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The Investment Channel of Monetary Policy: Evidence from Norway

NORGES BANK RESEARCH

5 | 2023

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ISSN 1502-8143 (online)
ISBN 978-82-8379-281-2 (online)

The Investment Channel of Monetary Policy: Evidence from Norway*

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May 2023

Abstract

We investigate the transmission of monetary policy to investment using Norwegian administrative data. We have two main findings. First, financially constrained firms are more responsive to monetary policy, but the effect 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 in most cases provides a sufficiently detailed description of the investment channel of monetary policy.

JEL: E22, E52, D22, G31

Keywords: Monetary policy, Investment

*We thank an anonymous referee for Norges Bank working paper series, Husnu C. Dalgic, conference and seminar participants at the Junior Finance and Macro Conference in 2021, Helsinki GSE, Young Researcher Spring Institute 2022, Bank of Finland, Oslo Macro Group, Waseda University, CRC TR 224 Retreat, and Norges Bank for valuable comments and feedback. This project has received funding from the Research Council of Norway (#316301). Tobias König acknowledges financial support from the German Research Foundation (DFG) through CRC TR 224 (Projects C03). This paper should not be reported as representing the views of Norges Bank or the Norwegian Ministry of Finance. The views expressed are those of the authors and do not necessarily reflect those of Norges Bank or the Norwegian Ministry of Finance. Cao: jin.cao@norges-bank.no; Hegna: torje.hegna@econ.uio.no; Holm: m.b.holm@econ.uio.no; Juelsrud: ragnar.juelsrud@norges-bank.no; König: tkoenig@uni-bonn.de; Riiser: mikkel.riiser@bi.no.

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 from 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).

Our main contribution to the literature is twofold. 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] Our second contribution to the literature is to 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); Thürwächter (2022); Jungherr, Meier, Reinelt, and Schott (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 capital responses to monetary policy. Several channels have been proposed through which the vast heterogeneity among firms may affect monetary transmission. We explore six 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 capital responses. Earnings-based constraints are relevant because firms' lending capacity is often related to earnings and not collateral (Lian and Ma, 2021; Ivashina, Laeven, and Moral-Benito, 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 the 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 capital response to monetary policy by one percentage point, from −2.9% to −3.9%. Heterogeneity among firms, therefore, seems to play a minor role in understanding and explaining aggregate monetary transmission. Instead, firms respond relatively similarly to monetary policy, reducing capital 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 capital through direct effects, the investment response is 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 detailed 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 closer to consumers should be more responsive 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. 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 the way in which 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 Norwegian limited liability companies' income statements and balance sheets. Below we describe the data sources, the sample selection criteria, descriptive statistics, and relevant institutional details about Norway.

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 very 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.[3] Furthermore, we will use several variables as interaction variables when investigating the role of firm heterogeneity in monetary transmission. *Age* is the age since the firm's foundation. 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. For borrowing constraints, we follow Lian and Ma (2021) and define borrowing constraints as either a *earnings-based constraint* (proxied by a firm's interest costs as a share of earnings) or an *asset-based constraint* (proxied by a firm's tangible assets to debt ratio).

Sample selection. Our initial sample contains all limited liability companies in Norway, excluding utilities, financial institutions, real estate firms, and the public sector.[4] 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

[3]In the analysis, we use the percentage change in fixed assets rather than the change in investment as our main variable of interest. While analyses using data from national accounts typically use changes in investment, this is a variable we cannot use for individual firms because many firms have years with zero investments.

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

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 loans to total assets higher than 10 and the 1st and the 99th percentile of the main explanatory variables. Moreover, we trim investment (change in fixed assets) at the 5th and 95th percentiles to remove extreme outliers. Our final main sample consists of 8,359 unique firms.

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, for example, 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 about 14 times as large as 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 our main variables of interest in the analysis. When we use standardized variables in Section 4, they are constructed with the means and standard deviations from Panel E.

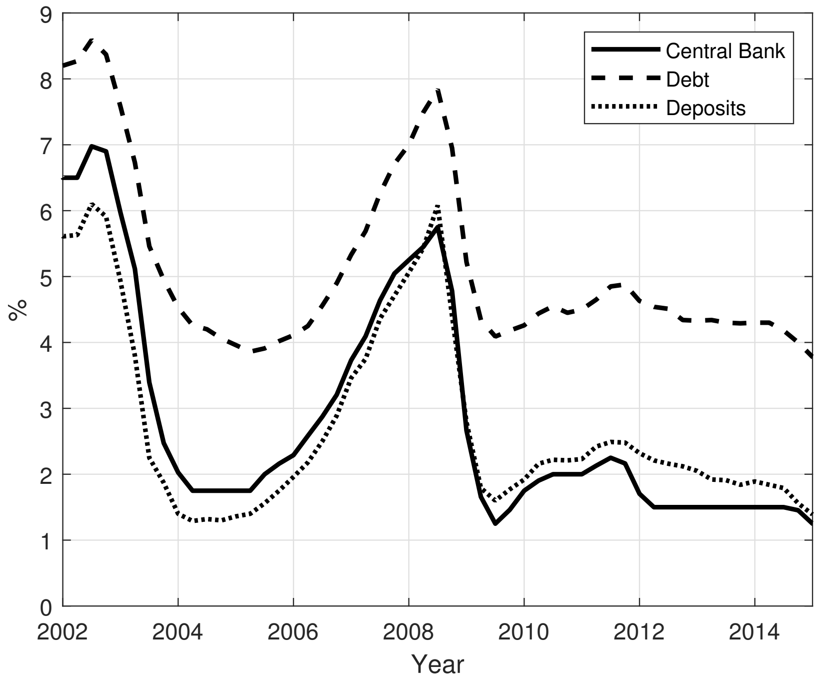
Cash flow sample. In Section 6 we evaluate the role of cash-flow effects on the investment channel of monetary policy. In this section, we additionally use a debt dataset from the Norwegian Tax Administration containing detailed data on individual loans (level and interest payments) from 2003 to 2018. We use the same sample restriction criteria as above, but additionally, 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. The descriptive statistics of the resulting cash-flow sample are summarized in Table A.1. Firms with fixed and adjustable rate contracts are relatively similar. Firms with fixed rate contracts tend to have slightly more debt and fixed assets, and thus higher financial costs.

	Mean	SD	P10	Median	P90
Panel A: Demographics					
Age	17	12	5	15	31
Employees	36	213	3	11	53
Panel B: Income statement					
Sales	89,865	54,9794	3,029	16,818	130,855
Wage bill	17,732	91,050	997	4,669	25,927
Acquisition cost of goods sold	48,111	28,4243	35	5,637	70,897
Other operating expenses	13,777	85,416	682	2,761	19,529
Earnings	8,735	148,517	161	1,187	9,197
Net financial income	-274	37,749	-1,175	-164	118
Interest expenses	1,066	12,991	45	221	1,274
Interest income	312	4,432	1	30	337
Profits before tax	8,461	164,417	-35	903	8,520
Taxes	3,158	103,611	0	245	2,314
Profits after tax	5,301	70,764	-33	652	6,165
Panel C: Assets					
Total fixed assets	37,821	419,859	1,770	5,233	36,866
Intangible assets	3,637	46,863	0	0	906
Tangible (Real) assets	26,624	341,330	1,583	4,539	29,339
Total current assets	32,447	222,049	943	5,291	45,520
Inventory	9,829	67,630	0	607	14,112
Cash & deposits	6,628	66,613	127	1,193	8,442
Panel D: Liabilities					
Total liabilities	47,685	476,674	2,498	8,253	56,236
Long-term debt	23,008	311,038	510	3,317	22,749
Short-term debt	25,613	216,439	743	3,715	31,436
Total assets	70,268	599,519	3,622	11,965	82,914
Equity	21,638	157,625	500	3,026	26,817
Panel E: Main variables					
Investment (percent growth in fixed assets)	2.10	19.28	-14.78	-3.88	28.54
Sales (percent growth)	7.30	34.01	-15.12	3.38	29.73
Size (log of total assets)	9.61	1.30	8.19	9.39	11.33
Firm age (years)	17.28	12.84	5.00	15.00	31.00
Leverage	0.36	0.24	0.04	0.34	0.70
Liquidity	0.14	0.13	0.01	0.10	0.33
EBC (interest costs to EBITA)	0.39	0.61	0.02	0.21	0.88
ABC (debt to intangible assets)	0.72	0.18	0.47	0.74	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 34,628 firm-year observations. Values are in USD 1,000 in 2015.

Table 1: Descriptive statistics.

Institutional setting. The Norwegian corporate sector primarily funds investment through internal funding, bank debt, and equity issuance. A few very large, publicly listed companies issue non-bank external financing.[5] 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 high, illustrated in Figure 1.



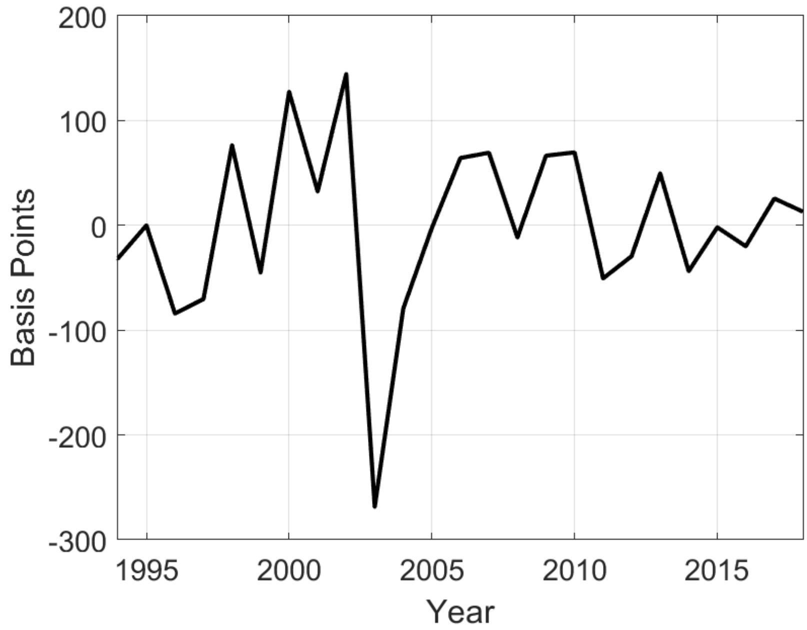
Notes: The figure displays the average interest rate on all outstanding debt and deposits of non-financial firms. "Central Bank" refers to the policy rate of Norges Bank.

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

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 own 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.

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

[5] Around 300 companies in our sample were publicly listed by the end of 2020.



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

Figure 2: Annual monetary policy shocks.

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).[6]

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.

