The Investment Channel of Monetary Policy: Evidence from Norway*

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Abstract

We study the transmission of monetary policy to firm investment using Norwegian administrative data. We distinguish the role of borrowing constraints from the indirect effects of policy shocks on the marginal profitability of investment. Our main finding is that financially constrained firms exhibit stronger investment responses, while profitability effects are limited. Heterogeneity, however, plays only a minor role in *aggregate* monetary transmission. These results suggest that a representative-firm framework with investment adjustment frictions provides a sufficiently rich description of the investment channel of monetary policy.

JEL: E22, E52, D22, G31

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1 Introduction

Investment is one of the most responsive components of GDP to monetary policy. This makes the investment channel of monetary policy one of the critical ways in which monetary policy affects the real economy. This paper aims to understand how this investment channel of monetary policy operates.

To discipline our empirical investigation, we first present a conceptual framework that identifies three mechanisms through which monetary policy affects investment: discounting, the tightness of borrowing constraints, and its impact on future marginal profitability of capital. The first channel is standard in the investment literature. Our focus is on understanding the relative and absolute importance of the latter two mechanisms for how monetary policy transmits to firms' fixed-asset investment.

We use detailed administrative data covering the universe of Norwegian firms to study within-firm transmission. Using income and balance-sheet statements from 2000 to 2019, we estimate firms' fixed-asset responses to monetary policy, both on average and across the distribution of firm characteristics. We employ local projections and use a monetary policy shock à la Romer and Romer (2004) for Norway, constructed by Holm, Paul, and Tischbirek (2021), as an instrument for changes in the Norwegian policy rate.

We make two contributions to the literature. First, while several papers study monetary transmission to investment,[1] we exploit the granularity of our data to trace monetary transmission for the full universe of firms, not only publicly listed firms. We therefore estimate transmission not only for large incorporated firms but also for small and medium-sized enterprises.[2] As documented by Kalemli-Özcan, Sørensen, Villegas-Sanchez, Volosovych, and Yeşiltaş (2024), these firms account for a large share of aggregate economic activity. Second, we explicitly test the extent to which monetary transmission to investment operates through the classical discount channel, borrowing constraints, or firms' marginal profitability. Understanding the relative importance of these channels is crucial for fully understanding how monetary policy affects the real economy (Auclert, Rognlie, and Straub, 2020; Bilbiie, Känzig, and Surico, 2022) and for disciplining large macroeconomic models. For example, there seems to be no clear consensus on whether firm heterogeneity is quantitatively relevant enough to justify its inclusion in models aimed at understanding

[1]See, for example, Ottonello and Winberry (2020); Cloyne, Ferreira, Froemel, and Surico (2023); Jeenas (2023); Ippolito, Ozdagli, and Perez-Orive (2018); Krusell, Thürwächter, and Weiss (2023); Jungherr, Meier, Reinelt, and Schott (2024); Deng and Fang (2022); Silva Paranhos (2024); Bonin, Cucic, Kuchler, and Otte (2024); Best, Born, and Menkhoff (2025); Gnewuch and Zhang (2025).

[2]In this respect, our paper is most closely related to Caglio, Darst, and Kalemli-Özcan (2024), who analyze the role of firm heterogeneity in the transmission of monetary policy to credit and capital misallocation for SMEs and listed firms, and to Albrizio, Gonzalez, and Khametshin (2024), who study the effect of monetary policy on capital misallocation for the full population of Spanish firms.

aggregate monetary transmission.[3]

Our empirical analysis proceeds in two steps. First, we validate the microdata by estimating the investment response of the average firm and comparing it with the aggregate capital response in the national accounts. We also estimate a size-weighted version of the firm-level local projections. The dynamics and magnitudes of both the average and size-weighted micro responses closely align with those of the aggregate response. We therefore argue that our data is representative of the universe of firms that account for aggregate investment in the national accounts.

Second, we examine heterogeneity in firms' fixed-asset responses to monetary policy. Our goal is to understand to what extent monetary transmission to investment operates via discounting, the tightness of borrowing constraints, and the marginal profitability of capital. We study six balance-sheet proxies for the tightness of borrowing constraints: age, size, asset-based constraints, earnings-based constraints, liquidity, and leverage. To capture exposure to changes in marginal profitability, we compare firms in tradable and non-tradable sectors and construct a continuous measure of proximity to final consumers based on input–output linkages. Our main result is that only a proxy for earnings-based constraints—interest costs relative to earnings—robustly explains heterogeneity in fixed-asset responses. For profitability, differences in exposure to local demand conditions generate little additional heterogeneity: firms in tradable and non-tradable sectors, and firms closer or farther from consumers, respond similarly to monetary policy.

Earnings-based constraints are plausible frictions because lending capacity is often tied to earnings rather than collateral (Lian and Ma, 2021; Ivashina, Laeven, and Moral-Benito, 2022; Öztürk, 2022; Drechsel, 2023). In our data, firms with higher interest-cost-to-earnings ratios respond more strongly to monetary policy. This finding is consistent with international evidence indicating that borrowing constraints help explain heterogeneity in investment responses (Ottonello and Winberry, 2020; Durante, Ferrando, and Vermeulen, 2022; Cloyne et al., 2023; Chiţu, Grothe, Schulze, and Van Robays, 2023; Caglio et al., 2024; Almeida, Johnson, Oliveira, and Zhou, 2024; Silva Paranhos, 2024). However, even though earnings-based constraints robustly explain variation, the magnitude of this effect is limited. The estimated responses at the 10th and 90th percentiles of the interest-cost-to-earnings distribution almost always lie within the 95% confidence band of the average response. We therefore cannot conclude that firm heterogeneity, whether in balance-sheet characteristics or exposure to local demand, has a major impact on aggregate monetary

[3] For example, a central philosophy in economics is that a model should never be judged by the realism of its assumptions, but rather that a model is important and useful if it "explains much by little" (Friedman, 1953). Hence, the inclusion of, e.g., firm heterogeneity in a model must be justified by its quantitative relevance to the questions one seeks to address.

transmission. Firms of different ages, leverage levels, liquidity positions, demand exposures, and constraint statuses respond in broadly similar ways, reducing fixed assets when interest rates rise.

Through the lens of a structural model, our results suggest that monetary transmission to investment primarily operates via a common channel. Financial constraints and the effects of interest rate changes on marginal profitability appear to play minor roles in aggregate monetary transmission. We show, in a final quantitative model exercise, that these findings are consistent with a firm model with investment adjustment frictions. In these models, monetary policy operates primarily via discounting, a channel common to all firms, and the marginal profitability channel is relatively muted. Hence, we argue that a representative-firm model with investment adjustment frictions is in many cases sufficiently rich to account for the investment channel of monetary policy.

2 Conceptual framework

This section presents a q–theory framework in which firms face a generic investment constraint to motivate and discipline the empirical investigation later in the paper.

2.1 The environment and investment optimality conditions

Time t is discrete, and firm i produces using capital K_t^i. Profits in period t is

$$\pi^i(K_t^i, \Theta_t), \tag{1}$$

where Θ_t is the aggregate state of the economy. The function $\pi^i(K^i, \Theta)$ summarizes how capital and the state of the economy affect firm profitability. This function potentially varies by firm and can be microfounded, for instance, from a CES production function.[4]

Capital accumulates according to

$$K_{t+1}^i = (1-\delta)K_t^i + I_t^i, \tag{2}$$

[4] We assume that

$$\pi_K^i(K_t^i, \Theta_t) > 0, \qquad \pi_{KK}^i(K_t^i, \Theta_t) < 0, \qquad \pi_{K\Theta}^i(K_t^i, \Theta_t) > 0,$$

and that a contractionary change in monetary policy (a higher policy rate r_t) worsens the aggregate state Θ_t with a lag,

$$\frac{\partial \Theta_{t+k}}{\partial r_t} \leq 0 \; \forall \; k \; \geq 1.$$

where I_t^i is gross investment and $\delta \in (0,1)$ is the depreciation rate. Investment is subject to quadratic adjustment costs of the Hayashi-type:

$$\text{AC}(I,K) = \frac{\phi}{2}\left(\frac{I}{K} - \delta\right)^2 K, \qquad \phi > 0. \tag{3}$$

The firm also faces a generic constraint on investment

$$g^i(I,K,r) \leq 0, \tag{4}$$

where the constraint can represent a variety of frictions (financial, organizational, institutional).

The firm chooses $\{I_t^i, K_{t+1}^i\}_{t\geq 0}$ to maximize the present value of dividends:

$$\max_{\{I_t^i, K_{t+1}^i\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \left(\prod_{s=1}^{t} \frac{1}{1+r_s}\right)\left[\pi^i(K_t^i, \Theta_t) - I_t^i - \text{AC}(I_t^i, K_t^i)\right] \tag{5}$$

subject to capital accumulation (2) and the constraint (4). The relevance of the constraint is captured entirely by its Lagrange multiplier $\mu_t^i \geq 0$.

Letting q_t^i denote the shadow value of relaxing the capital accumulation constraint, the investment behavior of a firm is

$$\frac{I_t^i}{K_t^i} = \delta + \frac{1}{\phi}\left(q_t^i - 1 - \mu_t^i g_{I,t}^i\right), \tag{6}$$

where

$$q_t^i \equiv \sum_{j=1}^{\infty} \overbrace{(1-\delta)^{j-1}\left(\prod_{s=1}^{j} \frac{1}{1+r_{t+s}}\right)}^{\beta_{t,t+j}} \overbrace{\left[\underbrace{\frac{\partial \pi^i(K_{t+j}^i, \Theta_{t+j})}{\partial K_{t+j}^i} - \frac{\partial \text{AC}(I_{t+j}^i, K_{t+j}^i)}{\partial K_{t+j}^i}}_{\eta_{t+j}^i} - \mu_{t+j}^i g_{K,t+j}^i\right]}^{\varphi_{t+j}^i}. \tag{7}$$

In Equation (7), we use the short-hand $g_{I,t}^i = \frac{\partial g^i(I_t^i, K_t^i)}{\partial I_t^i}$ and $g_{K,t+j}^i = \frac{\partial g^i(I_{t+j}^i, K_{t+j}^i)}{\partial K_{t+j}^i}$. We use a rewritten version of Equation (7) to ease exposition

$$q_t^i \equiv \sum_{j=1}^{\infty} \beta_{t,t+j}\left[\eta_{t+j}^i - \mu_{t+j}^i g_{K,t+j}^i\right], \tag{8}$$

where $\beta_{t,t+j}$ is the relevant discount factor for q_t^i and η_{t+j}^i is the marginal effect of K_{t+j}^i on cash-flow in period $t+j$.

2.2 The effect of an unanticipated interest rate change on investment

An unanticipated increase in the interest rate has several distinct impacts on firm investment. Formally, the marginal effect of an interest rate change on the investment rate is[5]

$$\frac{\partial(I_t^i/K_t^i)}{\partial r_t} = \frac{1}{\phi + \mu_t^i g_{II,t}^i}\left[\sum_{j=1}^{\infty}\Big(\overbrace{\frac{\partial\beta_{t,t+j}}{\partial r_t}\varphi_{t+j}^i}^{\text{Discount rate channel}} \underbrace{+\beta_{t,t+j}\frac{\partial\eta_{t+j}^i}{\partial r_t}}_{\text{Marginal profitability channel}} \overbrace{-\beta_{t,t+j}\frac{\partial\mu_{t+j}^i g_{K,t+j}^i}{\partial r_t}\Big) - \frac{\partial\mu_t^i g_{I,t}^i}{\partial r_t}}^{\text{Constraint channel}}\right]. \tag{9}$$

There are three channels through which changes in the interest rate affect investment. First, there is the standard discount rate channel, where the interest rate directly affects the net present value calculation of potential projects. Second, there is a *marginal profitability channel* where policy-induced movements in the interest rate affect expected future marginal profitability from capital η_{t+j}^i. This change in future marginal profitability then affects the shadow value of capital, q_t^i, and, in turn, current investment. An example of this channel is when an interest rate change affects aggregate demand, in turn, affecting the marginal product of capital. Third, there is a *constraint channel* in which changes in the interest rate affect current and future wedges μ and constraints g, thereby tightening or relaxing the constraints' impact and shifting optimal investment.

2.3 Empirical mapping and heterogeneity

To capture the distinct channels in our data, we construct proxies that reflect firms' sensitivity to them. In particular, we need proxies for how the marginal investment response to monetary policy shocks depends on (i) how exposed the firm's future profitability is to interest rate changes and (ii) how constrained the firm is.

Proxies for marginal profitability exposure. In the model, there may be differences in how firms' future profits respond to changes in the interest rate. We will primarily proxy for this marginal profitability exposure using sector identifiers. Specifically, one hypothesis is that firms in sectors closer to selling directly to households are more exposed

[5] Note that while we define Equation (9) as the marginal effect of the interest rate on I_t^i/K_t^i, this is the same as the marginal effect on investment I_t^i because K_t^i is pre-determined.

to demand changes and, thus, to interest rates. Similarly, we expect firms' marginal profits in the non-tradable sector to be more exposed to interest rate changes than those in the tradable sector.

Proxies for constraint tightness. In the model, tighter constraints show up as higher multipliers μ_t, whereas these multipliers are unobserved in the data. We will expect firm characteristics such as size, age, leverage, liquidity, pledgeable collateral, and interest costs to earnings to be correlated with the propensity for the constraint to bind, and thus with the distribution of current and future μ. Interacting monetary policy shocks with various proxies for constraints may enable us to test whether firms that are more likely to be constrained differ in their investment responses to interest rate changes.

3 Data

Our study uses Norwegian administrative data on the income statements and balance sheets of all limited liability companies. Below, we describe the data sources, the sample selection criteria, descriptive statistics, and relevant institutional details.

Data sources. We use the Norwegian firm balance sheets and accounting information from the Brønnøysund Register of Business Enterprises, with annual data from 2000 to 2019, as our primary data source. This sample comprises all enterprises operating in Norway that must submit accounting data to the Norwegian authorities. We also use non-financial information, like founding years and the number of employees, provided by the same register. The full sample comprises a panel of financial data for the universe of firms in Norway, ranging from the smallest non-listed private firms to the very large multinational firms. Although the data is self-reported, our sample restrictions below ensure that a third party audits the data.

