Administrative Expenses (*sgaq*).[5] As is common, all variables are deflated using the implied price index of gross value added in the U.S. nonfarm business sector (BEA-NIPA Table 1.3.4 Line 3).

We also use data on several firm-level characteristics from Compustat: firm asset size (log of real atq), price-to-cost margin ($\frac{saleq-cogsq}{saleq}$), receivables-minus-payables to sales ($\frac{rectq-apq}{saleq}$), market capitalization (log of real cshoq multiplied by prccq), fiscal quarter (fqtr), leverage (debt to capital, measured as the sum of debt in current liabilities dlcq and long-term debt dlttq over the sum of debt in current liabilities, long-term debt and stockholder's equity seqq), liquidity (the ratio of cash and cash equivalents cheq to atq), the ratio of depreciation (dpq) to assets, Tobin's q, firm sector and sales growth (log change in real saleq, relative to 4-quarter lagged real saleq).

Table A.1 shows summary statistics for our baseline monetary policy shock (FF4) and key firm-level variables of interest broken down by low and high uncertainty firms. The table shows that there is a systematic difference between high and low uncertainty firms. For instance, low uncertainty firms are bigger, have higher leverage, lower liquidity and lower sales growth than high uncertainty firms. Importantly, in our empirical specification we will control for these characteristics and their interaction with monetary policy shocks to isolate the effects

[4] This is a simplification of the Peters and Taylor (2017) methodology, but it should not meaningfully affect our results.

[5] See Peters and Taylor (2017) for further details on why 30% of the value of Selling, General and Administrative Expenses is an appropriate proxy for organization capital.

coming from uncertainty.

3 Results

This section presents our main results. We first explore the differential response of physical capital investment to monetary policy shocks using quarterly firm-level data followed by an analysis of the response of intangible investment. We conclude this section by presenting results from high frequency stock price movements at the firm level on FOMC announcement days.

3.1 Evidence from physical capital investment

Our main goal is to study how firm-level uncertainty affects the transmission of monetary policy to investment. To this end we run panel local projections (Jordà (2005)) with quarterly data from 1996:Q1 to 2008:Q2. We begin the sample in 1996 due to the availability of the options data and we end in 2008 to focus on the effects of conventional monetary policy. The empirical specification is

$$\Delta_h log(k_{i,t+h}) = \alpha_i^h + \beta^h \text{mps}_t \text{ x } \text{ivol}_{i,t-1} + \delta^h \text{mps}_t + \gamma^h \text{ivol}_{i,t-1} + \Gamma_z^h Z_{i,t-1} + \Gamma_w^h W_{t-1} + \varepsilon_{i,t}^h \tag{1}$$

where $\Delta_h log(k_{i,t+h}) \equiv log(k_{i,t+h}) - log(k_{i,t-1})$ is the cumulative difference in physical capital stock. mps_t is the monetary policy shock constructed from high-frequency data on FOMC announcement days cumulated to quarterly frequency. $ivol_{i,t-1}$ is our measure of firm-level uncertainty averaged over the previous quarter. $Z_{i,t-1}$ are the standard firm-level controls which include sales growth, asset value, liquidity ratio, price-to-cost margin, receivables minus payables, depreciation to assets ratio, log of market cap, Tobin's Q, leverage ratio, and indicators for sector and fiscal quarter. W_{t-1} are aggregate controls, including GDP growth, inflation rate, unemployment rate, NASDAQ index and the federal funds rate.

Figure 1 shows the impulse response of physical capital investment (or tangible investment) to a one standard-deviation expansionary monetary policy shock for a firm at the 30th percentile of uncertainty (low uncertainty firm represented by the blue line) and one with 70th percentile of uncertainty (high uncertainty firm represented by the red line). We have standardized the uncertainty measure so that a value of 0 represents the 30th percentile or low uncertainty and a value of 1 represents the 70th percentile or high uncertainty. Thus, the response of the low uncertainty firm is given by δ^h and high uncertainty firm by $\delta^h + \beta^h$. We report confidence intervals calculated using Driscoll-Kraay standard errors. In the appendix, we show that using two-way clustered standard errors (by firm and quarter) produces very similar results.

For a firm facing low uncertainty, the expansionary shock leads to a hump-shaped rise in investment with a peak effect of 1.4% after 8 quarters. For a high uncertainty firm, the investment response is close to zero after 8 quarters and the effect is not statistically significant. The difference in the investment response between high and low uncertainty firms is plotted in the second panel of Figure 1 and clearly shows our main result: a firm with high uncertainty responds substantially less to a monetary policy shock relative to a firm that has lower uncertainty and this difference is strongly statistically significant.

This result is robust across a variety of specifications. We show in Appendix Figure A.2 panel (a) that our results are very similar when using two-way clustered standard errors. For the baseline specification, we do not include a time-fixed effect to allow for the estimation of the stand-alone effect of the monetary policy shock. We show in panel (b) that the interaction effect coefficients are very similar to this baseline case when we do include a time-fixed effect. In panel (c) our results are robust to using an alternative aggregation procedure for constructing the quarterly monetary policy shock measure that takes into account when the FOMC meeting occurs within the quarter. We also find that our results are robust to including the interaction of the firm characteristics with the monetary policy shock, i.e. including $Z_{i,t-1}$ x mps_t (see panel (d)). In further unreported results we confirm robustness when we control for other firm characteristics such as distance to default and also aggregate variables like the VIX together with interactions with the monetary policy shock.

Our results are also remarkably similar across a variety of different measures of monetary policy shocks. Our baseline measure uses daily changes in the 3 month ahead fed funds futures. In Appendix Figure A.3, we use six alternative measures of monetary shocks: i) the current month's fed funds futures, ii) the Nakamura and Steinsson (2018) policy news shock that combines futures rates up to 1 year ahead, iii) the 2 year-ahead Eurodollar futures rate (ED8), iv) the 30 minute changes in 3-month ahead futures, v) the measure from Bu et al. (2021) which is devoid of the information effect in monetary surprises (see for example discussion in Lakdawala (2019)) and vi) the monetary shock measure of Romer and Romer (2004) which relies on Greenbook forecasts rather than futures market data. For all six measures we get very similar results.

3.2 Evidence from intangible capital

Our results so far have focused on physical capital investment, but intangible investments have become an increasing share of firm capital in recent decades (see for example Corrado and Hulten (2010)). Even with the increased importance of intangible capital, there is very little work on understanding its interaction with uncertainty and monetary policy (some recent papers are Döttling and Ratnovski (2021), Howes et al. (2022) and Palombo (2020)). We now study if intangible investment is also affected differentially by firm-level uncertainty. To create a measure of the firm's intangible capital, we follow the procedure of Peters and Taylor (2017) as outlined in Section 2.3. The knowledge capital variable is intended to capture the "stock" of R&D capital for the firm, while the organization capital variable is intended to capture intangible capital such as human capital, brand loyalty, customer relationships, and distribution systems.