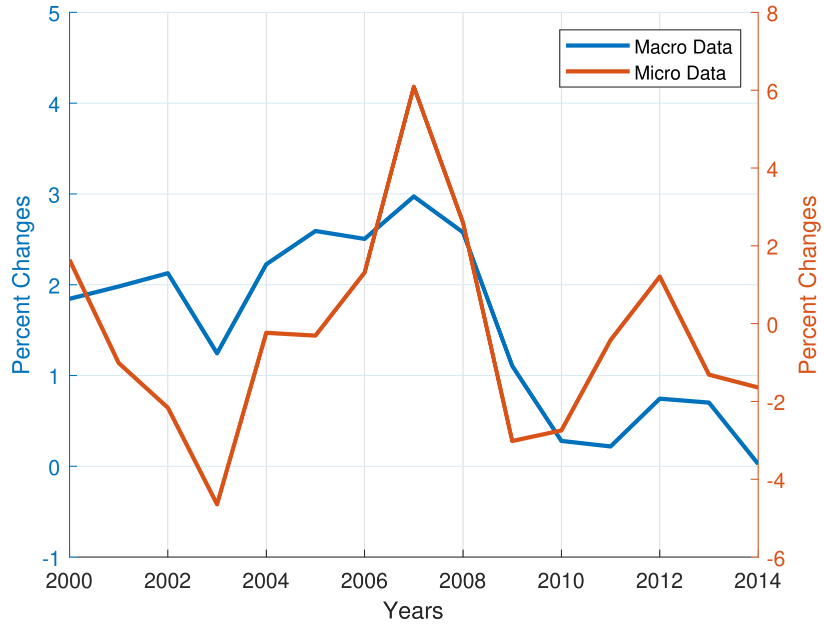
In the following sections, we will regress the firm-level investment rate on annual monetary policy shocks. We argue that the resulting impulse responses are in shape and magnitude similar to the responses we would have gotten when using shocks and investment rates at a higher frequency. Holm et al. (2021) use the same annual monetary policy shock series and demonstrate in Appendix A.10 that time aggregation to annual frequency can produce responses that are identical to responses at quarterly or even monthly frequency.[7] This result relies on the responses of variables to monetary policy being quite persistent and the assumption that the underlying shocks occur with equal

[6]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).

[7]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.

probability within a year. Since investment responses to monetary policy are persistent (see among others, Ottonello and Winberry, 2020; Holm et al., 2021), we argue that these 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.[8] 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.

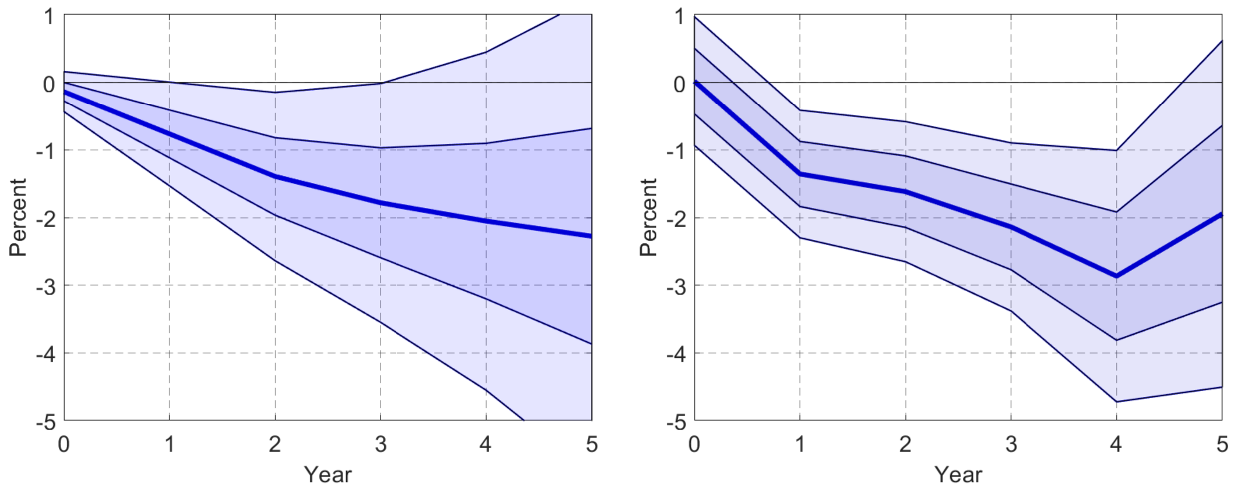


Notes: "Micro Data" shows the growth rate of aggregated fixed assets in the micro data. "Macro data" displays the growth rate of fixed assets in the national accounts using the 13 sectors corresponding to the micro data.

Figure 3: Investment in aggregate and micro data.

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 inflation rate, the three-month

[8] 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).



(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 (1) and (2). 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.

NIBOR (Norwegian Interbank Offered Rate), the 10-year yield on Norwegian sovereign debt, the NOK-USD exchange rate, and house and oil prices. In addition, we include a measure of Norwegian unemployment rates that we retrieved from the Federal Reserve Bank of St. Louis's FRED database.

3 Aggregate and Average Investment Responses

This section presents our results on how monetary policy affects average investment. We first use local projects 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

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

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 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

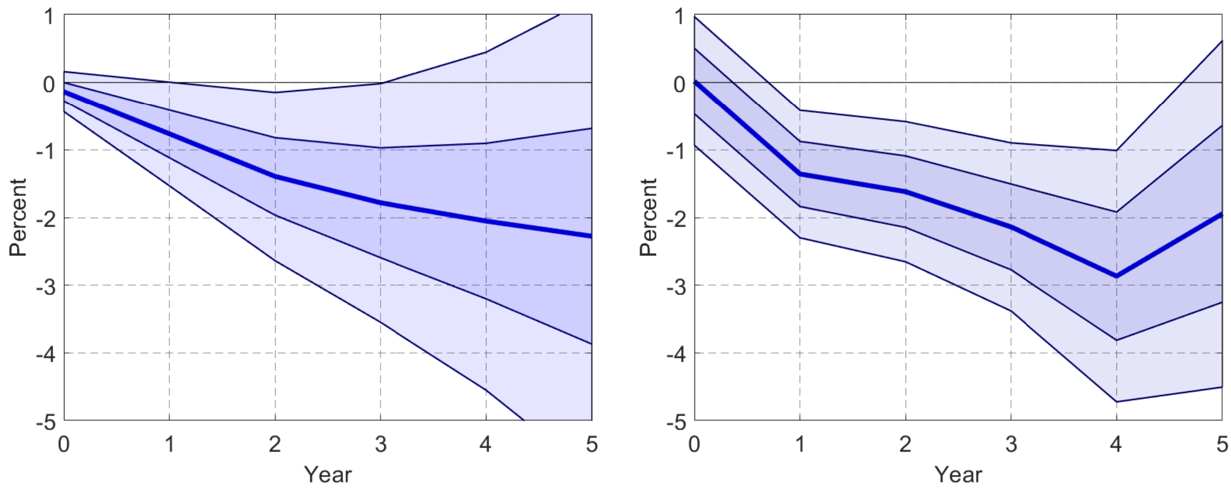
$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \beta^h \cdot \varepsilon_t^{MP} + \gamma^h X_{i,t-1} + u_{i,t}^h, \tag{2}$$

where $h = 0, 1, ..., 5$. The main difference from (1) is that we now control for firm fixed effects. To ensure a relative conservative inference accounting for cross-sectional correlations, we follow Driscoll and Kraay (1998) when computing the standard errors robust to general correlations between firms and years.

Results. Figure 5 presents the results of estimating (1) and (2) 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 around 2 percent in years 4 and 5.[9]

Robustness. We delegate the robustness exercises for the average firm-level investment responses to Appendix B. Figure A.3 contains five robustness exercises. Figures A.3(a) and (b) show results when we control for several macroeconomic variables and factors. Both 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 A.3(c), (d), and (e) 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 these cases.

[9]The macro investment response we estimate differs from the one estimated in Holm et al. (2021) for two reasons. 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 change 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.



(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 (1) and (2). 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 5: Aggregate and average investment responses to monetary policy.

4 Heterogeneous Investment Responses

There is substantial heterogeneity among firms. Several papers document different observable variables relevant to explain 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 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 effect* of, for example, liquidity on 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

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

where $h = 0, 1, ..., 5$. Specification (3) is similar to (2) except that we include interaction terms where we interact the monetary policy shock with variable (or vector) $z_{i,t-1}$. The regression also includes fixed effects and the same vector of controls as in (2). We standardize all interaction variables $z_{i,t-1}$ to facilitate comparisons.[10]

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),[11] a proxy for exposure to earnings-based constraints (interest costs over earnings, Lian and Ma, 2021) a proxy for exposure to asset-based constraints (tangible assets to debt), leverage (long-term debt/total assets), and liquidity (liquid assets/total assets, Jeenas, 2019).[12]

Results. Figure 6 summarizes our main results. For each variable, we show two lines describing the marginal effects: when controlling for the single interaction in (3) and when including all six interactions simultaneously in (3).

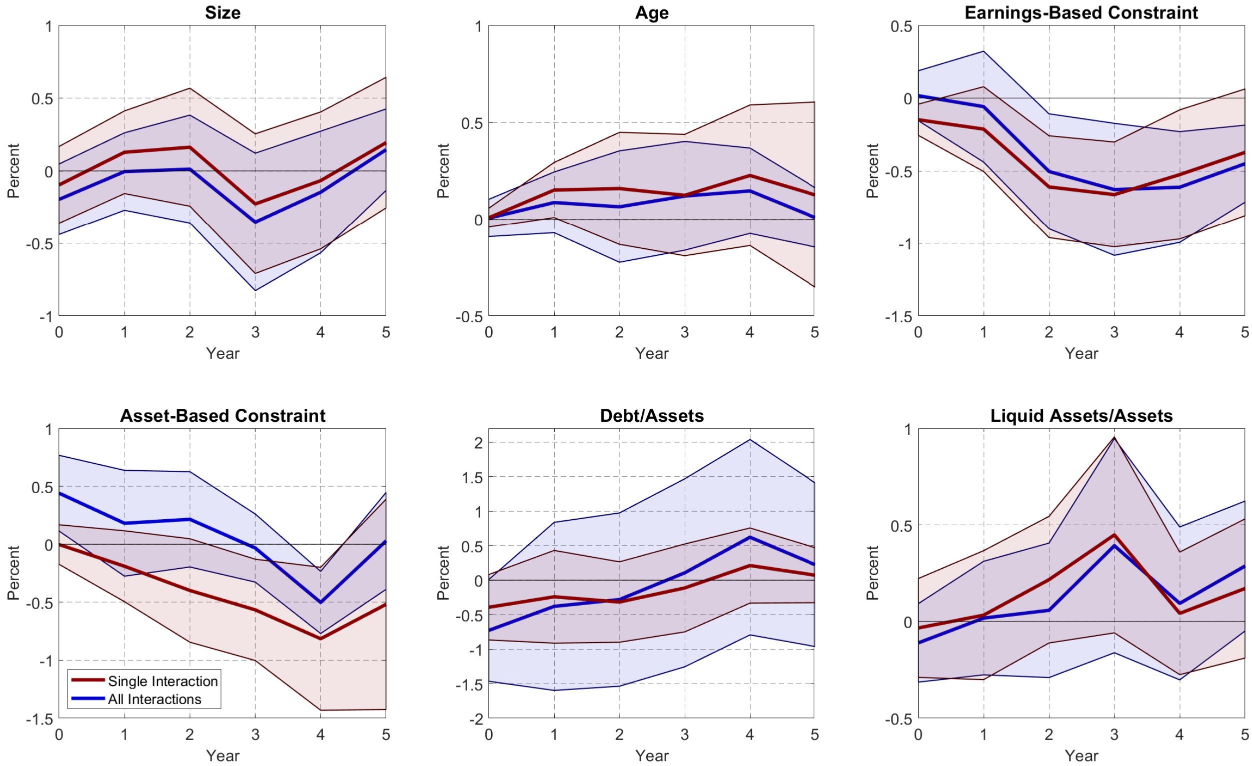
Only one variable robustly explains variation in the investment responses to monetary policy: the proxy for the exposure to earnings-based constraint. Firms that are more constrained according to our measure, meaning that the firms have larger interest costs relative to earnings, respond *more* to monetary policy. One standard deviation increase in our earnings-based constraint measure (0.61 increase in interest costs to earnings) strengthens the investment response by about 0.5 percentage points. The proxy for the asset-based constraint also significantly affects the investment response to monetary policy, but the estimates are imprecise and close to zero when we control for the other firm variables, reducing our confidence in claiming that the asset-based constraint is also important.

