Beyond the Short Run: Monetary Policy and Innovation Investment

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Abstract

Using a novel approach implemented in a unique survey of German firms, we study how monetary policy affects firms' innovation investment. We find that the ECB's policy rate hike of cumulative 450 basis points at the end of 2023 led 33% of firms to cut innovation spending by 67% on average, with effects persisting through 2024-2025. We show further that while rate hikes discourage innovation investment, cuts stimulate firms' innovation spending. We further demonstrate that forward guidance communication can provide significant additional stimulus, suggesting longer-term, supply-side effects of forward guidance. Monetary policy transmission operates through both financial and demand channels, with stronger effects for smaller firms, those with a higher share of bank loans, and those with weak expectations about demand. Our findings indicate persistent effects of monetary policy on longer-term aggregate supply, challenge long-run monetary neutrality and suggest policy-endogeneity of the natural rate of interest R^*.

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Keywords: Monetary Policy Transmission, R&D, Endogenous Growth, Forward Guidance, R^*.

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1 Introduction

How does monetary policy affect long-term growth? While a large body of research has studied the short-run effects of monetary policy, less is known about its impact on firms' innovation decisions and, by extension, longer-term economic growth and output dynamics. It is well-established by endogenous growth theory (Aghion and Howitt (1992), Grossman and Helpman (1991), Romer (1990), Jones (1999)) that innovation investment constitutes the main driver of technology growth and thus long-run growth. New Keynesian models, in turn, typically abstract from endogenous technology dynamics and are built on the assumption of long-run neutrality: transitory shocks have short-run effects and do not spill over to longer-term aggregate supply. In this paper, we study the effect ofmonetary policy on firms' innovation investment, which has strong implications for output dynamic beyond the short run.

More specifically, this paper provides novel empirical evidence on how monetary policy shapes firms' innovation investment. Using strategic survey approach in a special module embedded in a representative survey of German firms (Bundesbank Online Survey of Firms), we study three key questions: 1) the effect of the large interest rate hike (due to the euro area hiking cycle 2022-23) on firms' innovation investment, 2) the impact of incremental policy rate shocks (both hikes and cuts) on investment in innovation 3) the role of forward guidance communication on innovation investment and thus the potential longer-term aggregate supply effects of forward guidance.

Our first set of results concerns the effect of the recent policy rate hike. We show that this change had a significant impact on firms' innovation investment. 33% of firms cut their innovation expenditures in response to the cumulative 450 basis point increase in the policy rate. These cuts were substantial, averaging 67% among firms that decreased investment, with approximately 45% of these firms cutting investment to zero. Moreover, the innovation investment cuts were persistent – with 83% of firms that cut investment in the short run also cutting planned innovation investment over 2024-2025, with similar intensity of innovation cuts as documented for the short-run response.

Second, exploiting the hypothetical policy rate scenarios, we show that both rate hikes and cuts affect innovation investment. We find that a 100 basis point increase in the policy rate from 4.5% would lead to an average reduction in innovation investment of 28%, while a 50 basis point increase would result in a 25% reduction. Conversely, a 100 basis point cut would limit the reduction in innovation investment to 8%, while a 50 basis point cut would result in a 15% reduction relative to pre-hike plans. The impact appears non-linear and potentially asymmetric, with larger rate changes hikes having less impact relatively to cuts, whereas large rate cuts have a proportionally stronger effect than smaller rate

cuts.

Third, we demonstrate that forward guidance significantly influences innovation investment. When a 100 basis point policy rate cut is combined with forward guidance indicating rates will remain low for an extended period, the mean decline in innovation investment is only 2%, compared to a 15% decline with the rate cut alone - a substantial additional innovation stimulus of 12 percentage points. This suggests that forward guidance communication can have a strong amplification effect on the impact of rate changes on firms' innovation investment decisions.

