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The Investment Channel of Monetary Policy: Evidence from Norway

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The Investment Channel of Monetary Policy: Evidence from Norway*

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Abstract

We investigate monetary policy transmission to investment using Norwegian administrative data. We have two main findings. First, financially constrained firms respond more. The effect, however, is modest, suggesting that firm heterogeneity plays a minor role in monetary transmission. Second, we disentangle the investment channel of monetary policy into direct effects from interest rate changes and indirect general equilibrium effects. We find that the investment channel of monetary policy is due almost exclusively to direct effects. The two results imply that a representative firm framework with investment adjustment frictions provides a sufficiently detailed description of the investment channel of monetary policy.

JEL: E22, E52, D22, G31

Keywords: Monetary policy, Investment

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1 Introduction

Investment is one of the most responsive components of GDP to monetary policy. This paper aims to understand the relative and absolute importance of the channels through which monetary policy transmits to firm investment in fixed assets. In theory, interest rate changes affect firm investment through several direct and indirect channels. First, interest rate changes may directly impact firms' investment decisions, for instance, by changing the discount rate used to evaluate future cash flows, the tightness of credit constraints that firms face, or the cost of externally financing a new investment project. Second, monetary policy can affect firm investment via more indirect channels, for instance, by affecting aggregate demand and the expected future cash flows of an investment project.

In this paper, we use detailed administrative data on the universe of Norwegian firms to understand how monetary policy transmits to investment within firms. Using income and balance sheet statements from 2000 to 2019, we estimate the fixed asset responses of firms to monetary policy, both on average and across distributions of firm characteristics, using local projections and a monetary policy shock à la Romer and Romer (2004) for Norway from Holm, Paul, and Tischbirek (2021).

We make two contributions to the literature. First, while several existing papers investigate monetary transmission to investments,[1] we exploit the granularity of our data to trace out the monetary transmission to investment for the universe of firms, not only a subset of publicly listed firms. Thus, we estimate the transmission of monetary policy not only among large incorporated firms but also small- and medium-sized businesses.[2] Second, we investigate whether the monetary transmission to firm investment primarily operates through *direct* or *indirect* channels. Answering this question is important for understanding how monetary policy affects the real economy (Auclert, Rognlie, and Straub, 2020; Bilbiie, Känzig, and Surico, 2022).

Our empirical analysis consists of four main steps. The first step is to validate the micro data by estimating the average investment response and comparing it to the aggregate capital response using the data from the national accounts. The dynamics and magnitude of the average capital response in the micro data are similar to the aggregate capital response. Hence, we argue that our data is representative of the universe of firms

[1] See, for example, Ottonello and Winberry (2020); Cloyne, Ferreira, Froemel, and Surico (2023); Jeenas (2019); Ippolito, Ozdagli, and Perez-Orive (2018); Krusell, Thürwächter, and Weiss (2023); Jungherr, Meier, Reinelt, and Schott (2022); Deng and Fang (2022); Gnewuch and Zhang (2022).

[2] Our paper is in this aspect most related to Caglio, Darst, and Kalemli-Özcan (2022) who also study the role of firm heterogeneity in the transmission of monetary policy for private small- and medium-sized companies, and publicly listed firms. Unlike their paper, we use administrative data that includes the entire universe of Norwegian firms, whereas their sample is a smaller subset of the universe of US firms.

accounting for aggregate investments in the national accounts.

In the second step, we explore the heterogeneity of fixed asset responses to monetary policy. Several channels have been proposed through which the vast heterogeneity among firms may affect monetary transmission. We explore six proposed channels, individually and jointly: age, size, borrowing constraints (asset-based and earnings-based), liquidity, and leverage. Our main finding is that only a proxy for earnings-based constraints, interest costs as a share of earnings, robustly explains any heterogeneity in fixed asset responses. Earnings-based constraints are plausibly relevant because firms' lending capacity is often related to earnings and not collateral (Lian and Ma, 2021; Ivashina, Laeven, and Moral-Benito, 2022; Öztürk, 2022). In our data, firms with higher interest costs relative to earnings are more responsive to monetary policy. This result is consistent with the literature using U.S. data to argue that borrowing constraints are important to explain firm heterogeneity in investment responses to monetary policy (Ottonello and Winberry, 2020; Cloyne et al., 2023).

However, although earnings-based constraints robustly explain variation in capital responses to monetary policy, the effects are relatively small. Moving from the 10th to the 90th percentile of the distribution of earnings-based constraints strengthens the maximum fixed asset response to monetary policy by 0.8 percentage points, from −1.4% to −2.2%. Heterogeneity among firms, therefore, seems to play a minor role in understanding and explaining aggregate monetary transmission. Instead, firms, whether young or old, leveraged or with ample liquid reserves, constrained or not constrained, respond similarly to monetary policy, reducing fixed assets in response to higher interest rates.

In the third step, we disentangle the channels through which monetary policy affects firm investment, focusing on the direct vs. indirect channels. This focus is motivated by the literature on heterogeneous households that has revealed that monetary policy transmits through direct effects of interest rate changes and indirect effects of how interest rate changes affect other parts of the economy. For firms, interest rate changes may affect firms *directly* by, for instance, affecting the net present value of the future cash flows from projects or current interest rate costs, or *indirectly* because interest rate changes affect the real economy and thus the expected cash flows from investment projects. Understanding how monetary policy transmits to firms is important to form a more complete understanding of how monetary policy transmits to the economy. For example, Holm et al. (2021) document that monetary policy affects households via direct cash flow effects and indirect effects of wage changes in Norway. But for these wage responses to get started, there need to be sizeable direct effects of monetary policy somewhere in the economy. One such candidate is the investment channel of monetary policy. Hence, if monetary policy transmits to fixed assets through direct effects, the investment response may be a crucial component of aggregate monetary transmission, as argued in Auclert et al. (2020) and Bilbiie et al. (2022).

We use two methods to investigate the role of indirect channels of monetary policy. First, we control for future sales changes as a measure of demand effects in the local projections. If indirect effects are important, controlling for these sales changes should affect the shape of the impulse responses to monetary policy. Second, we use input-output tables to measure firms' exposure to changes in local demand conditions. We focus primarily on a binary definition of whether the firm operates in the tradable vs. non-tradable sector but also adopt a continuous measure of proximity to consumers, i.e., how much of the revenue for a given firm is sold directly to households. If indirect effects are important, firms operating in the non-tradable sector or close to consumers should be more sensitive to local demand conditions and respond more to monetary policy. Both exercises suggest that indirect effects play a minor role in the monetary transmission to investment. The flip side is that almost all monetary transmission to investment goes through direct effects, suggesting that the investment channel of monetary policy is an important component in getting the aggregate monetary transmission to the real economy started.

In the fourth step, we further explore whether the direct effects are due to the revaluation of the net present value of the future projects or the cash flow effects (Ippolito et al., 2018). To explore the role of cash flow effects, we compare the investment responses to interest rate changes of firms facing a fixed interest rate to firms with adjustable rate debt contracts in a subset of our sample. We find no difference in investment responses between firms with fixed and adjustable rate debt contracts, suggesting that the direct channel from interest rate changes to interest costs plays a minor role in explaining the investment channel of monetary policy. Instead, monetary policy transmits to investment primarily through how interest rate changes affect the net present value of future projects.

Our empirical results thus suggest (i) that firm heterogeneity plays a minor role in monetary transmission, (ii) that monetary policy primarily affects firms' investment via direct effects, and (iii) that this direct effect is not due to the effect of interest rate changes on interest costs. In a final section, we show that a representative firm model with investment adjustment frictions is sufficiently rich to describe the investment channel of monetary policy (Christiano, Eichenbaum, and Evans, 2005; Eberly, Rebelo, and Vincent, 2012; Auclert et al., 2020).

Roadmap. The rest of this paper proceeds as follows. Section 2 presents the data. Section 3 compares average investment responses to monetary policy in micro data with investment responses using aggregate data. We explore the heterogeneity of investment responses in Section 4. Section 5 decomposes the investment responses to monetary policy into direct and indirect effect and Section 6 explores the cash-flow channel in more detail. Section 7 discusses how our results relate to structural models. Section 8 concludes.

2 Data

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

Data sources. We use the Norwegian firm balance sheet and accounting information from the Brønnøysund Register of Business Enterprises with annual data from 2000 to 2019 as our main data source. This sample consists of every enterprise 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 - which we refer to as the main sample - contains a panel of financial information for the universe of firms in Norway, 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) build up a measure of fixed assets by cumulating capital expenditure at the firm level, a measure 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

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

A challenge with our approach is that capital is typically hard to measure in the data. We select a measure of capital in the balance sheet by choosing the concept that most closely resembles the idea of productive capital in neoclassical production models. In the Norwegian accounting framework, this category is called tangible fixed assets and contains, among others, buildings, structural installations, plant and machinery, ships, rigs, aircraft, motor vehicles, and office machines. Notably, it does not include intangible assets, inventory, current assets, or financial investments.

Our measure of investment is the growth rate of capital $\frac{K_t - K_{t-1}}{K_{t-1}}$ which is the same as $\frac{I_t}{K_{t-1}} - \delta$ using (1).[3] 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 because depreciation is accounted for in the data. However, if it had not been taken out or the method is imprecise, our estimation flexibly allows for firm-specific depreciation rates. Indeed, assuming that the depreciation rates are stable across time within firms, they are part of firm-fixed effects. Hence, our approach estimates how investments as a share of capital respond to monetary policy.

We will use several interaction variables when investigating the role of firm heterogeneity in monetary transmission. *Age* is the number of years since the firm's establishment year. We define *size* as the natural logarithm of a firm's total assets. *Leverage* is defined as the ratio of long-term debt to total assets, and *liquidity* is defined as the sum of cash and deposit holdings as a share of total assets.

Borrowing constraints are notoriously hard to measure, as reflected by the plethora of proxies suggested by the literature. The ideal measure would be a direct estimate of the availability of funding on existing credit lines or a measure of the marginal funding costs of firms. Because neither of these are observed in our data, we restrict attention to two proxies of borrowing constraints. Concretely, we follow Lian and Ma (2021) and define borrowing constraints as either an *earnings-based constraint* (proxied by a firm's interest costs as a share of earnings)[4] or an *asset-based constraint* (proxied by a firm's tangible assets to debt ratio).

[3] Similarly,

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

[4] Because earnings are not positive in each year, we define 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.

	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 tangible assets)	0.70	0.21	0.41	0.72	0.92

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.

Sample selection. Our initial sample contains all limited liability companies in Norway, excluding utilities, financial institutions, real estate firms,[5] and the public sector.[6] 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. Second, since the earnings-based borrowing constraint 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 the earnings-based constraint. Third, we trim the sample based on the key explanatory variables and investment. Specifically, we exclude firms with long-term debt to total assets higher than 10 and the 1st and the 99th percentile 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 consists of 33,674 unique firms and 159,187 firm-year observations.

Summary statistics. Table 1 presents some key descriptive statistics for the main 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 4. When we use standardized variables, these are constructed using the cross-sectional means and standard deviations from Panel E.

Cash flow sample. In Section 6, we evaluate the role of cash-flow effects on the investment channel of monetary policy. In that analysis, we additionally use a dataset containing debt data from the Norwegian Tax Administration containing detailed data on individual loans (level and interest payments) from 2003 to 2018. To evaluate the extent to which cash-flow channels are important, we compare the responses to monetary policy shocks of firms with fixed and adjustable rate contracts. Ideally, we would use the type of contract the firms have, which, unfortunately, is not observed in our data. Instead, we

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

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

impute the type of contract based on annual information on interest costs and the loan level. To separate firms into those with fixed and adjustable rate contracts, we restrict attention to firms with only one debt contract that can be identified as either a fixed or adjustable interest rate debt contract according to the procedure described in Section 6. This restriction limits our sample in this part of the analysis to relatively small firms. The descriptive statistics of the resulting cash-flow sample are summarized in Table A.1 in Appendix A. Firms with fixed and adjustable rate contracts are relatively similar, except that firms with fixed-rate contracts tend to have slightly more debt and fixed assets.

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.[7] 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.

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-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).