Figure 2 shows the response of knowledge and organization capital to monetary policy shocks by focusing on how firms with high and low uncertainty respond differentially. Specifically, we plot the dynamic response of the interaction coefficient β^h, estimated using the same right hand side specification as our baseline specification in Equation 1. The figure shows that high and low uncertainty firms show no difference in how they adjust their knowledge capital in response to monetary policy shocks. On the other hand, there is a substantial difference in how they adjust their organization capital. Similar to physical capital investment, firms with higher uncertainty adjust their organizational capital much less in response to monetary shocks; however, the dampening effect of uncertainty is even larger than estimated for physical capital. In response to a one standard deviation expansionary monetary policy shock, firms with low uncertainty adjust upwards their organization capital by 3.6% (after 8 quarters) while the response for firms with high uncertainty is statistically indistinguishable from zero.

What explains the differential response of knowledge and organization capital? In the next section we will provide empirical evidence for the real-options channel as the mechanism underlying our tangible and knowledge capital results. This mechanism focuses on the adjustment costs involved in reversing investment decisions. But, the literature has found differences in how R&D capital responds to uncertainty. Bloom (2007) discusses that R&D faces flow adjustment costs rather than stock adjustment costs, which makes knowledge capital investment less sensitive to business conditions. Thus, it is not surprising that physical and organization capital display the dampening effects of uncertainty, while knowledge capital does not.

Overall, our results show that uncertainty plays a similar role in the transmission of monetary shocks to organization capital, which includes brand loyalty, human capital and customer relationships, as it does to tangible capital. But, knowledge capital, which captures R&D investment, does not show a similar attenuating effect of higher uncertainty.

3.3 Evidence from firm-level stock prices

To complement our results of the response of firm-level investment, we also study how firm-level stock prices respond differentially to monetary policy shocks. We conduct an event-study analysis on the day of the FOMC announcement. Specifically, we study how the stock price return of high uncertainty firm responds differentially to surprise actions and communication from the FOMC (as captured by our monetary policy shock measure mps_t). Our baseline regression takes the following general form:

$$s_{i,t} = \alpha_i + \beta \mathrm{mps}_t \text{ x } \mathrm{ivol}_{i,t-1} + \delta \mathrm{mps}_t + \gamma \mathrm{ivol}_{i,t-1} + \Gamma'_z Z_{i,t-1} + \Gamma'_{mz} Z_{i,t-1} \text{ x } \mathrm{mps}_t + \varepsilon_{i,t} \qquad (2)$$

where $s_{i,t}$ is the (daily) return on firm i's share price on FOMC meeting day t, i.e. $s_{i,t} = ln(p_{i,t}) - ln(p_{i,t-1})$ where the stock price p is measured at the end of the day. α_i is a firm i fixed effect, $ivol_{i,t-1}$ is firm i's uncertainty measured on the day before FOMC announcement, mps_t is the monetary policy shock, and $Z_{i,t-1}$ is a vector of firm-level controls (lagged by a quarter). $Z_{i,t-1}$ includes the same firm-level financial measures as used in the investment regressions above. The standard errors reported in the parentheses are calculated using two-way clustering along the time and firm dimensions and our results are robust to using Driscoll-Kraay standard errors.

We show the results in Table 1. The first row of the table shows the effect on the stock price of low uncertainty firms.[6] The first column shows results without interacting any firm-level characteristics with the monetary policy shock. A one standard deviation expansionary monetary policy shock increases the stock price of low uncertainty firms by around 0.4% consistent qualitatively with the evidence of Bernanke and Kuttner (2005) which considers the market index.[7] More pertinently, we are interested in how firms with high and low uncertainty respond differentially to monetary policy shocks. The second row shows that the interaction coefficient β is negative and significant. Moreover the negative interaction coefficient is roughly the same size as the baseline effect for low uncertainty firms. This means that the positive effect of an expansionary monetary policy shock is completely nullified for a firm with high uncertainty.

[6] Recall that we standardize the firm-level uncertainty measure so that a value of 0 represents a firm at the 30th percentile of uncertainty (low uncertainty firm) and a value of 1 represents a firm at the 70th percentile of uncertainty (high uncertainty firm).

[7] The magnitude of the effect here is lower than that found by Bernanke and Kuttner (2005). As discussed in Lakdawala and Schaffer (2019), this is a feature of the post-2000 data.

Each column after the first one interacts one firm-level characteristic with the monetary policy shock. The last column displays the specification with all firm-level controls interacted with the monetary policy shock. For all columns, we continue to see the negative and statistically significant coefficient on the interaction of uncertainty and monetary policy. Thus, we can be confident that a higher level of uncertainty results in the dampening of the firm's stock price in response to a monetary policy shock.

Overall, the evidence from stock prices is supportive of our main results from firm-level investment data, that higher uncertainty at the firm-level makes firms less responsive to monetary policy shocks.

4 Understanding the results

Our results are consistent with the "real options" or "wait-and-see" mechanism of uncertainty. This mechanism has been widely explored in the literature, see Bernanke (1983), Dixit et al. (1994) and Bloom (2007) for prominent examples. The idea is that when facing uncertainty, firms may decide to hold off on investment decisions due to the costs associated with (partial) irreversibility. In this framework, higher uncertainty dampens the response of investment to demand shocks. Instead of reiterating the well-documented theory behind this channel, here we provide empirical evidence that is consistent with two important predictions of this theory.

First, if the mechanism behind our results is working through reversibility costs, then we would expect our results to be stronger for firms that have higher costs. We test this prediction using a measure of asset redeployability constructed by Kim and Kung (2017). They use detailed data from the Bureau of Economic Analysis to create a redeployability score for each firm based on how many other firms use the assets on its balance sheet. The idea is that a higher score is associated with a higher ease of selling the asset. Consistent with this, they find empirically that more redeployable assets have higher liquidation values and are more actively traded in secondary markets.

Our empirical strategy is to take our baseline specification from Equation 1 and add a triple interaction term ($\text{redeploy}_{i,t-1}$ x mps_t x $\text{ivol}_{i,t-1}$).[8] This will allow us to see if the dampening effect of uncertainty is affected by redeployability at the firm-level. Specifically, since the redeployability measure is inversely related to reversibility costs, a positive coefficient on the interaction term will mean that the dampening effect is stronger for firms with higher reversibility costs. Recall that the coefficient on the double interaction term (mps_t x $\text{ivol}_{i,t-1}$) is negative, thus a positive term on the triple interaction says that the dampening effect is weaker for higher redeployability.

Figure 3 shows the dynamic triple interaction coefficients for physical capital (in the left panel) and for organization capital (in the right panel). We include organization capital here because the asset redeployability score is relevant for intangible capital as well.[9] Both panels show a positive and statistically significant interaction coefficient after 2 years. This evidence is consistent with the real options mechanism at play for how uncertainty affects the investment response to monetary policy shocks.