Finally, we identify key transmission channels and heterogeneities in the transmission of monetary policy to innovation. Smaller firms and those with higher bank loan shares exhibit stronger responses to monetary policy changes. The effects are particularly pronounced for firms with variable-rate loans and those expecting weaker demand, highlighting both financial and demand channels in the transmission of monetary policy to innovation investment.

Our findings have important implications for monetary policy and macroeconomic theory by challenging several fundamental assumptions in monetary economics. First, by showing that monetary policy affects innovation investment, our results suggest the effect of monetary policy beyond the short run through its impact on the longer-term supply side of the economy. Since innovation drives technology growth and long-term growth, this indicates more persistent effects than traditionally recognized. Second, these findings challenge the conventional assumption of long-run monetary neutrality that underlies New Keynesian DSGE models, which posit that monetary policy only influences the economy in the short run without affecting long-run output trajectory. Finally, the results provide evidence for the policy-endogeneity of the natural rate of interest (R^*). By demonstrating that monetary policy affects innovation investment and thereby long-run growth—a key determinant of the natural rate—the findings suggest R* is not purely exogenous but is influenced by monetary policy decisions themselves, creating a more complex relationship than assumed in conventional models.

This paper relates to several strands of the literature. The first concerns the literature that investigates the supply-side effects of monetary policy (see, for instance Baqaee et al. (2023)), where our specific angle concerns the effects of monetary policy on innovation and thus technology growth and long-term aggregate supply. We review this literature below. Our work adds also to the body of research examining the liftoff from the zero lower bound and the supply effects of the ongoing monetary policy tightening cycle. We further contribute to the literature studying the effects of different monetary policy tools and their transmission mechanisms, where we focus on rate hikes vs. rate cuts, as well as

on the role of monetary policy announcements in the form of forward guidance.
This study is closely linked to literature which investigates the effects of monetary policy shocks on innovation and long-term aggregate supply. Jordà et al. (2020) and Ma and Zimmermann (2023) demonstrate the persistent effects of contractionary monetary policy shocks on innovation and TFP using aggregated data and local projections. Grimm et al. (2021) study the effects of quantitative easing policy on corporate innovation. Moran and Queralto (2018) provide further empirical evidence on the long-lasting effects of monetary policy shocks on TFP via innovation investment using a VAR model. Finally, evidence based on estimated New Keynesian models with endogenous innovation investment and TFP growth show that recessionary shocks can result in persistent adverse effects on technology growth due to the depressing effect on both research and development and technology adoption (Moran and Queralto (2018), Anzoategui et al. (2019), , Ikeda and Kurozumi (2019), Bianchi et al. (2019), Elfsbacka Schmöller and Spitzer (2021)).

This paper also contributes to the literature which use hypothetical questions to study economic decisions. While to the best of our knowledge we are the first ones to use structured hypothetical questions to access how firms change innovation investments in response to monetary policy surprises, Armantier et al. (2022) use similar approach to assess anchoring of households' inflation expectations. Following Ameriks et al. (2011) they argue that the use of hypothetical scenarios - strategic surveys - allows to causally identify objects of interest by creating exogenous within-subject variation. While these studies are a part of well-establish tradition of using survey experiments with hypothetical scenarios to make inference about behavior of households (Fuster et al. (2021), Christelis et al. (2024), Fuster and Zafar (2021)), or - closely related and more broadly - using hypothetical questions in surveys to access preferences such as marginal propensity to consume (Jappelli and Pistaferri (2014), Bunn et al. (2018)), the use of strategic surveys to study behavior of firms is much less prevalent, in part due to the limited data availability. One of the few examples, Gödl-Hanisch and Menkhoff (2023) use hypothetical questions embedded in survey of German firms to study pass-through of cost shocks to prices along different time horizons.