Variable definitions. The main variable of interest in our study is investment. We define investment as the change in fixed assets. Similar studies to ours (e.g., using Compustat) construct a measure of fixed assets by cumulating capital expenditures at the firm level, a variable not observed in our data. Nevertheless, these two approaches are similar because capital expenditure and capital are connected through the law of motion of capital

$$K_{t+1} = (1 - \delta)K_t + I_t. \tag{10}$$

A challenge with our approach is that capital is typically hard to measure in the data. We select a measure of capital from the balance sheet data by choosing the concept that most closely approximates productive capital in neoclassical production models. In the Norwegian accounting framework, this category is called tangible fixed assets and contains, among others, buildings, plant and machinery, ships, rigs, aircraft, motor vehicles, and office machines. Notably, it excludes intangible assets, inventory, current assets, and financial investments.

Our measure of investment is the growth rate of capital, $\frac{K_t - K_{t-1}}{K_{t-1}}$, where all capital variables are deflated by the consumer price index before the growth rate is computed. The definition we use is the same as $\frac{I_{t-1}}{K_{t-1}} - \delta$ using Equation (10).[6] In the accounting data, tangible fixed assets are valued at historical cost net of depreciation. The capital growth rate should therefore equal I_t/K_t, since depreciation is already accounted for in the data. However, if it was not removed or the method is imprecise, our estimation allows for firm-specific depreciation rates.[7] Hence, our approach estimates how investment, as a share of capital, responds to monetary policy.

We will use several interaction variables when investigating the role of firm heterogeneity in monetary transmission. We capture the tightness of borrowing constraints in a parsimonious way by including a wide range of characteristics emphasized in the literature. In particular, *age* is the number of years since the firm's establishment year, *size* is the natural logarithm of a firm's total assets, *leverage* is the ratio of long-term debt to total assets[8], and *liquidity* is the sum of cash and deposit holdings as a share of total assets. Further, we follow Lian and Ma (2021) and proxy for an *earnings-based constraint* using the firm's interest costs as a share of earnings,[9] and proxy for an *asset-based constraint* using a firm's tangible assets to debt ratio.

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[6]Similarly,

$$\frac{K_{t+h} - K_{t-1}}{K_{t-1}} = \frac{\sum_{s=0}^{h}(1-\delta)^s I_{t+s-1}}{K_{t-1}} + ((1-\delta)^h - 1) \approx \frac{\sum_{s=0}^{h}(1-\delta)^s I_{t+s-1}}{K_{t-1}} - h\delta$$

where the last approximation only holds for small h.

[7]Assuming depreciation rates are constant over time within firms, depreciation rates will be included as part of firm fixed effects.

[8]We use long-term debt instead of total debt because the majority of firms prefer to match maturities, i.e. most firms prefer to finance long-term investments with long-term debt. Hence, the long-term debt leverage ratio is informative about the degree of financial constraints Jungherr and Schott (2021)

[9]Because earnings are not positive in each year, we define the proxy of the earnings-based constraint as the interest cost divided by the average of earnings over the past three years. This results in somewhat higher levels of the interest costs to earnings than expected in annual data, as seen as a mean of 0.38 in our sample in Table 1.

Sample selection. Our initial sample contains all limited liability companies in Norway, excluding utilities, financial institutions, real estate firms,[10] and the public sector.[11] We then impose three sample restriction criteria to construct our main sample. First, we focus on firms with fixed assets above USD 100,000 to restrict our attention to firms where capital is a non-negligible input in production.[12] Second, since the interest costs to earnings is an important variable, we restrict attention to firms with positive earnings on average over the last three years to ensure that we can measure interest costs to earnings. Third, we trim the sample based on the key explanatory variables and investment. Specifically, we exclude firms with long-term debt-to-total assets exceeding 10, as well as those at the 1st and 99th percentiles of the main explanatory variables. Moreover, we trim investment (changes in fixed assets) at the 5th and 95th percentiles to remove extreme outliers. Our final sample comprises 33,674 unique firms and 159,187 firm-year observations, covering approximately 2/3 of annual sales in each year.[13]

Summary statistics. Table 1 presents some key descriptive statistics for our sample. Other studies on monetary transmission to firm investment often rely on the firm data for the US from Compustat (see, e.g., Ottonello and Winberry, 2020). Compared with Compustat, our sample consists of relatively young and small companies. For example, the median of total assets is around USD 150 million in Compustat, which is more than 100 times larger than the median in our sample. Furthermore, since firms in our sample are smaller, they tend to have more liquidity and leverage than those in Compustat.

In Panel E in Table 1, we present the main interaction variables used in Section 5. When we use standardized variables, these are constructed using the cross-sectional means and standard deviations from Panel E.

[10] We exclude sector L in the NACE code register, consisting of firms that buy and sell real estate, rent and operate real estate, or otherwise manage real estate. The construction sector (sector F) is included in our sample.

[11] When selecting the initial sample, we also drop observations with obvious measurement issues, i.e., firms with negative sales, assets, deposits, or debt.

[12] Compared with other studies, this size restriction allows us to include smaller firms in our dataset. For example, Caglio et al. (2024) study the credit response of small-and-medium-sized firms in the U.S., restricted to firms that borrow at least USD 1 million.

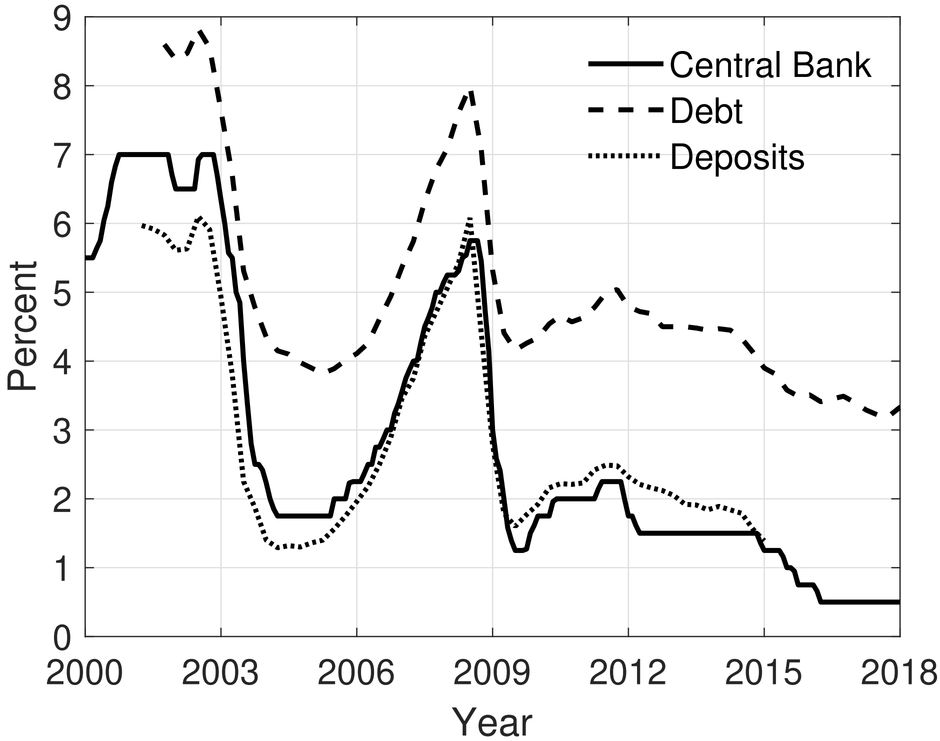
[13] This coverage is comparable to what is obtained using Orbis data in, e.g., the representative samples in Kalemli-Özcan et al. (2024).

	Mean	SD	P10	Median	P90
Panel A: Demographics					
Employees	36	212	2	12	56
Panel B: Income statement					
Sales	11,799	92,887	314	2,034	16,083
Wage bill	2,202	12,437	102	566	3,310
Acquisition cost of goods sold	6,379	52,608	1	619	8,928
Other operating expenses	1,732	13,073	78	353	2,312
Earnings	1,268	36,046	2	127	1,048
Net financial income	-18	7,937	-114	-13	22
Interest expenses	108	1,420	2	18	122
Interest income	33	618	0	2	36
Profits before tax	1,251	40,328	-21	103	1,001
Taxes	539	25,876	-3	26	257
Profits after tax	711	16,098	-18	76	742
Panel C: Assets					
Total assets	9,820	140,074	377	1,335	9,703
Intangible assets	417	6,537	0	0	124
Tangible (real) assets	3,674	80,964	143	402	2,720
Total current assets	4,249	31,866	105	666	5,705
Inventory	1,076	8,303	0	52	1,586
Cash & deposits	784	7,631	14	145	1,101
Panel D: Liabilities					
Total liabilities	6,525	92,865	242	881	6,344
Long-term debt	3,071	67,430	9	282	2,212
Short-term debt	3,592	40,482	83	457	3,926
Equity	3,157	46,362	55	371	3,226
Panel E: Main variables					
Investment (percent growth in fixed assets)	-0.19	19.99	-19.85	-5.02	26.92
Sales (percent growth)	6.04	37.26	-18.98	2.32	30.66
Size (log of total assets)	7.42	1.35	5.93	7.20	9.18
Firm age (years)	17.05	12.87	5.00	14.00	31.00
Leverage	0.30	0.24	0.01	0.26	0.66
Liquidity	0.16	0.15	0.01	0.12	0.38
EBC (interest costs to EBITA)	0.38	0.74	0.01	0.16	0.88
ABC (Debt to Intangible Assets)	0.70	0.21	0.41	0.72	0.92
Proximity to consumer (percent)	20.47	20.51	0.41	14.24	46.05
Firms in the tradable sector (Dummy)	0.19	0.39	0.00	0.00	1.00

Notes: The table summarizes demographic characteristics, income statements, balance sheet variables, and main variables of interest for firms in our sample from 2000 to 2019. There are 159,187 firm-year observations. Values are in USD 1,000 in 2015.

Table 1: Descriptive statistics.

Institutional setting. The Norwegian corporate sector primarily funds investment using internal funding, bank debt, and equity issuance. A few very large, publicly listed companies issue non-bank external financing.[14] For bank debt, around 90% of debt and deposit contracts have adjustable rates where the interest rates are typically set as a premium over the money market rate. Hence, the pass-through from the central bank policy rate to relevant rates on outstanding debt and deposits is almost immediate, as illustrated in Figure 1.



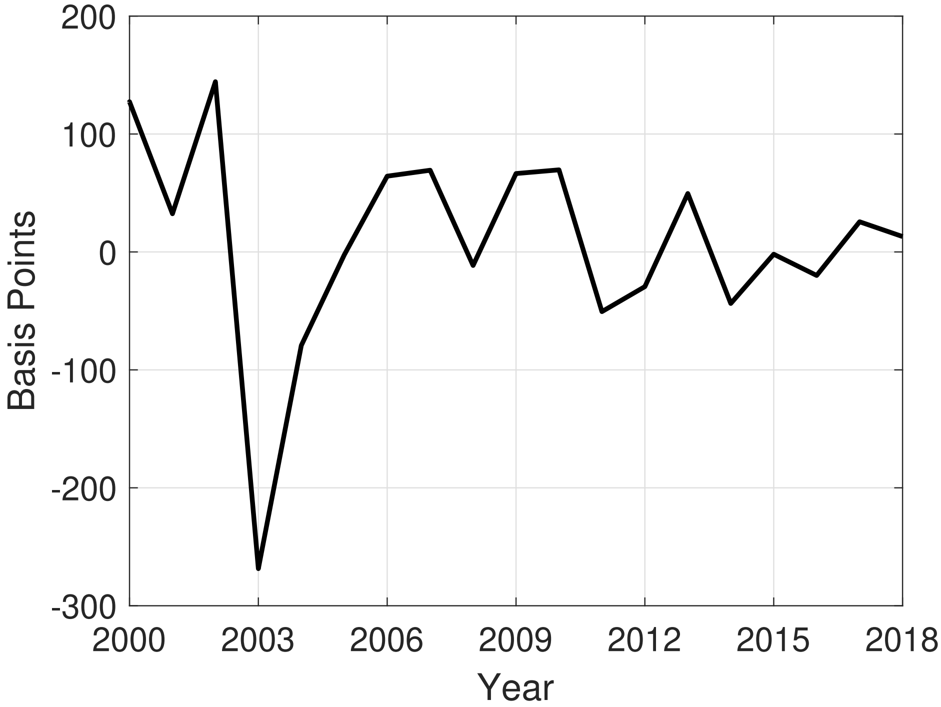
Notes: The figure displays the average interest rate on all outstanding debt and deposits of non-financial firms (tables 07200 and 07222 at Statistics Norway, respectively). The deposit interest rate series for non-financial firms discontinued in 2015. "Central Bank" refers to the policy rate of Norges Bank.

Figure 1: Interest rates on existing debt contracts among non-financial firms.

Monetary policy shocks. We use the Norwegian monetary policy shock series from Holm et al. (2021). The shocks are identified using the narrative approach pioneered by Romer and Romer (2004), using Norges Bank's forecasts. The original series ranges from 1994:M1-2018:M12 and is aggregated to the annual frequency by summing up the meeting-

[14] Around 300 Norwegian companies were publicly listed at the end of 2020.

by-meeting monetary policy shocks. In a robustness exercise, we also use high-frequency identified monetary policy shocks for Norway from Ellen, Larsen, and Thorsrud (2021).



Notes: The figure displays the annual monetary policy shocks from Holm et al. (2021).

Figure 2: Annual monetary policy shocks.

We plot the aggregate shocks in Figure 2. Notably, in the early 2000s, the Norwegian economy was hit by multiple large contractionary shocks, followed by a very large expansionary shock in 2003. External observers criticized the Norwegian monetary policy decisions in 2002 and 2003 as policy mistakes: rates being too contractionary in 2002 and too expansionary in 2003 (Bjørnland, Ekeli, Geraats, and Leitemo, 2004).[15]

In addition, we note that monetary policy in Norway was never constrained by the zero lower bound in our sample. Thus, we can study the effects of conventional monetary policy on firm-level investment without having to account for periods of constrained monetary policy, as seen in Figure 1.