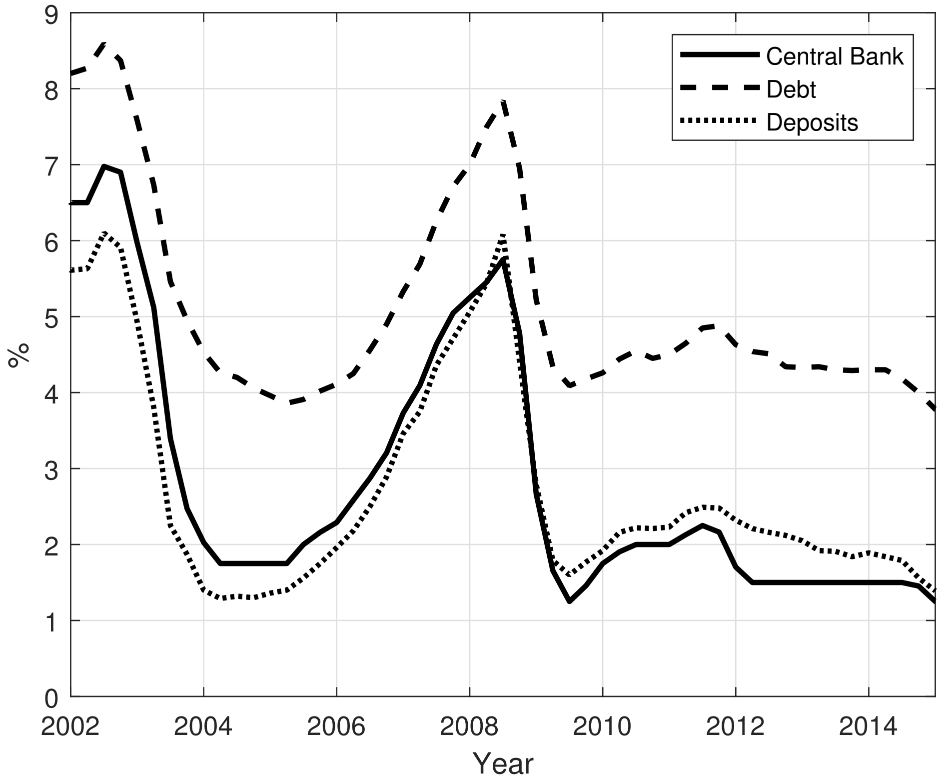
We plot the aggregate shocks in Figure 2. Notably, in the early 2000s, the Norwegian economy was hit by multiple large contractionary shocks, followed by a very large expansionary shock in 2003. External observers criticized the Norwegian monetary policy decisions in 2002 and 2003 as policy mistakes: rates being too contractionary in 2002 and too expansionary in 2003 (Bjørnland, Ekeli, Geraats, and Leitemo, 2004).[8]

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

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

[8]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).

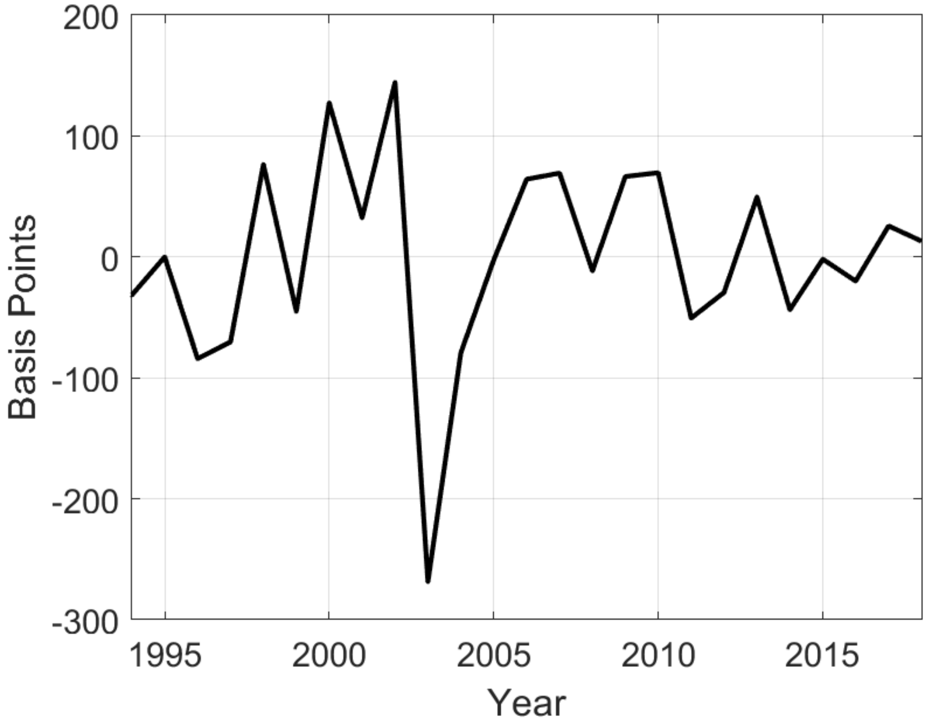


Notes: The figure displays the average interest rate on all outstanding debt and deposits of non-financial firms. "Central Bank" refers to the policy rate of Norges Bank.

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

and magnitude similar to the responses we would have gotten when using shocks and 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.[9] 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.

[9] 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.



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

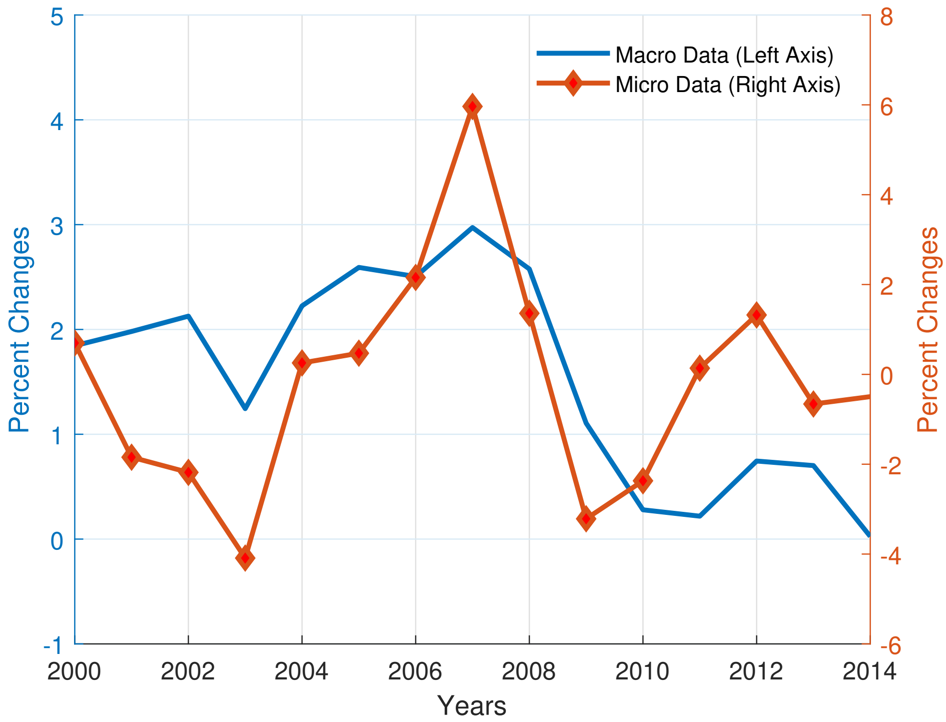
Figure 2: Annual monetary policy shocks.

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.[10] 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 similarly to the investment rate in the micro data.

For the robustness checks in section B and section C, we use the following annual data series from Statistics Norway: Real GDP growth rate, CPI-ATE inflation rate,[11] the monetary policy rate, the NOK-USD exchange rate, and house prices.

[10]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).

[11]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" displays the growth rate of fixed assets in the national accounts using the 13 sectors corresponding to the micro data.

Figure 3: Investment in aggregate and micro data.

3 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), we estimate impulse responses using the following local projections at annual frequency

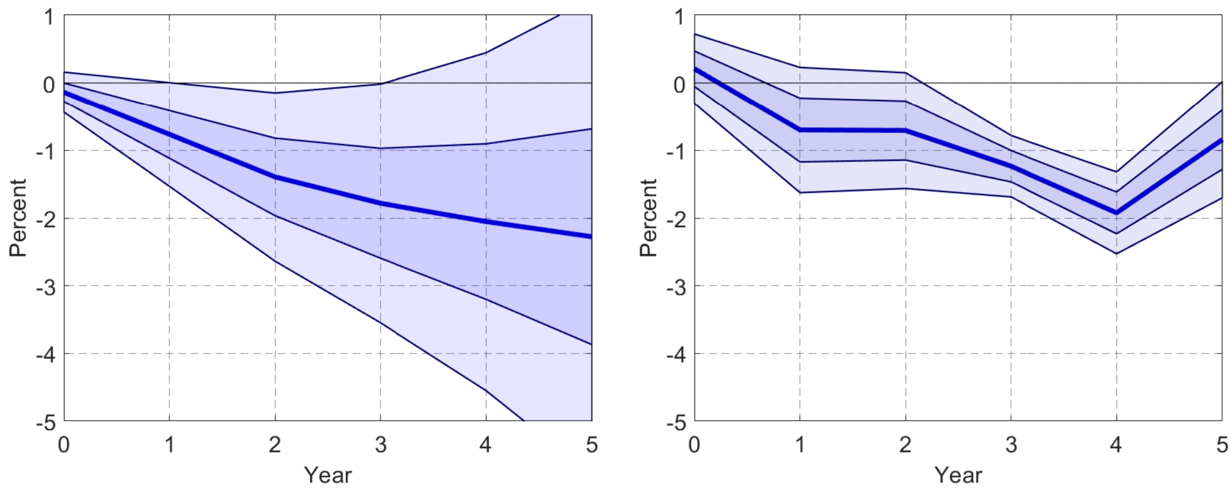
$$\frac{k_{t+h} - k_{t-1}}{k_{t-1}} = \alpha^h + \beta^h \cdot \varepsilon_t^{MP} + \gamma^h X_{t-1} + u_t^h, \tag{2}$$

where $h = 0, 1, ..., 5$ and k is fixed assets. The estimated coefficients β^h give the percentage change at horizon $t + h$ (relative to period $t - 1$) in response to a 100-basis point monetary policy shock in period t. X_{t-1} denotes a vector of pre-determined controls which, for the aggregate specification, includes three years of lagged values of the monetary policy shock 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 an adjusted version of the ones we run in aggregate data. Let $k_{i,t}$ be fixed assets for firm i at time t. The local projections we estimate are

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \beta^h \cdot \varepsilon_t^{MP} + \gamma^h X_{i,t-1} + u_{i,t}^h, \tag{3}$$

where $h = 0, 1, ..., 5$. The main difference from (2) is that we now control for individual firm variables (one lag of firm-specific investment rates instead of aggregate investment rates, firm size, firm leverage, and firm liquidity), individual fixed effects α_i^h and that we include some additional macro controls (lagged GDP growth and CPI-ATE growth). By including the firm fixed effects, we, among other things, allow for permanent differences in depreciation rates between firms. To ensure a relatively conservative inference, we follow Driscoll and Kraay (1998) when computing the standard errors, which are robust to general correlations between firms and years.



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

Notes: Impulse responses to a one percentage point contractionary monetary policy shock at annual frequency, based on the local projection approach in (2) and (3). 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.

Results. Figure 4 presents the results of estimating (2) and (3) 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.[12]

Robustness. We delegate the robustness exercises for the average firm-level investment responses to Appendix B. Figure B.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). To compare the transmission of firm investment rate between both shock series, we specify a two-stage IV regression. We visualize the high-frequency Norwegian monetary policy shocks in Figure B.1a in the Appendix.

Figure B.2 contains four additional robustness exercises. Figure B.2a shows results when we control for several additional macroeconomic variables such as the monetary policy rate, growth rate of house prices, and 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 shocks, so our empirical estimates do not represent the responses to Norwegian monetary policy. Figures B.2b, B.2c, and B.2d show results when controlling for identified monetary policy shocks in the US, the UK, and the euro area. The average responses lie within our main specification's 68% confidence bands in all three cases.

4 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 (2019) and Greenwald, Krainer, and Paul (2020) 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 channel of monetary

[12] 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 instead. Second, we restrict attention to the 13 sectors specified in the sample selection while Holm et al. (2021) consider all sectors.

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.