Still, the use of hypothetical questions in the survey has its limits. One of the challenges to this class of empirical methods is whether respondents would actually behave as they say they would. And indeed, Parker and Souleles (2019) as well as Bunn et al. (2018) establish that answers to hypothetical scenarios and actual outcomes largely match. In the case of a firm, which follows basic management practices such as planning and risk analysis, or creating business cases for investment purposes, being confronted with hypothetical scenarios should be at least relatable[1]. Indeed, the responses we receive are

[1]

meaningful, differ across scenarios, and align with the observable characteristics of firms as anticipated. A further concern is that even given the exogenous controlled treatment and the ability of the respondents to relate to the scenarios, researchers can not know the mechanism which respondents have in mind when answering the questions. This is however a challenge shared by most of the empirical studies, in particular those which estimate reaction to policy shocks, while Almås et al. (2024) argue for the use of the novel empirical evidence, including hypothetical situation-dependent survey questions, to inform and "allow the estimation of richer and more realistic models that rest on weaker identifying assumptions."

The paper is structured as follows. Section 2 presents our data and empirical approach. We show our results as to the effect of a large policy rate increase on firms' innovation investment in Section 3. Section 4 demonstrates the results on the effect of incremental policy rate shifts (rate hikes and cuts) on innovation. Next, we present the persistent effect of forward guidance communication on long-term aggregate supply in Section 5. Section 6 concludes.

2 Data and Empirical Approach

The aim of this paper is to examine empirically how innovation expenditure of firms respond to changes in the monetary policy. To do so, we introduced a special module in a large, representative survey of German firms, conducted in October-December 2023. Within this module we implement an experiment-like approach to asses how firms would respond to actual as well as hypothetical changes in the key interest rate. In what follows we describe the main survey as well as the innovation module and discuss the survey-based identification strategy.

2.1 Bundesbank Online Panel of Firms

The Bundesbank Online Panel of Firms (BOP-F) is a survey of German firms, which have at least one employee, pay social security contributions, and have a turnover which exceeds 22,000 euro. BOP-F is representative of German population of firms in terms of economic sectors, sizes and geography. Moreover and importantly, for this paper, innovation activity of firms reported in BOP-F matches closely estimates on aggregate innovation activity in Germany.[2]

[2]According to the Mannheim Innovation Panel (MIP), 57% of firms engaged in some innovation activities in 2022 (Rammer et al. (2023)), compared with 59% in the BOP-F survey we are using. Also,

Since its launch in July 2021, the survey has been conducted monthly, with more than 3,000 firms participating each month. Target respondents are top management, with survey response rates that are comparable to other firm-level surveys in Germany.

The BOP-F core survey collects information on a rich set of firm-level characteristics. It includes detailed firms' demographics, such as employment, sales, and sector, along with financial information like loan shares and types. Notably, the survey also captures firms' expectations regarding firm-level outcomes, such as anticipated turnover, as well as predictions for key macroeconomic variables like inflation and economic or financial conditions. This granular micro-level data makes the BOP-F survey particularly valuable for analyzing monetary policy.

2.2 Monetary Policy and Innovation Module: Identification Strategy

To understand how firms adjust their innovation spending in response to monetary policy changes, we designed and implemented a dedicated module within the BOP-F survey. The module was conducted withing three months, between October and December 2023. It consists of two distinct parts. In the first part, in light of the European Central Bank's cumulative 4.5 percentage point increase in the key interest rate since July 2022, we invited firms to retrospectively evaluate how this monetary tightening has influenced their actual spending on innovation, both on research and development (R&D) and technology adoption, since 2022, as well as their plans to invest in innovation in 2024-2025. By combining these assessments of the impact on realized and planned innovation investment, we study how this episode of the actual large interest rate hike has impacted firm's innovation expenditure in both the short and medium term.