Our second approach starts by noting that the real options theory predicts that firms that face higher uncertainty will respond less to demand shocks broadly and not just monetary policy shocks. We use two measures of demand shocks to see if this prediction is borne out in our data. We consider sales growth shocks and tax shocks.[10]

For the tax shock we consider the measures of Leeper et al. (2012) and Romer and Romer (2010). The former focuses on the lag in when a tax policy is proposed and when it is enacted and identify news concerning taxes by studying the spread between municipal bonds and

[8] The full specification is $\Delta_h log(k_{i,t+h}) = \alpha_i^h + \beta_1^h \text{mps}_t \text{ x } \text{ivol}_{i,t-1} + \beta_2^h \text{redeploy}_{i,t-1} \text{ x } \text{mps}_t + \beta_3^h \text{redeploy}_{i,t-1} \text{ x } \text{mps}_t \text{ x } \text{ivol}_{i,t-1} + \delta^h \text{mps}_t + \gamma_1^h \text{ivol}_{i,t-1} + \gamma_2^h \text{redeploy}_{i,t-1} + \gamma_3^h \text{redeploy}_{i,t-1} \text{ x } \text{ivol}_{i,t-1} + \Gamma_z^h Z_{i,t-1} + \Gamma_w^h W_{t-1} + \varepsilon_{i,t}^h$. We report β_3^h in our results.

[9] For example, according to Kim and Kung (2017) one of the most redeployable industries is "Lessors of nonfinancial intangible assets" which include establishments that are primarily engaged in assigning rights to assets, such as patents, trademarks, brand names, and/or franchise agreements for which a royalty payment or licensing fee is paid to the asset holder.

[10] We also considered some of the government spending shocks discussed in Ramey (2016). We do find some evidence of differential response between high and low uncertainty firms but the baseline effect of an "expansionary" government spending shock causes investment to decrease. Thus we decided not to focus on these shocks.

treasury bonds. The latter use a narrative approach to estimate exogenous changes in taxes by analyzing presidential speeches and congressional reports. We find similar results for both tax shocks but report the results with the Leeper et al. (2012) measure since, in our sample, the Romer and Romer (2010) measure is completely driven by the Bush tax cuts of the early 2000s. In Appendix Figure A.4 we show that results using the Romer and Romer (2010) unanticipated tax shock are very similar. For the empirical specification we simply replace the monetary policy shock with the tax shock in our baseline specification in Equation 1. For the sales growth shock, we use the firm's year-over-year sales growth to proxy for a demand shock, as in Bloom et al. (2007).[11]

Figure 4 shows the difference between the physical capital responses of high and low uncertainty firms for the sales and tax shock. Both shocks induce a differential response that is consistent with our estimates using monetary policy shocks. High uncertainty firms adjust investment less than low uncertainty firms in response to these shocks. In results not presented here we also find similar responses of intangible capital to these two shocks.

Overall, the sets of results presented provide evidence for the real options mechanism of uncertainty driving the investment response to monetary policy shocks.

5 Conclusion

In this paper we document that uncertainty at the firm level acts as an important source of heterogeneity in the transmission of monetary policy to investment decisions. We use option prices to measure forward-looking uncertainty at the firm level and find that high uncertainty dampens the investment response to monetary policy shocks. This effect is present for investment decisions that involve physical capital and organization capital but not knowledge capital. Consistent with the response of investment, the stock price of firms with higher

[11] To keep our empirical specification consistent, we use only this sales growth proxy; however, the results are qualitatively very similar if we instead use the exact empirical specification of Bloom et al. (2007), i.e. adding a squared sales growth term and an error correction term (lagged sales level minus lagged capital stock).

uncertainty also responds less to monetary shocks on the day of the FOMC announcement.

Our results are consistent with the real options channel of uncertainty where costs associated with reversing investment decisions makes firms more cautious in the face of higher uncertainty. Consistent with this framework, we use a measure of asset redeployability to show that firms that face higher reversibility costs display a stronger dampening response to monetary policy shocks. We also show that the dampening effect of higher uncertainty is evident in response to demand shocks more broadly, including tax and sales growth shocks.

References

Bachmann, R., Elstner, S., and Sims, E. R. (2013). Uncertainty and economic activity: Evidence from business survey data. *American Economic Journal: Macroeconomics*, 5(2):217–49.

Baker, S. R., Bloom, N., and Terry, S. J. (2020). Using disasters to estimate the impact of uncertainty. Technical report, National Bureau of Economic Research.

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

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

Bloom, N. (2007). Uncertainty and the dynamics of R&D. *American Economic Review*, 97(2):250–255.

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

Bloom, N. (2014). Fluctuations in uncertainty. *Journal of Economic Perspectives*, 28(2):153–76.

Bloom, N., Bond, S., and Van Reenen, J. (2007). Uncertainty and investment dynamics. *The Review of Economic Studies*, 74(2):391–415.

Bloom, N., Floetotto, M., Jaimovich, N., Saporta-Eksten, I., and Terry, S. J. (2018). Really uncertain business cycles. *Econometrica*, 86(3):1031–1065.

Bu, C., Rogers, J., and Wu, W. (2021). A unified measure of Fed monetary policy shocks. *Journal of Monetary Economics*, 118:331–349.

Cascaldi-Garcia, D., Sarisoy, C., Londono, J. M., Rogers, J. H., Datta, D., RT Ferreira, T., Grishchenko, O. V., Jahan-Parvar, M. R., Loria, F., Ma, S., et al. (2020). What is certain about uncertainty? *International Finance Discussion Paper*, (1294).

Chang, H., d'Avernas, A., and Eisfeldt, A. L. (2022). Bonds vs. equities: Information for investment. *Working Paper*.

Christiano, L. J., Motto, R., and Rostagno, M. (2014). Risk shocks. *American Economic Review*, 104(1):27–65.

Cloyne, J., Ferreira, C., Froemel, M., and Surico, P. (2018). Monetary policy, corporate finance and investment. Working Paper w25366, National Bureau of Economic Research.

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

Darmouni, O., Giesecke, O., and Rodnyansky, A. (2020). The bond lending channel of monetary policy. CEPR Discussion Paper No. DP14659.

Dew-Becker, I. and Giglio, S. (2020). Cross-sectional uncertainty and the business cycle: evidence from 40 years of options data. Technical report, National Bureau of Economic Research.

Dixit, R. K., Dixit, A. K., and Pindyck, R. S. (1994). *Investment under uncertainty*. Princeton university press.

Döttling, R. and Ratnovski, L. (2021). Monetary policy and intangible investment. *Available at SSRN 3612304*.

Fang, M. (2020). Lumpy investment, fluctuations in volatility and monetary policy. Technical report, SSRN Working Paper.

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

Gürkaynak, R. S., Karasoy-Can, H. G., and Lee, S. S. (2019). Stock market's assessment of monetary policy transmission: The cash flow effect. CEPR Discussion Paper No. DP14017.

Handley, K. and Li, J. F. (2020). Measuring the effects of firm uncertainty on economic activity: New evidence from one million documents. Technical report, National Bureau of Economic Research.