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

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \nu_t^h + \beta_z^h \cdot \varepsilon_t^{MP} \cdot z_{i,t-1} + \gamma_z^h z_{i,t-1} + \gamma^h X_{i,t-1} + u_{i,t}^h, \tag{4}$$

where $h = 0, 1, ..., 5$. Specification (4) is similar to (3) except that we include terms where we interact the monetary policy shock with variable (or vector) $z_{i,t-1}$. The regression also includes the interaction variables $z_{i,t-1}$ along with firm fixed effects α_i^h, time fixed effects ν_t^h, and the same vector of controls as in (3). We standardize all interaction variables $z_{i,t-1}$ to facilitate comparisons.[13]

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, 2022),[14] 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), and liquidity (liquid assets/total assets, Jeenas, 2019).[15]

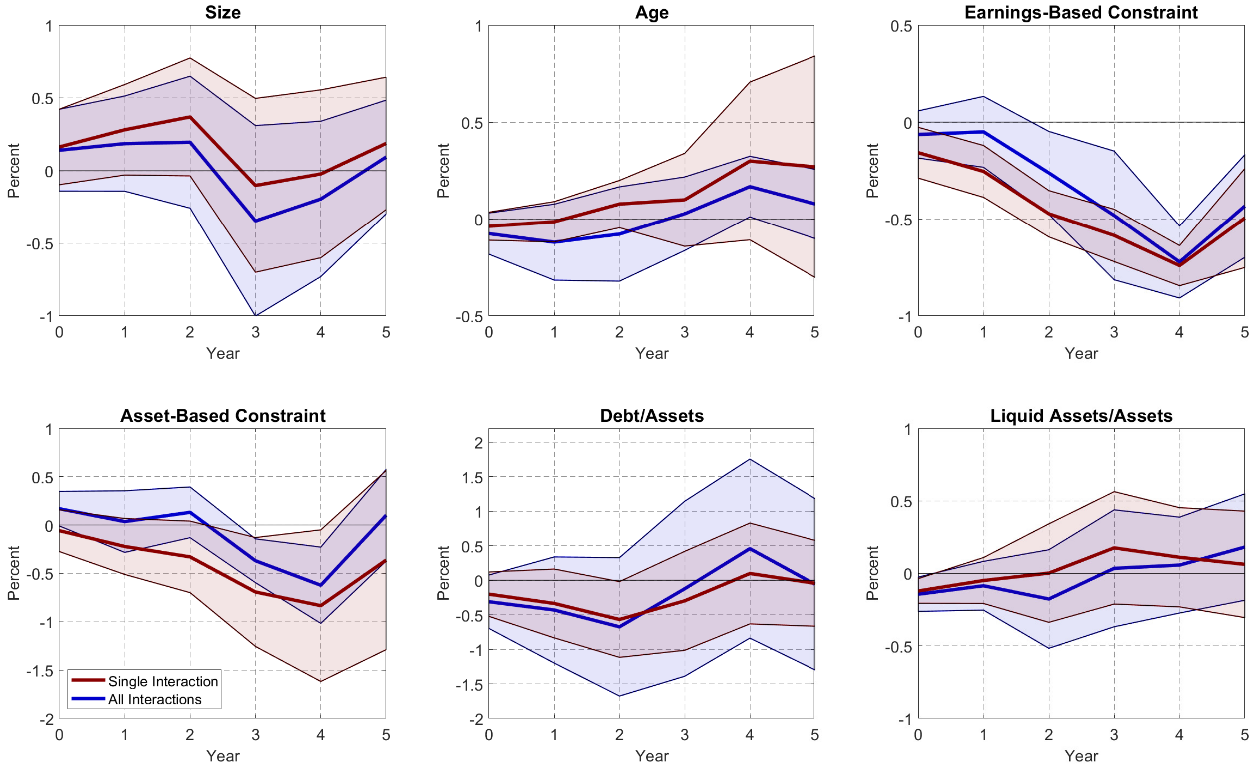
Results. Figure 5 summarizes our first main results. For each variable, we show two lines describing the marginal effects: when controlling for the single interaction in (4) and when including all six interactions simultaneously in (4).

Two variables are robustly associated with the investment responses to monetary policy: the proxies for the asset-based and the earnings-based constraint. More constrained firms, meaning they either have more debt relative to tangible assets or higher interest

[13]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 sectors. In the results we present below, we standardize along the cross-section. In Appendix C, we show that the results are similar when standardizing within sectors.

[14]Gnewuch and Zhang (2022) highlight the role of firm age for the transmission of monetary policy on the distribution of firm investment rates. In contrast the majority of papers in the literature, Gnewuch and Zhang (2022) study the effects of monetary policy on the extensive margin of firm investment.

[15]When investigating direct vs. indirect effects, we also explore the role of floating vs. fixed rate debt in Section 6.

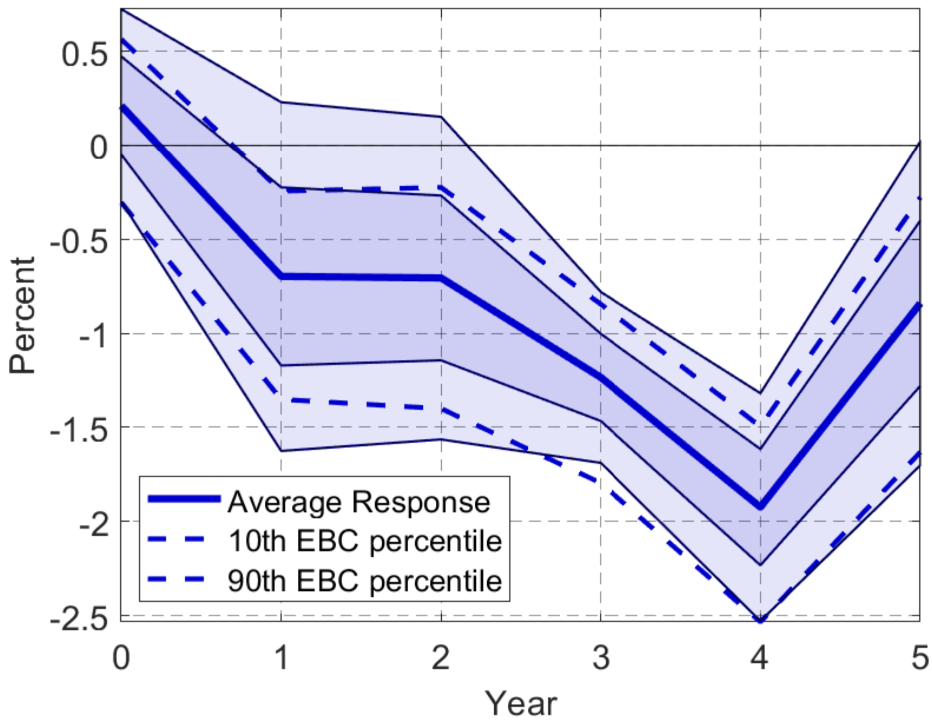


Notes: The figure shows estimated interaction coefficients with a 1 percentage point contractionary monetary policy shock at annual frequency, based on the local projection approach in (4). 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

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

costs to earnings, respond *more* to monetary policy. However, because the proxy for the asset-based constraint is not significantly associated with the investment response to monetary policy in some of our robustness exercises (e.g., using market-based monetary policy shocks instead), we focus on the earnings-based constraint. One standard deviation increase in our earnings-based constraint measure (0.74 increase in interest costs to earnings) is associated with a -0.7 percentage point reduction in the investment response in year four.

Another notable finding is that the estimated marginal effects are relatively similar irrespective of whether one controls for all effects jointly or only one at a time. An implication is that including only single interactions when estimating marginal effects, as is common in other papers, seems to yield potentially relevant estimates for most variables.



Notes: The figure shows estimated coefficients under a one percentage point contractionary monetary policy shock at annual frequency, based on the local projection approach in (3), together with the implied investment responses for firms in the 10th and 90th percentile of the earnings-based constraint distribution and the mean earning-based constraint effect from (4). 68 and 95 percent confidence are bands shown, using Driscoll and Kraay (1998) standard errors.

Figure 6: Investment responses to monetary policy. The quantitative relevance of earnings-based constraints.

Quantitative relevance. 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 whether the association is quantitatively important. To illustrate the quantitative relevance of heterogeneity in the earnings-based constraint on the firm investment response to monetary policy, we present the average investment response with the implied responses for firms in the 10th percentile and the 90th percentile of the earnings-based constraint distribution using the estimated marginal effects from Figure 5. The marginal effects we document in Figure 5 are relatively small. Going from the 10th percentile to the 90th percentile in the earnings-based constraint distribution, the peak investment response changes from -1.4% to -2.2%. Moreover, the implied investment response is almost always within the confidence bands of the average investment response. Hence, although the marginal effect of the earnings-based constraint on the investment response to monetary policy is statistically significant, the investment response to monetary policy is still relatively similar across firms.

Robustness. We discuss several robustness exercises for the marginal effects in Appendix C. 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. We use the monetary policy shock series from Ellen et al. (2021) and specify a two-stage IV regression. Figure C.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 C.2 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 new interaction terms as additional control variables. We find no evidence that differences in business cycle cyclicality matter for the estimated marginal effects (see Figure C.3).

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

5 Direct and Indirect Effects of Monetary Policy

In Section 4, we document heterogeneity in the investment response to monetary policy among firms, but this heterogeneity is quantitatively relatively minor. In this section, we explore the extent to which indirect channels, i.e., changes in aggregate demand, play an important role in the firm investment response to monetary policy.

In theory, firms respond directly to monetary policy because the interest rate directly affects the net present value of investment projects. In addition, interest rate changes also affect other sectors in the economy, such as the household sector, which generates indirect effects because monetary policy affects firms' demand, and firms may respond to these demand changes by adjusting investment. Holm et al. (2021) document the importance of indirect channels of monetary policy for the household spending response to monetary policy. This section explores to what extent indirect monetary policy channels are important for the firm investment response.

We propose two methods to disentangle the role of direct and indirect transmission channels of monetary policy. First, we follow Holm et al. (2021) and control for demand components when we estimate the average investment response to monetary policy. Second, we investigate whether the impact of monetary policy depends on whether the sector the firm operates in is sensitive to household demand. We capture exposure to household demand by using the (Leontief-inverted) input-output tables. First, we define the tradable sector as sectors in the top 20 % of the distribution of export shares and the non-tradable sector as retail, hotels, restaurants and other services. We then investigate whether there are differences in the average response for firms in the non-tradable vs. the tradable sector. As a complementary approach, we adopt a continuous measure of "proximity" to households at the sector level, i.e., sectoral-level sales shares to households, and estimate whether this proximity measure explains the firm investment response to monetary policy.