Further, to evaluate how firms react to *exogenous* monetary policy shocks in terms of their innovation investments, we implement a survey-based experiment. Our experiment follows the strategic survey approach (Ameriks et al. (2011), Armantier et al. (2022)). Each firm is presented *several* hypothetical scenarios concerning key interest rate changes by the European Central Bank, specifically five scenarios are provided: a large interest rate hike (of 1%), a moderate interest rate hike (or 0.5%), a large as well as moderate interest rate decrease (of 0.5% and 1% respectively) and a scenario with forward guidance (announcement by the ECB that no further interest rate changes are expected until the end of 2025). Given this thought experiment, firms are then asked to report how they

the amounts spent on innovation activities align well with 190.7 bn Euro calculated in MIP and 171 bn. Euro in the BOP-F. The difference could be explained by the differences in firm's populations of the two surveys: MIP covers firms with at least 5 employees, the BOP-F covers firms with at least one employee

would adjust their planned investments in innovations for 2024 and 2025 in response to *each* of the scenarios. More specifically, they are confronted with the following question: *"To what extent would your enterprise change its planned expenditure on all innovation activities for 2024 and 2025 if the European Central Bank were to change its key interest rates as follows in its next meetings?"* [3]

This empirical approach has numerous advantages. First, it allows to establish the relevant benchmark. .Studies so far used data on *realized investments in innovations*, such as actual spending on R&D, venture capital or patents (see, e.g., Ma and Zimmermann (2023)). We propose that the relevant benchmark should be the ex-ante (in the absence of an interest rate change) plans for innovation spending. Second, the monetary policy shifts as suggested in scenarios can be interpreted as the exogenous controlled variation in the monetary policy, which allows to isolate the effect of the monetary policy change on innovation spending of a firm[4]. Third, multiple responses of the same firm at the same point in time to different, incremental policy rate changes, allows to avoid contamination of the estimates with unobserved time-varying or firm-specific factors. As a result, the combination of the *within-firm* variation with *exogenous shocks* allows to causally identify the sensitivity of innovation spending to unexpected monetary policy changes. Finally, the availability of responses to both positive and negative interest rate changes, as well as forward guidance for *the same firm in the same economic environment* provides crucial insights as to monetary policy transmission. This setup permits us to analyze and compare rate hikes and cuts of similar magnitude and thus to investigate for potential asymmetries between contractionary vs. expansionary monetary policy shocks. Moreover, it enables us to compare policy rate changes of different increments to analyze for potential non-linearities in transmission. Finally, we evaluate the role of forward guidance communication. Given that such counterfactuals can not be observed in actual setting, our method offers a unique opportunity to study empirically firms' responses to different monetary policy interventions and speaks directly to the needs of monetary policy design and assessment.

[3] See `https://www.bundesbank.de/resource/blob/825472/364c2516c59e88d49abd1457d6134420/mL/fragebogen-15-data.pdf` for a detailed description of the questionnaire.

[4] Alternative methods use the standard measurements of monetary policy shocks for identification. However, as Hack et al. (2023) argue, such measures may be contaminated by other macroeconomic shocks. Additionally, standard time series of monetary policy shocks may be too minor in magnitude to identify the effect on long-term oriented innovation expenditure of firms.

3 The Effect of a Large Rate Increase on Innovation

As a first part of the innovation module, in October-December 2023, we have asked firms-participants of the Bundesbank Online Panel survey to estimate the impact of the European Central Bank's (ECB) interest rate increases on their innovation investment. Specifically, the question presented reads as follows (see Section A.1 for a detailed description).

QUESTION: *The European Central Bank (ECB) has raised its key interest rates by a total of 4.50 percentage points since July 2022. How have these interest rar te increases affected your enterprise's actual expenditure in* ***2022*** *and* ***2023*** *as well as your enterprise's planned expenditure for all innovation activities in* ***2024*** *and* ***2025****?*

a*:Actual expenditure on R&D and other innovation activities in 2022 and 2023:* _____

b*: Planned expenditure on R&D and other innovation activities in 2024 and 2025:* ____

The question aimed to gauge both the immediate, i.e. short-run, impact (2022-2023, question (a)) and the medium-run response, i.e., the impact on their innovation expenditure plans over 2024 to 2025 (question (b)).