Howes, C., von Ende-Becker, A., et al. (2022). Monetary policy and intangible investment. *Economic Review*, 107(2).

Ilut, C., Kehrig, M., and Schneider, M. (2018). Slow to hire, quick to fire: Employment dynamics with asymmetric responses to news. *Journal of Political Economy*, 126(5):2011–2071.

Ippolito, F., Ozdagli, A. K., and Perez-Orive, A. (2018). The transmission of monetary policy through bank lending: The floating rate channel. *Journal of Monetary Economics*, 95:49–71.

Jeenas, P. (2019). Firm balance sheet liquidity, monetary policy shocks, and investment dynamics. Working Paper.

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

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

Kroner, N. (2021). Firm-level uncertainty and the transmission of forward guidance to investment. *Available at SSRN 3931591*.

Kurt, E. (2022). The role of corporate tax policy on monetary effectiveness: A quasi-experimental approach. *Available at SSRN 4201750*.

Lakdawala, A. (2019). Decomposing the effects of monetary policy using an external instruments SVAR. *Journal of Applied Econometrics*, 34(6):934–950.

Lakdawala, A. and Moreland, T. (2021). Monetary policy and firm heterogeneity: The role of leverage since the financial crisis. *Available at SSRN 3405420*.

Lakdawala, A. and Schaffer, M. (2019). Federal reserve private information and the stock market. *Journal of Banking & Finance*, 106:34–49.

Leahy, J. V. and Whited, T. M. (1996). The effect of uncertainty on investment: Some stylized trends. *Journal of Money, Credit & Banking*, 28(1):64–84.

Leeper, E. M., Richter, A. W., and Walker, T. B. (2012). Quantitative effects of fiscal foresight. *American Economic Journal: Economic Policy*, 4(2):115–44.

Nakamura, E. and Steinsson, J. (2018). High-frequency identification of monetary non-neutrality: The information effect. *The Quarterly Journal of Economics*, 133(3):1283–1330.

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

Palombo, E. (2020). Uncertainty, intangible capital, and productivity dynamics. Technical report, Working Paper.

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

Ramey, V. A. (2016). Macroeconomic shocks and their propagation. In *Handbook of Macroeconomics*, volume 2, pages 71–162. Elsevier.

Romer, C. D. and Romer, D. H. (2004). A New Measure of Monetary Shocks: Derivation and Implications. *American Economic Review*, 94(4):1055–1084.

Romer, C. D. and Romer, D. H. (2010). The macroeconomic effects of tax changes: Estimates based on a new measure of fiscal shocks. *American Economic Review*, 100(3):763–801.

Stein, L. C. and Stone, E. (2013). The effect of uncertainty on investment, hiring, and r&d: Causal evidence from equity options. *Hiring, and R&D: Causal Evidence from Equity Options (October 4, 2013)*.

Wieland, J. F. and Yang, M.-J. (2020). Financial dampening. *Journal of Money, Credit and Banking*, 52(1):79–113.

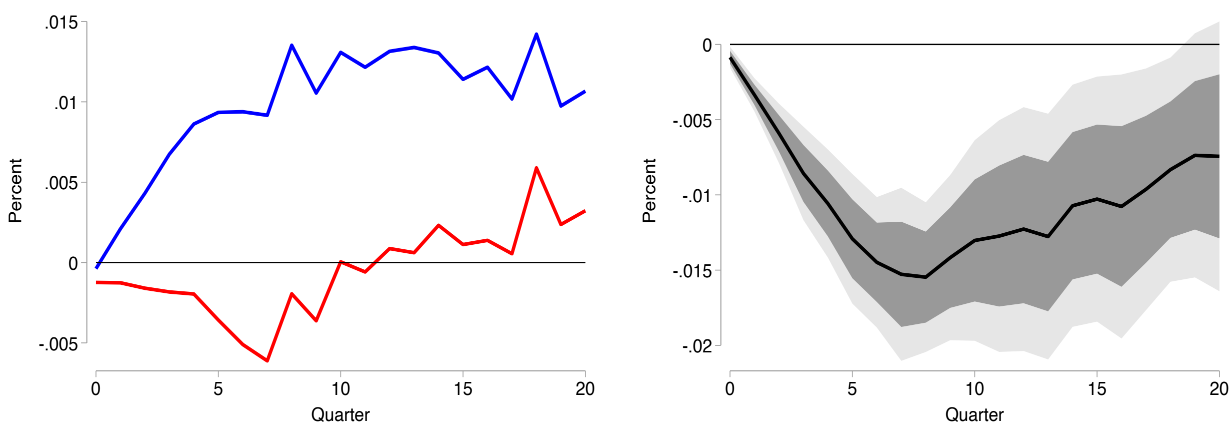
Table 1: Response of firm-level stock returns to expansionary monetary shock

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
mps_t	0.37	0.38	0.46*	0.47*	0.42	0.38	0.37	0.49*
	(0.282)	(0.279)	(0.267)	(0.277)	(0.268)	(0.277)	(0.280)	(0.255)
mps_t x $ivol_{i,t-1}$	-0.33**	-0.34**	-0.45***	-0.46**	-0.39***	-0.35**	-0.33**	-0.50***
	(0.142)	(0.137)	(0.167)	(0.176)	(0.144)	(0.142)	(0.139)	(0.171)
mps_t x $sales_{i,t-1}$		0.01						0.03
		(0.059)						(0.042)
mps_t x $size_{i,t-1}$			-0.26**					-0.04
			(0.104)					(0.155)
mps_t x $MktCap_{i,t-1}$				-0.28**				-0.22
				(0.112)				(0.156)
mps_t x $liquidity_{i,t-1}$					0.13*			0.07
					(0.068)			(0.070)
mps_t x $lev_{i,t-1}$						-0.09*		-0.03
						(0.047)		(0.052)
mps_t x $TobinQ_{i,t-1}$							-0.04	-0.06
							(0.058)	(0.040)
Observations	51,546	51,546	51,546	51,546	51,546	51,546	51,546	51,546
R-squared	0.076	0.076	0.078	0.078	0.077	0.077	0.077	0.078

This table shows estimates from the following specification:
$s_{i,t} = \alpha_i + \beta \text{mps}_t \text{ x } \text{ivol}_{i,t-1} + \delta \text{mps}_t + \gamma \text{ivol}_{i,t-1} + \Gamma'_z Z_{i,t-1} + \Gamma'_{mz} Z_{i,t-1} \text{ x } \text{mps}_t + \varepsilon_{i,t}$ where $s_{i,t}$ is the (daily) return on firm i's share price on FOMC meeting day t, α_i is a firm i fixed effect, $ivol_{i,t-1}$ is firm i's uncertainty measured on the day before FOMC announcement, mps_t is the monetary policy shock, and $Z_{i,t-1}$ is a vector of firm-level controls (lagged by a quarter). $Z_{i,t-1}$ includes the same firm-level financial measures as used in the investment regressions above. The standard errors reported in the parentheses are calculated using two-way clustering along the time and firm dimensions. The sample period is Jan-1996 to Jun-2008 and includes scheduled FOMC announcements only. Two-way clustered (by firm and day) standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