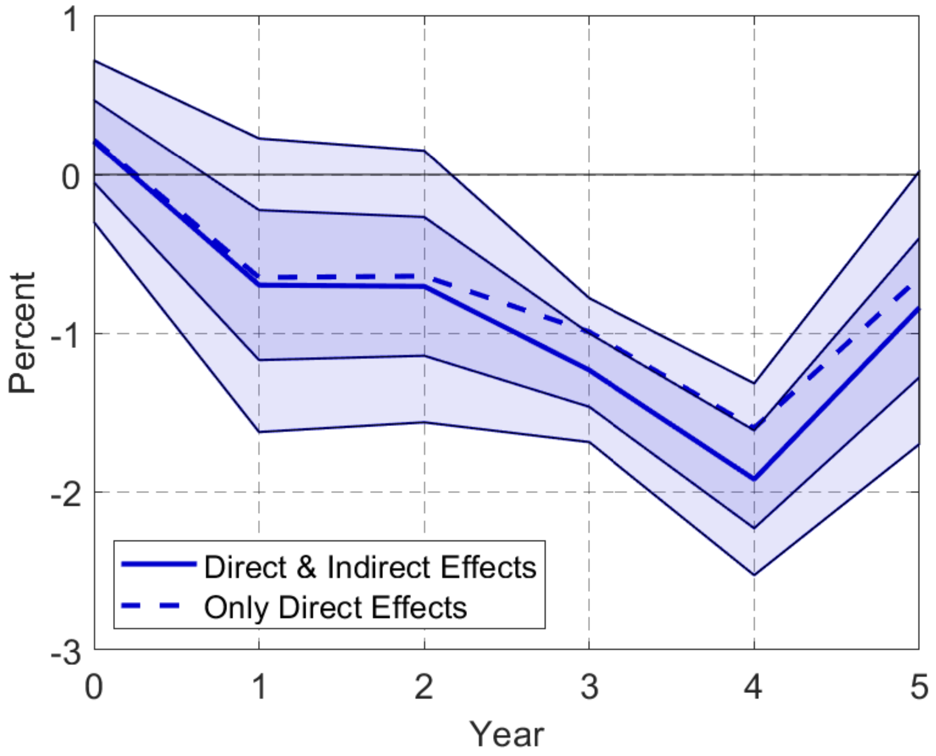
Controlling for demand. In this exercise, we follow Holm et al. (2021) in decomposing monetary transmission into direct and indirect effects. The idea is to run the main average local projection specification (3) but control for the evolution of movements in firm demand, proxied by firm sales.[16] The local projections we estimate are

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \beta^h \cdot \varepsilon_t^{MP} + \gamma^h X_{i,t-1} + \sum_{m=0}^{h} \gamma_m^h \frac{sales_{i,t+m}}{k_{i,t-1}} + u_{i,t}^h, \tag{5}$$

where the only change from (3) is the term $\sum_{m=0}^{h} \gamma_m^h \frac{sales_{i,t+m}}{k_{i,t-1}}$. When we estimate the firm investment response at horizon h, we control for movements in sales in all horizons up to and including h. The normalization by capital ensures the same unit of account for the variables on the left-hand and right-hand sides.[17]

[16] The underlying assumption here is that monetary policy affects firms' investments through two channels: directly via interest rate changes and indirectly via sales. By controlling for firm sales, we estimate the effect of monetary policy only coming from the direct effect of interest rate changes. The assumptions required to make this work are arguably very strong, and, at best, the exercise provides a glimpse of the potential relevance of indirect effects for monetary transmission to firms' investment.

[17] This normalization by capital may be problematic because it may induce a spurious correlation between the normalized variables if there are systematic differences between firms with high and low capital levels



Notes: The figure shows estimated coefficients under a 1 percentage point contractionary monetary policy shock at annual frequency, based on the local projection approach in (3) and (5). 68 and 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

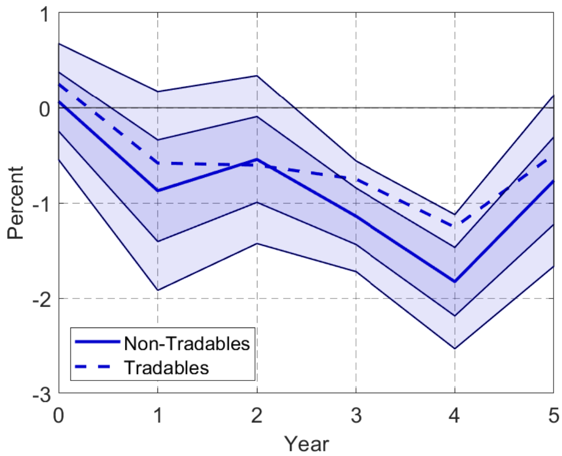
Figure 7: Direct and indirect effects of monetary policy on firm investment. Controlling for sales.

Figure 7 shows the estimates of β^h using (3) (direct and indirect effects) and (5) (direct effects only). The direct effects are smaller than the total effects but remain close to the total effects at all horizons. The results thus indicate that firms' investment responses to monetary policy are primarily driven by direct effects (interest rate changes) and not by changes in aggregate demand.

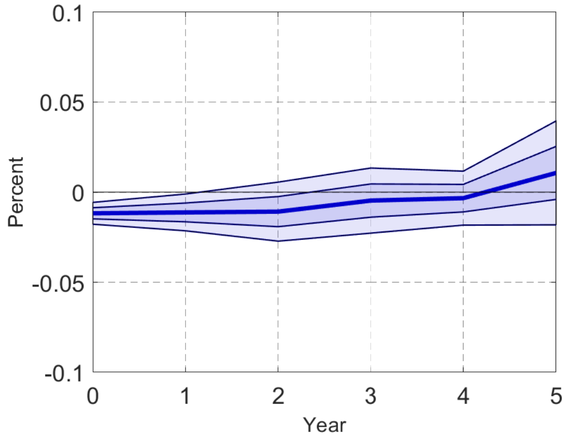
Exposure to local demand. In this exercise we explore whether exposure to local demand affects the investment response to monetary policy. If indirect income effects are important for the transmission of monetary policy to firm investment, we expect firms more exposed to local demand to respond more to monetary policy.

(Welch, 2022). However, note that the results do not change materially when we control for sales, implying that the potential spurious correlation is unimportant in explaining our results. Second, the results are similar also when we include $\log(k_{i,t-1})$ as part of the controls in (5), which is suggested by Welch (2022) as a way of testing this issue.

We proceed by estimating the average investment response for firms operating in the tradable vs. non-tradable sector. In Figure 8a, we plot the average investment response for the two types of firms. The average investment response is very similar for the tradable and non-tradable sectors, suggesting that changes in local demand conditions in response to the monetary policy shocks play a minor role.



(a) Tradable vs. non-tradable



(b) Proximity to consumers

Notes: The right figure shows the average impact of investment to a 1 percentage point contractionary monetary policy shock at annual frequency, based on the local projection approach in (3). We separately estimate the average response for firms operating in the tradable sector (top 20 % export shares) and the non-tradable sector. The right graph shows the estimated interaction coefficient to a 1 percentage point contractionary monetary policy shock at annual frequency, based on the local projection approach in (4). 68 and 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

Figure 8: The average investment response to monetary policy.

As a complementary approach to the exercise above, we adopt a continuous measure of (direct) exposures to household demand. We first define a proximity measure for each firm. 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 f as

$$\tilde{m}_i^h \equiv \frac{m_{s(i)}^h}{M_{s(i)}}. \tag{6}$$

We include this proximity-to-consumers measure in the local projection regression as an interaction term, similar to (4). Figure 8b shows the estimated marginal effect of being closer to consumers on the investment response to monetary policy. We find no evidence that proximity to consumers is important to explain the investment response to monetary policy.[18] Hence, our evidence does not suggest that the indirect effects of monetary policy are important in explaining the firm investment response to monetary policy.

Robustness. Appendix D presents several robustness exercises. First, in the specification with sales above (equation (5)), we control for sales up to the horizon in the local projection. In theory, firms care about the net present value of future projects and thus care about expected future sales. In the first robustness exercise, we, therefore, control for firm sales three years into the future at each horizon as a proxy for expected sales. Figure D.1 shows that controlling for future sales responses in the local projections does not alter our baseline results on the direct effects of monetary policy on firm investment responses.

In a second exercise presented in Figure D.2, we show that our results for the proximity to consumers interaction term are robust to the inclusion of the additional six interaction terms from Figure 5: firm size, firm age, leverage, liquidity, earning-based constraints, and asset-based constraints.

6 Cash Flow Effects of Monetary Policy

So far, our results suggest that heterogeneity plays a relatively minor role in explaining the investment channel of monetary policy and that monetary policy primarily transmits via direct effects of interest rate changes on investment. Theoretically, interest rate changes affect firms because they affect the net present value of investment projects but also because they affect the cash flow of firms that hold debt or deposits. The cash flow channel of monetary policy has been shown to be important for households (see, e.g., Flodén, Kilström, Sigurdsson, and Vestman, 2020; Holm et al., 2021) and firms (Ippolito et al., 2018; Gürkaynak et al., 2022). This section explores to what extent the cash-flow channel of monetary policy plays a relevant role in the investment channel of monetary policy in our sample of firms.

Empirical setup. We employ a difference-in-difference setup to evaluate the cash flow channel of monetary policy. We first identify whether firms have an adjustable or fixed-rate debt contract. In this exercise, we rely on a sub-sample of firms with one debt contract as

[18] Figure 8b shows the results when we include proximity to households as a single interaction term. Figure D.2 in Appendix D shows the results where we include all interaction terms from Figure 5. The results are indistinguishable.

described in Section 2. Next, we compare their investment response to a monetary policy shock. The idea is that since aggregate monetary policy affects both groups equally, the differencing takes out all effects of interest rate changes on the interest rate faced on new borrowing or its effect on aggregated demand. The difference-in-difference setup thus attempts to identify the cash flow channel of monetary policy.

The identification relies on two assumptions. First, we assume that firms with fixed rates are similar to firms with adjustable-rate debt contracts. We demonstrate in Table A.1 that firms in the two groups are relatively similar and that the pre-trends are similar below. Second, we assume that the monetary policy shocks are exogenous to firms (as before) and that this exogeneity is uncorrelated with the type of debt contracts firms have.

Specifically, the empirical equation we estimate is

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_h + \theta_t + \beta_1(\varepsilon_{m,t} \cdot \mathbb{1}_{fr,i,t}) + \beta_2 \mathbb{1}_{fr,i,t} + \beta_3 \varepsilon_{m,t} + u_{i,t} \tag{7}$$

where k is an outcome variable (net financial costs, cash, equity, and fixed assets), α_h is a horizon-fixed effect, θ_t is a time-fixed effect, $\varepsilon_{m,t}$ is the monetary policy shock, $\mathbb{1}_{fr,i,t}$ is an indicator for the firm having a fixed rate debt contract between $t-1$ and t, and $u_{i,t}$ is an error term. We estimate (7) for $h = -2, -1, ..., 2$ in the analysis.

Constructing the fixed interest rate variable $\mathbb{1}_{fr,i,t}$. The key challenge of the identification strategy is to distinguish firms with adjustable and fixed interest rate debt contracts. The debt data does not contain debt contract information directly, and we have to infer the type of interest rate contract from interest payments and outstanding debt. We proceed as follows.

First, we compute a measure of the interest rate on each individual loan j in year t as

$$r_{j,t} = \frac{\text{interest payments}_{j,t}}{0.5 \cdot (\text{debt}_{j,t-1} + \text{debt}_{j,t})},$$

which gives us a measure of the interest rate for each contract in the data. We only compute this measure of the interest rate for loans where the change in debt from $t-1$ to t is less than 10% in absolute value. Second, we compute the median interest rate each year and the change in this median interest rate. When the median interest rate change by more than 0.1 percentage points, we identify loan contracts with fixed rates as those whose change in interest rate is less than 0.1 percentage points. Conversely, we define a loan as having an adjustable rate contract if the rate change is greater than 0.1 percentage points and the observed rate change differs by less than 0.1 percentage points from the median interest rate change. We restrict our attention to firms having only one debt contract.