Innovation module was presented to 6,300 firms - participants of the BOP-F survey in October-December 2023. In the analysis which follows, we restrict the sample to "innovation-active" firms, which report any positive innovation expenditures in 2022 or reports to have reduced the innovation expenditure to zero as a result of the rate hike. between 2022-2023, resulting in a sample size of about 3000 observations.[5]

Section 3.1) studies the short-run innovation response, Section 3.2) the respective medium-run effect, and Section 3.3 analyzes the firm-level determinants behind the innovation investment response.

3.1 Short-run Innovation Investment Response

Table 1 shows firms' short-run innovation investment response, i.e. their adjustment during 2022 and 2023 in response to the actual policy rate hike from 0% to 4.5%, using

[5]We abstract from the possibility that firms without any innovation expenditure were induced by the rate hikes to start spending on innovation. This is consistent with recent evidence (Elfsbacka-Schmöller et al. (2024)), which shows that a negligible share of firms which did not plan innovation started to invest in innovation in response to contractionary shocks.

the responses to sub question (a).

Table 1: Firms' Short-run Response: Change in Innovation Investments 2022-2023

	Reduce	No Change	Expand	Total
% of firms	33%	58%	9%	100%
Average change	-67%	0	+23%	-20%
N				2593

Source: BOP-F October - December 2023, own calculations.
Notes: Weighted results, subset of innovation-active firms (firms with innovation activities in 2022 or 100% reduction relative to planned before the interest rate hike)

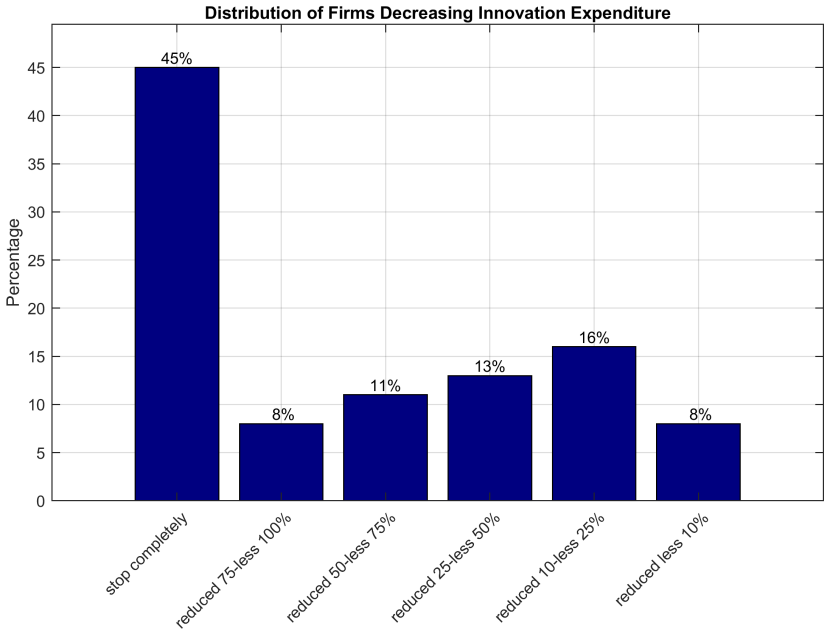
Our analysis of firms' innovation investment responses to the interest rate hikes from 0% to 4.5%, yields the following results. There is a substantial share of firms (33%) which cut innovation investment in response to the interest rate hike. We also observed a pronounced share of firms (58%) which were not responsive to the interest rate increase. Further, a small share of firms (9%) responded to the rate hike by increasing their innovation investment. Crucially, cuts and increases differ substantially in terms of the intensive margin, meaning that cuts are very substantial (mean cut: -67%)[6], whereas average increases are considerably smaller (+23%). These patterns deliver an aggregate mean cut per firm of -20% vis-à-vis the counterfactual in the absence of interest rate hikes. This suggests large and pronounced cuts to innovation expenditure in response to the interest rate hikes. We undertake a back-of-the-envelope calculation[7] and show that these cuts correspond to at least -€10.7 billion.[8]