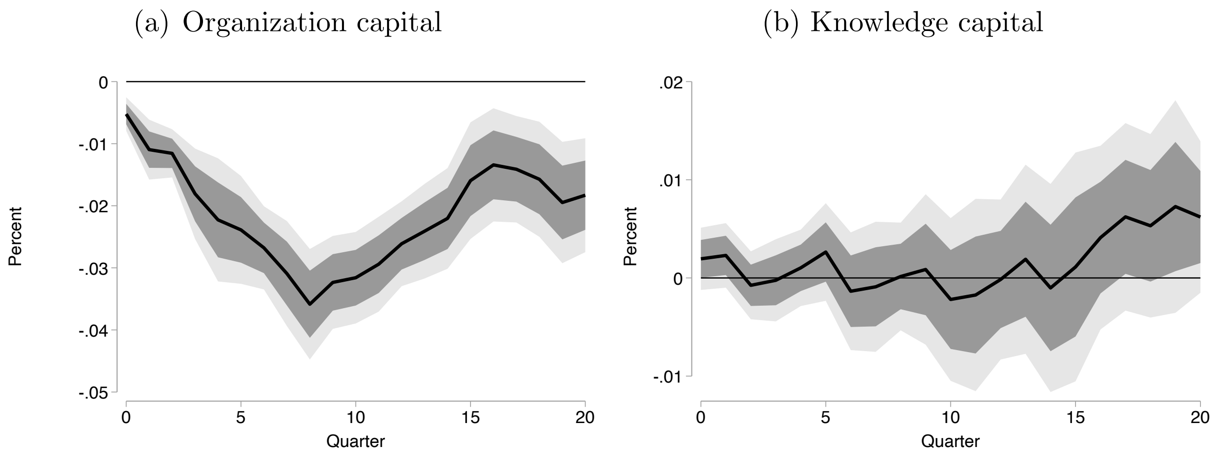
Figure 1: Response of firm-level physical capital to expansionary monetary shock

(a) Low uncertainty (blue), high uncertainty (red)　　(b) High minus low uncertainty



Panel (a) plots the local projection estimates for the coefficients δ^h (in blue) and $\delta^h + \beta^h$ (in red) from the following specification:
$\Delta_h log(k_{i,t+h}) = \alpha_i^h + \beta^h \text{mps}_t \text{ x } \text{ivol}_{i,t-1} + \delta^h \text{mps}_t + \gamma^h \text{ivol}_{i,t-1} + \Gamma_z^h Z_{i,t-1} + \Gamma_w^h W_{t-1} + \varepsilon_{i,t}^h$
where $\Delta_h log(k_{i,t+h}) \equiv log(k_{i,t+h}) - log(k_{i,t-1})$ is the cumulative difference in the physical capital stock, mps_t is our FF4 monetary policy shock constructed from high-frequency data on FOMC announcement days cumulated to quarterly frequency, $ivol_{i,t-1}$ is our measure of firm-level uncertainty averaged over the previous quarter and $Z_{i,t-1}$ are standard firm-level controls which include sales growth, asset value, liquidity ratio, price-to-cost margin, receivables minus payables, depreciation to assets ratio, log of market cap, Tobin's Q, leverage ratio, and indicators for sector and fiscal quarter. W_{t-1} are aggregate controls, including GDP growth, inflation rate, unemployment rate, NASDAQ index and the federal funds rate. The sample period is 1996:Q1 to 2008:Q2. Panel (b) plots the coefficient β^h from the above specification. Confidence intervals are the 90th percentile and 68th percentile intervals using Driscoll-Kraay standard errors.

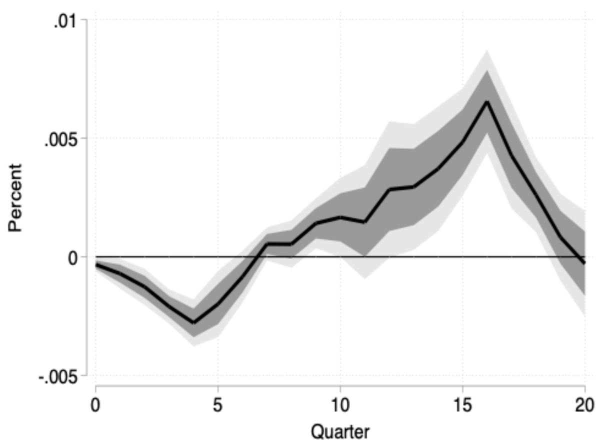
Figure 2: Response of firm-level intangible capital to expansionary monetary shock (high minus low uncertainty)



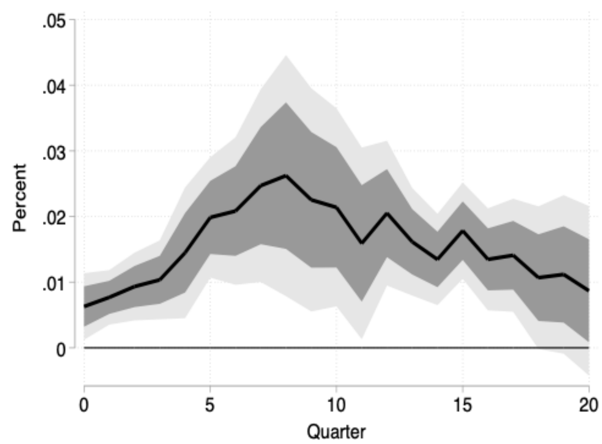
Panel (a) plots estimates for β^h from the specification:
$\Delta_h log(k_{i,t+h}) = \alpha_i^h + \beta^h \text{mps}_t \text{ x } \text{ivol}_{i,t-1} + \delta^h \text{mps}_t + \gamma^h \text{ivol}_{i,t-1} + \Gamma_z^h Z_{i,t-1} + \Gamma_w^h W_{t-1} + \varepsilon_{i,t}^h$
where $\Delta_h log(k_{i,t+h}) \equiv log(k_{i,t+h}) - log(k_{i,t-1})$ is the cumulative difference in the organizational capital stock, mps_t is our FF4 monetary policy shock constructed from high-frequency data on FOMC announcement days cumulated to quarterly frequency, $ivol_{i,t-1}$ is our measure of firm-level uncertainty averaged over the previous quarter and $Z_{i,t-1}$ are standard firm-level controls which include sales growth, asset value, liquidity ratio, price-to-cost margin, receivables minus payables, depreciation to assets ratio, log of market cap, Tobin's Q, leverage ratio, and indicators for sector and fiscal quarter. W_{t-1} are aggregate controls, including GDP growth, inflation rate, unemployment rate, NASDAQ index and the federal funds rate. The sample period is 1996:Q1 to 2008:Q2. Panel (b) uses the knowledge capital stock as the dependent variable. Confidence intervals are the 90th percentile and 68th percentile intervals using Driscoll-Kraay standard errors.