Another notable finding is that the estimated marginal effects – except the case of the asset-based constraint – 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

[10]See Panel E in Table 1 for the relevant values used for standardization. Two possible methods exist for standardizing z, either by cross-section or within sectors (by subtracting the sector-level mean). In the results we present below, we standardize along the cross-section. The results are similar when we standardize within sectors, see Appendix C.

[11]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.

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



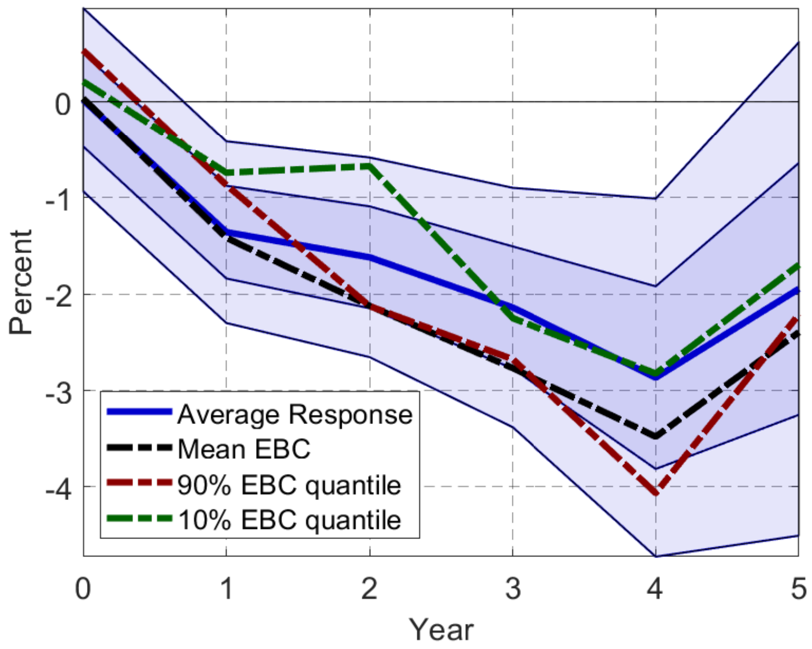
Notes: The figure shows estimated interaction coefficients with a 1 percentage point contractionary monetary policy shock at annual frequency, based on the local projection approach in (3). 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

Figure 6: Marginal effects on the investment response to monetary policy.

yield relevant estimates for most variables. However, verifying the relative independence of variables by including all interactions in the same regression is important.

Quantitative relevance. A remaining question is: while Figure 6 shows that the earnings-based constraint explains variation in the firm investment response to monetary policy, it is unclear whether the marginal effect of varying the earnings-based constraint is quantitatively important. To explore 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 average responses for firms in the 10th percentile and the 90th percentile of the distribution of earnings-based constraints.

The marginal effects we document in Figure 6 are small, implying that the investment response to monetary policy is relatively similar across firms. Figure 7 shows the average investment response together with the implied investment responses in the 10th and



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 (2), 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 (3). 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 earnings-based constraints.

90th percentile in the distribution of earnings-based constraints and the mean investment response of firms having one standard deviation higher earning-based constraints, based on the results in Figure 6.[13]

We highlight two observations. First, while the responses do differ, the variation is relatively small. For example, the average investment response in year 3 is -2.14% and identical to the response in the 10th percentile. Both the response of the 90th percentile and the mean earning-based response are around 0.6 percentage points lower and lie within the 68% error bands of the average response. Second, we find a nonlinear effect for earning-based constraints. Firms at the bottom of the earning-based constraint distribution are not different from the average firm. Instead, the mean effect depicted in the results in Figure 6 is driven by the top percentiles of the distribution, as suggested by theory.

[13] We estimate for this exercise equation (3) twice but replace the baseline earning-based constraint measure either with a dummy for firms in the 10th percentile of the earning-based constraint distribution or with a dummy variable for the 90th percentile of the earning-based constraint distribution. We then add the estimated marginal coefficients on top of the average response.

Robustness. We discuss several robustness exercises for the marginal effects in Appendix C. First, we provide an additional exercise where we control for a dummy of young dividend-paying firms as suggested by Cloyne et al. (2023). We visualize in Figure A.4 that the estimated baseline marginal effects are robust to the inclusion of the Cloyne et al. (2023) variable. Second, we include time-fixed effects in the baseline local projection (3). We then demonstrate in Figure A.5 that the quantitative role of firm heterogeneity for the transmission of monetary policy in this section is neither confounded by business cycle effects nor other macroeconomic shocks. The estimated marginal effects are indistinguishable from our baseline results.

Third, to rule out that differences in business cycle cyclicality drive our marginal effects, 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 A.6). Fourth, our estimated marginal effects are also robust to controlling for foreign monetary policy shocks. We show in Figure A.7 that the investment response of firms with high interest costs relative to earnings (our proxy of earning-based constraints) is not confounded by the effects of foreign monetary policy.

In addition, the baseline marginal effects we estimate in this section are similar to those we find when we standardize the interaction terms within sectors rather than along the cross-section. We visualize this finding in Figure A.8. 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. The only measurable differences we find with respect to different standardization methods are for firm size and firm age. But the marginal effects are insignificant for age and firm size irrespective of the standardization approach applied.

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 relatively unimportant quantitatively. 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, because interest rate changes also affect other sectors in the economy, such as households, there will be indirect effects where monetary policy affects firms' demand. 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 (2) but control for the evolution of movements in firm demand, proxied by firm sales.[14] The local projections we estimate are

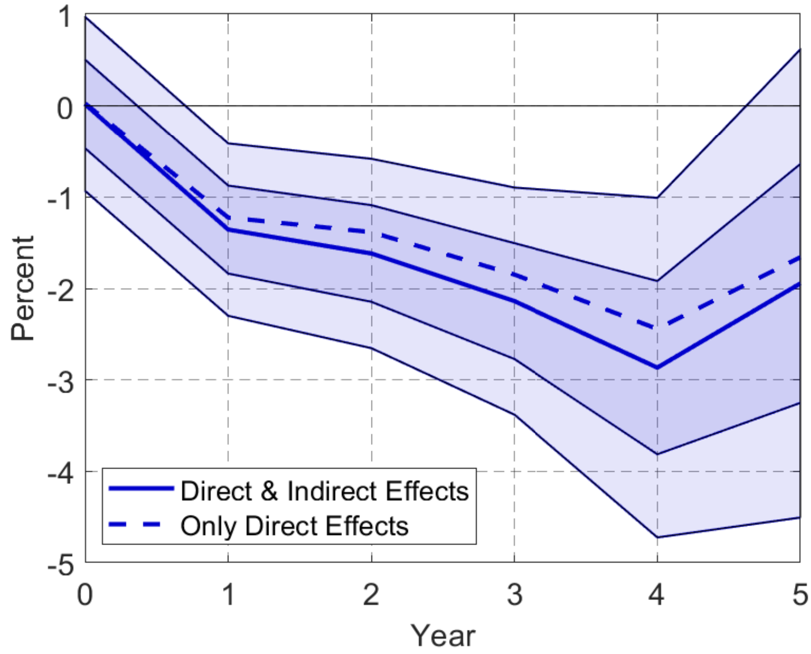
$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \beta^h \cdot \varepsilon_t^{MP} + \gamma^h X_{i,t-1} + \sum_{m=0}^{h} \gamma_m^h \frac{sales_{i,t+m}}{k_{i,t-1}} + u_{i,t}^h, \tag{4}$$

where the only change from (2) 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.

Figure 8 shows the estimates of β^h using (2) (direct and indirect effects) and (4) (direct effects only).[15] The firm investment response to monetary policy is primarily driven by

[14] The underlying assumption here is that by controlling for firm sales, we control for all effects of aggregate demand on firms' investment. This is arguably a strong assumption and represents at best a lower bound on the potential strength of the indirect effects.

[15] In (4), using sales as a proxy for individual firm demand is potentially problematic. Firm sales may respond to aggregate demand movements and to firm investment through supply channels. To address



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 (2) and (4). 68 and 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

Figure 8: Direct and indirect effects of monetary policy on firm investment. Controlling for sales.

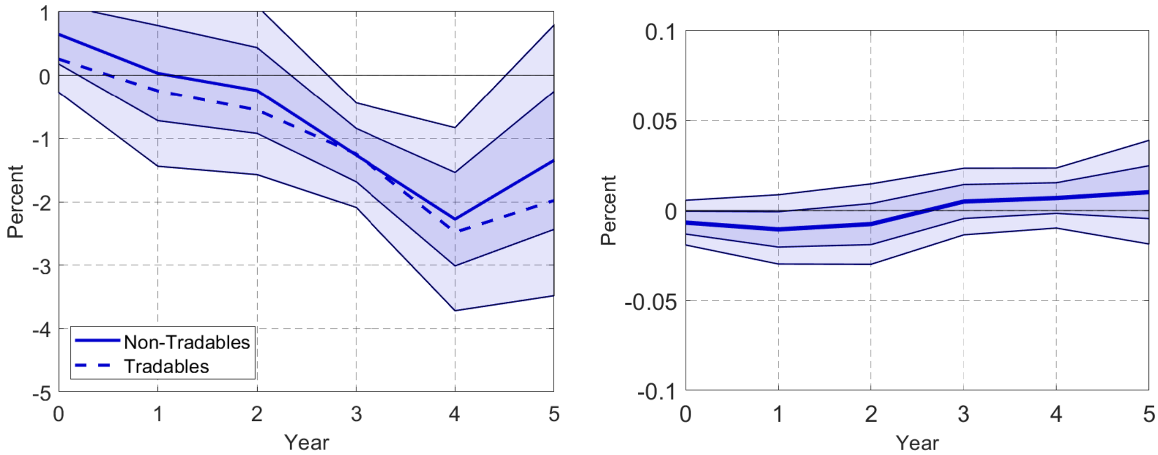
direct effects, i.e., interest rate changes, and not by changes in aggregate demand. The direct effects are smaller than the total effects but remain close to the total effects at all horizons. Hence, our results suggest that the indirect effects of monetary policy only play a minor role in driving the firm investment response to monetary policy.

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.

We proceed by estimating the average investment response for firms operating in the tradable vs. non-tradable sector. In Figure 9a, we plot the average investment response for the two types of firms. The average investment response is virtually indistinguishable between the two sectors, suggesting that changes in local demand conditions in response

this issue, we run a specification where we control for aggregate variables as proxies for aggregate demand instead of firm-level sales. In Figure A.10 in Appendix D, we use movements in GDP and unemployment as measures of aggregate demand. The results are indistinguishable from Figure 8.

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 (2). 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 (3). 68 and 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

Figure 9: 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

$$\tilde{m}_i^h \equiv \frac{m_{s(i)}^h}{M_{s(i)}}. \tag{5}$$

We include this proximity-to-consumers measure in the local projection regression as an interaction term, similar to (3). Figure 9b 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.[16] Hence, our evidence does not suggest that the indirect effects of monetary policy

[16]Figure 9b shows the results when we include proximity to households as a single interaction term.

are important in explaining the firm investment response to monetary policy.