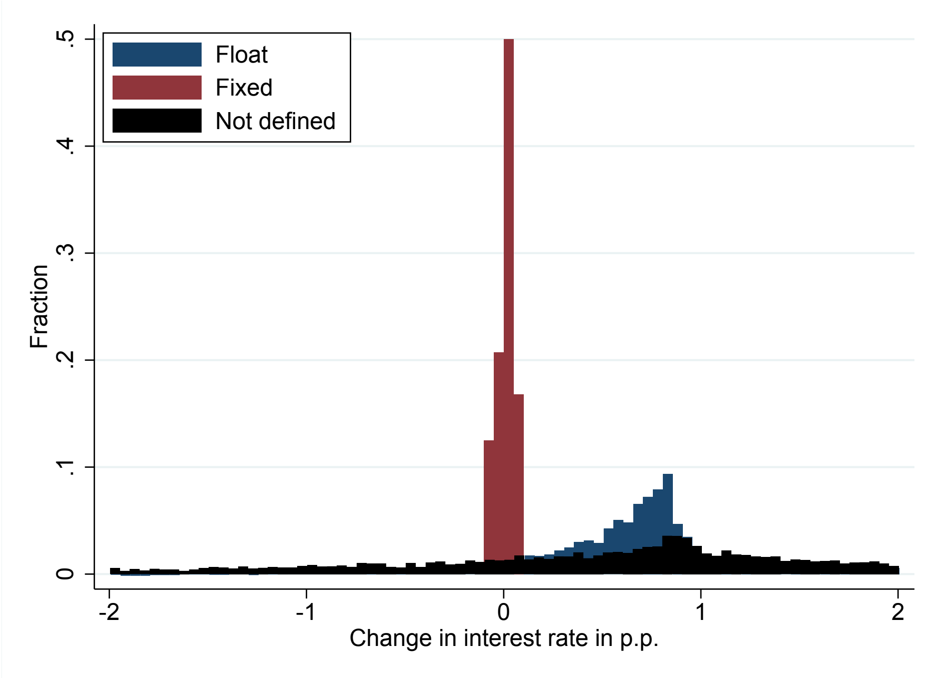
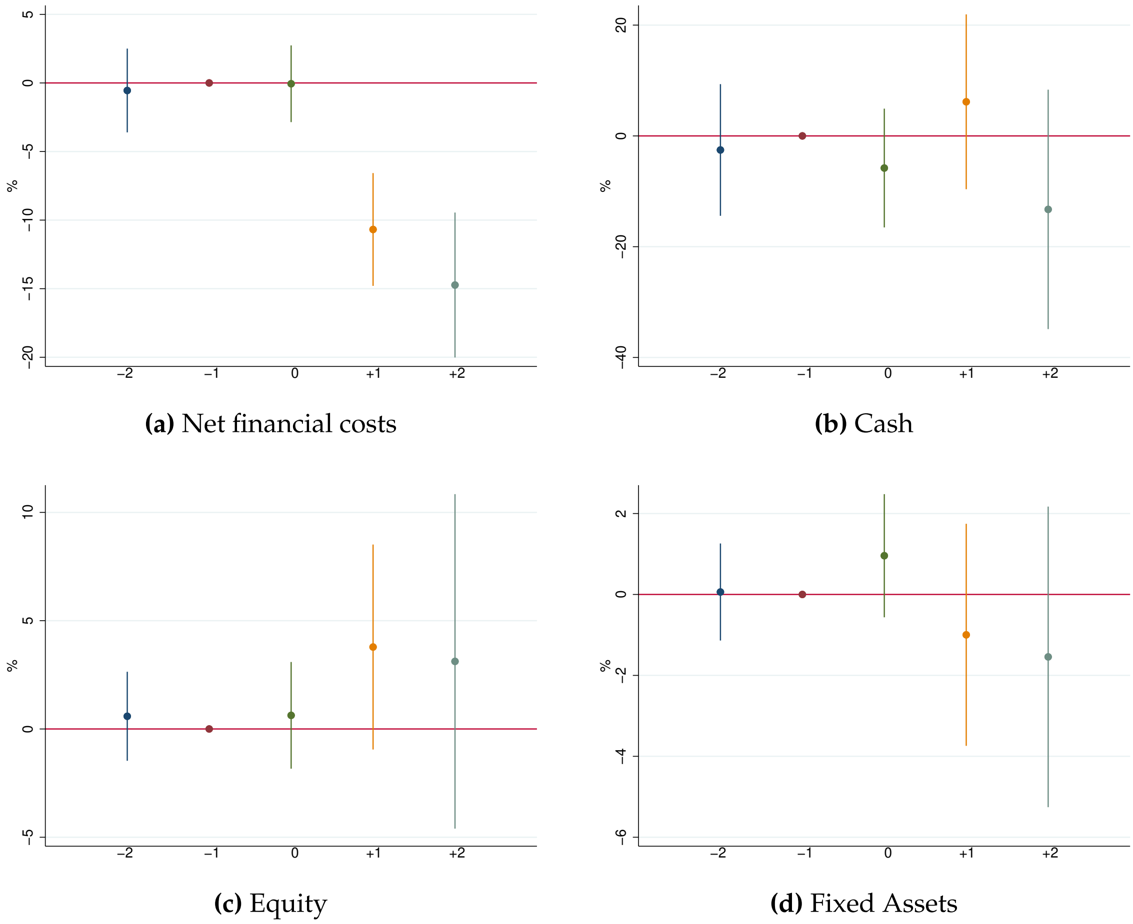


Figure 9: Decomposition into fixed and adjustable interest rate debt contracts.

Figure 9 shows the distribution of interest rate changes in 2006. The distribution of rate changes features a bimodal distribution in years with sufficiently large changes in the key policy rate. There is substantial mass around no change in the interest rate, which we identify as fixed rate contracts. Similarly, there is a substantial mass around 0.8 percentage points, containing contracts we identify as adjustable rate contracts. We identify 4.9% percent of firms as having fixed-rate contracts compared with 4.2% in aggregated data from Statistics Norway.

Results. Figure 10 shows our main results. We first note that the pre-trends are flat, suggesting no systematic difference in growth rates between firms with adjustable and fixed interest rate contracts prior to the monetary policy shock. Second, Figure 10a show that the monetary policy shock affects the two groups of firms differently. Firms with fixed-rate debt contracts tend to have lower financial costs in response to a higher interest rate, as expected.

The rest of the figures show how the firms spend the lower financial costs. They can either use the money to pay dividends, accumulate cash, and thus increase equity, or invest. Our evidence indicates, albeit statistically insignificant, that some of the extra liquidity is saved in cash and thus leads to increased equity. Moreover, we find no effect on fixed assets Figure 10d. Indeed, although statistically insignificant, our results point in the direction of a negative investment response, the opposite of what we should expect from the cash-flow effect.



(a) Net financial costs

(b) Cash

(c) Equity

(d) Fixed Assets

Notes: The figure shows the marginal effect of having a fixed rate mortgage in response to a one percentage point contractionary monetary policy shock using Equation (7). 95 percent confidence bands are shown.

Figure 10: Dynamic effects of monetary policy for firms with fixed relative to firms with adjustable rate debt contracts.

Based on these results, we argue that the cash flow channel of monetary policy to firm investment seems to play a relatively minor role in the investment channel of monetary policy. Our results thus suggest that monetary policy operates primarily via direct channels *unrelated to firm cash flow*.

7 Relationship with Structural Models

The main results in the three preceding sections are that (i) the heterogeneity in investment responses to monetary policy exists but it is relatively small, (ii) that monetary transmission to firm investment works primarily through direct effects, and (iii) that the direct effect is not primarily due to cash-flow effects. This section explores to what extent these results are consistent with standard models of firm investment.

The model. Because heterogeneity plays a relatively minor role in the investment channel of monetary policy, we restrict attention to a representative firm model. The model is quarterly and based on the capital firms in the New Keynesian literature (Christiano et al., 2005; Eberly et al., 2012; Auclert et al., 2020). The firm maximizes profits net of investment subject to the law of motion of capital. The firm also faces investment adjustment costs and time-to-build in investment.

$$\max_{\{I_t,K_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty}\left(\prod_{s=0}^{t}\frac{1}{1+r_s}\right)\left(A_tK_{t-1}^{\alpha}-\left(I_t+S\left(\frac{I_t}{I_{t-1}}\right)\right)\right)$$

subject to

$$K_t = (1-\delta)K_{t-1}+I_t \tag{8}$$

where I is investment, K is capital, A is productivity, r is the interest rate, δ is the depreciation rate, α the capital share of output, and $S(\cdot)$ is an investment adjustment function satisfying $S(1)=0$, $S'(1)=0$, and $S''(1)=\phi$.[19]

The first-order conditions of the problem above are

$$1+S'\left(\frac{I_t}{I_{t-1}}\right)\frac{1}{I_{t-1}} = \frac{q_{t+1}}{1+r_t}+S'\left(\frac{I_{t+1}}{I_t}\right)\frac{I_{t+1}}{I_t^2} \tag{9}$$

$$q_t = \frac{1-\delta}{1+r_t}q_{t+1}+\alpha A_tK_{t-1}^{\alpha-1} \tag{10}$$

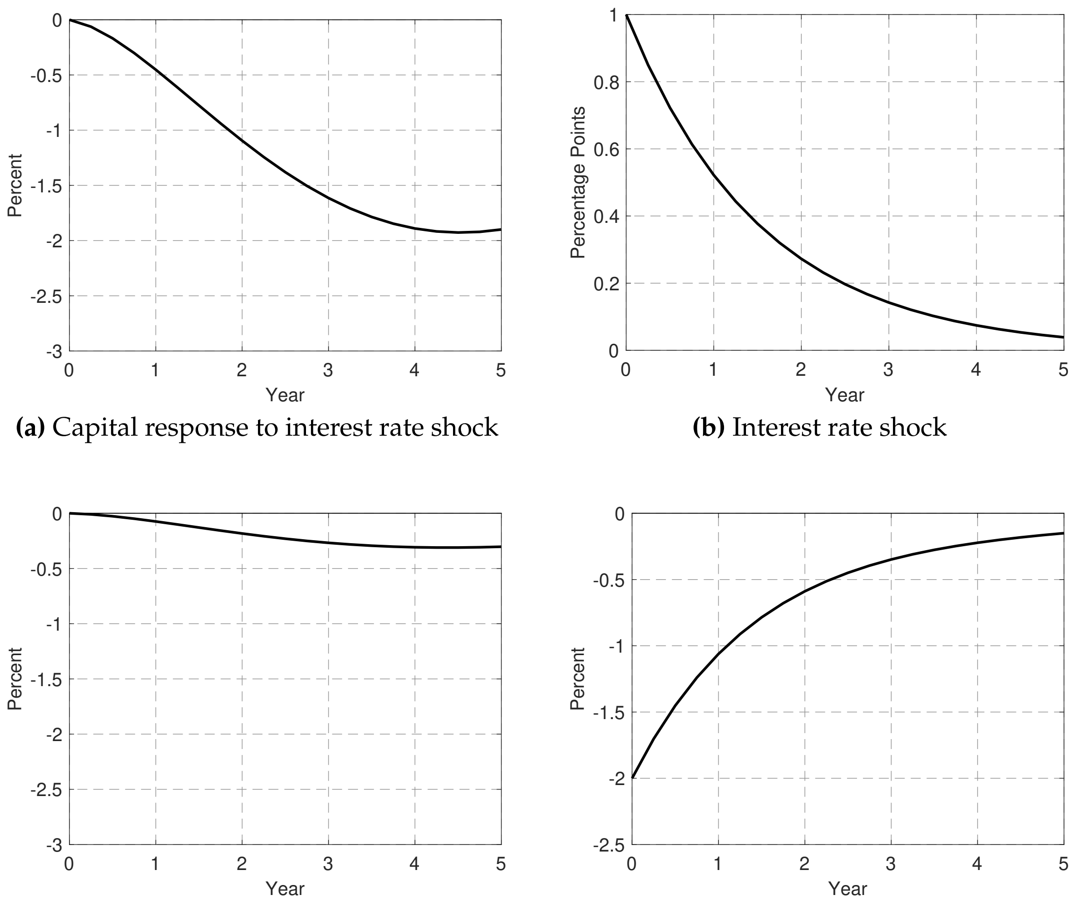
where q is the shadow cost of capital. The model has two shock processes: the interest rate and productivity. These shocks evolve according to

$$r_t = r+\rho_r(r_{t-1}-r)+\varepsilon_t^r,$$
$$A_t = A+\rho_a(A_{t-1}-A)+\varepsilon_t^a,$$

where ρ_r and ρ_a determine persistence, and ε^r and ε^a are shocks. Our calibration follows

[19]The function we use is $S(X)=\frac{\phi}{2}(X-1)^2$.

[Auclert et al.](2020), adjusted to quarterly frequencies. We use the following values: $r = 0.04$ (annual), $K = 9.7$ (determines A), $\delta = 0.052$ (annual), $\phi = 0.025$, $\alpha = 0.24$, $\rho_r = 0.85$ (quarterly), and $\rho_a = 0.85$ (quarterly). We adjust ϕ to ensure that the shape and size of the investment response are similar to the empirical results.



(a) Capital response to interest rate shock

(b) Interest rate shock

(c) Capital response to productivity shock

(d) Productivity shock

Notes: Figures (a) and (b) show the capital and interest responses to a one percentage point interest rate increase using the structural model from Section 7. Figures (c) and (d) show capital and productivity responses to a 2 percent reduction in productivity (similar to the maximum output response to a one percentage point interest rate increase in Holm et al., 2021).

Figure 11: Impulse responses to interest rate and productivity shocks.

Simulation results. Figure 11 shows the capital (change in capital, same as (2)) responses to interest rate and productivity shocks. There are two main findings. First, our relatively standard model with investment adjustment costs can match the empirical evidence on the capital response to interest rate changes well. We use a one percentage point increase in the interest rate in the empirical regression setup in Section 3 and the current simulation. The capital response in the model is hump-shaped, with a maximum response of around 2 percent in years 3 and 4, similar to the empirical results.