In the following sections, we will regress the firm-level investment rate on annual monetary policy shocks. We argue that the resulting impulse responses are in shape and magnitude similar to the responses we would have gotten when using shocks and

[15]For a more detailed discussion on the identification procedure and the properties of these large shocks, we refer to Appendix A.4 in Holm et al. (2021).

investment rates at a higher frequency. Holm et al. (2021) use the same annual monetary policy shock series and demonstrate in their Appendix A.10 that time aggregation to annual frequency can produce responses that are identical to responses at quarterly or even monthly frequency.[16] This result relies on the responses of variables to monetary policy being quite persistent and the assumption that the underlying shocks occur with equal probability within a year. Since investment responses to monetary policy are persistent (see among others, Ottonello and Winberry, 2020; Holm et al., 2021) and shocks are relatively uniformly distributed within the years (see Appendix A.10 in Holm et al., 2021), these necessary properties are fulfilled.

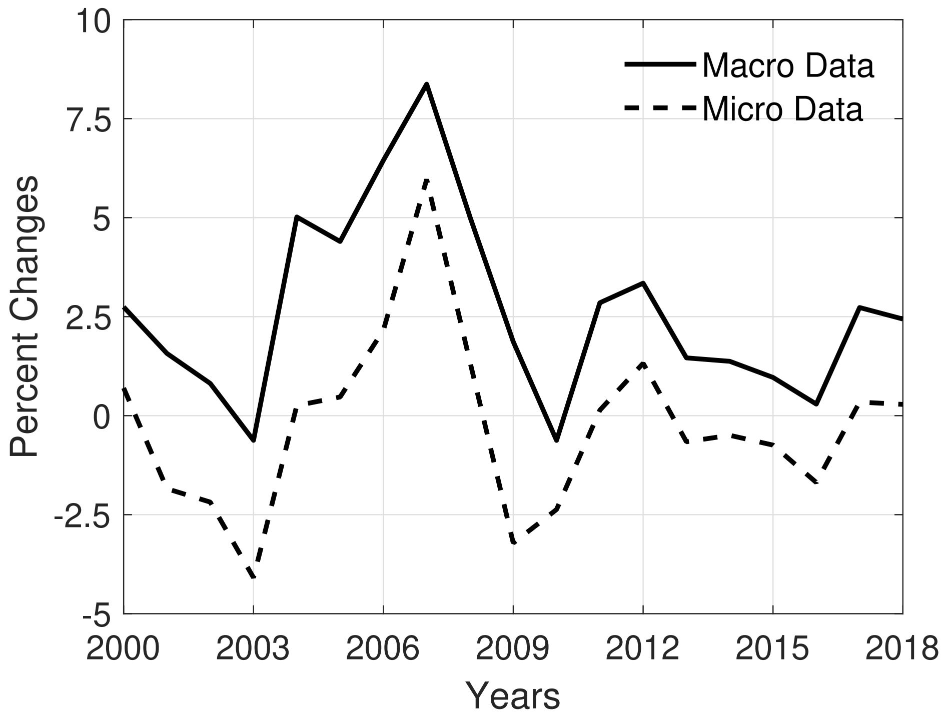
Aggregate data. We use fixed assets from the national accounts to compare the firm-level investment responses with the aggregate responses. We construct our aggregate measure of fixed assets by summing fixed assets in 13 sectors corresponding to the sample selection in the micro data.[17] Figure 3 shows the evolution of the aggregate investment rate in the national accounts with the average investment rate in the micro data. The investment rate in the macro data is less volatile but evolves in a manner similar to that of the investment rate in the micro data.

For the robustness checks in section A and section B, we use the following annual data series from Statistics Norway: Real GDP growth rate, CPI-ATE inflation rate,[18] the monetary policy rate, the NOK-USD exchange rate, and house prices.

[16] Holm et al. (2021) also compare macro-level Norwegian investment rate responses to the same monetary policy shock series at a monthly, quarterly, and annual frequency. They demonstrate that the attenuation of the investment responses is small and the shape and the magnitude of the responses are nearly identical across all three frequencies.

[17] The 13 sectors include agriculture, forestry and fishing (A), mining and quarrying (B), manufacturing (C), construction (F), wholesale and retail (G), transport (H), accommodation and food service (I), information and communication (J), professional, scientific and technical (M), administrative and support services (N), education (P), health and social work (Q), and arts, entertainment and recreation (R). We deflate the sum of fixed assets using the consumer price index, as we do in the micro data.

[18] CPI-ATE is the consumer price index adjusted for taxes and energy prices.



Notes: "Micro Data" shows the growth rate of aggregated fixed assets in the micro data. "Macro data" presents the growth rate of fixed assets in the national accounts, using the 13 sectors corresponding to the sample selection in the micro data.

Figure 3: Investment in aggregate and micro data.

4 Aggregate and average investment responses

This section presents our results on how monetary policy affects average investment. We first use local projections to estimate the investment response using aggregate data from the national accounts. Next, we estimate the average investment response in the micro data.

Empirical specification. Following Jordà (2005) and Jordà, Schularick, and Taylor (2015), we estimate impulse responses using the following local projection instrumental variable (LP-IV) equation at the annual frequency:

$$\frac{k_{t+h} - k_{t-1}}{k_{t-1}} = \alpha^h + \beta^h \cdot \Delta i_t + \gamma^h X_{t-1} + u_t^h, \tag{11}$$

where $h = 0, 1, ..., 5$ and k is fixed assets. We instrument the change in the nominal Norwegian monetary policy rate Δi_t with the monetary policy shocks ε_t^{MP}. The estimated coefficients β^h give the percentage change at horizon $t + h$ (relative to the period $t - 1$) in response to a 100 basis point increase in the monetary policy rate in period t. X_{t-1} denotes a vector of pre-determined controls which, for the aggregate specification, includes one lag of the change in the Norwegian monetary policy rate and one-year growth rates of the dependent variable. Standard errors are computed following Newey and West (1987).

The local projections we estimate in the micro data are adjusted versions of Equation (11). Let $k_{i,t}$ be fixed assets for firm i at time t. The local projections we estimate are

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \beta^h \cdot \Delta i_t + \gamma^h X_{i,t-1} + u_{i,t}^h, \tag{12}$$

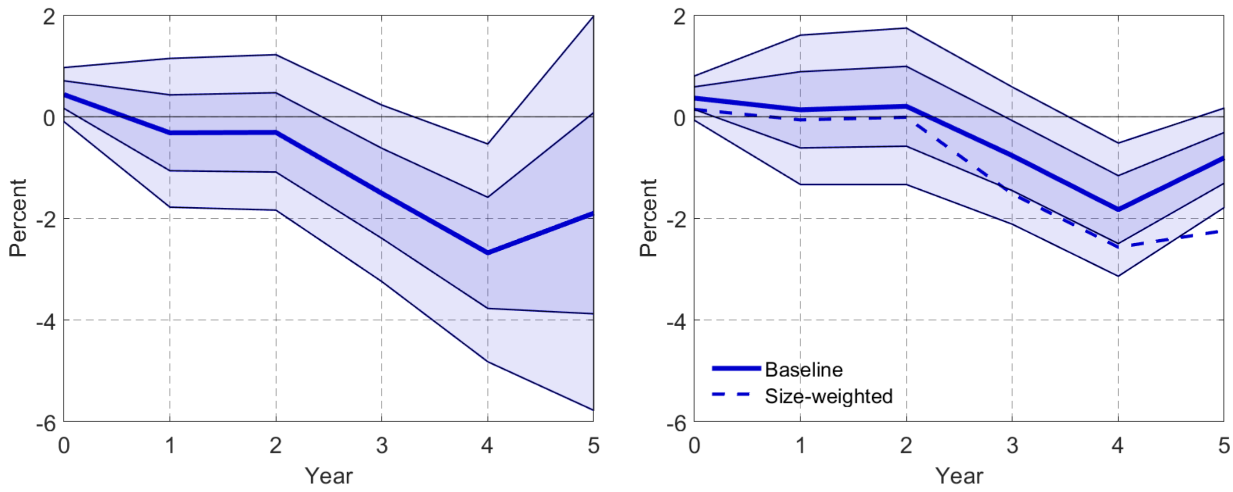
where $h = 0, 1, ..., 5$. The main difference from Equation (11) is that $X_{i,t-1}$ also includes individual firm variables (one lag of firm-specific investment rates, firm size, firm leverage, and firm liquidity),[19] and three macro controls (lagged GDP growth, CPI-ATE growth, and monetary policy change), and we include firm fixed effects α_i^h. To ensure a relatively conservative inference, we follow Driscoll and Kraay (1998) when computing the standard errors, which are robust to general correlations across firms and years. Our baseline version of the firm-level regression specification (12) does not include any weighting of observations. We also estimate a weighted version of (12), using a one-year lag of the firm size as regression weights.

Results. Figure 4 presents the results of estimating Equations (11) and (12) using national accounts and micro data, respectively. Our main finding is that the investment responses to monetary policy are relatively similar using macro and micro data. In both the macro and micro data, the investment response gradually strengthens to a peak response of approximately 2 percent.[20] The size-weighted firm-level regression suggests that larger firms reduce investment slightly more. In Section 5, we examine the role of firm size in greater detail and show that, while firm size has a negative marginal effect on the investment response to monetary policy, the effect is small and only barely statistically significant.

Table 2 reports the estimated coefficients from the instrumental variable local projection specified in Equation (12), including the F-statistics from the first-stage regressions. Based on the Kleibergen-Paap F-statistic, we can reject the null hypothesis that monetary policy shocks are weak instruments for Norwegian monetary policy changes.

[19] When we estimate the size-weighted local projections, we exclude firm size from the right-hand side of the regression equation.

[20] There are two reasons why the macro investment response we estimate differs from the one estimated in Holm et al. (2021). First, Holm et al. (2021) estimate the change in log gross capital formation, that is, the change in the log of investment. We cannot apply this specification at the firm level because firms often have no investment in a given year; therefore, we use changes in fixed assets as the investment variable. Second, we restrict attention to the 13 sectors specified in the sample selection, while Holm et al. (2021) consider all sectors.



(a) Macro Data **(b)** Micro Data

Notes: Impulse responses of fixed assets to a 100 basis point increase in the Norwegian monetary policy rate at annual frequency, based on the local projection approach in (11) and the instrumental variable local projection approach in (12). We instrument the change in the Norwegian monetary policy rate using narratively identified Norwegian monetary policy shocks. The dashed blue line represents a weighted regression version of specification (12), using a one-year lag of the firm size variable as regression weights. 95 and 68 percent confidence bands are shown, using Newey and West (1987) standard errors (macro data) and Driscoll and Kraay (1998) standard errors (micro data).

Figure 4: Aggregate and average investment responses to monetary policy.

Robustness. We delegate the robustness exercises for the average firm-level investment responses to Appendix A. Figure A.1b demonstrates that the magnitude of the investment responses on the firm level is identical to the baseline results when instead using high-frequency identified Norwegian monetary policy shocks from Ellen et al. (2021) as instruments for Norwegian monetary policy changes. We visualize the high-frequency Norwegian monetary policy shocks in Figure A.1a in the Appendix.

Figure A.2 contains five additional robustness exercises. Figure A.2a shows results when we control for several additional macroeconomic variables, such as the growth rate of house prices and changes in the nominal exchange rate to the US dollar. The magnitude and the shape of the micro-level responses are robust to including additional macroeconomic controls. One concern may be that Norwegian monetary policy is endogenous to foreign monetary policy, so our empirical estimates do not represent the responses to Norwegian monetary policy. Figures A.2b, A.2c, and A.2d show results when adding identified monetary policy shocks for the US, the UK, and the Euro-area as additional instrumental variables to the firm-level LP-IV regression. The average responses lie within our main specification's 68% confidence bands in all three cases. For the capital impulse responses shown in Figure A.2e, we exclude the large negative realization in the monetary

	Non-size-weighted regression (baseline)					
	$\frac{k_{i,t}-k_{i,t-1}}{k_{i,t-1}}$	$\frac{k_{i,t+1}-k_{i,t-1}}{k_{i,t-1}}$	$\frac{k_{i,t+2}-k_{i,t-1}}{k_{i,t-1}}$	$\frac{k_{i,t+3}-k_{i,t-1}}{k_{i,t-1}}$	$\frac{k_{i,t+4}-k_{i,t-1}}{k_{i,t-1}}$	$\frac{k_{i,t+5}-k_{i,t-1}}{k_{i,t-1}}$
Δi_t	0.366	0.136	0.205	-0.765	-1.827	-0.808
	(0.223)	(0.749)	(0.785)	(0.688)	(0.668)	(0.498)
R^2	0.04	0.07	0.12	0.15	0.19	0.23
F-statistic (Kleibergen-Paap)	13.55	13.97	14.41	12.96	13.95	13.31
Number of firms	18,514	14,379	10,881	8,416	6,303	4,863
Number of observations	102,451	78,814	58,301	43,700	32,572	24,527

	Size-weighted regression					
	$\frac{k_{i,t}-k_{i,t-1}}{k_{i,t-1}}$	$\frac{k_{i,t+1}-k_{i,t-1}}{k_{i,t-1}}$	$\frac{k_{i,t+2}-k_{i,t-1}}{k_{i,t-1}}$	$\frac{k_{i,t+3}-k_{i,t-1}}{k_{i,t-1}}$	$\frac{k_{i,t+4}-k_{i,t-1}}{k_{i,t-1}}$	$\frac{k_{i,t+5}-k_{i,t-1}}{k_{i,t-1}}$
Δi_t	0.144	-0.062	-0.010	-1.518	-2.566	-2.240
	(0.443)	(1.128)	(1.202)	(1.014)	(1.288)	(1.419)
R^2	0.03	0.05	0.07	0.08	0.09	0.11
F-statistic (Kleibergen-Paap)	11.05	11.53	12.25	12.11	12.32	10.63
Number of firms	17,638	13,750	10,385	7,851	5,979	4,591
Number of observations	95,761	73,793	54,406	40,415	30,195	22,620

Notes: This table summarizes the impulse responses of fixed assets to a 100 basis point increase in the Norwegian monetary policy rate, estimated using Equation (12). The top panel reports the results using no weights; the bottom panel shows the results with one-year lags of the firm-size variable as weights. Reported standard errors are calculated using Driscoll and Kraay (1998) standard errors.