Robustness. As we show in the following Section 6, the investment decisions of firms are predominately driven by changes in the net present value of future projects. Thus, we repeat in the first exercise in Appendix D the estimation of the direct effects from local projection regressions (4) but this time we control for expected firm sale responses up to a time horizon of three years in the future. We show that controlling for expected 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, we modify the local projection equation (4) and use the responses of aggregate Norwegian GDP and the unemployment rate instead of firm-level sales responses as proxies for changes in aggregate demand. We show that the identified direct effects of monetary policy on firm investment are robust to the inclusion of these alternative proxies.

In a third exercise depicted in Appendix D, we show that our identified results for the proximity to consumers interaction term are robust to the inclusion of the additional six interaction terms from Figure 6: 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 (i) they affect the net present value of investment projects and (ii) 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 large role in the investment channel of monetary policy.

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. Next, we compare their investment response to a monetary policy

Figure A.11 in Appendix D shows the results where we include all interaction terms from Figure 6. The results are indistinguishable.

shock. The idea is that since aggregate monetary policy affects both groups equally, the differencing takes out all aggregate effects and the difference-in-difference setup identifies 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. Second, we assume that the monetary policy shocks are exogenous to firms and that this exogeneity is uncorrelated with the type of debt contracts firms have. In Appendix B, we show that the monetary policy shock satisfies the lead-lag exogeneity (Stock and Watson, 2018) and is orthogonal to foreign monetary policy shocks.

Specifically, the empirical equation we estimate is

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_h + \theta_t + \beta_1(\varepsilon_{m,t} \cdot \mathbb{1}_{fr,i,t}) + \beta_2 \mathbb{1}_{fr,i,t} + \beta_3 \varepsilon_{m,t} + u_{i,t} \tag{6}$$

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 (6) 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 contact 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 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.

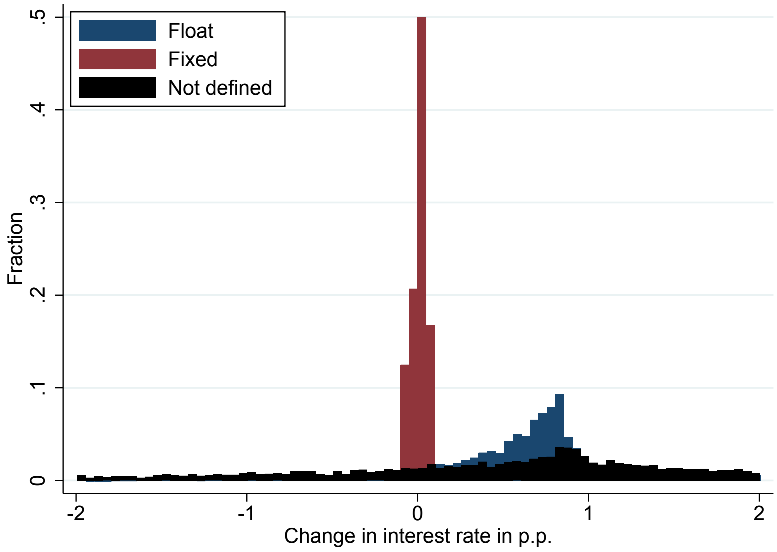
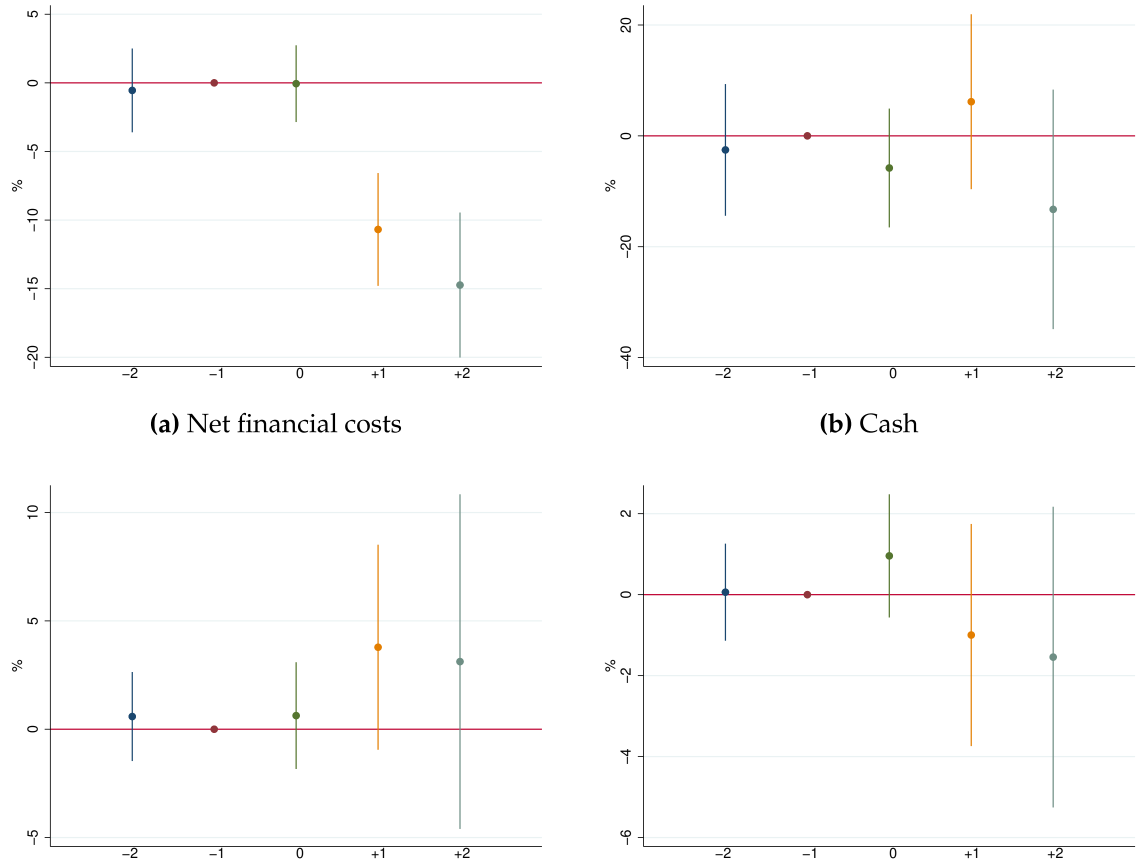


Figure 10: Decomposition into fixed and adjustable interest rate debt contracts.

Figure 10 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 publicly available data.

Results. Figure 11 shows our main results. We first note that the pre-trends are flat, suggesting that there is no systematic difference in growth rates between firms with adjustable and fixed interest rate contracts. Second, Figure 11a 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 11d. 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 (6). 95 percent confidence bands are shown.

Figure 11: Dynamic effects of monetary policy for firms with fixed relative to firms with adjustable rate debt ontracts.

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.

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

subject to

$$K_{t+1} = (1-\delta) K_t + I_t \tag{7}$$

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 $S''(1) = \phi$.

The first-order conditions of the problem above are

$$S'\left(\frac{I_t}{I_{t-1}}\right)\frac{1}{I_{t-1}} = \frac{q_{t+1}}{1+r_t} - 1 \tag{8}$$

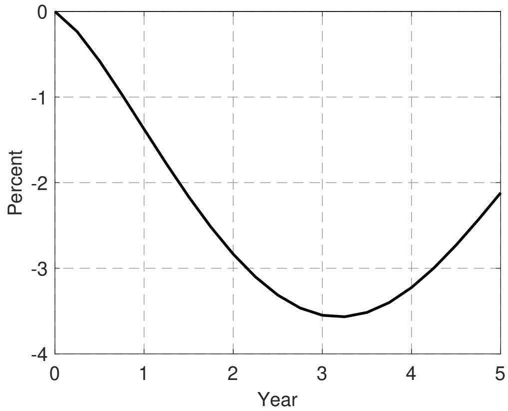
$$q_t = \frac{1-\delta}{1+r_t} q_{t+1} + \alpha A_t K_t^{\alpha-1} \tag{9}$$

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

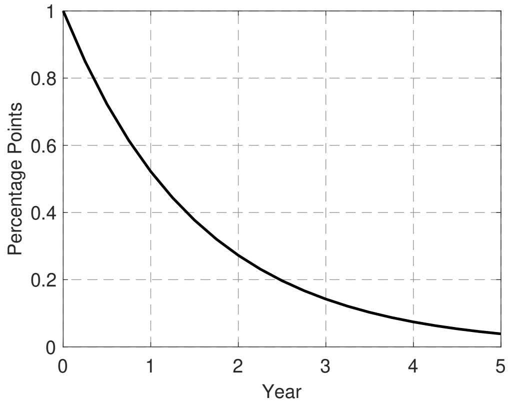
$$r_t = r + \rho_r (r_{t-1} - r) + \varepsilon_t^r,$$
$$A_t = A + \rho_a (A_{t-1} - A) + \varepsilon_t^a,$$

where ρ_r and ρ_a determine persistence, and ε^r and ε^a are shocks. Our calibration follows Auclert et al. (2020), adjusted to quarterly frequencies. We use the following values:

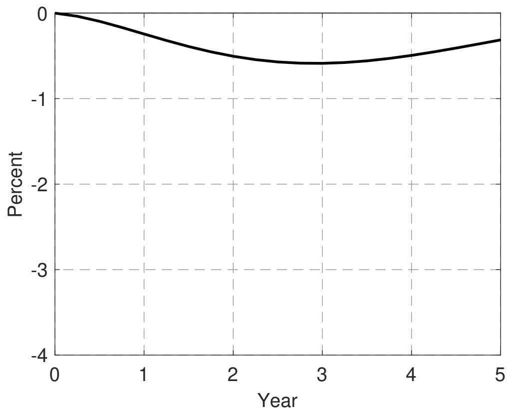
$r = 0.04$ (annual), $K = 9.7$ (determines A), $\delta = 0.052$ (annual), $\phi = 0.005$, $\alpha = 0.24$, $\rho_r = 0.85$ (quarterly), and $\rho_a = 0.85$ (quarterly). We adjust ϕ to ensure that the shape and size of the investment response are similar to the empirical results.



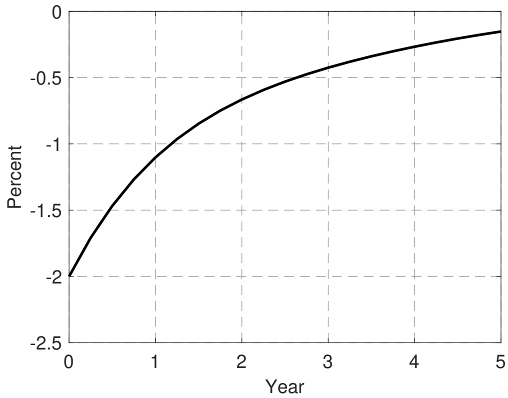
(a) Capital response to interest rate shock



(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 12: Impulse responses to interest rate and productivity shocks.

Simulation results. Figure 12 shows the capital (change in capital, same as (1)) 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 3 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. The main reason for this difference is that the productivity shock (i.e., the change in aggregate demand) is much smaller in relative size compared with the interest rate shock. 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 plays 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.[17]

8 Conclusion

The main results in this paper are that (i) heterogeneity in investment responses to monetary policy exists but is relatively small, and (ii) that monetary transmission to firm investment works predominately through direct effects. These results are consistent with a representative firm model with investment adjustment frictions. We therefore argue that such a representative firm model with investment adjustment frictions provides a sufficiently detailed description of the investment channel of monetary policy.

The results imply that financial constraints play a minor role in aggregate investment dynamics. 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. Moreover, 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 important firms in the economy. However, we

[17]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.

emphasize that financial constraints may be important for research questions other than monetary policy 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 through 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), and thus contributes to affecting also other sectors via indirect general equilibrium effects.