Figure 3: Response of firm-level capital to expansionary shocks (coefficient of $\text{redeploy}_{i,t-1}$ x mps_t x $\text{ivol}_{i,t-1}$)

(a) MP Shock, Physical Capital



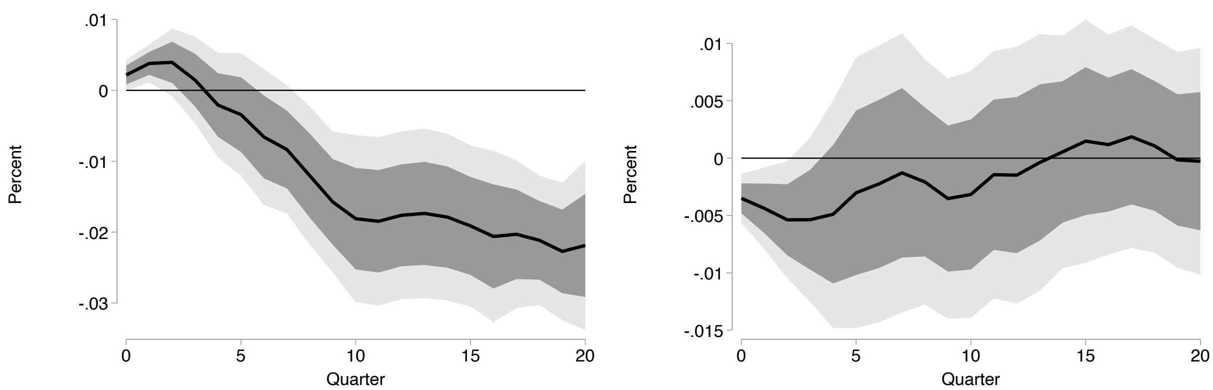
(b) MP Shock, Organization Capital



This figure plots the estimates for the coefficient β_3^h from the specification: $\Delta_h log(k_{i,t+h}) = \alpha_i^h + \beta_1^h \text{mps}_t \text{ x } \text{ivol}_{i,t-1} + \beta_2^h \text{redeploy}_{i,t-1} \text{ x } \text{mps}_t + \beta_3^h \text{redeploy}_{i,t-1} \text{ x } \text{mps}_t \text{ x } \text{ivol}_{i,t-1} + \delta^h \text{mps}_t + \gamma_1^h \text{ivol}_{i,t-1} + \gamma_2^h \text{redeploy}_{i,t-1} + \gamma_3^h \text{redeploy}_{i,t-1} \text{ x } \text{ivol}_{i,t-1} + \Gamma_z^h Z_{i,t-1} + \Gamma_w^h W_{t-1} + \varepsilon_{i,t}^h$. where $\Delta_h log(k_{i,t+h}) \equiv log(k_{i,t+h}) - log(k_{i,t-1})$ is the cumulative difference in the capital stock (physical capital in panel (a) and organization capital in panel (b)), mps_t is our FF4 monetary policy shock constructed from high-frequency data on FOMC announcement days cumulated to quarterly frequency, $ivol_{i,t-1}$ is our measure of firm-level uncertainty averaged over the previous quarter, $redeploy_{i,t-1}$ is our measure of asset redeployability and $Z_{i,t-1}$ are standard firm-level controls which include sales growth, asset value, liquidity ratio, price-to-cost margin, receivables minus payables, depreciation to assets ratio, log of market cap, Tobin's Q, leverage ratio, and indicators for sector and fiscal quarter. W_{t-1} are aggregate controls, including GDP growth, inflation rate, unemployment rate, NASDAQ index and the federal funds rate. The sample period is 1996:Q1 to 2008:Q2. Confidence intervals are the 90th percentile and 68th percentile intervals using Driscoll-Kraay standard errors.

Figure 4: Response of firm-level physical capital to demand shocks (high minus low uncertainty)

(a) Sales growth shock (b) Tax shock



This figure plots estimates for β^h from the specification:
$\Delta_h log(k_{i,t+h}) = \alpha_i^h + \beta^h \text{shock}_t \text{ x } \text{ivol}_{i,t-1} + \delta^h \text{shock}_t + \gamma^h \text{ivol}_{i,t-1} + \Gamma_z^h Z_{i,t-1} + \Gamma_w^h W_{t-1} + \varepsilon_{i,t}^h$
where $\Delta_h log(k_{i,t+h}) \equiv log(k_{i,t+h}) - log(k_{i,t-1})$ is the cumulative difference in the physical capital stock, shock_t is our demand shock measure (sales growth shock in panel (a) and unanticipated tax shock in panel (b)), $ivol_{i,t-1}$ is our measure of firm-level uncertainty averaged over the previous quarter and $Z_{i,t-1}$ are standard firm-level controls which include sales growth, asset value, liquidity ratio, price-to-cost margin, receivables minus payables, depreciation to assets ratio, log of market cap, Tobin's Q, leverage ratio, and indicators for sector and fiscal quarter. W_{t-1} are aggregate controls, including GDP growth, inflation rate, unemployment rate, NASDAQ index and the federal funds rate. The sample period is 1996:Q1 to 2008:Q2. Confidence intervals are the 90th percentile and 68th percentile intervals using Driscoll-Kraay standard errors.

Table A.1: Summary Statistics

	Firm-Qtrs	Mean	SD
Implied Volatility	60,821	54.01	27.11
Distance to Default	52,179	7.21	5.05
$\Delta log(K_{i,t})$	60,821	0.02	0.08
$\Delta log(K_{i,t}^{know})$	32,647	0.03	0.20
$\Delta log(K_{i,t}^{org})$	48,624	0.04	0.39