Second, while the capital response to interest rate changes is large, the capital response to a productivity shock is relatively small. In our partial equilibrium setting, we use the productivity shock as a stand-in for a reduction in aggregate demand, calibrated to the output response to a one percentage point contractionary monetary policy shock in Holm et al. (2021) (about 2%). The firm responds to lower productivity by reducing capital, but the response is small compared with the investment response to interest rate changes. Hence, although firms respond to changes in productivity (demand), these changes are small, such that when the central bank raises the policy rate, the indirect effects on investment via aggregate demand play a relatively minor role. Instead, almost all of the investment channel of monetary policy comes from firms responding directly to changes in the policy rate, consistent with our empirical results.[20]

8 Conclusion

In this paper, we explore 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 is relatively modest and (ii) monetary transmission to firm investment works predominately through direct effects. 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 precisely describes *the transmission channels* from monetary policy to investment. Hence, the representative firm model with investment adjustment frictions is not only simple yet fruitful in the spirit of Friedman (1953), but it also depicts how the investment channel of monetary policy operates.

The results imply that financial constraints play a minor role in aggregate investment dynamics. First, while the empirical results in Section 4 show that financial constraints affect the investment response to monetary policy, the effects of heterogeneity in financial constraints are relatively small compared to the average investment response. Second,

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

our exercise investigating the importance of cash flow effects suggests that the effect of monetary policy on firms' interest expenses is relatively unimportant for the firm investment response, again suggesting a limited role for financial constraints. These findings are consistent with the view that capital markets work well for the important firms in the economy. However, we want to emphasize that financial constraints may be important for monetary transmission in other countries or for other research questions such as firm dynamism and misallocation.

The combination of the current paper with Holm et al. (2021) provides a fuller view of aggregate monetary transmission in an advanced economy. Holm et al. (2021) show that monetary transmission to households works primarily through changes in disposable income. Direct effects dominate in the first few years, while indirect effects of monetary policy through wage movements gradually build up. An implication of Holm et al. (2021) is that the initial consumption response to monetary policy is relatively muted because the household sector holds both debt and deposits. In contrast, the current paper's results show that the firm investment response to monetary policy works primarily via direct effects. The combination of the two papers aligns with the view that firm investment plays a crucial role in aggregate monetary transmission because they respond directly to interest rate changes, consistent with recent research by, e.g., Auclert et al. (2020) and Bilbiie et al. (2022).

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

A Appendix to Section 2

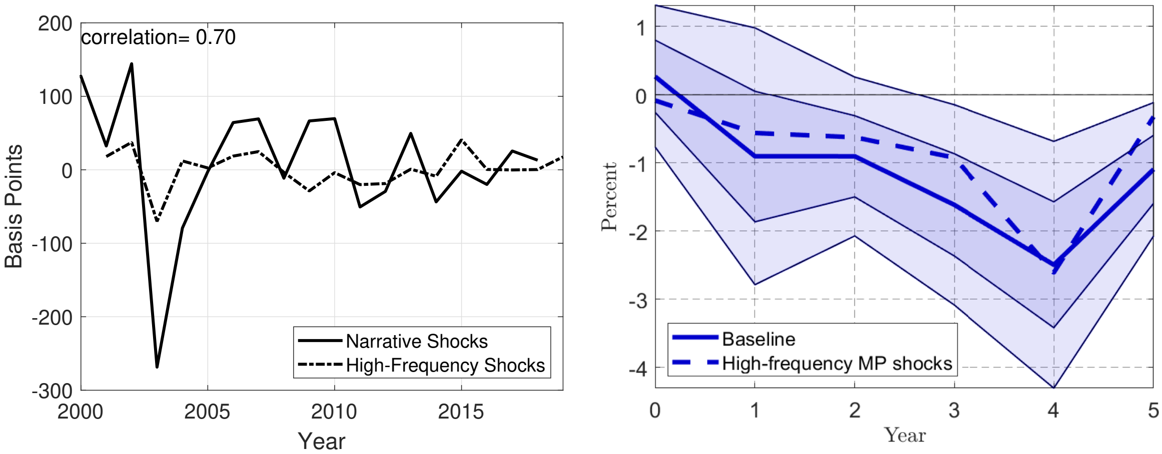
	Fixed	Adjustable
Panel A: Income statement		
Revenue	1,028.78	1,140.43
Payroll expenses	213.35	212.47
Operating expenses	812.36	981.20
Net financial expenses	100.61	75.77
Net profit	79.23	60.28
Dividends	16.60	14.86
Panel B: Balance sheet		
Total assets	3,164.89	2,581.85
Fixed assets	2,657.60	2,087.30
Current assets	507.29	494.55
Cash holdings	191.56	175.59
Equity	705.63	584.43
Debt	2,467.72	2,003.73
Panel C: Demographics		
Age	9.62	9.07
Observations	*8,991*	*50,585*

Notes: All values are mean observations measured in thousands of 2015 USD (except age and the number of observations). The sample covers the period from 2003 to 2018.

Table A.1: Descriptive statistics - cash flow sample.

B Appendix to Section 3

We show in Section 3 that the investment response of the average Norwegian firm to a contractionary monetary policy shock 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 using market-based shocks. Second, we show that the size and the shape of the average investment response do not change when including



(a) Comparison of shocks **(b)** Average investment responses

Notes: Figure B.1b displays impulse responses to a one percentage point contractionary monetary policy shock at annual frequency, based on the local projection approach in (B.2) 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). 95 percent and 68% confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

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

additional macroeconomic controls. Third, we demonstrate that the estimated Norwegian monetary shock series is orthogonal to monetary policy in the US, the UK, and the euro area.

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

In Figure B.1a, we visualize both the Norwegian narrative shocks and the Norwegian high-frequency shocks. The two shock series are correlated, with a correlation of 0.70 in our sample. The magnitude of the high-frequency shocks is smaller, though, than the baseline Romer & Romer shocks.

In the following, we compare the average firm-level investment responses to both monetary shock series. In order to ensure comparability between the coefficients, we apply a two-stage regression and treat the market-based shocks as instruments to the true unobservable shock series. This ensures that the units of the shocks is normalized to one percentage points, similar to the narrative shock series. In the first stage, we regress changes in the Norwegian policy rate Δi_t on the monetary policy shock series

$$\Delta i_t = \alpha_i^{h,1} + \beta^{h,1} \cdot \varepsilon_t^{MP,hf} + \gamma^{h,1} X_{i,t-1} + u_{i,t}^h, \tag{B.1}$$

where $\varepsilon^{MP,hf}$ is the shock series from Ellen et al. (2021) and X_{t-1} includes one lag of investment rates, one lag of real GDP growth rates, and lags of the monetary policy shocks.

Second, we use the first-stage regression results as an instrument for Δi_t. The second stage regression is defined as

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^{h,2} + \beta_j^{h,2} \cdot \widehat{\Delta i}_t + \gamma^{h,2} X_{i,t-1} + u_{i,t}^h, \tag{B.2}$$

where $\widehat{\Delta i}_t$ is the predicted interest rate change from equation (B.1). As depicted in Figure B.1b, the magnitude of the investment responses to high-frequency identified Norwegian monetary policy shocks is similar to the baseline response reported in Figure 4.

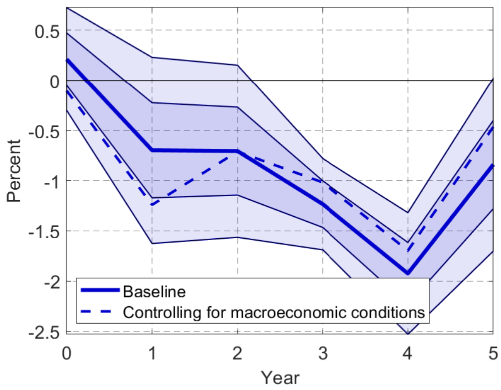
Robustness to macroeconomic conditions. The average investment response of Norwegian firms to a contractionary monetary policy could be biased if the monetary policy series violates the lead-lag exogeneity (Stock and Watson, 2018). We can evaluate the exogeneity of the Norwegian monetary policy by including lagged macroeconomic variables. First, we extend the regression equation (3) from the main text by including a set of common macroeconomic variables Y_{t-1}

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \beta^h \cdot \varepsilon_t^{MP} + \gamma^h X_{i,t-1} + \delta^h Y_{t-1} + u_{i,t}^h. \tag{B.3}$$

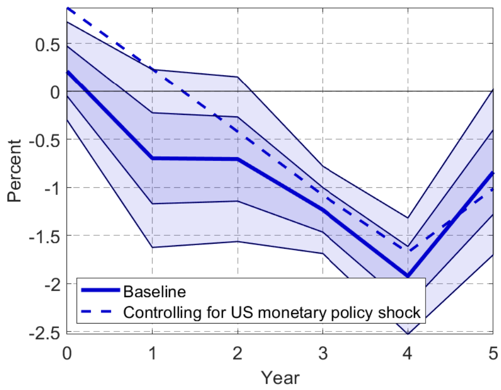
The vector Y_{t-1} includes the one-year lag of the following macroeconomic variables: real GDP growth rate, CPI inflation rate, the change in Norwegian monetary policy, the growth rate of the NOK-USD exchange rate, and the growth rates of house prices. The rationale to include three additional macroeconomic controls is the following:

First, in addition to specification (3), we add lagged monetary policy changes to ensure that our narrative monetary policy shock measure indeed capture the exogenous component of monetary policy.

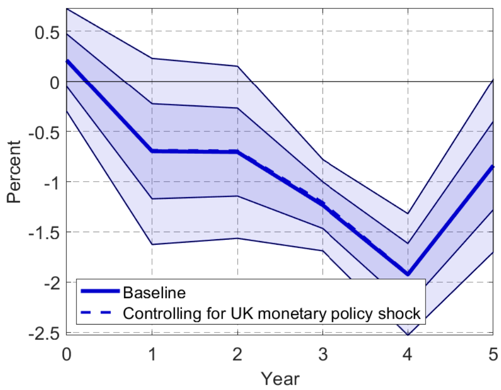
Second, since Norway is a small-open economy, we add lagged growth rates of the



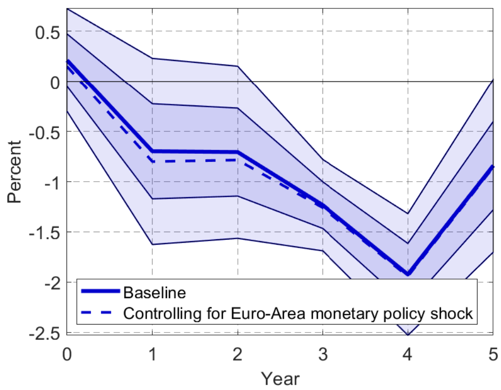
(a) Robustness: macroeconomic variables



(b) Robustness: US monetary policy



(c) Robustness: UK monetary policy



(d) Robustness: Euro-area monetary policy

Notes: Impulse responses to a 1 percentage point contractionary monetary policy shock at annual frequency, based on the local projection approach in respectively equations (B.3) and (B.4). 95 and 68 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

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

NOK-USD exchange rate to ensure that the monetary policy shocks are exogenous to Norges Bank's reaction to a devalution/appreciation of the Norwegian currency.

Eventually, 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.[21]

Figure B.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.

Robustness to foreign monetary policy. In this paragraph, we test whether the identified Norwegian monetary policy shock series we use is exogenous to monetary policy shocks of other major currencies. Norway as a small-open economy might especially be

[21] See for example Norges Bank (2014)

affected by monetary policy decisions of its main trading partners: the euro area, the UK, and the US. Thus, it could be the case that Norwegian monetary policy shocks, identified in Holm et al. (2021) via the narrative approach, is confounded by shocks to foreign monetary policy decisions.

We control for these potential confounding factors by adding foreign monetary policy shocks to the baseline regression equation

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \beta^h \cdot \varepsilon_t^{MP} + \gamma^h X_{i,t-1} + \delta^h \zeta_t^{FMP} + u_{i,t}^h, \tag{B.4}$$

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).

Figures B.2b, B.2c, and B.2d show that the responses of firm-level investment rates to Norwegian monetary policy shocks, after controlling for the foreign monetary policy, is similar to our baseline results.