Table 2: Average firm-level investment responses to monetary policy

policy shock series from 2003. The resulting average firm-level responses again fall within the 68% confidence bands of our main specification.

In a final exercise, we evaluate the role of firm size in explaining why the unweighted average firm investment response to monetary policy is already quite close to the response estimated in macro data. Table A.1 in Appendix A illustrates the cyclicality of firm investment rates (correlation with business cycle movements) and their behavior around policy rate changes for the largest 10% of firms in our sample. The largest 10% of firms (excluding the top 0.5%) exhibit a small, insignificant cyclical pattern around real economic expansions. The marginal effects range from 0.4 to 0.7 percentage points. In contrast, the very largest firms (top 0.5%) exhibit pronounced countercyclical behavior, with an investment rate 6.6 percentage points below that of the average firm. This result is consistent with existing studies highlighting countercyclical investment behavior among very large firms, thereby dampening the aggregate sensitivity of investment rates to business cycle fluctuations (Gertler and Gilchrist, 1994; Crouzet and Mehrotra, 2020). However, the role of firm size in shaping the response to monetary policy shocks appears more ambiguous. The coefficients for firms in the highest firm-size percentile (the top 0.5%) and the largest 1% of firms (excluding the top 0.5%) are similar in magnitude but have different signs. Moreover, neither of the estimated marginal effects of firm-size bins on investment rates around monetary policy changes is statistically significant. Overall, our results corroborate Crouzet and Mehrotra (2020): firm size does not explain differences in the response of fixed capital to monetary policy shocks. Yet firm size appears relevant to the cyclical behavior of investment rates.

In the next section, we analyze the role of firm size and other dimensions of firm heterogeneity in more detail.

5 Heterogeneous investment responses

There is substantial heterogeneity among firms. Several papers document how different observable variables are associated with the investment response to monetary policy. Recently, Ottonello and Winberry (2020) and Cloyne et al. (2023) argue that financial constraints, measured by distance-to-default or being young non-dividend paying firms, are an important dimension in explaining variation in investment responses to monetary policy. Similarly, Jeenas (2023) and Greenwald, Krainer, and Paul (2023) argue that liquidity (liquid assets relative to total assets) is important. In contrast, Ippolito et al. (2018) and Gürkaynak, Karasoy-Can, and Lee (2022) argue that the cash flow effect (or "floating rate channel") of monetary policy is important. The studies discussed above use Compustat data from the US, which consists of a relatively small sample of incorporated firms. In this section, we revisit these results using administrative data from Norway and extend the analysis to examine heterogeneity in marginal profitability exposure to monetary policy.

Empirical specification. Our empirical specification is inspired by the current literature investigating the heterogeneous effects of monetary policy. The idea is to interact the change in monetary policy with variables to estimate the *marginal association* of, for example, liquidity with the investment response to monetary policy. We instrument the change in Norwegian monetary policy with the estimated monetary policy shocks. Specifically, let $z_{i,t-1}$ be a firm characteristic deemed relevant in the past literature. The instrumental variable local projections we estimate are

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \nu_{s,t}^h + \beta_z^h \cdot \Delta i_t \cdot z_{i,t-1} + \gamma_z^h z_{i,t-1} + \gamma^h X_{i,t-1} + u_{i,t}^h, \tag{13}$$

where $h = 0, 1, ..., 5$. Specification (13) is similar to (12) except that we include the interactions of monetary policy shocks with variable (or vector) $z_{i,t-1}$ to instrument for the interaction of monetary policy changes Δi_t with $z_{i,t-1}$. The regression also includes the interaction variables $z_{i,t-1}$ along with firm fixed effects α_i^h, sector-year fixed effects $\nu_{s,t}^h$, and the same vector of controls as in (12). We standardize all interaction variables $z_{i,t-1}$ to facilitate comparisons.[21]

We focus on six measures of firm heterogeneity, motivated by the existing literature: size (log of total assets, Gertler and Gilchrist, 1994), age (Cloyne et al., 2023; Gnewuch and Zhang, 2025),[22] a proxy for exposure to earnings-based constraints (interest costs over earnings, Lian and Ma, 2021), a proxy for exposure to asset-based constraints (debt to tangible assets), leverage (long-term debt/total assets, Jungherr and Schott (2021)), and liquidity (liquid assets/total assets, Jeenas, 2023).

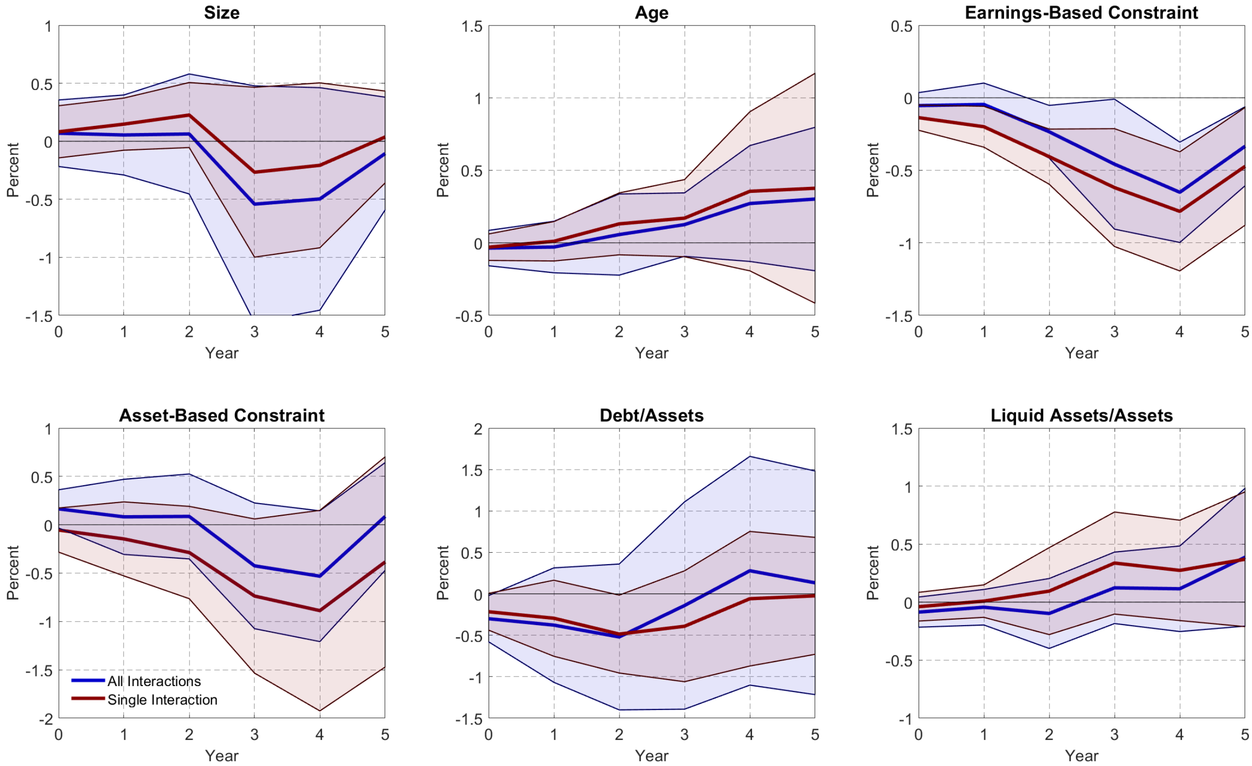
In addition, and motivated by the conceptual framework in Section 2, we study heterogeneity in *exposure to changes in marginal profitability*. Our core approach is to investigate whether firms that are more sensitive to changes in final demand respond differently. To do so, we use sector-level proxies for operating in the tradable versus non-tradable sector and a continuous measure of proximity to consumers. We return to these demand-exposure measures below. Because Equation (13) includes sector-year fixed effects, these sectoral exposures to changes in marginal profitability are not included in the first part of the heterogeneity analysis because they are absorbed in the fixed effects.

Role of borrowing constraints. Figure 5 summarizes our first main results on the role of borrowing constraint heterogeneity. For each variable, we show two lines describing the marginal effects: when controlling for the single interaction in Equation (13) and when including all six balance-sheet interactions simultaneously.

The three variables measuring different dimensions of firm indebtedness are associated with a stronger contraction in investment in response to contractionary monetary policy. Firms with either a high debt ratio, more debt relative to tangible assets (the proxy for the asset-based constraint), or higher interest costs to earnings (the proxy for the earnings-based constraint) respond *more* to monetary policy. However, because neither the debt ratio nor the debt-to-tangible-assets ratio is significantly associated with the investment

[21] See Panel E in Table 1 for the relevant values used for standardization. Two possible methods exist for standardizing z, either using cross-sectional means and standard deviations or the same moments within a firm. In the results we present below, we standardize along the cross-section. In Appendix B.4, we show that the results are similar when standardizing within firms.

[22] Gnewuch and Zhang (2025) highlight the role of firm age for the transmission of monetary policy on the distribution of firm investment rates. In contrast to the majority of papers in the literature, Gnewuch and Zhang (2025) study the effects of monetary policy on the extensive margin of firm investment.



Notes: The figure shows estimated interaction coefficients with a 100 basis points contractionary monetary policy at annual frequency, based on the local projection approach in (13) and its extensions that add proxies for exposure to demand (tradable vs. non-tradable status and proximity to consumers). We instrument the change in the Norwegian monetary policy rate using narratively identified Norwegian monetary policy shocks. 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

Figure 5: Marginal effects on the investment response to monetary policy.

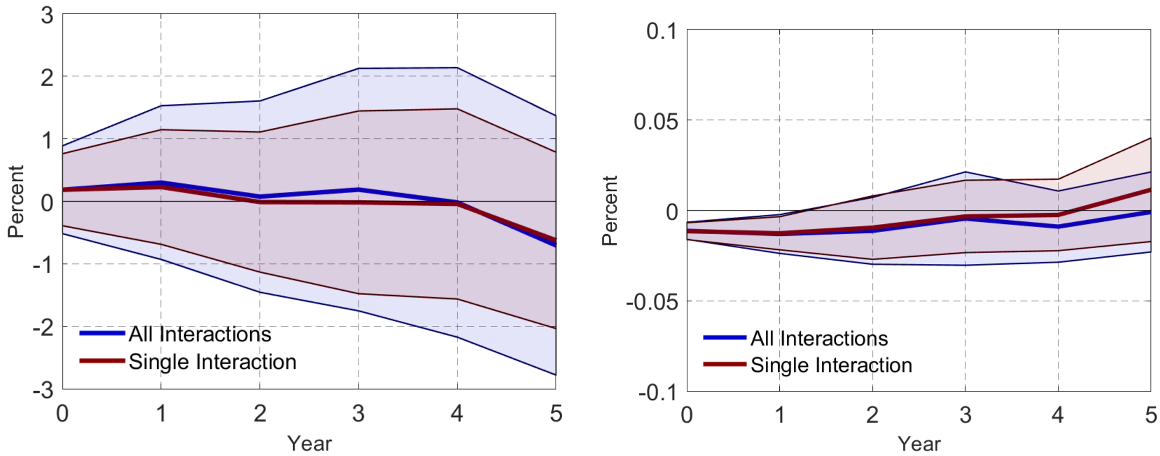
response to monetary policy in most of our robustness exercises (e.g., using market-based monetary policy shocks), we focus on the only proxy that is robustly associated with the investment response to monetary policy: the interest cost-to-earnings ratio. A one standard deviation increase in interest costs to earnings (0.74 percentage points) is associated with a -0.65 percentage point reduction in the investment response in year four.

The estimated marginal effects are relatively similar, irrespective of whether one controls for all interactions jointly or only one at a time. An implication is that including only single interactions when estimating marginal effects, as is common in prior research, yields potentially relevant estimates of the association.

Exposure to changes in marginal profitability. We next investigate whether heterogeneity in exposure to changes in profitability is associated with differences in the investment response to monetary policy. If, for instance, monetary policy reduces demand and thereby the marginal profitability of capital, firms that are more directly exposed to final demand should exhibit stronger responses.

We follow a two-step procedure. First, we classify firms as operating in the tradable sector or not, defined as the top 20% of the distribution of export shares. Second, we adopt a continuous measure of (direct) exposure to household demand. We use the flow of goods between sectors to define a sector-specific distance measure, defined as the share of sales going to consumers. Specifically, suppose the revenue of a sector s from sales to households is m_s^h and the total revenue of the sector is M_s, we define household proximity $\tilde{m}_i^h$ for a firm i as

$$\tilde{m}_i^h \equiv \frac{m_{s(i)}^h}{M_{s(i)}}. \tag{14}$$



(a) Firms operating in the tradable sector **(b)** Proximity to consumers

Notes: The left panel reports the estimated interaction coefficient for the tradable-sector dummy in response to a 100 basis point contractionary monetary policy shock at the annual frequency, based on the local projection specification in (15). The right panel reports the corresponding interaction coefficient for the continuous proximity-to-consumers measure. Changes in the Norwegian policy rate are instrumented using narratively identified Norwegian monetary policy shocks. Shaded areas denote 95 percent confidence bands, using Driscoll and Kraay (1998) standard errors.

Figure 6: The role of the tradable sector and the proximity to consumers.