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

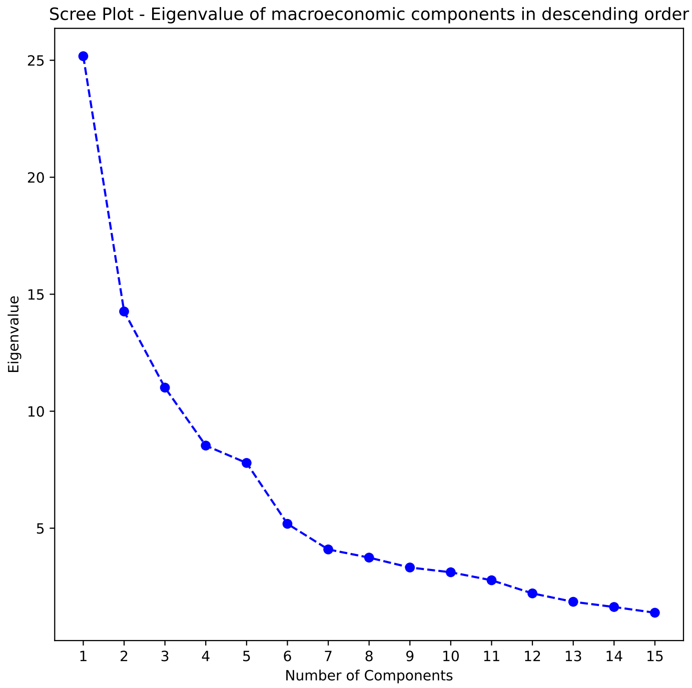
A Appendix to Section 2

	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.

Estimating Norwegian macroeconomic factors. In this section we provide an overview of estimated Norwegian macroeconomic factors that are used at a later stage as additional control variables for the local projections. Using estimated macroeconomic factors as controls guarantees that the estimated impulse response functions are not confounded by a potential violation of the orthogonality assumption between our monetary policy shock series and macroeconomic conditions. The macroeconomic controls that are used, capture a large variety of real and nominal variables including all national account aggregates, all



Notes: Scree plot visualizing the eigenvalues of the estimated Norwegian macroeconomic components in descending order.

Figure A.1: Ordered eigenvalues of macroeconomics components in descending order.

financial account aggregates, a variety of labor market variables, and price indices. For the comprehensive set of macroeconomic controls, we collect around 100 time series publicly available on the Statistics Norway website.[18] The data series in the sample, measured at annual frequency, are in the range 1999:Q4-2019:Q4.

We reduce the dimensionality of the macroeconomic dataset by applying a principal component analysis. Constructing a comprehensive dataset of macroeconomic series and subsequently estimating principal components relates to the work of (Stock and Watson, 2005, 2006; McCracken and Ng, 2016). From the 109 series, we exclude any missing values in the dataset to get a balanced panel by dropping six variables.[19] The dataset is standardized and demeaned.

[18]The collected dataset is available on request.
[19]The series we drop due to missing values is a series of producer price indices for different sectors.

Following König (2022), we define the following factor model:

$$\check{\mathbf{x}}_{i,t} = \Lambda \eta_t^{factor} + \check{u}_{i,t}, \tag{10}$$

with η_t^{factor} denoting the macroeconomic factors. As in Stock and Watson (2002), we estimate the factor loadings Λ and the factors η_t^{factor} via a Principal Component Analysis.

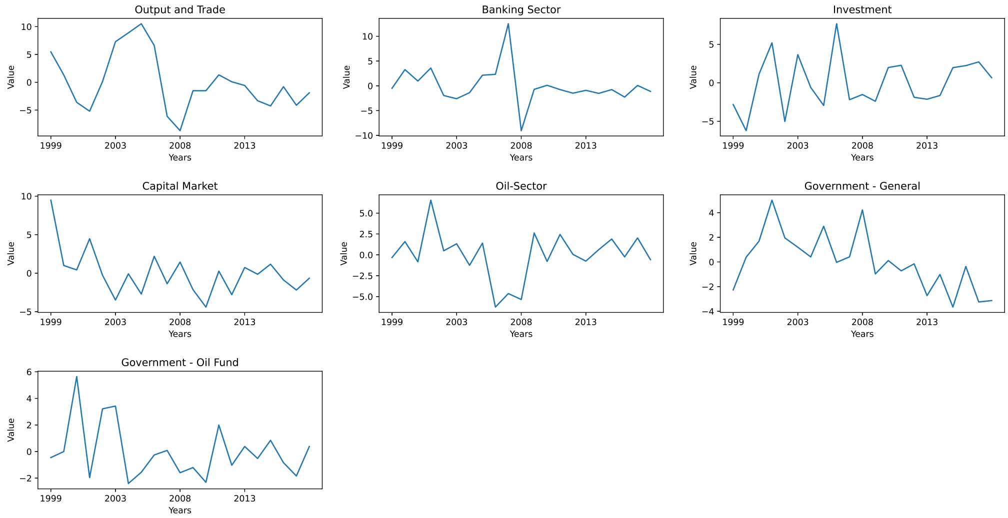
Let $\mathbf{X}$ be a $N \times T$ matrix representing the dataset on the 103 Norwegian macroeconomic series. We estimate the eigenvalues and eigenvectors of the covariance matrix $\mathbf{X^T X}$ via the eigendecomposition:

$$(\mathbf{X^T X})\eta^{\mathbf{factors}} = \lambda \eta^{\mathbf{factors}}, \tag{11}$$

with λ denoting a vector of k eigenvalues and $\eta^{\mathbf{factors}}$ denoting a $T \times k$ matrix with the columns of $\eta^{\mathbf{factors}}$ given by the k eigenvectors.

The eigenvalues of the first 15 components are plotted in a scree plot visualized in Figure A.1. We use the scree plot as an analytical tool to determine the number of relevant macroeconomic components that we will keep. The last non-trivial component – explaining at least 1% of the volatility of the macroeconomic dataset – is the component with the corresponding eigenvalue immediately at the end of the straight scree line. Hence, we include seven macroeconomic components in the robustness checks depicted in Figure A.3.

The seven components explain together more than 76% of the entire volatility in Norwegian macroeconomic variables. As a next step we impose economic meaning on the estimated components. Therefore we estimate the correlation coefficient between each individual component and the 100 Norwegian macroeconomic series.



Notes: The figure shows the estimated seven Norwegian macroeconomic components over time.

Figure A.2: Macroeconomic componentsuUsed as controls in Figure A.3b.

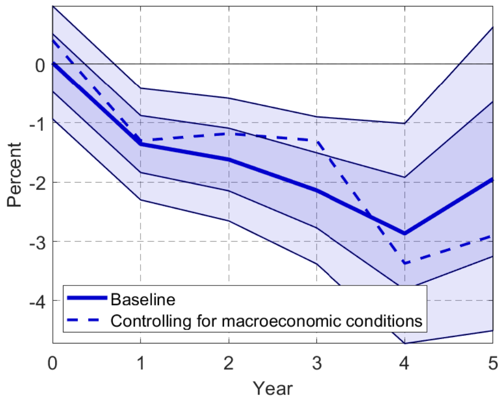
Our results imply the following interpretation for the ordered components:

1. Factor: Real activity – Aggregate output and trade
2. Factor: Banking sector: Loans and long-term debt
3. Factor: Firm investment
4. Factor: Financial markets: Equity and short-term debt
5. Factor: Oil sector
6. Factor: Government – General
7. Factor: Government – Government Pension Fund Global

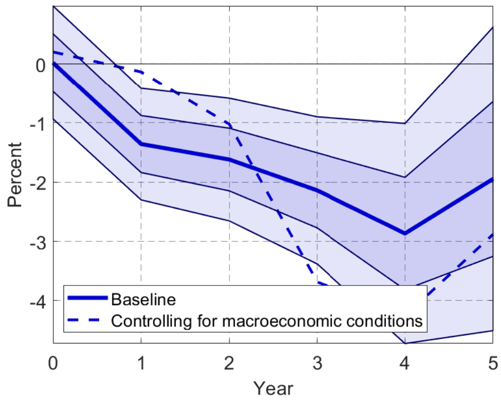
We visualize the seven factors in Figure A.2. The macroeconomic factors are then used as additional controls in the robustness check exercise outlined in Section B.

B Appendix to Section 3

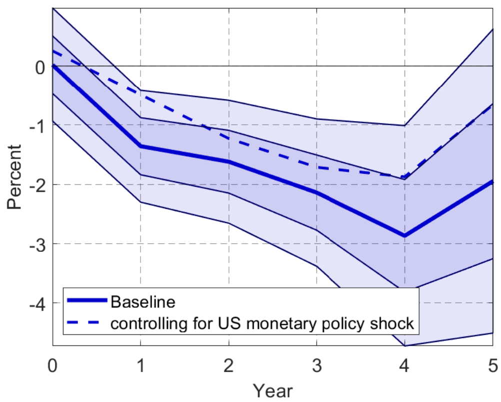
We show in Section 3 that the investment response of the average Norwegian firm to a contractionary monetary policy shock is hump-shaped with a significant peak-to-trough



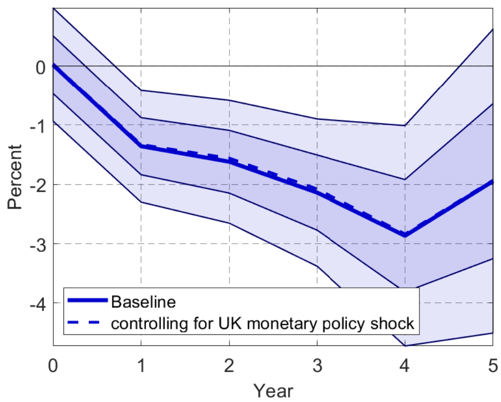
(a) Robustness: macro-economic variables



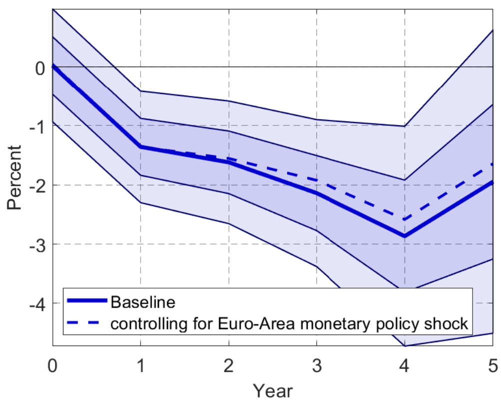
(b) Robustness: macro-economic factors



(c) Robustness: US monetary policy



(d) Robustness: UK monetary policy



(e) 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 (12), (13), and(14). 95 and 68 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

Figure A.3: Robustness of the average firm-level investment response.

response of −3%. In this section, we evaluate the robustness of this finding. First, we show that the size and the shape of the average investment response do not change when including additional macroeconomic controls. Second, we demonstrate that the estimated Norwegian monetary shock series is orthogonal to monetary policy in the US, the UK, and the euro area.

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 2 from the main text by including a set of common macroeconomic variables Y_{t-1}:

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \beta^h \cdot \varepsilon_t^{MP} + \gamma^h X_{i,t-1} + \delta^h Y_{t-1} + u_{i,t}^h. \tag{12}$$

The vector Y_{t-1} includes the one-year lag of the following macroeconomic variables: real GDP growth rate, CPI inflation rate, the three-month NIBOR (Norwegian Interbank Offered Rate), the 10-year yield on Norwegian sovereign debt, the NOK-USD exchange rate, and the rates of increase for both house prices and oil prices.