C Appendix to Section 4

In Section 4 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.

Using high-frequency identified Norwegian monetary policy shocks. In this analysis, we 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. As we depict previously in Figure B.1a, the magnitude of the monetary shocks differs across both series. In order to ensure comparability between the coefficients of both the narratively-identified shocks and the high-frequency shocks, we apply a two-stage regression and treat the high-frequency shocks as instruments to the true unobservable shock series. In the first stage, we regress the Norwegian policy rate on either one of the monetary policy shock series

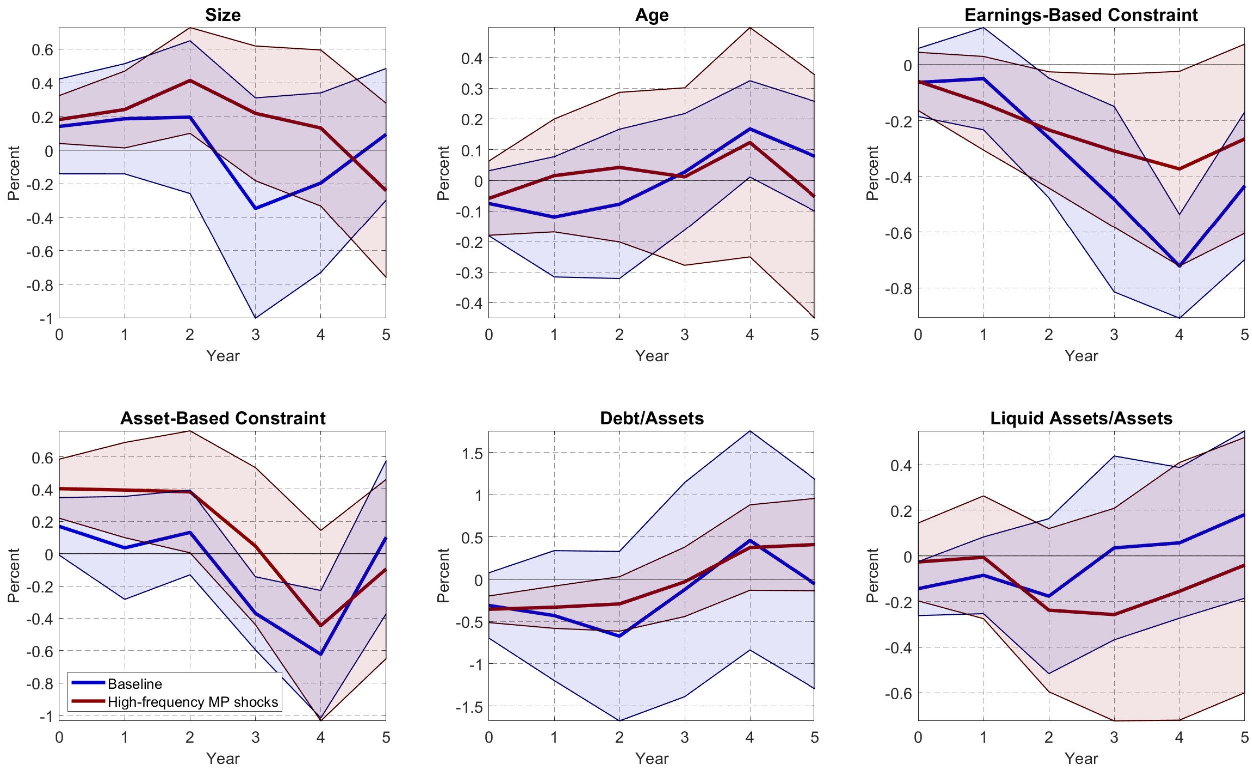
$$\Delta i_t = \alpha_i^{h,1} + \nu_t^h + \beta_z^h \cdot \varepsilon_t^{MP,hf} \cdot z_{i,t-1} + \gamma_z^h z_{i,t-1} + \gamma^{h,1} X_{i,t-1} + u_{i,t}^{h,1}, \tag{C.1}$$

where $\varepsilon_t^{MP,hf}$ is the high-frequency shock series from Ellen et al. (2021) and X_{t-1} includes one lag of investment rates.

In the second stage, we use the results from the first stage as an instrument for Δi_t: the true unobservable shock by replacing the narratively identified shocks in the local projection equation with the high-frequency instrument

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^{h,2} + \nu_t^{h,2} + \beta_{z,j}^{h,2} \cdot \widehat{\Delta i}_t \cdot z_{i,t-1} + \gamma_z^{h,2} z_{i,t-1} + \gamma^h X_{i,t-1} + u_{i,t}^{h,2}, \tag{C.2}$$

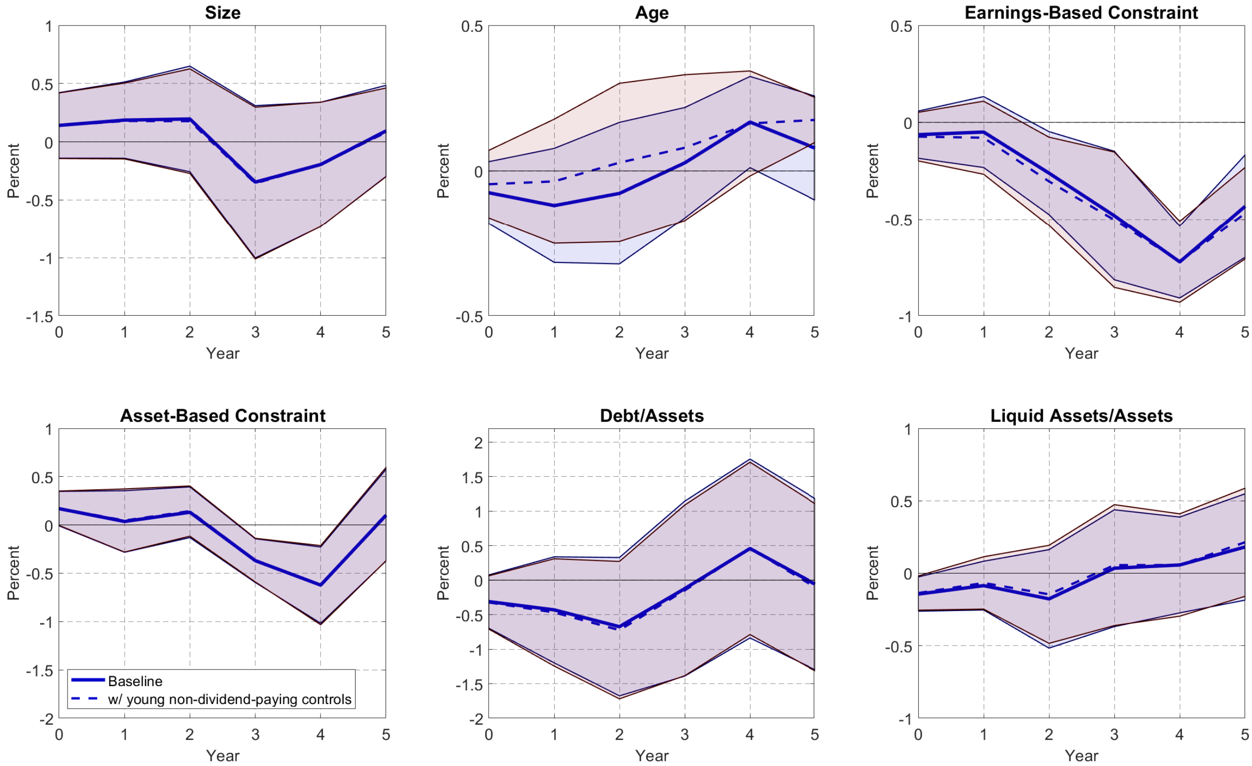
where $\widehat{\Delta i}_t$ is the predicted interest rate change from (C.1).



Notes: The figure shows estimated interaction coefficients with a 1 percentage point contractionary monetary policy shock at annual frequency, based on the local projection approach in (C.2). 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

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

As we can verify in Figure C.1 our baseline qualitative results do not change. The only finding that is robust across the type of monetary policy shocks applied is the proxy for the earnings-based constraint. The sizes of the coefficients of the six interaction terms are also very similar across the monetary policy shock series.



Notes: The figure shows estimated interaction coefficients with a 1 percentage point contractionary monetary policy shock at annual frequency, based on the local projection approach in (C.3). 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

Figure C.2: Marginal effects on the investment response to monetary policy, controlling for young non-dividend-paying firms.

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 is more sensitive to monetary policy. We control for this channel by adding a dummy for young non-dividend-paying firms into our baseline regression (4)

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \nu_t^h + \beta_z^h \cdot \varepsilon_t^{MP} \cdot z_{i,t-1} + \beta_d^h \cdot \varepsilon_t^{MP} \cdot \mathbb{1}_{i,t-1}^{Div} + \gamma_z^h z_{i,t-1} + \gamma_d^h \mathbb{1}_{i,t-1}^{Div} + \gamma^h X_{i,t-1} + u_{i,t}^h, \quad \text{(C.3)}$$

with $\mathbb{1}_{i,t-1}^{Div}$ being a dummy variable that is one for firms being young[22] and do not pay dividends.

We plot the marginal effects of all six interaction terms from equation (C.3) in Figure C.2 and compare the responses with our baseline results from Section 4. The estimated coefficients are very similar, and the prominent role of earning-based constraints on the

[22]The firm age has to be smaller than or equal to 15 years.

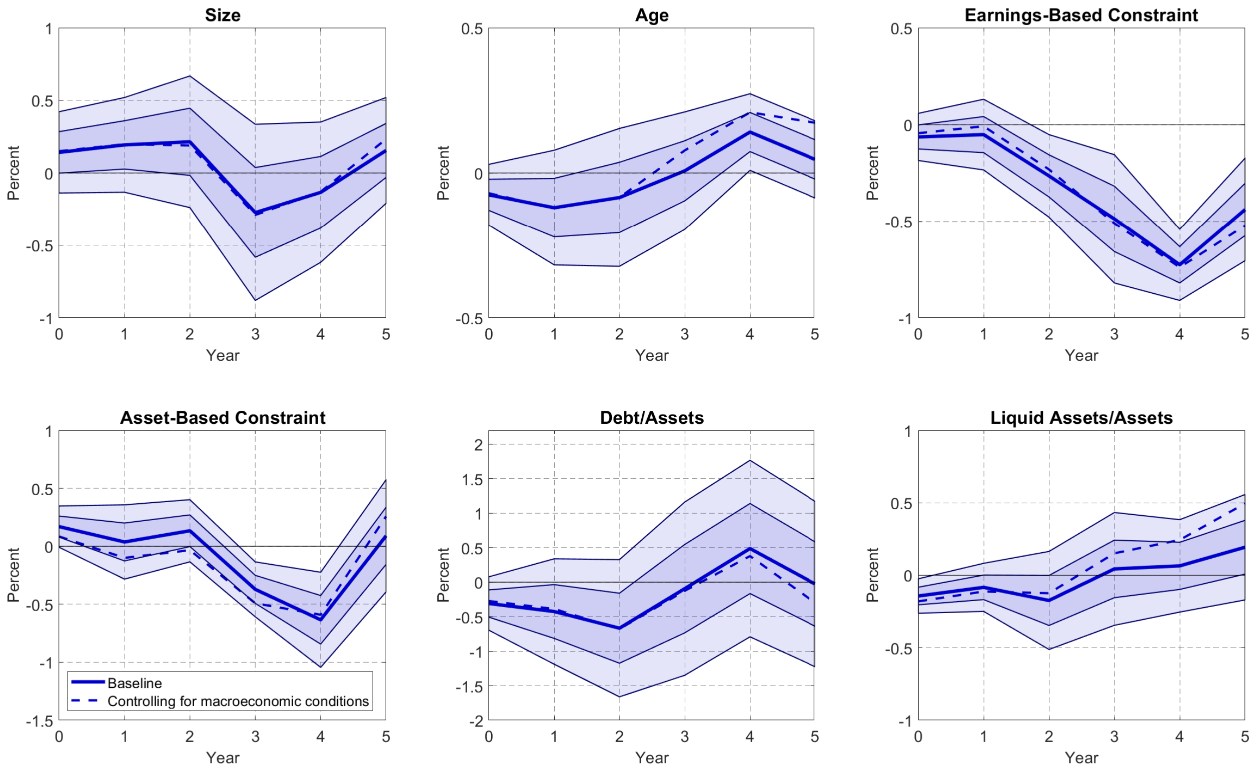
transmission of monetary policy is robust to the inclusion of the dummy for young non-dividend-paying firms.