We then estimate local projections with an interaction between monetary policy and these two exposure measures,

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \nu_t^h + \beta_z^h \cdot \Delta i_t \cdot \tilde{m}_{i,t-1}^h + \gamma_z^h \tilde{m}_{i,t-1}^{hh} + \gamma^h X_{i,t-1} + u_{i,t}^h, \tag{15}$$

with ν_t^h denoting year fixed effects,[23] and we include all the interactions with borrowing constraints as part of Equation (15)

Figure 6 collects the marginal effects for these exposure-to-demand measures. In neither setup do we find any evidence suggesting that exposure to demand plays an important role in explaining the investment response to monetary policy: the interaction coefficients are small and statistically insignificant at most horizons. Hence, heterogeneity in exposure to demand conditions does not seem to generate sizeable additional dispersion in investment responses to monetary policy.

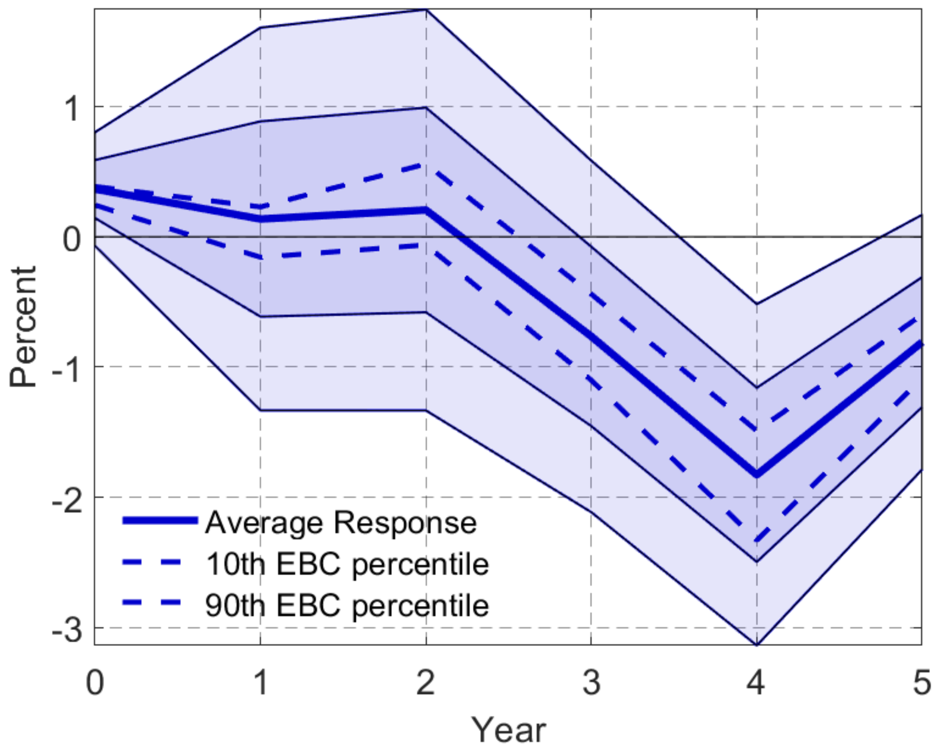
Quantitative relevance of the role of borrowing constraints. A remaining question is: while Figure 5 shows that our proxy for the earnings-based constraint is associated with the firm investment response to monetary policy, it is unclear how economically relevant this effect is.

As a final exercise, we therefore compare the average investment response with the implied responses for firms in the 10th percentile and the 90th percentile of the distribution of interest costs to earnings using the estimated marginal effects from Figure 5. The marginal effects we document in Figure 5 are almost always within the standard errors of the estimated average response. Hence, although the association between interest costs to earnings and the investment response to monetary policy is statistically significant, we cannot confidently argue that interest costs to earnings play a quantitatively important role in explaining aggregate investment responses.

Robustness. We discuss several robustness exercises for the marginal effects in Appendix B. First, our baseline results on the role of different firm heterogeneity measures do not qualitatively change when using high-frequency identified Norwegian monetary policy shocks as instruments for changes in the Norwegian monetary policy rate. We use the monetary policy shock series from Ellen et al. (2021) and specify a two-stage IV regression. Figure B.1 demonstrates that only the proxy for the earnings-based constraint is robustly associated with the investment response to monetary policy across the type of shocks. Quantitatively, the coefficients of the interaction terms with the high-frequency monetary policy shocks are similar to the interaction coefficients using the narrative shocks in the paper.

Second, we provide an additional exercise where we control for a dummy of young non-dividend-paying firms as suggested by Cloyne et al. (2023). We visualize in Figure

[23] Note that we cannot control for sector-time fixed effects as in Equation (13) because we now explicitly want to consider the interaction between monetary policy and sectoral exposure.



Notes: The figure shows estimated coefficients under a 100 basis points contractionary monetary policy at annual frequency, based on the local projection approach in (12), together with the implied investment responses for firms in the 10th and 90th percentile of the distribution of interest costs to earnings and the mean interest costs to earnings from (13). We instrument the change in the Norwegian monetary policy rate using narratively identified Norwegian monetary policy shocks. 68 and 95 percent confidence are bands shown, using Driscoll and Kraay (1998) standard errors.

Figure 7: Investment responses to monetary policy. The quantitative relevance of interest costs to earnings.

B.3 that the estimated interaction coefficients are robust to the inclusion of this extra interaction term.

Third, to rule out that differences in business-cycle cyclicality drive our interaction coefficients, we interact the six firm measures with macroeconomic aggregates and include the resulting interaction terms as additional control variables. We find no evidence that differences in business cycle cyclicality matter for the estimated marginal effects (see Figure B.2).

Fourth, the estimated interaction coefficients are similar to those obtained when standardizing the interaction terms within firms rather than across the cross-section. We visualize this finding in Figure B.4. Again, we find that firms with one standard deviation higher interest costs relative to earnings than the average firm in the corresponding sector are more sensitive to monetary policy. The marginal effects of earnings-based constraints standardized within the sector are indistinguishable from the cross-sectional marginal effects.

Fifth, instead of using six prominent measures of firm heterogeneity from the existing literature, we estimate a firm-level factor for financial constraints and interact it with monetary policy shocks. The estimated factor for firm financial constraints allows us to account for a non-linear combination of several potentially binding financial constraints at once.[24] The results on the estimated coefficient for the interaction between the factor and monetary policy shocks in Figure B.5 confirm that financial constraints significantly influence the transmission of monetary policy on firm investment. However, their quantitative effects are similar to those of earnings-based constraints and thus remain small and limited.

Sixth, Figure B.6 shows that both interest coverage covenants and covenants based on the debt-to-earnings ratio influence firms' marginal investment responses to monetary policy. When using the debt-to-earnings ratio as a proxy for earnings-based constraints, the interaction with monetary policy remains statistically significant and quantitatively similar to the results obtained using the interest-payment-to-earnings ratio. Hence, regardless of how we proxy for earnings-based financial constraints—whether by debt-to-earnings or by interest payments-to-earnings—these constraints similarly correlated with how firms adjust their investment in response to changes in interest rates.

6 Relationship with structural models

The main result of this paper is that heterogeneity in investment responses to monetary policy exists but is relatively limited. This section explores the extent to which these results are quantitatively consistent with our models of firm investment. Because of the limited role of heterogeneity in the investment channel of monetary policy, we restrict attention to a version of the model in Section 2 in which there is no firm heterogeneity and no borrowing constraints. The model nevertheless retains two monetary transmission channels: discount rates and future marginal profitability.

The model. The firm maximizes revenue net of investment and adjustment costs, subject to the law of motion of capital.

$$\max_{\{I_t, K_{t+1}\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \left(\prod_{s=0}^{t} \frac{1}{1+r_s} \right) (\Theta(r_t) K_t^{\alpha} - I_t - \mathrm{AC}(I_t, K_t))$$

[24] E.g., firms with high levels of long-term debt, low earnings, and low levels of liquidity.

subject to

$$K_{t+1} = (1-\delta)K_t + I_t \tag{16}$$

where I is investment, K is capital, δ is the depreciation rate, and α is the capital share of output. We include the marginal profitability channel in a reduced-form manner via the function $\Theta(r)$, defined as

$$\Theta(r_t) = \Theta - \nu(r_t - r)\Theta \tag{17}$$

where ν is a parameter describing the sensitivity of marginal profitability to the interest rate, and Θ is the steady state value. This functional form is necessarily a simplification and serves only to illustrate the potential role of the marginal profitability channel in monetary transmission to investment.

The adjustment cost function is the same as in Section 2, $AC(I,K) = \frac{\varphi}{2}\left(\frac{I}{K} - \delta\right)K$. The first-order conditions of the problem are

$$\frac{I_t}{K_t} = \delta + \frac{1}{\phi}\Big(q_t - 1\Big), \tag{18}$$

$$q_t = \frac{1}{1+r_t}\left((1-\delta)q_{t+1} + \alpha\Theta(r_{t+1})K_{t+1}^{\alpha-1} + \varphi\left(\frac{I_{t+1}}{K_{t+1}} - \delta\right)\frac{I_{t+1}}{K_{t+1}}\right) \tag{19}$$

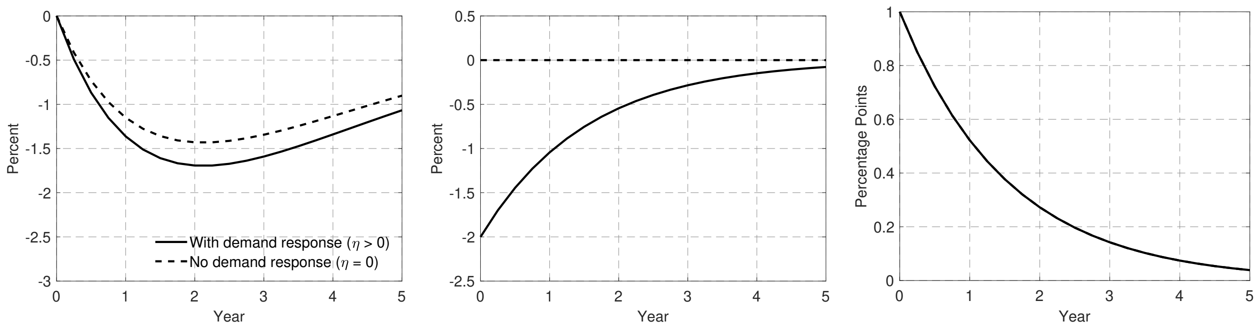
where q is the shadow cost on Equation (16). We further assume that the interest rate evolves according to

$$r_t = r + \rho_r(r_{t-1} - r) + \varepsilon_t^r,$$

where ρ_r determines persistence, and ε^r is an interest rate shock.

Calibration. Our calibration follows Auclert et al. (2020), adjusted to quarterly frequencies. We use the following values: $r = 0.04$ (annual), $K = 9.7$ (determines Θ), $\delta = 0.052$ (annual), $\alpha = 0.24$, and $\rho_r = 0.85$ (quarterly). We adjust φ to ensure that the investment response's shape and size are similar to the empirical results ($\varphi = 2.5$). We vary ν to illustrate the importance of the marginal profitability channel in the simulation.

Simulation results. Figure 8 shows the capital (percent change in capital) and profitability responses to a one percentage point interest rate shock. We highlight two main points. First, our relatively standard model with adjustment costs can match the empirical evidence on the capital response to interest rate changes well. The model's capital response is hump-shaped, with a maximum at approximately 2%, consistent with the empirical results.



(a) Capital K response **(b)** Profitability Θ response **(c)** Interest rate shock

Notes: The figures show the capital K, profitability Θ, and interest rate responses to a one percentage point interest rate increase using the structural model from Section 6.

Figure 8: Impulse responses to an interest rate shock.

Second, when we also include the marginal profitability channel, the capital response is amplified. However, even when this marginal-profitability channel is quite large, calibrated to match the output response to a one-percentage-point contractionary monetary policy shock in Holm et al. (2021) at about 2% ($\nu = 2$), the effect on the capital response is limited. The maximal capital response increases by about 18%, implying that less than 1/5 of the capital response is explained by the marginal profitability channel in this model. Instead, almost all of the investment channel of monetary policy comes from firms responding directly to changes in the policy rate, the discounting channel, consistent with our empirical results.[25]

We conclude that a representative-firm model with adjustment frictions captures the investment channel of monetary policy remarkably well despite its simplicity.

7 Conclusion

This paper explores the investment channel of monetary policy using administrative data for Norway. Our main results are that (i) heterogeneity in investment responses to monetary policy exists, but (ii) the quantitative magnitude of these effects is limited.

[25]Our finding that a representative firm model with adjustment costs performs well in explaining micro-level firm investment is in line with Eberly, Rebelo, and Vincent (2012). Eberly et al. (2012) find no significant role for financial constraints, Tobin's Q, or interest costs in their empirical study and demonstrate that a Christiano, Eichenbaum, and Evans (2005) style model with capital adjustment costs explains well the investment behavior of large US companies.

These results are consistent with a representative firm model with investment adjustment frictions for two reasons. First, the representative firm model matches the aggregate investment response to monetary policy, a well-known fact from the literature. But second, and more importantly, the representative firm model also describes *the transmission channels* from monetary policy to investment remarkably well. Hence, the representative firm model with investment adjustment frictions is not only simple but also fruitful in the spirit of Friedman (1953) – it explains much by little – but it also depicts how the investment channel of monetary policy seems to operate.

The results suggest that financial constraints play a minor role in aggregate investment dynamics. While the empirical results in Section 5 show that proxies for financial constraints are correlated with the investment response to monetary policy, the effects of this heterogeneity in financial constraints are relatively small compared to the variation in the average investment response. Nevertheless, financial constraints may obviously play a more critical role in other questions than monetary transmission, such as firm dynamism and misallocation.