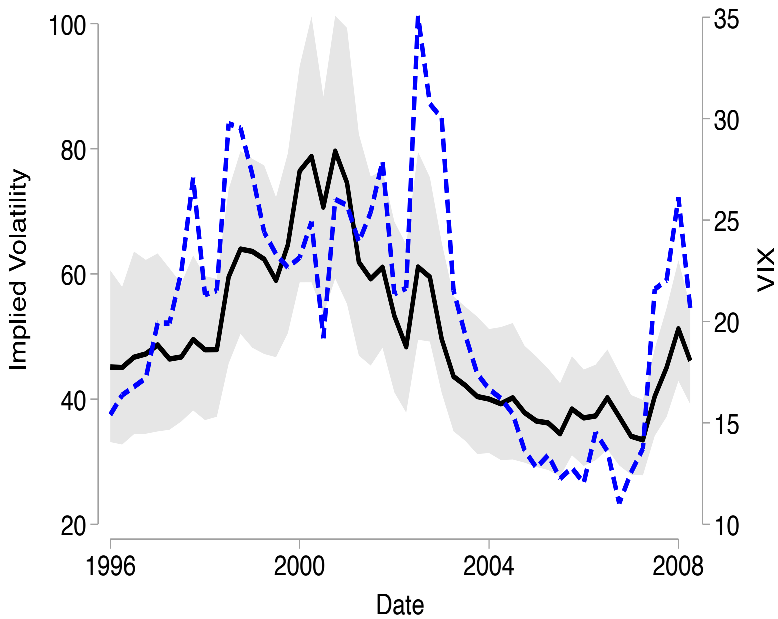
	Qtrs	Mean	SD
FF4	50	-0.03	0.09

	Firm-Days	Mean	SD
Firm stock price change	107,687	0.31	3.97

	High Uncertainty Firms		Low Uncertainty Firms	
	Mean	SD	Mean	SD
Implied Volatility	82.05	27.08	30.88	9.22
Sales Growth	17.01	57.79	7.00	22.13
Asset Size	5.81	1.45	8.77	1.39
Liquidity	0.38	0.27	0.08	0.11
Price-to-Cost Margin	-0.79	5.18	0.36	0.21
Receivables to Payables	-0.08	3.74	0.38	1.55
Depreciation to Assets	0.01	0.01	0.01	0.01
Log of Market Cap	6.40	1.09	8.78	1.23
Tobin's Q	3.72	5.24	2.01	1.33
Leverage (Debt-to-Capital)	0.22	0.29	0.41	0.23

The table shows the summary statistics for the sample from Jan-1996 to Jun-2008. Implied Volatility is the quarterly firm-level implied volatility measured by weighting the implied volatility of each option contract (that expires within 15 to 45 days) by its trading volume on a given day and averaging within a quarter. Investment is reported for our three capital stocks (physical, knowledge and organizational) as the log change from quarter $t-1$ to quarter t. FF4 is the sum of the daily change in the three-month-ahead fed funds futures contract on FOMC days in a quarter. Firm stock price change is the log change on FOMC days in the share price of firm i from the closing time on day $t-1$ to the closing time on day t. High (Low) Uncertainty firms are those with an implied volatility at or above (below) the 70th (30th) percentile in a quarter.

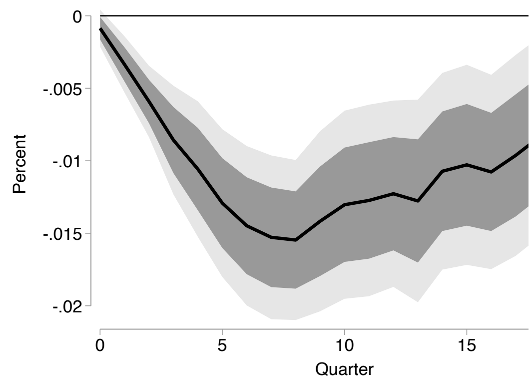
Figure A.1: Time Series of Implied Volatility



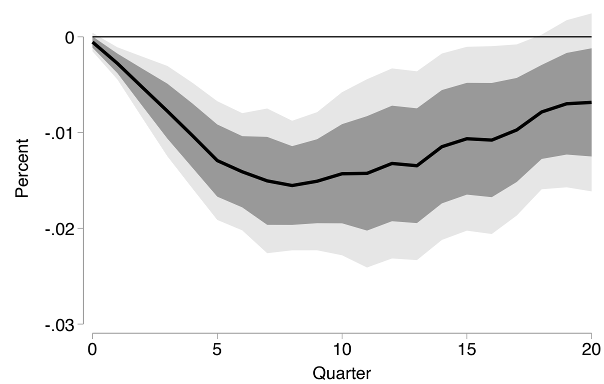
This figure plots the 30th percentile, mean and 70th percentile values of quarterly firm-level implied volatility from 1996:Q1 to 2008:Q2. Implied volatility is calculated using firm-level option contracts that expire within 15 to 45 days.

Figure A.2: Response of firm-level physical capital to expansionary monetary shock (high minus low uncertainty)

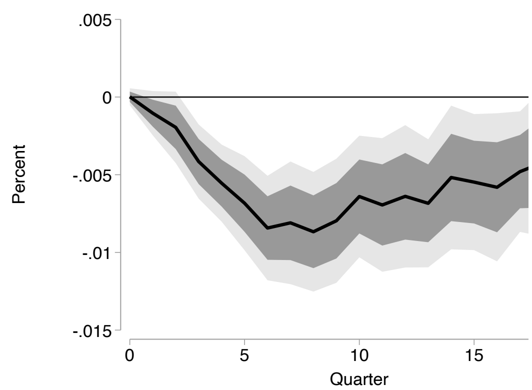
(a) Two-way clustered standard errors



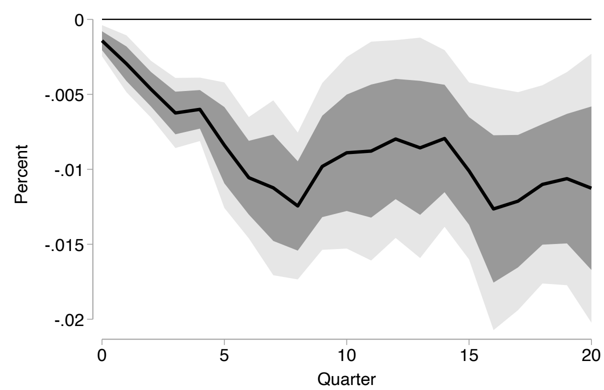
(b) Time-fixed effect



(c) Smoothed aggregation of mp shock



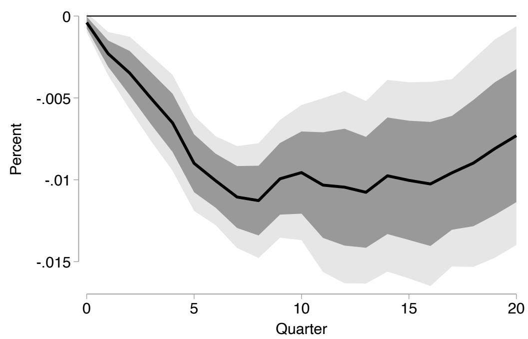
(d) Interact mp shock with firm controls



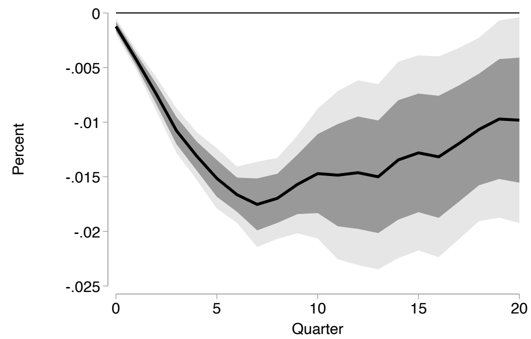
This figure plots local projection estimates for the coefficient β^h from the specification: $\Delta_h log(k_{i,t+h}) = \alpha_i^h + \beta^h \text{mps}_t \text{ x ivol}_{i,t-1} + \delta^h \text{mps}_t + \gamma^h \text{ivol}_{i,t-1} + \Gamma_z^h Z_{i,t-1} + \Gamma_w^h W_{t-1} + \varepsilon_{i,t}^h$. The sample period is 1996:Q1 to 2008:Q2. Panel (a) calculates confidence intervals using two-way (firm and quarter) clustered standard errors. Panel (b) includes a time fixed effect. Panel (c) aggregates monetary policy shocks to the quarterly level by weighting mps_t and mps_{t-1} based on when the shocks occur within the quarter. Panel (d) includes interactions of the the firm controls (plus firm age) with mps_t. Confidence intervals are the 90th percentile and 68th percentile intervals using Driscoll-Kraay standard errors (except for in panel (a)).