Controlling for macroeconomics conditions. In this section, we show that the role of the six interaction terms that we discussed in Section 4 is not affected by the business cycle. In order to evaluate whether the business cycle affects the marginal effect results, we interact the six firm variables – firm size, firm age, earning-based constraints, asset-based constraints, debt-to-assets, and liquidity – with a set of macroeconomic conditions. We modify the baseline regression equation in the following way

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \nu_t^h + \beta_z^h \cdot \varepsilon_t^{MP} \cdot z_{i,t-1} + \delta_z^h \cdot Y_{t-1} \cdot z_{i,t-1} + \gamma_z^h z_{i,t-1} + \gamma^h X_{i,t-1} + u_{i,t}^h, \tag{C.4}$$

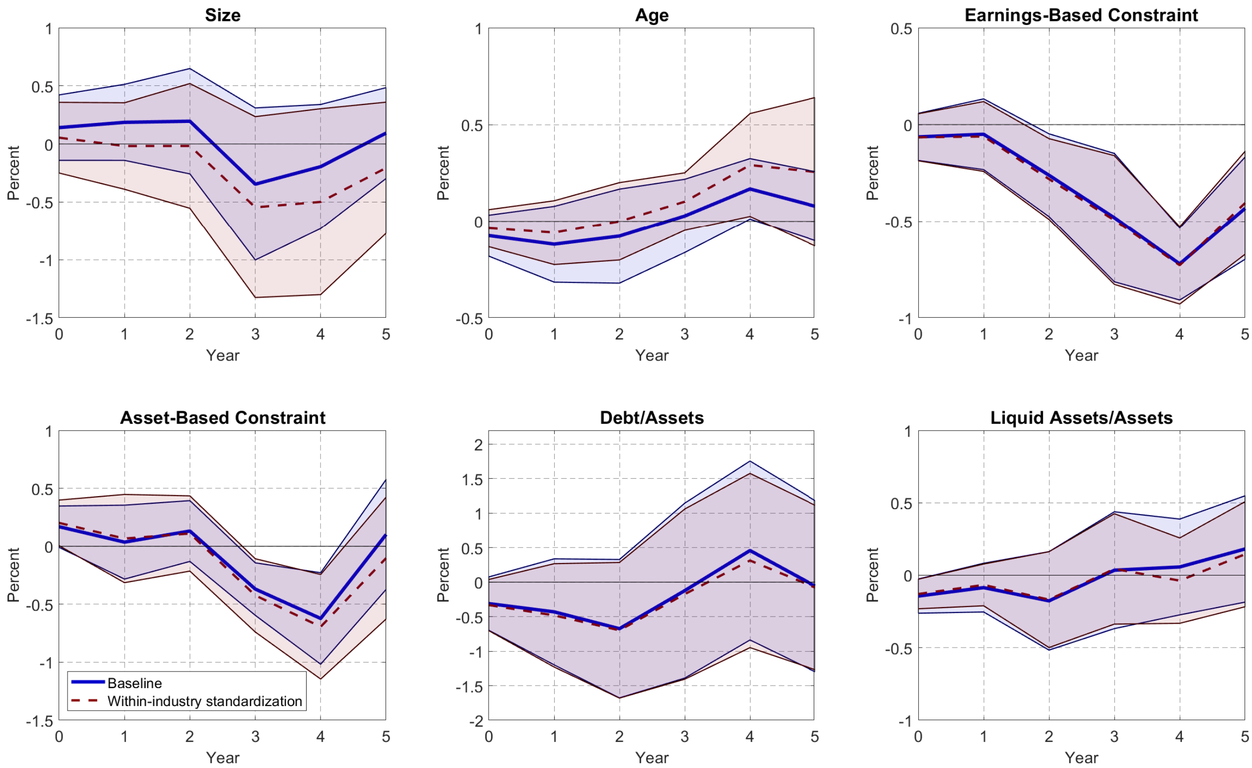
where the set of macroeconomic conditions include one lag of GDP growth, CPI inflation rate, and the change in Norwegian monetary policy rate. The results in Figure C.3 imply that the role of the marginal effects that we find in section 4 is not affected by business cycle fluctuations.

Standardizing the interaction terms within industry. In the body of the paper, we standardize each interaction term variable $z_{i,t-1}$ using the cross-sectional mean and standard deviation. In this section, we instead use within-industry means and standard deviations to standardize. The regression specification itself is the same as in the body of the paper (4). In Figure C.4, we depict the associations between variables and the investment responses to monetary policy using both standardization routines. There are only very minor differences between the two standardization approaches.



Notes: The figure shows estimated interaction coefficients with a 1 percentage point contractionary monetary policy shock at annual frequency, based on the local projection approach in (C.4). 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

Figure C.3: Marginal effects on the investment response to monetary policy, controlling for macroeconomic conditions.



Notes: The figure shows estimated interaction coefficients with a 1 percentage point contractionary monetary policy shock at annual frequency, based on the local projection approach in (4). 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

Figure C.4: Marginal effects on the investment response to monetary policy, cross-sectional standardized interaction terms.

D Appendix to Section 5

In this section, we study the robustness of our findings regarding the direct effects of monetary policy on firm investment rates. We perform two exercises. First, we control for future sales in the direct-indirect regression to test for the potential role of expected sales. Second, we explore the robustness of our findings that proximity to consumers does not seem to play a role in monetary transmission.

Controlling for future sales. In the paper, we disentangle the direct effect of monetary policy on firm investment responses by simultaneously controlling for the contemporaneous firm-level sale responses on horizon h. A concern may be that firms do not only respond to past sales, they also care about future sales when deciding on investments. Hence, in principle, one should control for expected future sales as the theoretically consistent measure of the indirect effect of monetary policy. We therefore repeat the estimation of the direct effects from local projection regressions (5) but this time we control for future firm sales up to horizon $sales_{i,t+h+k}$ with k being a non-negative integer. We specify the following local projection regressions

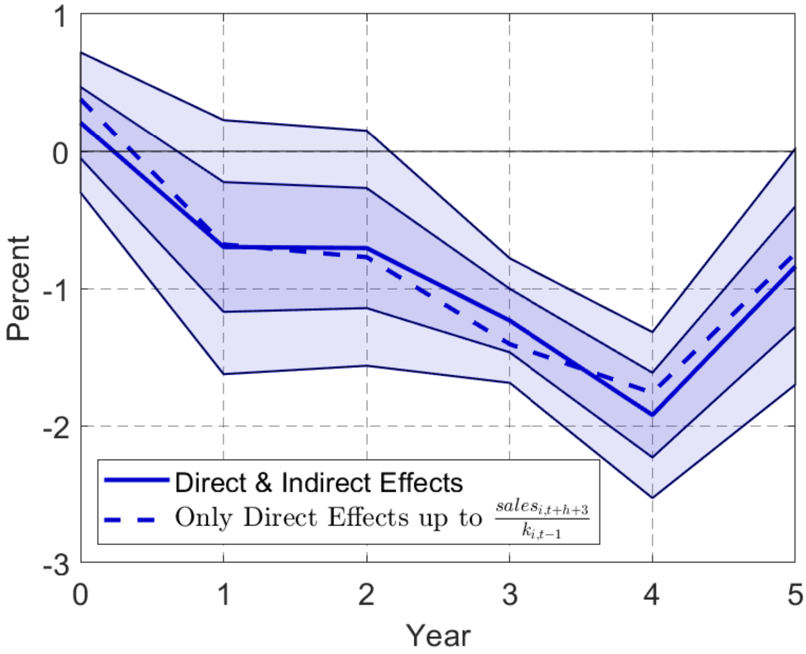
$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \beta^h \cdot \varepsilon_t^{MP} + \gamma^h X_{i,t-1} + \sum_{m=0}^{h+k} \gamma_m^h \frac{sales_{i,t+m}}{k_{i,t-1}} + u_{i,t}^h, \tag{D.1}$$

with k being the forward-looking horizon of expected future sales.

Figure D.1 shows the direct and indirect effects of monetary policy for the case where $k = 3$. Controlling for future sales does not alter our baseline results on the direct effects of monetary policy on firm investment responses. The depicted investment response in Figure D.1 are similar to our results in Section 5.[23]

The effect of proximity to consumers when controlling for all other variables. In a third exercise in the paper, we study the role of indirect effects of monetary policy on firm investment by using the proximity-to-consumers measure. In Section 5 we use proximity-to-consumers as the single interaction term and visualize the association between proximity-to-consumers and the investment response to monetary policy in Figure 8b. In the following, we now include the six other interaction terms from Figure 5: firm size, firm age, leverage, liquidity, earning-based constraints, and asset-based constraints.

[23] When k is large, we lose observations because it requires balancing on more years. We therefore restrict attention to $k = 3$ but the results are almost identical if we use $k < 3$.



Notes: The figure shows estimated coefficients under a 1 percentage point contractionary monetary policy shock at annual frequency, based on the local projection approach in (D.1). 68 and 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

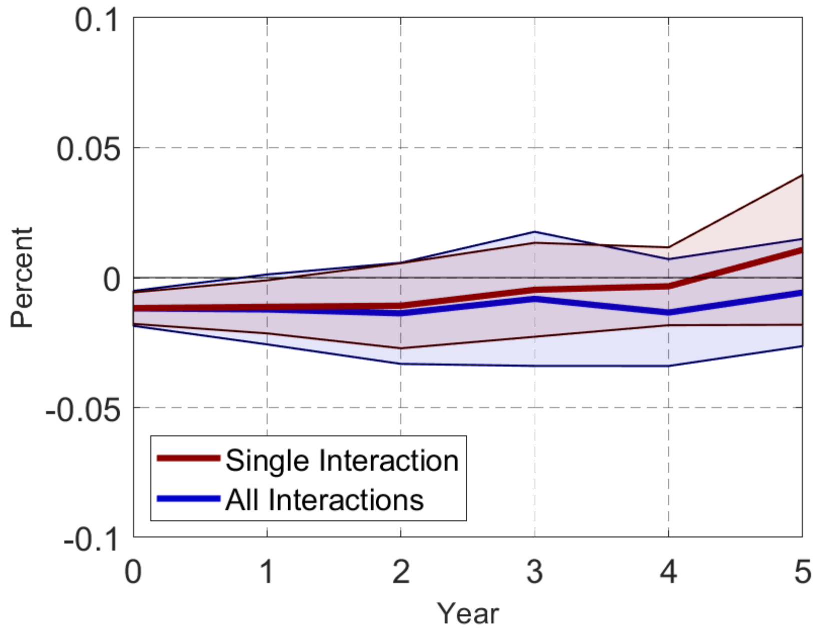
Figure D.1: Direct and indirect effects of monetary Policy on firm investment controlling for future sales.

We estimate the local projections

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \nu_t^h + \beta_z^h \cdot \varepsilon_t^{MP} \cdot z_{i,t-1} + \beta_{z,m}^h \cdot \varepsilon_t^{MP} \cdot \tilde{m}_i + \gamma_z^h z_{i,t-1} + \gamma_{z,m}^h \cdot \tilde{m}_i + \gamma^h X_{i,t-1} + u_{i,t}^h. \quad \text{(D.2)}$$

with $\tilde{m}_i$ denoting the proximity-to-consumers and the vector $z_{i,t-1}$ includes all other six interaction terms.

The difference in the association between $\tilde{m}_i$ and the investment response to monetary policy when controlling for all seven interaction terms instead of including only proximity-to-households are indistinguishable. Figure D.2 displays the estimated interaction coefficients for the proximity-to-consumers using a single interaction and including all other interactions as well. The estimated interaction coefficients are very similar, still suggesting that proximity to consumers plays a minor role in explaining variation in the investment response to monetary policy.



Notes: The figure shows the estimated interaction coefficient to a 1 percentage point contractionary monetary policy shock at annual frequency, based on the local projection approach in (D.2). 68 and 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

Figure D.2: The marginal impact of proximity to consumers on the average investment response to monetary policy.