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Online Appendix to
“The Investment Channel of Monetary Policy: Evidence from Norway”

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Ragnar Juelsrud   Tobias König   Mikkel Riiser

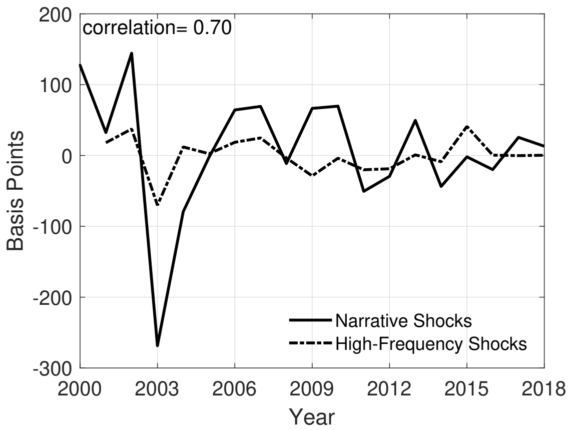
Contents

A Appendix to Section 4

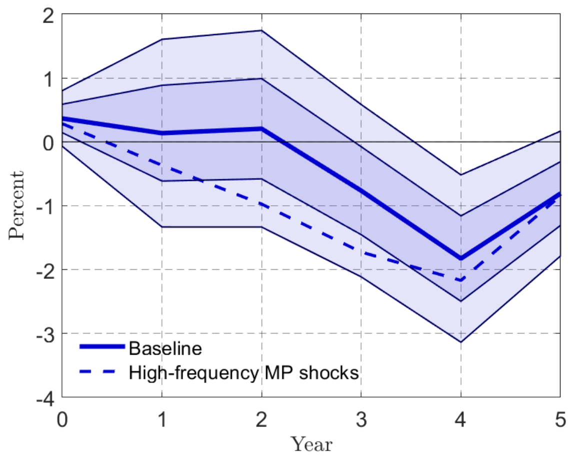
We show in Section 4 that the investment response of the average Norwegian firm to contractionary monetary policy is hump-shaped with a significant peak-to-trough response of around −2%. In this section, we evaluate the robustness of this finding. First, we show that our results are robust to the use of market-based monetary policy shocks as instruments for changes in the Norwegian monetary policy rate. Second, we show that the size and shape of the average investment response do not change when additional macroeconomic controls are included. Third, we demonstrate that the estimated Norwegian monetary shock series used as instruments in the main body of our paper is orthogonal to monetary policy in the US, the UK, and the Euro area. Fourth, we show that excluding the 2003 episode from the shock sample does not affect the main result.

A.1 Using high frequency identified monetary policy shocks

In the main body of the paper, we use narratively identified Norwegian monetary policy shocks from Holm et al. (2021) as instruments for monetary policy. In this section, we test the robustness of our baseline average investment responses by using, as instruments, high-frequency monetary policy shocks for Norway from Ellen et al. (2021). High-frequency monetary policy shocks are available monthly from 2001M1-2019M9. As with the narratively identified monetary policy shocks, we annualize the high-frequency shocks by summing the meeting-by-meeting shocks for each year.



(a) Comparison of shocks



(b) Average investment responses

Notes: Figure A.1b displays impulse responses to a 100 basis points contractionary monetary policy shock at annual frequency, based on the local projection approach in (**??**) using high-frequency identified Norwegian monetary policy shocks from Ellen et al. (2021) (dashed line). As a reference, we add the results from the main body of the paper using narratively identified monetary policy shocks (solid line). We instrument the change in the Norwegian monetary policy rate using either the high-frequency monetary policy shocks or the narratively identified Norwegian monetary policy shocks. 95 percent and 68% confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

Figure A.1: Comparison of Norwegian narrative and high-frequency monetary policy shocks

In Figure A.1a, we display the Norwegian narrative and high-frequency shocks. The two shock series are correlated (0.70) in our sample. For example, the shock series agrees on the 2002-2003 episode as important. However, the magnitude of the high-frequency shocks is smaller than the narrative shocks.

In the following, we compare the average firm-level investment responses to both monetary shock series. We estimate Equation (12) using high-frequency shocks as instruments for interest rate changes and compare the results with the same specification using narrative shocks as instruments. Figure A.1b displays both responses. The magnitude and shape of the investment responses to high-frequency identified Norwegian monetary policy shocks are similar to those reported in the baseline response shown in Figure 4.

A.2 Robustness to macroeconomic conditions

The average investment response of Norwegian firms to a contractionary monetary policy could be biased if the monetary policy series violates the lead-lag exogeneity (Stock and Watson, 2018). We can evaluate the exogeneity of the Norwegian monetary policy by including lagged macroeconomic variables in the first and second stage equations. We extend Equation (12) from the main text by including a set of common macroeconomic variables Y_{t-1}

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \beta^h \cdot \Delta i_t + \gamma^h X_{i,t-1} + \delta^h Y_{t-1} + u_{i,t}^h. \tag{A.1}$$

As before in specification (12), the vector $X_{i,t-1}$ includes the one-year lag of the following variables: firm-level investment rates, real GDP growth rate, CPI inflation rate, and the change in Norwegian monetary policy. Y_{t-1} includes the one-year lag of the following additional macroeconomic controls: (i) the growth rate of the NOK-USD exchange rate and (ii) the growth rates of house prices.

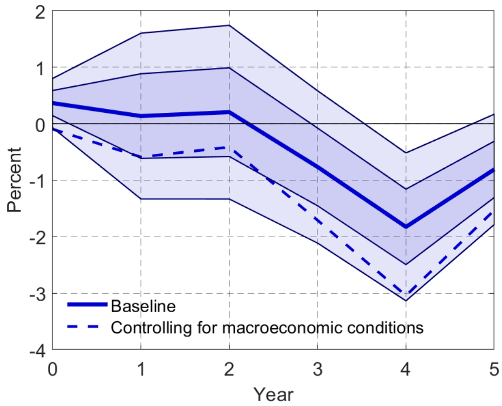
The rationales to include two additional macroeconomic controls are the following:

1. Since Norway is a small-open economy, we add lagged growth rates of the NOK-USD exchange rate to ensure that the monetary policy shocks are exogenous to Norges Bank's reaction to a devaluation/appreciation of the Norwegian currency.

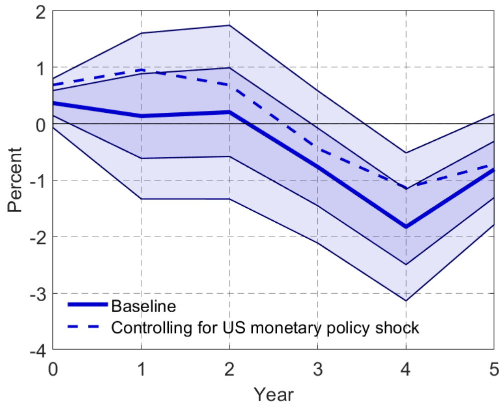
2. We add lagged growth rates of house prices to the regression because the development of housing prices is featured prominently in several Norges Bank monetary policy reports.[1]

Figure A.2a shows that controlling for these variables neither affects the magnitude of the response nor the hump-shaped pattern of the investment response to monetary policy.

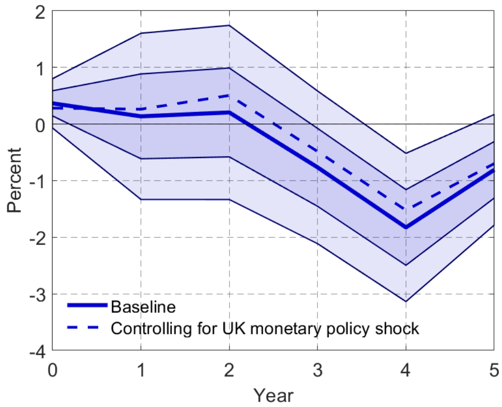
[1]See for example Norges Bank (2014).



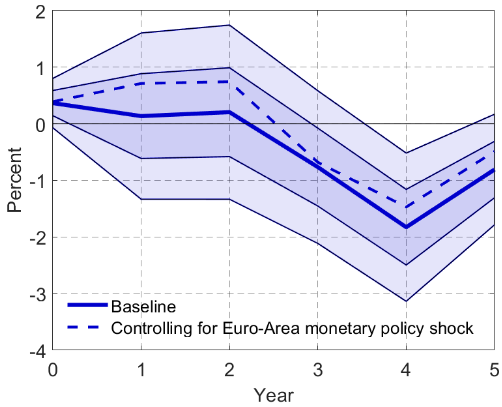
(a) Robustness: macroeconomic variables



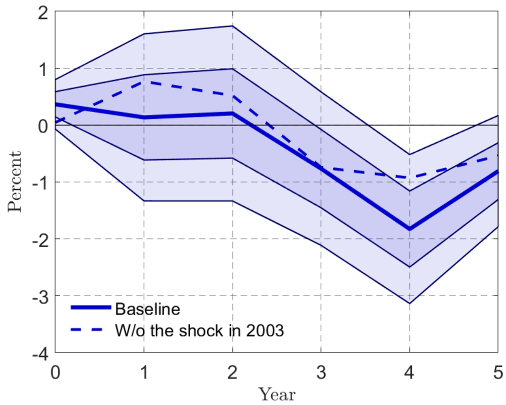
(b) Robustness: US monetary policy



(c) Robustness: UK monetary policy



(d) Robustness: Euro-area monetary policy



(e) Excluding the large negative shock realization in 2003.

Notes: Impulse responses to a 100 basis points contractionary monetary policy shock at annual frequency, based on the local projection approach in Equations (A.1) and (A.3). In panels (a) and (e), we instrument the change in the Norwegian monetary policy rate using the narratively identified Norwegian monetary policy shocks. In panels (b)-(d), we instrument the change in the Norwegian monetary policy rate using both the Norwegian monetary policy shocks and either one of the monetary policy shocks for the US, the UK, and the Euro-area that we take from Jarociński and Karadi (2020). 95 and 68 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

Figure A.2: Robustness of the average firm-level investment response.

A.3 Robustness to foreign monetary policy

We next test whether the identified Norwegian monetary policy shock series is exogenous to monetary policy shocks in other major currencies. Norway, as a small open economy, may be particularly affected by monetary policy decisions of its main trading partners: the Euro area, the UK, and the US. Thus, it is possible that Norwegian monetary policy shocks, identified in Holm et al. (2021) via the narrative approach, are confounded by foreign monetary policy shocks.

We control for these potential confounding factors by including foreign monetary policy shocks as additional instruments in the baseline regression. Hence, we modify the first-stage regression in the following way:

$$\Delta i_t = \alpha_i^{h,1} + \beta^{h,1} \cdot \varepsilon_t^{MP} + \omega^{h,1} \cdot \varepsilon_{t-1}^{MP} + \delta^{h,1} \zeta_t^{FMP} + \phi^{h,1} \Delta i_t^{FMP} + \gamma^{h,1} X_{i,t-1} + u_{i,t}^{h}, \tag{A.2}$$

with ζ_t^{FMP} including either one of the monetary policy shocks for the US, the UK, and the Euro-area that we take from Jarociński and Karadi (2020). We instrument changes in the Norwegian monetary policy rate using both Norwegian and foreign monetary policy shocks. We also include the contemporaneous change in foreign monetary policy, i_t^{FMP}, as an additional control variable in both the first and second stages. By controlling for the foreign monetary policy changes, we ensure that the instruments are orthogonal to systemic changes in foreign monetary policy.

The second stage equation is similar to the Equation (12) with the additional control for foreign interest rates:

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^{h,2} + \beta^{h,2} \cdot \widehat{\Delta i_t} + \phi^{h,2} \Delta i_t^{FMP} + \gamma^{h,2} X_{i,t-1} + u_{i,t}^{h,2}. \tag{A.3}$$

This time, $\widehat{\Delta i_t}$ denotes the predicted values of Norwegian monetary policy changes using both Norwegian and foreign monetary policy shocks as instruments. Hence, the local projections describe how firms respond to changes in the Norwegian interest rate resulting from domestic or foreign exogenous monetary shocks.

Figures A.2b, A.2c, and A.2d show that firm-level investment responses to Norwegian monetary policy, when instrumented with additional foreign monetary policy shocks, are similar to our baseline results.

A.4 Robustness to excluding the monetary policy shock in 2003

One concern is that our results may be driven by the unusually large expansionary monetary policy shock in 2003. To address this, we re-estimate our baseline specification excluding the 2003 value from the monetary policy shock series. Figure A.2e plots the resulting impulse responses. The shape, magnitude, and statistical significance of the investment response remain very similar to our baseline estimates. The 2003 monetary shock therefore does not seem to drive our findings.

	$\frac{\Delta k_{i,t+3}}{k_{i,t-1}}$	$\frac{\Delta k_{i,t+3}}{k_{i,t-1}}$
GDP growth	1.982*	
	(0.943)	
Firm size [90, 99)	8.195***	9.091***
	(0.505)	(1.009)
Firm size [99, 99.5)	14.78***	12.48*
	(1.667)	(5.042)
Firm size [99.5, 100]	28.71***	23.29**
	(4.389)	(9.017)
Firm size [90, 99) × GDP growth	0.721	
	(0.465)	
Firm size [99, 99.5) × GDP growth	0.426	
	(0.970)	
Firm size [99.5, 100] × GDP growth	-6.621***	
	(1.775)	
Policy rate change		-1.127
		(1.090)
Firm size [90, 99) × Policy rate change		-0.162
		(0.816)
Firm size [99, 99.5) × Policy rate change		-7.151
		(7.855)
Firm size [99.5, 100] × Policy rate change		10.10
		(8.354)
R^2	0.01	0.00
Number of firms	14,166	13,567
Number of firms in size bin [90, 99)	1,413	1,375
Number of firms in size bin [99, 99.5)	96	94
Number of firms in size bin [99.5, 100]	78	78
Number of observations	61,586	57,588

Notes: This table reports the regression coefficients of the following specification: $\frac{k_{i,t+3}-k_{i,t-1}}{k_{i,t-1}} = \alpha + \beta \cdot Y_t + \gamma \cdot size\_bins_{i,t-1} + \delta \cdot Y_t \cdot size\_bins_{i,t-1} + u_{i,t}$. We estimate two versions of the specification: (i) Y_t includes the growth rate of real GDP, and (ii) Y_t includes the change in the monetary policy rate. For the second version, we instrument the Norwegian monetary policy rate change using narratively identified Norwegian monetary policy shocks. The vector $size\_bins_{i,t-1}$ includes three indicator variables for firms being in either the top [90, 99), the top [99, 99.5), or the top [99.5, 100] percentiles. Reported standard errors are calculated using Driscoll and Kraay (1998) standard errors.