Figure A.3: Response of firm-level physical capital to expansionary monetary shock (high minus low uncertainty)

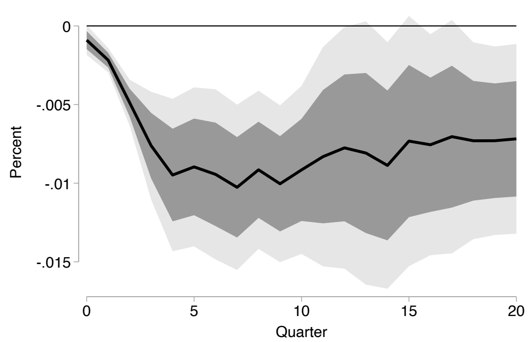
(a) MPS = Fed funds futures shock



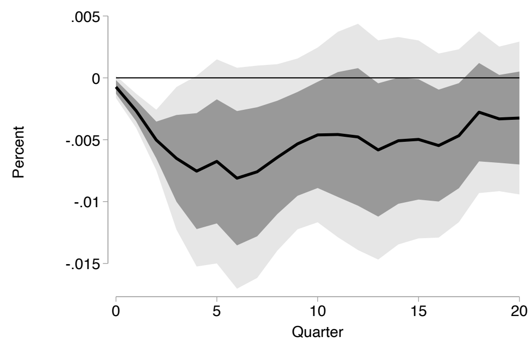
(b) MPS = NS policy news shock



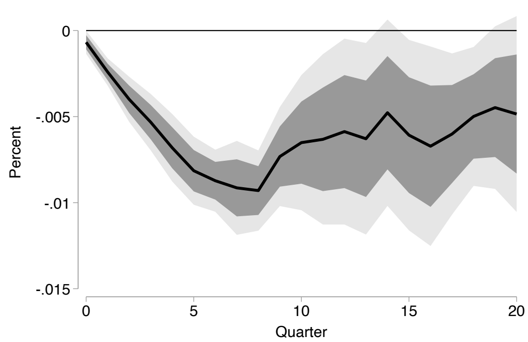
(c) MPS = BRW monetary shock



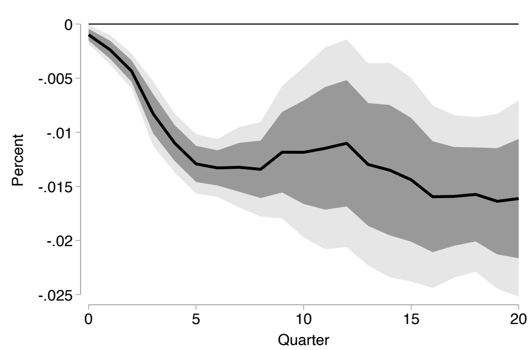
(d) MPS = 2 year eurodollar futures shock



(e) MPS = FF4 (30 min) monetary shock

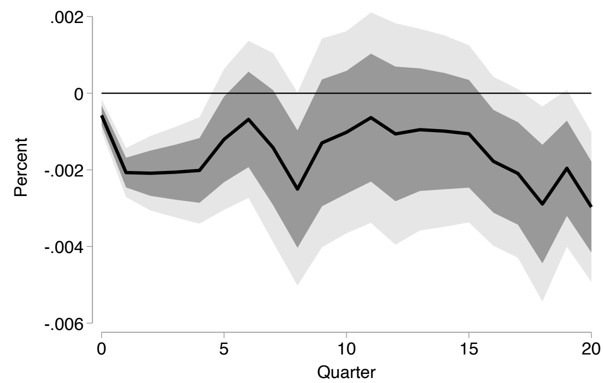


(f) MPS = R & R monetary shock



This figure plots the estimates for the coefficient β^h from the specification:
$\Delta_h log(k_{i,t+h}) = \alpha_i^h + \beta^h \text{mps}_t \text{ x } \text{ivol}_{i,t-1} + \delta^h \text{mps}_t + \gamma^h \text{ivol}_{i,t-1} + \Gamma_z^h Z_{i,t-1} + \Gamma_w^h W_{t-1} + \varepsilon_{i,t}^h$.
The sample period is 1996:Q1 to 2008:Q2. Panel (a) *mps* is the current month's federal funds future rate. Panel (b) *mps* is the Nakamura and Steinsson (2018) policy news shock. Panel (c) *mps* is the Bu et al. (2021) shock. Panel (d) *mps* is the the 2-year-ahead future on 3-month Eurodollar deposits (ED8). Panel (e) *mps* is 30 minute changes in 3-month ahead futures (FF4). Panel (f) *mps* is the Romer and Romer (2004) monetary policy shock, as updated in Wieland and Yang (2020). Confidence intervals are the 90th percentile and 68th percentile intervals using Driscoll-Kraay standard errors.

Figure A.4: Response of firm-level physical capital to Romer & Romer tax shock (high minus low uncertainty)



This figure plots estimates for β^h from the specification:
$\Delta_h log(k_{i,t+h}) = \alpha_i^h + \beta^h \text{shock}_t \text{ x ivol}_{i,t-1} + \delta^h \text{shock}_t + \gamma^h \text{ivol}_{i,t-1} + \Gamma_z^h Z_{i,t-1} + \Gamma_w^h W_{t-1} + \varepsilon_{i,t}^h$
where $\Delta_h log(k_{i,t+h}) \equiv log(k_{i,t+h}) - log(k_{i,t-1})$ is the cumulative difference in the physical capital stock, shock_t is the Romer and Romer (2010) unanticipated tax shock, $ivol_{i,t-1}$ is our measure of firm-level uncertainty averaged over the previous quarter and $Z_{i,t-1}$ are standard firm-level controls which include sales growth, asset value, liquidity ratio, price-to-cost margin, receivables minus payables, depreciation to assets ratio, log of market cap, Tobin's Q, leverage ratio, and indicators for sector and fiscal quarter. W_{t-1} are aggregate controls, including GDP growth, inflation rate, unemployment rate, NASDAQ index and the federal funds rate. The sample period is 1996:Q1 to 2008:Q2. Confidence intervals are the 90th percentile and 68th percentile intervals using Driscoll-Kraay standard errors.