Controlling for these variables neither affects the magnitude of the response nor the hump-shaped pattern of the investment rate as one see in Figure A.3a. The only macroeconomic control variable that is significant on a 5% level for the entire projection horizon is the yield on 10-year sovereign debt. Controlling for the 10-year yield most likely explains the slight deviations of the estimated responses at horizons three, four, and five from our baseline estimates. The real GDP growth rate, the exchange rate, the house price inflation rate, and the rate of increase of oil prices are statistically significant for the investment response on impact and for the one-year horizon. However, the change in the investment response on impact and after one year is numerically very small.

Although we already control for a large set of macroeconomic variables it might still be that we still fail to control for some important common macroeconomic conditions. To this end, we specify a second regression equation that includes the macroeconomic factors $\eta_{t-1}^{factors}$ estimated in section A:

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \beta^h \cdot \varepsilon_t^{MP} + \gamma^h X_{i,t-1} + \delta^h \eta_{t-1}^{factors} + u_{i,t}^h. \tag{13}$$

When controlling for the macroeconomic factors $\eta_{t-1}^{factors}$, the peak-to-trough cut in the investment rates is slightly larger with a value of around −4% as one can see in Figure A.3b. Nevertheless, the average response remains significant and hump-shaped. The first factor, aggregate output and trade, and the sixth factor, government expenditures, are the only significant factors for the investment response.

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 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:

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \beta^h \cdot \varepsilon_t^{MP} + \gamma^h X_{i,t-1} + \delta^h \zeta_t^{FMP} + u_{i,t}^h, \tag{14}$$

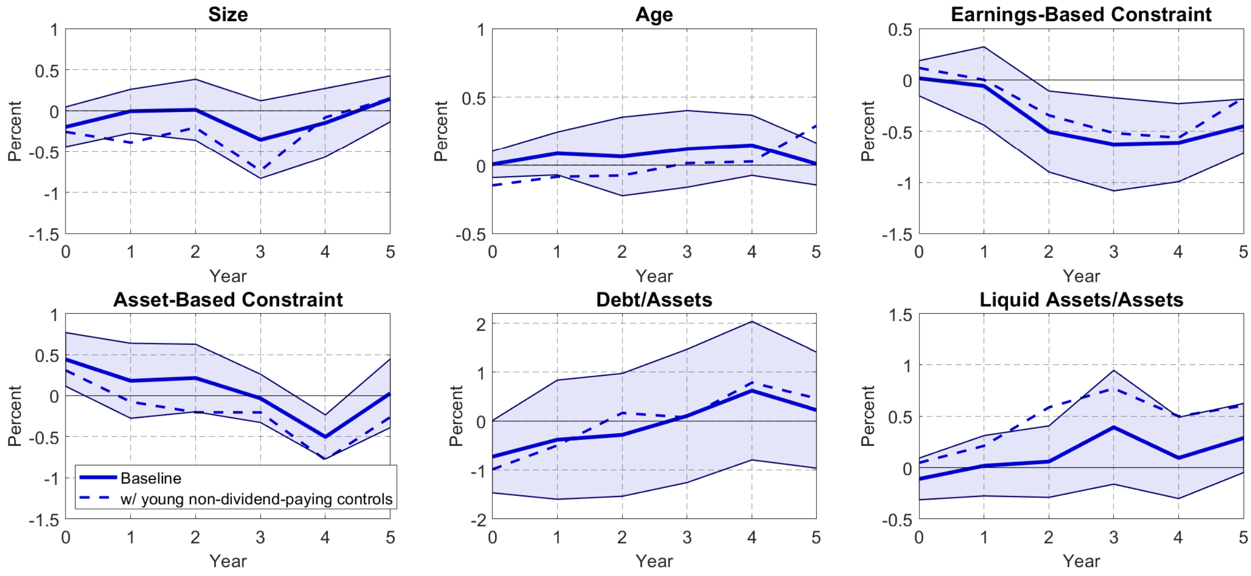
with ζ_t^{FMP} including either one of the monetary policy shocks for the US, the UK, and the euro area that we take from Jarociński and Karadi (2020).

The responses of firm-level investment rates to Norwegian monetary policy shocks, after controlling for the foreign monetary policy, all lie within the 68% confidence bands of our baseline results and the coefficients are numerically close to the results from the main text. We visualize this insight in Figures A.3c, A.3d, and A.3e. We observe the biggest difference in the baseline responses when controlling for US monetary policy. But again also, the investment responses after controlling for the US shocks are still within the 68% confidence bands of 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. Here in this appendix, we explore the robustness of this finding.

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



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 (15). 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

Figure A.4: Marginal effects on the investment response to monetary policy, controlling for young non-dividend-paying firms.

more sensitive to monetary policy. We control for this channel by adding a dummy for young non-dividend-paying firms into our baseline regression equation 3:

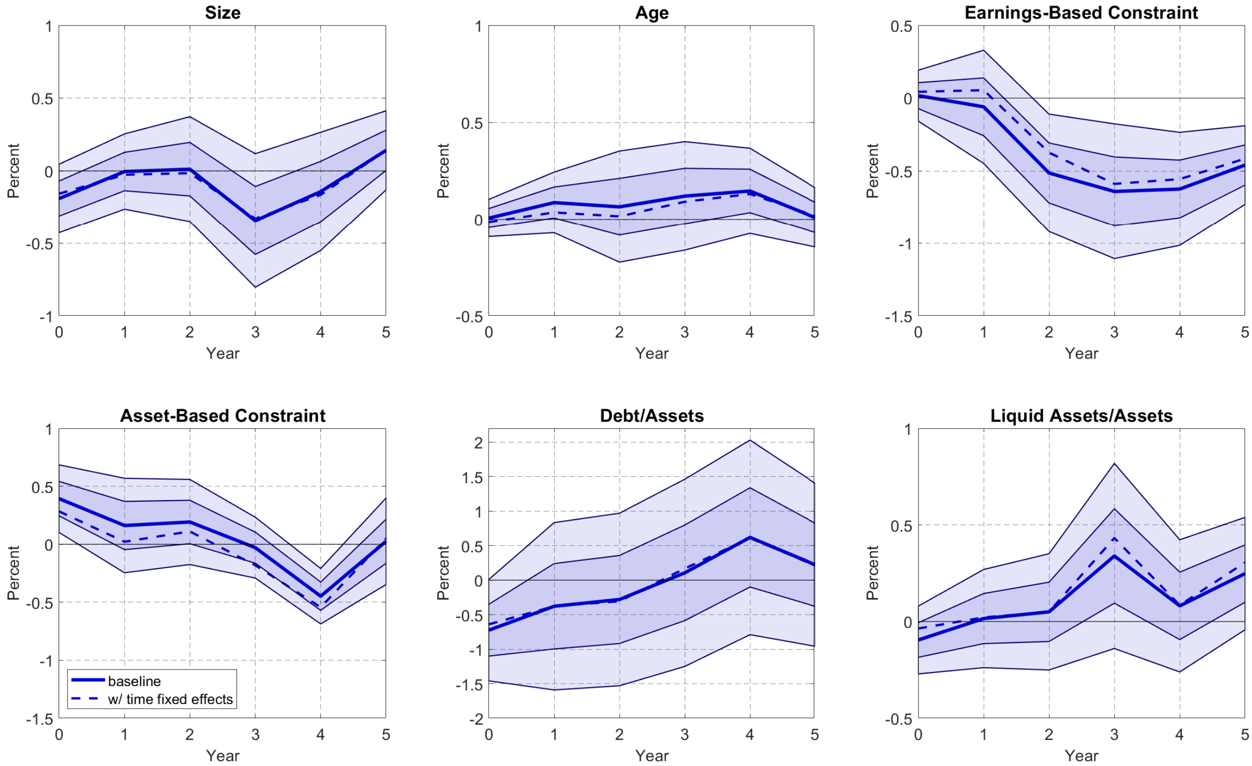
$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \beta^h \cdot \varepsilon_t^{MP} + \beta_z^h \cdot \varepsilon_t^{MP} \cdot z_{i,t-1} + \beta_d^h \cdot \varepsilon_t^{MP} \cdot \mathbb{1}_{i,t-1}^{Div} + \gamma_z^h z_{i,t-1} + \gamma_d^h \mathbb{1}_{i,t-1}^{Div} + \gamma^h X_{i,t-1} + u_{i,t}^h, \quad (15)$$

with $\mathbb{1}_{i,t-1}^{Div}$ being a dummy variable that is one for firms being young[20] and do not pay dividends.

We plot the marginal effects of all six interaction terms from regression 15 in Figure A.4 and compare the responses with our baseline results from section 4. The estimated coefficients are in both cases very similar and the prominent role of earning-based constraints on the transmission of monetary policy is robust to the inclusion of the dummy for young non-dividend-paying firms.

Controlling for additional shocks and cyclicality. In this paragraph, we demonstrate first that our baseline marginal effects results are not driven by macroeconomic shocks other than the Norwegian monetary policy shocks. Second, we show that the role of the

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



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 (16). 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

Figure A.5: Marginal effects on the investment response to monetary policy, controlling for time-fixed effects.

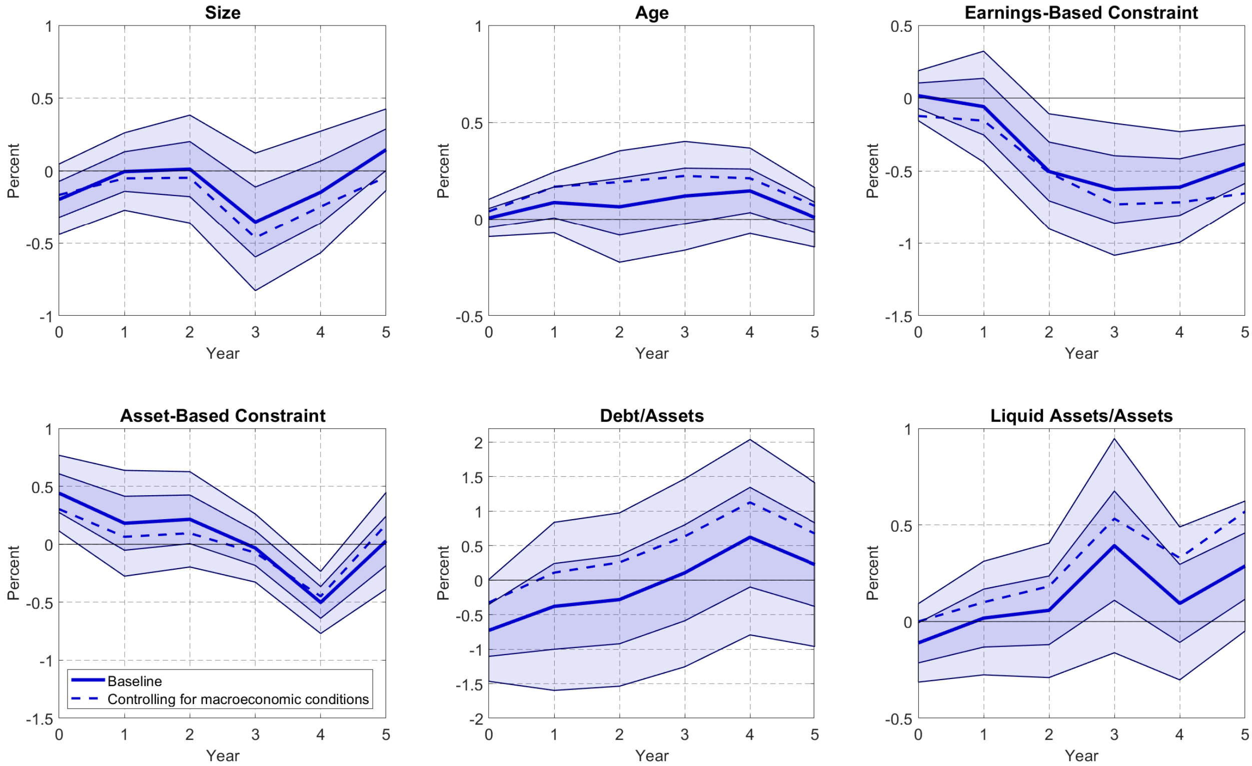
six interaction terms that we discussed in section 4 is not affected by the business cycle.