Table A.1: Cyclicality of Investment Rates

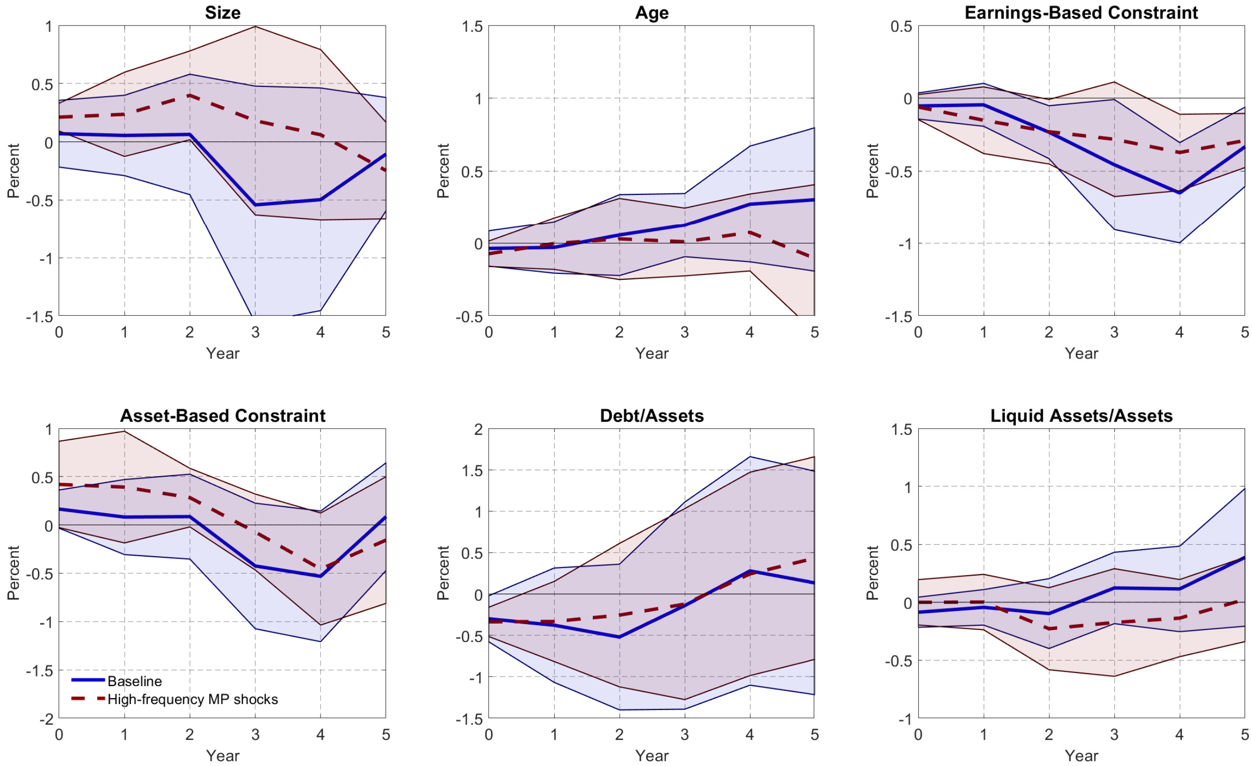
B Appendix to Section 5

In Section 5 in the paper, we demonstrate that only earning-based constraints matter empirically for explaining heterogeneity in the investment responses to monetary policy but their effects are quantitatively small. In this appendix, we explore the robustness of this finding to the use of high-frequency monetary identified policy shocks, controlling for macroeconomic conditions, controlling for young non-dividend-paying firms, standardizing the interaction variable within firms rather than across firms, using a factor to capture being financially constrained, and using an alternative proxy for the earnings-based constraint.

B.1 Using high-frequency identified monetary policy shocks

We first test the implications of using high-frequency identified Norwegian monetary policy shocks from Ellen et al. (2021) for the role of firm heterogeneity on firm investment responses. Our method is to estimate Equation (13) in the paper, but replacing the narrative monetary policy shocks with the high-frequency monetary policy shocks.

Figure B.1 compares the estimated interaction coefficients when we use our narrative shocks and the high-frequency shocks. The results are qualitatively similar: only the earnings-based constraint is robustly associated with monetary transmission.



Notes: The figure shows estimated interaction coefficients with a 100 basis points contractionary monetary policy shock at annual frequency, based on the local projection approach in (**??**). We instrument the change in the Norwegian monetary policy rate using (i) high-frequency identified Norwegian monetary policy shocks taken from Ellen et al. (2021) (dashed red lines) and (ii) narratively-identified monetary policy shocks (solid blue lines). 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

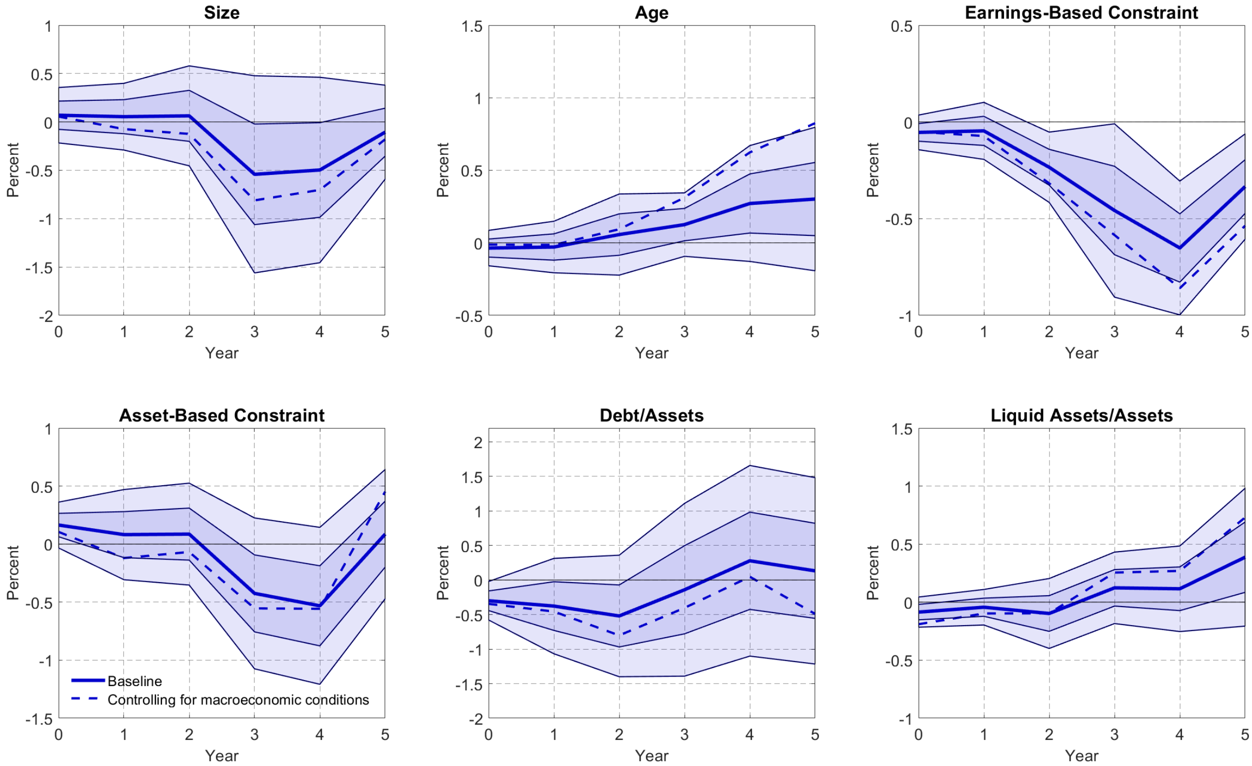
Figure B.1: Marginal effects on the investment response to high-frequency identified monetary policy.

B.2 Robustness to macroeconomic conditions

This section shows that the role of the six interaction terms discussed in Section 5 is unaffected by the business cycle. To evaluate the robustness of the results in Section 5 to macroeconomic conditions, we interact the six firm variables with a set of macroeconomic conditions. We modify the Equation (13) in the following way

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \nu_{s,t} + \beta_z^h \cdot \Delta i_t \cdot z_{i,t-1} + \delta_z^h \cdot Y_{t-1} \cdot z_{i,t-1} + \gamma_z^h z_{i,t-1} + \gamma^h X_{i,t-1} + u_{i,t}^h, \tag{B.1}$$

where the Y_{t-1} vector includes a one-year lag of the following variables: real GDP growth, CPI inflation rate, and the change in Norwegian monetary policy rate. The results in Figure B.2 imply that the role of the marginal effects that we find in Section 5 is not



Notes: The figure shows estimated interaction coefficients with a 100 basis points contractionary monetary policy shock at annual frequency. The dashed lines represent the marginal effects on the investment response based on the local projection approach in (B.1). The marginal effects depicted by the solid lines are based on the baseline local projection approach in (13). 95 percent and 68 percent confidence bands for the baseline local projections are shown, using Driscoll and Kraay (1998) standard errors.

Figure B.2: Marginal effects on the investment response to monetary policy, controlling for macroeconomic conditions.

affected by business cycle fluctuations.

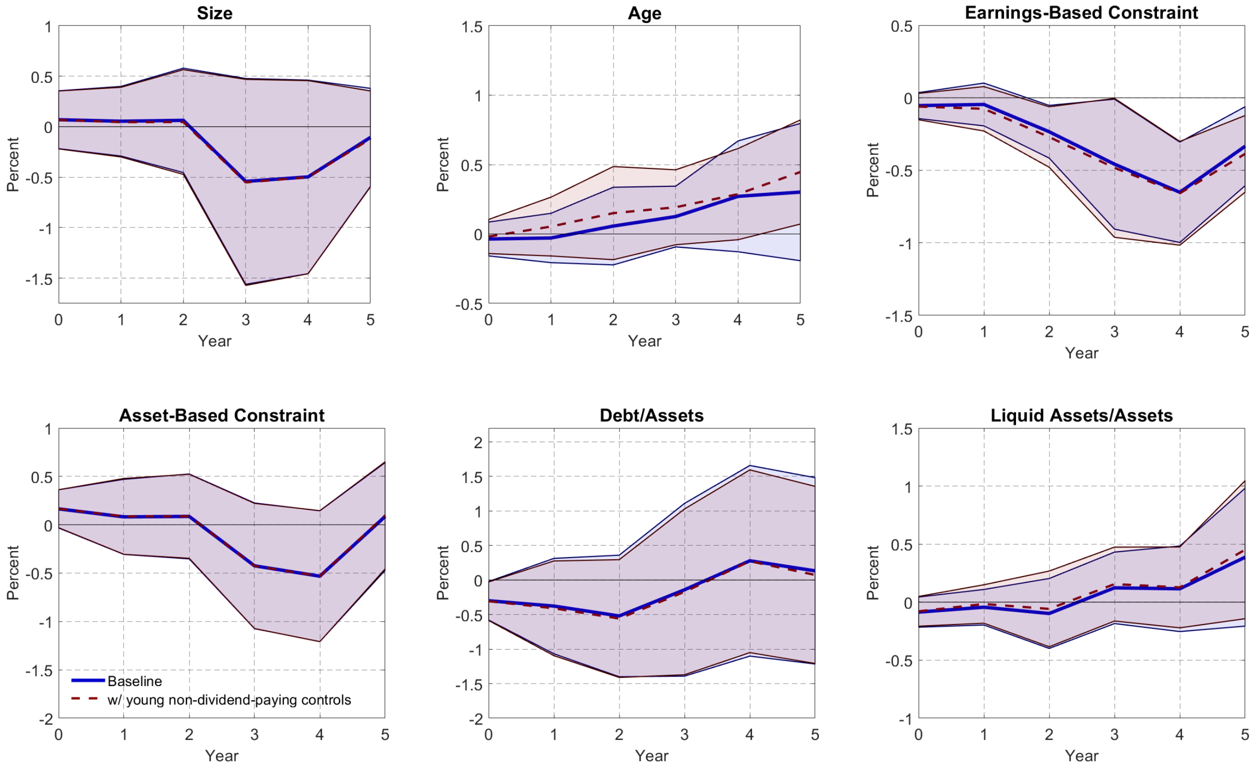
B.3 Controlling for young non-dividend-paying firms

Cloyne et al. (2023) provide evidence that the investment responses of young non-dividend-paying firms in the US are more sensitive to monetary policy. We control for this channel by adding a dummy for young non-dividend-paying firms into our baseline regression (13)

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \nu_{s,t}^h + \beta_z^h \cdot \Delta i_t \cdot z_{i,t-1} + \beta_d^h \cdot \Delta i_t \cdot \mathbb{1}_{i,t-1}^{Div} + \gamma_z^h z_{i,t-1} + \gamma_d^h \mathbb{1}_{i,t-1}^{Div} + \gamma^h X_{i,t-1} + u_{i,t}^h, \quad \text{(B.2)}$$

with $\mathbb{1}_{i,t-1}^{Div}$ being a dummy variable that is one for firms being young (firm age $\leq$ 15 years) and do not pay dividends.

We plot the marginal effects of all six interaction terms from Equation (B.2) in Figure B.3 and compare the responses with our baseline results from Section 5. The estimated coefficients are very similar, and the prominent role of earnings-based constraints on the transmission of monetary policy is robust to the inclusion of the dummy for young non-dividend-paying firms.



Notes: The figure shows estimated interaction coefficients with a 100 basis points contractionary monetary policy shock at annual frequency. The dashed red lines represent the marginal effects on the investment response based on the local projection approach in (B.2), controlling for young non-dividend-paying firms. The marginal effects depicted by the solid blue lines are based on the baseline local projection approach in (13). We instrument the change in the Norwegian monetary policy rate using narratively identified Norwegian monetary policy shocks. 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

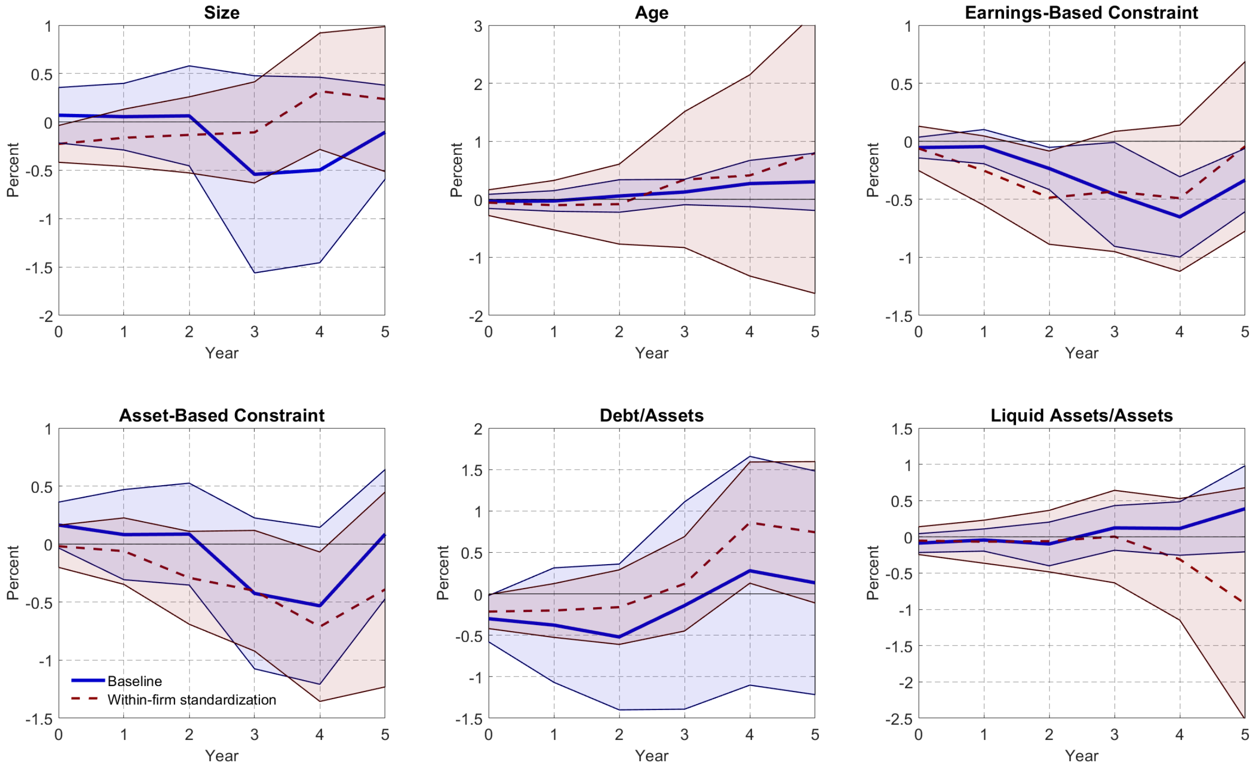
Figure B.3: Marginal effects on the investment response to monetary policy, controlling for young non-dividend-paying firms.

B.4 Standardizing the interaction terms within firms

In the paper, we standardize each interaction term variable, $z_{i,t-1}$, by its cross-sectional mean and standard deviation. In this section, we standardize $z_{i,t-1}$ using the within-firm variation, using the firm-specific mean and standard deviation. The regression specification is identical to that in Equation (13) of the paper.

Figure B.4 depicts the associations between variables and the investment responses to monetary policy using both standardization methods. There are only very minor differences between the two standardization approaches.

The similarity across these two approaches is informative. In particular, the similarity between the within-firm and within-time estimates indicates that when a firm's financial



Notes: The figure shows estimated interaction coefficients with a 100 basis points contractionary monetary policy shock at annual frequency, based on the local projection approach in Equation (13). The blue solid lines correspond to specifications in which the interaction term $z_{i,t-1}$ is standardized using the cross-sectional mean and standard deviation. In contrast, the red dashed lines use within-firm standardization of $z_{i,t-1}$. We instrument the change in the Norwegian monetary policy rate using narratively identified Norwegian monetary policy shocks. 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

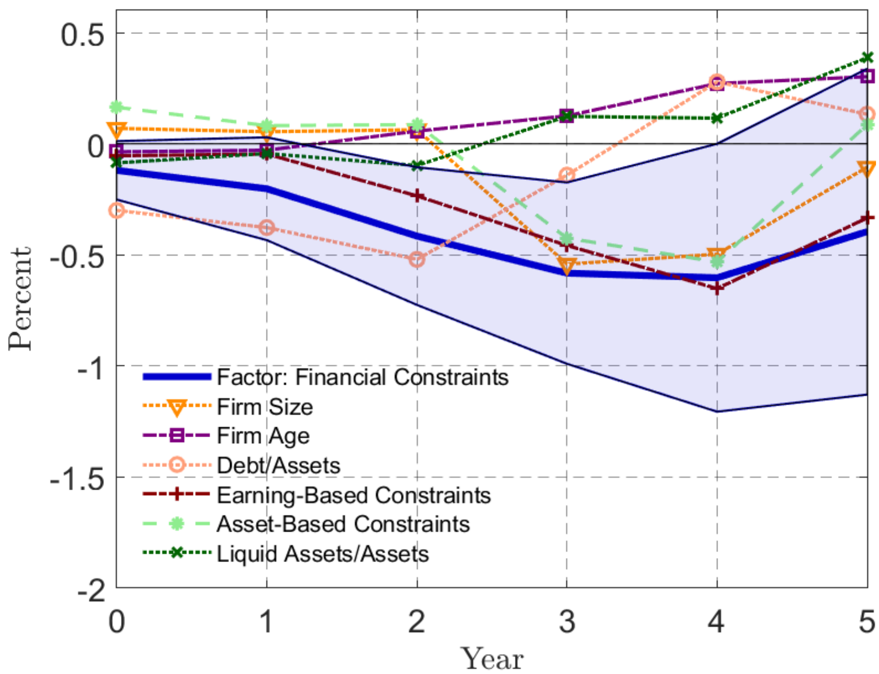
Figure B.4: Marginal effects on the investment response to monetary policy, within-firm standardized interaction terms.

characteristics deviate from its own historical average (for instance, when it becomes more leveraged or cash-constrained than usual), its investment response to monetary shocks changes by roughly the same magnitude as when a firm's characteristics differ from the cross-sectional average at a point in time (when it is more constrained than the average firm).

This suggests the financial amplification mechanism is a stable, structural feature of how monetary policy transmits to investment decisions, rather than being driven by persistent cross-sectional heterogeneity (some firms always being more sensitive) or by time-varying aggregate factors that would make the transmission mechanism differ between comparing firms at a point in time versus tracking individual firms over time. In other words, the financial constraints that affect monetary transmission operate consistently whether firms move in and out of constrained states over time or whether we compare more versus less constrained firms in the cross-section—pointing to a robust causal channel linking financial position to monetary policy sensitivity.

B.5 Interaction effect with a factor for financial constraints

Rather than testing multiple observable proxies for financial constraints, an alternative approach is to estimate a firm-level factor representing the degree of financial constraints. The advantage of the factor method is that it allows us to measure "being constrained" more flexibly. The disadvantage is that it is difficult to interpret what being constrained in this context means, as it is a combination of several observable characteristics.



Notes: The figure shows the estimated coefficients for the interaction of the financial constraint factor with a 100 basis points contractionary monetary policy shock at annual frequency (solid blue line), estimated using Equation (B.3). The dashed and dotted lines depict the estimated interaction coefficients from Figure 5 in Section 5 and are based on the local projection approach in (13). We instrument the change in the Norwegian monetary policy rate using narratively identified Norwegian monetary policy shocks. 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

Figure B.5: Marginal effects on the investment response to monetary policy, interaction between financial constraint factor and monetary policy shocks.

In the first step, we estimate the first principal component of the six measures of firm heterogeneity that we use in Section 5 based on the existing literature: (i) debt ratio, (ii) earning-based constraints, (iii) asset-based constraints, (iv) liquid assets to total assets, (v) firm size, and (vi) firm age. We estimate factor loadings and obtain a time-varying factor for the degree of binding financial constraints at the firm level.

In the next step, we interact the firm-level factor for financial constraints with the monetary policy shocks. We estimate the following local projections:

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \nu_{s,t}^h + \beta_z^h \cdot \Delta i_t \cdot z_{i,t-1} + \gamma_z^h z_{i,t-1} + \gamma^h X_{i,t-1} + u_{i,t}^h, \tag{B.3}$$

with $z_{i,t-1}$ denoting a vector including the factor for firm financial constraints. The rest of Equation (B.3) is similar to Equation (13).

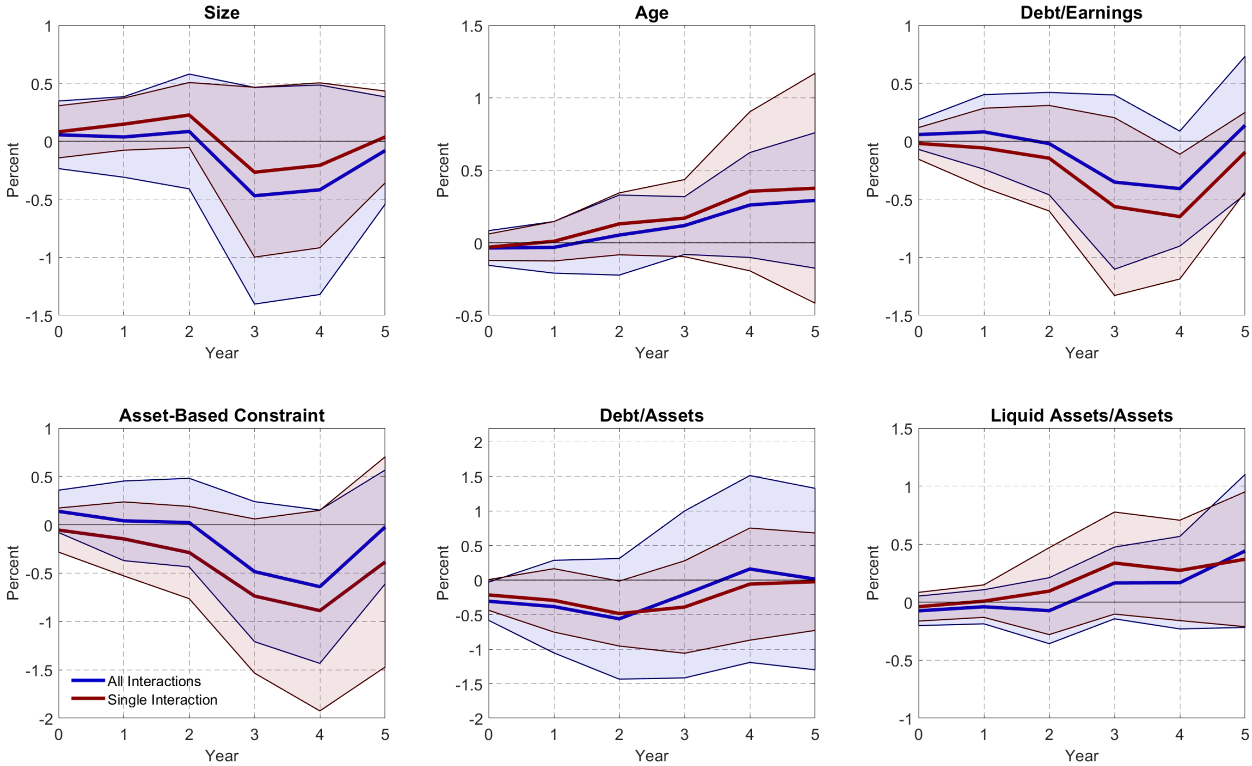
Figure B.5 visualizes the estimated coefficients β_z^h for the interaction between the financial-constraint factor and a 100-basis-point contractionary monetary policy shock. We find that the marginal effects, both in magnitude and shape, are not very different from the marginal effects of the earning-based constraint that we depict in Figure 5 in the body of the paper. We confirm in this paragraph that financial constraints play a significant role in the transmission of monetary policy on firm investment, but the quantitative effects are rather small and limited.

B.6 Alternative proxy for the earnings-based constraint

The two most commonly used earnings-based constraint measures are: (i) interest coverage covenants—e.g., interest payments on debt relative to EBITDA (Lian and Ma, 2021; Greenwald et al., 2023); and (ii) the ratio of total firm debt to EBITDA (Lian and Ma, 2021; Drechsel, 2023). We here estimate the six interaction coefficients from the main body of the paper when using the debt-to-earnings ratio as a proxy for earnings-based constraints, rather than the interest payments relative to earnings.

Figure B.6 presents the estimated interaction coefficients from Equation (13), where the interest-payment-to-earnings ratio, our baseline proxy for earnings-based constraints, is replaced with the debt-to-earnings ratio. The resulting coefficient on debt-to-earnings is quantitatively close to the baseline result in Figure 5, when using the interest-payments-to-earnings ratio. When we use the debt-to-earnings ratio as the only interaction term in Equation (13), the estimated coefficient on the interaction for the debt-to-earnings ratio is significant using 95% confidence bands. Controlling for all other interactions simultaneously increases the error bands slightly, reducing confidence in the relevance of the earnings-based constraint.

Our results indicate that both interest coverage covenants and covenants on the ratio



Notes: The figure shows estimated interaction coefficients with a 100 basis points contractionary monetary policy shock at annual frequency, based on the local projection approach in (13). For the earnings-based constraint in the right upper panel, we replaced the interest-costs-to-earnings ratio with the debt-to-earnings ratio. We instrument the change in the Norwegian monetary policy rate using narratively identified Norwegian monetary policy shocks. 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

Figure B.6: Marginal effects on the investment response to monetary policy, proxying the earnings-based constraint with the debt-to-earnings ratio.

of firms' debt to earnings affect firms' marginal investment response to monetary policy. We interpret the results across different proxies for earnings-based constraints as evidence that earnings-based constraint covenants are relevant to explaining investment decisions of Norwegian firms.