For the first exercise we include time-fixed effects ν_t into our baseline regression equation 3:

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \nu_t^h + \beta^h \cdot \varepsilon_t^{MP} + \beta_z^h \cdot \varepsilon_t^{MP} \cdot z_{i,t-1} + \gamma_z^h z_{i,t-1} + \gamma^h X_{i,t-1} + u_{i,t}^h. \tag{16}$$

Based on the results visualized in Figure A.5, we conclude that the estimated marginal effects are not confounded by the existence of shocks other than the Norwegian monetary policy shocks. The coefficients for all six interaction terms are all not different from their values in our baseline regression.

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



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 (17). 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

Figure A.6: Marginal effects on the investment response to monetary policy, controlling for macroeconomic conditions.

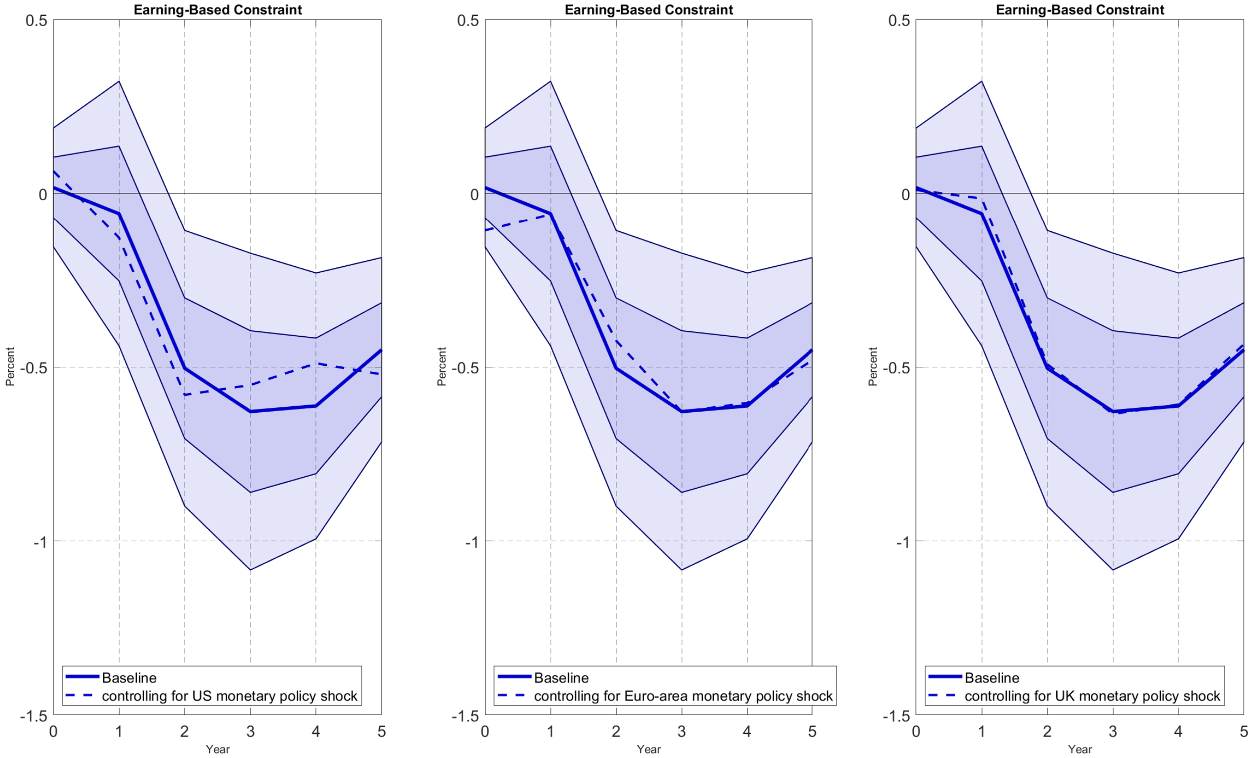
modify the baseline regression equation in the following way:

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \beta^h \cdot \varepsilon_t^{MP} + \beta_z^h \cdot \varepsilon_t^{MP} \cdot z_{i,t-1} + \delta_z^h \cdot Y_{t-1} \cdot z_{i,t-1} + \gamma_z^h z_{i,t-1} + \gamma^h X_{i,t-1} + u_{i,t}^h. \quad (17)$$

The set of macroeconomic conditions includes: lagged GDP growth, lagged unemployment rate, and lagged CPI inflation rate.

The results in Figure A.6 imply that the role of the marginal effects that we find in section 4 is not affected by the business cycle.

Controlling for the role of foreign monetary policy. With the previously reported exercise including time-fixed effects we are able to control for macroeconomic conditions and shocks that might bias the estimated coefficient of the interaction terms. However, by doing so we still can not control for heterogeneity in the firm investment response to



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 (18). 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

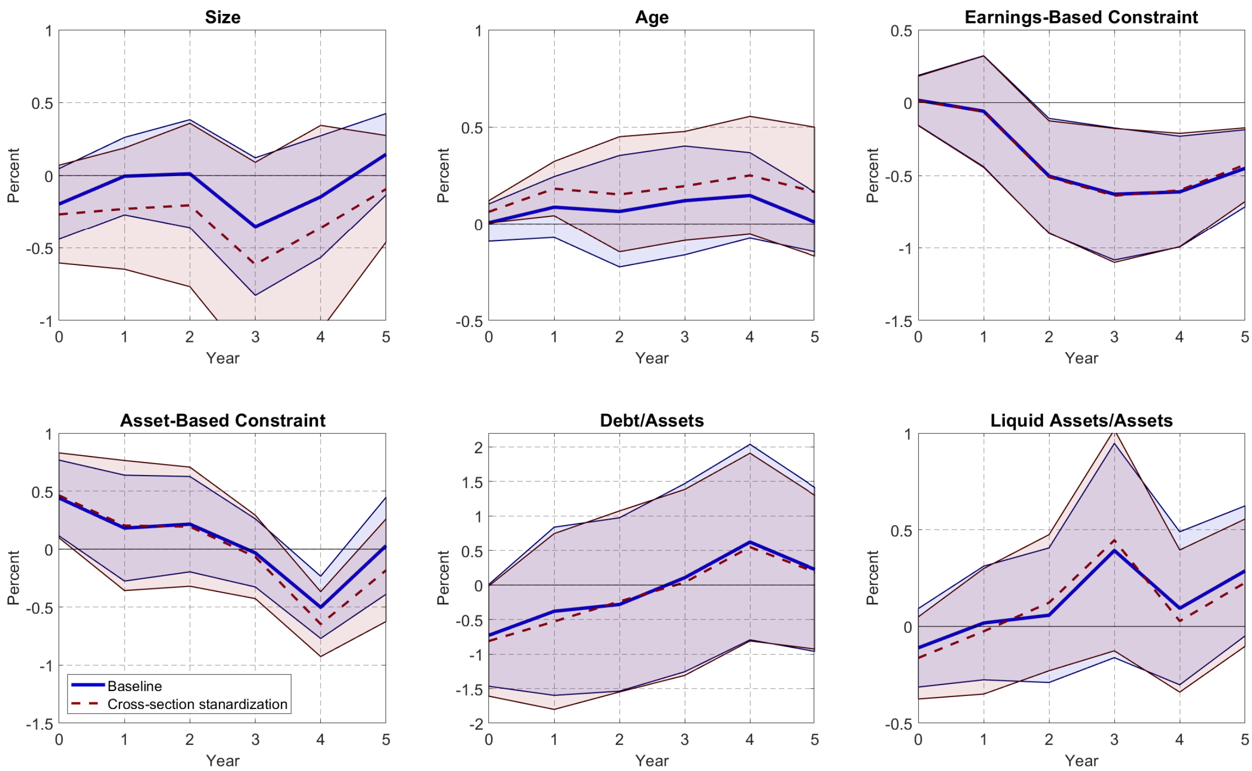
Figure A.7: Marginal effects of earning-based constraints on the investment response to monetary policy, controlling for different foreign monetary policy shocks.

alternative shocks, such as foreign monetary policy shocks. Thus, in this paragraph we test whether the observed role of earning-based constraints for firm investment rates is instead driven by the effects of foreign monetary policy decisions in either the US, the UK, or the euro area on Norwegian firms. To this end we interact the earning-based constraint measure with the three foreign monetary policy shock series ζ_t^{FMP} that we take from Jarociński and Karadi (2020). We modify the regression equation as follows:

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \beta^h \cdot \varepsilon_t^{MP} + \beta_z^h \cdot \varepsilon_t^{MP} \cdot z_{i,t-1} + \delta_z^h \cdot \zeta_t^{FMP} \cdot z_{i,t-1} + \gamma_z^h z_{i,t-1} + \gamma^h X_{i,t-1} + u_{i,t}^h. \quad (18)$$

The variable ζ_t^{FMP} denotes either one of the three monetary policy shock series for the UK, the US, or the euro area.

Our baseline results for the role of the earning-based constraints is unaffected by the



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 (19). 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

Figure A.8: Marginal effects on the investment response to monetary policy, cross-sectional standardized interaction terms.

inclusion of the additional interaction terms with foreign monetary policy shocks. We depict this finding in Figure A.7.[21]

Standardizing the interaction terms along the cross-section. In this last exercise of appendix C we standardize the interaction terms $z_{i,t-1}$ along the industry cross-section by subtracting the industry-level mean. Besides changing the standardization routine for the interaction terms, the regression specification itself is not different from the baseline in equation 3:

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \beta^h \cdot \varepsilon_t^{MP} + \beta_z^h \cdot \varepsilon_t^{MP} \cdot z_{i,t-1} + \gamma_z^h z_{i,t-1} + \gamma^h X_{i,t-1} + u_{i,t}^h. \quad (19)$$

[21]The marginal effects for the other five interaction terms are also unaffected. Due to space limitations we only report the robustness of the earning-based constraint.

Standardizing the interaction terms along the cross-section does not change our results significantly. In Figure A.8 we depict the marginal effects for both standardization routines. Firms' earning-based constraints and little else matter for monetary policy transmission. In fact, the only visible differences when changing the standardization are for firm size and firm age. In difference to the cross-sectional standardization, a firm with one standard deviation larger balance sheet than the sectoral mean cut investment more strongly after a contractionary monetary policy. In turn, in difference to the cross-sectional standardization, firms that are older than the average firm in the sector are less sensitive to monetary policy. However, both coefficients of these interaction terms remain insignificant.

D Appendix to Section 5

In this section of the appendix, we study the robustness of our findings regarding the direct effects of monetary policy on firm investment rates.

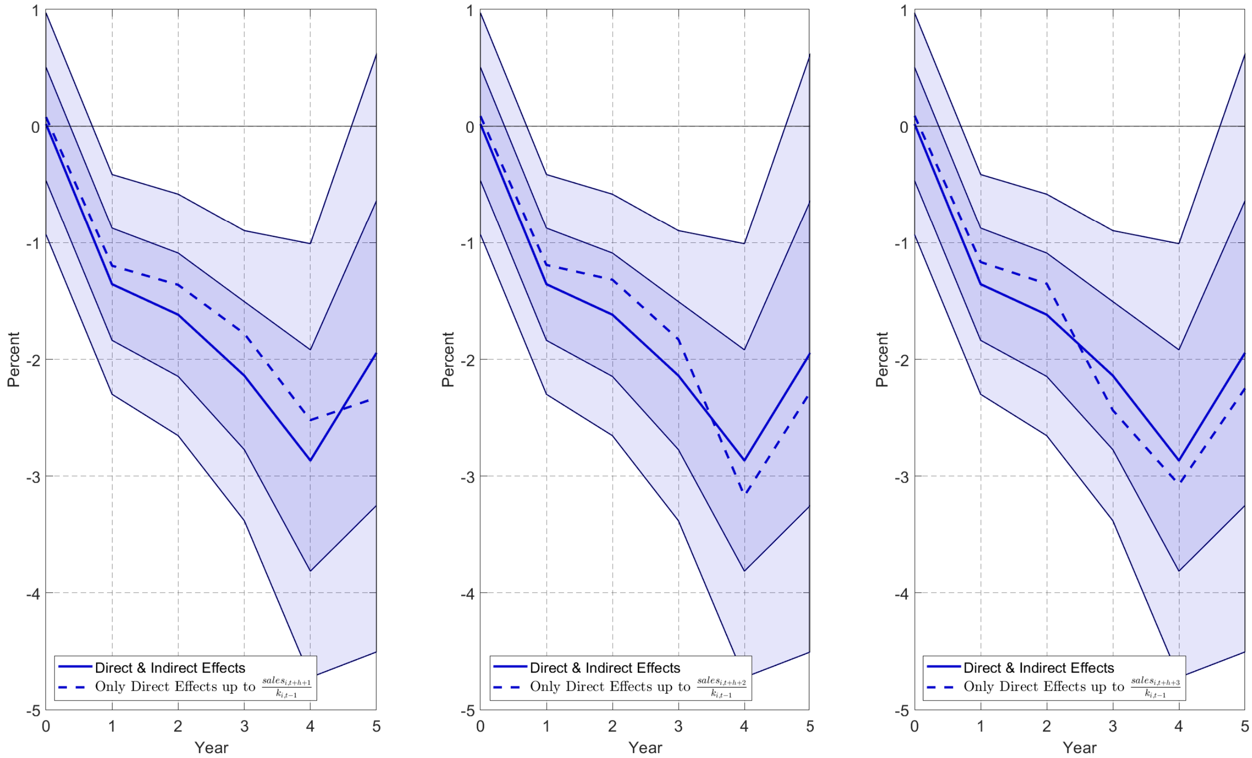
In the paper, we disentangle the direct effect of monetary policy on firm investment responses by simultaneously controlling for the contemporaneous firm-level sale responses on horizon h. However, as we show in Section 6, the investment decisions of firms are predominately driven by changes in the net present value of future projects. Thus, we repeat the estimation of the direct effects from local projection regressions (4) but this time we control for expected firm sale responses up to horizon $sales_{i,t+h+k}$, with $k \in \{1, 2, 3\}$. We thus specify the following local projection regressions:

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \beta^h \cdot \varepsilon_t^{MP} + \gamma^h X_{i,t-1} + \sum_{m=0}^{h+k} \gamma_m^h \frac{sales_{i,t+m}}{k_{i,t-1}} + u_{i,t}^h \text{ with } k \in \{1, 2, 3\}, \tag{20}$$

with $k \in \{1, 2, 3\}$ is the time horizon of the expected sales responses. Thus, we estimate the direct effects of monetary policy on firm investment for three different specifications: (i) when controlling for expected sales up to $t + h + 1$, (ii) when controlling for expected sales up to $t + h + 2$, and (iii) when controlling for expected sales up to $t + h + 3$.

Controlling for expected sales responses in the local projections does not alter our baseline results on the direct effects of monetary policy on firm investment responses. The depicted investment responses in Figure A.9 are qualitatively and numerically identical to our results in Section 5.[22] The reason is that firm sales are very persistent such that sales

[22]The longer the time horizon $t + h + k$ of expected changes in firm sales the fewer firm-year observations are left for regressions (20). That's why we limit the horizon of expected sales to a maximum of three years.



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 (21). 68 and 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

Figure A.9: Direct and indirect effects of monetary Policy on firm investment controlling for expected sales.

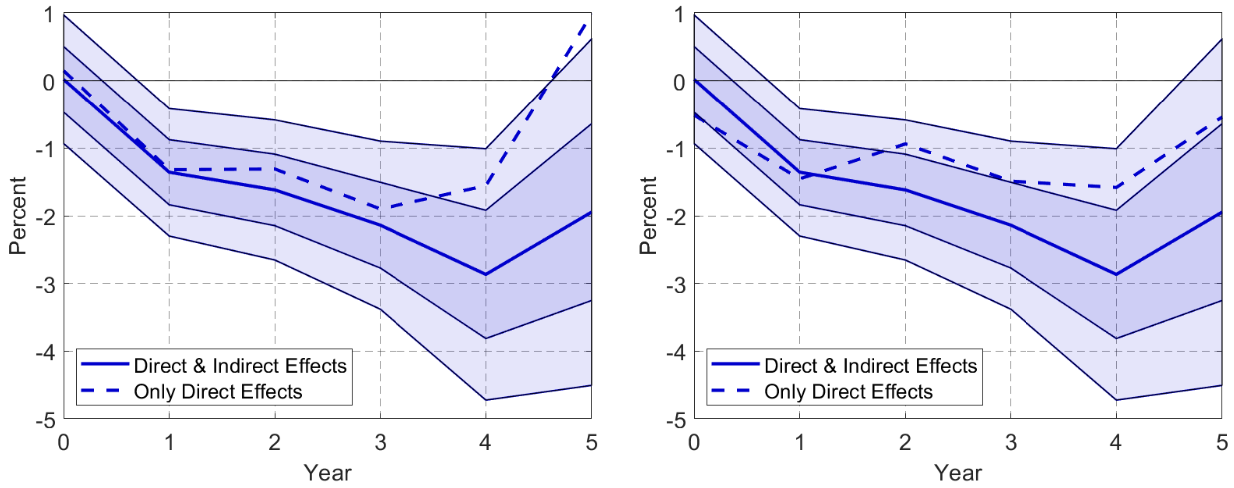
up to horizon $t + h$ do already control for expected changes in aggregate demand.

Controlling for aggregate demand effects by using the evolution of firms' sales, as we do in specification (4) and (20), might not be a perfect proxy for aggregate demand. Firms' sales may respond through supply channels. Instead in this section, we control for aggregate variables as proxies for aggregate demand to address this issue. We use two different proxies for aggregate demand: (i) the Norwegian aggregate GDP and (ii) the Norwegian unemployment rate. The local projections we estimate are the following:

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \beta^h \cdot \varepsilon_t^{MP} + \gamma^h X_{i,t-1} + \sum_{m=0}^{h} \gamma_m^h Z_{t+m} + u_{i,t}^h, \tag{21}$$

where Z_{t+m} includes either GDP or the unemployment rate. As in (4), we estimate the firm investment response at horizon h and we control for movements in the aggregate

The differing number of firm-year observations is also the reason why we observe minor differences in the investment responses on horizon $h = 5$ to our baseline results.



(a) Controlling for GDP **(b)** Controlling for Unemployment

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 (21). 68 and 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

Figure A.10: Direct and indirect effects of monetary policy on firm investment using macro aggregates as proxies for aggregate demand.

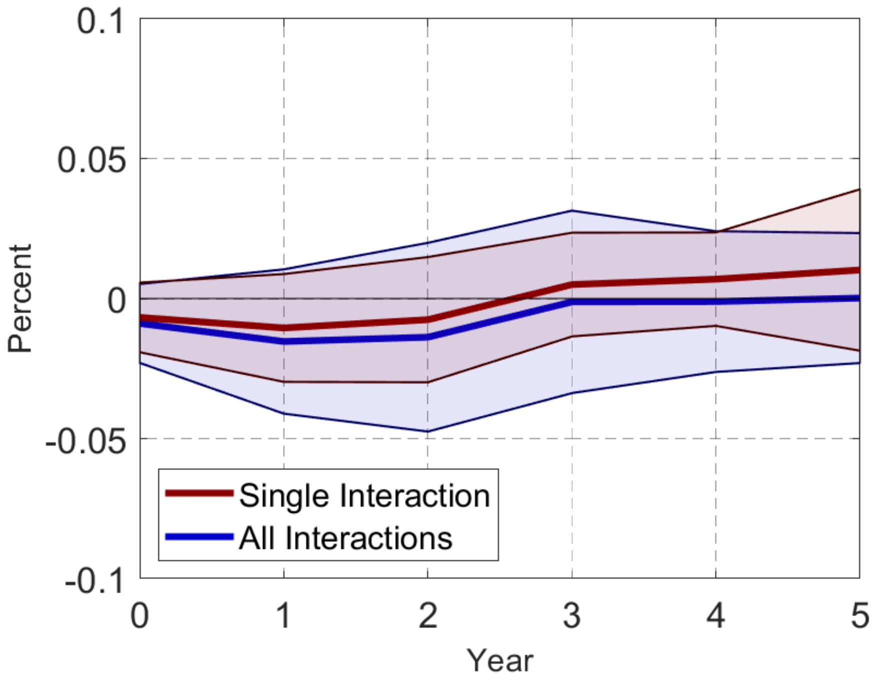
variables at all horizons up to and including h.

In line with our baseline results in Section 5, the indirect effects of monetary policy on firm investment response are small. After purging aggregate demand effects by using the macroeconomic variables, the direct effects still predominately drive the firm-level investment responses as we depict in Figure A.10. The estimated direct effects lie well within the 68% confidence bands of the firm-level responses from baseline regression (2).

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 marginal effects of the proximity-to-consumers on firm investment rates in Figure 9b. In the following, we now include all other six interaction terms from Figure 6: firm size, firm age, leverage, liquidity, earning-based constraints, and asset-based constraints. We estimate the local projections:

$$\frac{k_{i,t+h} - k_{i,t-1}}{k_{i,t-1}} = \alpha_i^h + \beta^h \cdot \varepsilon_t^{MP} + \beta_z^h \cdot \varepsilon_t^{MP} \cdot z_{i,t-1} + \beta_{z,m}^h \cdot \varepsilon_t^{MP} \cdot \tilde{m}_i + \gamma_z^h z_{i,t-1} + \gamma_{z,m}^h \cdot \tilde{m}_i + \gamma^h X_{i,t-1} + u_{i,t}^h. \quad (22)$$

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



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 (22). 68 and 95 percent confidence bands are shown, using Driscoll and Kraay (1998) standard errors.

Figure A.11: The marginal impact of proximity to consumers on the average investment response to monetary policy.

The difference in the marginal effects of $\tilde{m}_i$ when controlling for all seven interaction terms instead of including only proximity-to-households are indistinguishable. We visualize both the marginal effects of proximity-to-households as a single interaction term and when controlling for all interaction variables simultaneously in Figure A.11. The marginal effects depicted correspond to a one percentage point higher share of the proximity to the customers. The marginal effects are in both cases insignificant. The proximity to the final customer does not affect firms' investment decisions.

In both exercises that we portray in this section of the appendix, we do not find evidence that the transmission of monetary policy to firm investment is driven significantly by indirect effects. We show instead that investment responds predominately through direct channels.