[6]The average size of the cuts is calculated based on the mid-points of the bins shown to the respondents

[7]Note that this estimate constitutes a lower bound, as it does not include innovation investment cuts of firms which reduced their investment to zero. For the back-of-the-envelope calculation, we use information on the size of the cuts due to the rate hike and the innovation expenditure. We first estimate the innovation expenditure of firms in a counterfactual situation without the rate cut. To be more precise, we divide the innovation expenditure firms report for 2022 by (1+the midpoint of the interval of the reported cut). Next we multiply this number by the mid-point of the interval of the reported cuts in 2022 and 2023. Finally, we cross-up the resulting numbers across firms using the firm weights. This procedure is only feasible for firms, which did not stop their innovation activities completely in 2022 and 2023. The resulting number should thus be seen as a lower bound.

[8]This number is also sizeable when compared with the total amount invested in 2022 in our survey, which equals to €171 billion.

Figure 1: Distribution of Intensity of Innovation Investment Cuts (2022-2023).



Source: BOP-F October - December 2023, own calculations.
Notes: Weighted results, subset of innovation-active firms (firms with innovation activities in 2022 or 100% reduction relative to planned before the interest rate hike)

Figure 1 describes in detail the distribution of the intensity of innovation *cuts* across firms. It further emphasizes the intensity of the innovation investment decrease undertaken by firms that cut their spending. Crucially, among this category, the vast majority of firms cut their innovation investment by 100%, meaning they cut their innovation investment to zero and thus fully halted innovation investment in response to the interest rate hikes. This pattern can be interpreted as particularly severe. It suggests that firms at least transitorily dropped out of the set of innovation-active firms, defined as those with ongoing innovation investment[9], in response to the interest rate hike episode. This at least temporary exit from innovation activity may have particularly persistent effects on innovation investment as these firms put their innovation investment fully on hold, which may render ramping up innovation investment, for instance in response to a future policy rate cut, more unlikely.

[9]The set of innovation-active firms can be defined more broadly, such as by considering innovation investment over an extended time period rather than just contemporaneous activity. However, as demonstrated in the subsequent section, most firms that ceased innovation activities in the short run continued this pattern over the medium run. Thus, our findings as to exit from innovation activity are robust across different definitions of innovation-active firms, including those based on less frequent innovation investment.

3.2 Persistent Innovation Cuts: Medium-run Response

Are the innovation investment cuts documented in Section 3.1 confined to the short run or persistent? To answer this question we present next the results as to firms' innovation response over the medium term (Table 2). We show that the innovation cuts are not only a short run phenomenon, but are persistent. Specifically, firms' medium-run innovation response, defined as the change in firms' innovation investment plans for 2024 to 2025, compared to their pre-rate hike plans for the same period, reveals a pronounced downward adjustment of on averaging -20% per firm. We observe further that innovation cuts are concentrated in 35% of firms, which on average cut by 67%.

Table 2: Firms' Medium-run Response: Change in Planned Investment for 2024-2025.

	Reduce	No Change	Increase	Total
% of firms	35%	52%	14%	100%
Average change	-67%	0	+22%	-20%
N				2625

Source: BOP-F October - December 2023, own calculations.
Notes: Weighted results, subset of innovation-active firms (firms with innovation activities in 2022 or 100% reduction relative to planned before the interest rate hike)

Table 3 presents the detailed firm-level innovation investment behavior over the short and medium run. Our analysis shows a strong persistence of firm-level innovation investment cuts. The vast majority (83%) of firms which decreased investment in the short-run also downward-adjusted their investment plans for 2024 to 2025. These results suggest that the impact of interest rate hikes on innovation investment is both significant and long-lasting, thus potentially suppressing innovation investment for an extended time.

Table 3: Short-run vs. Medium-run Innovation Investment Response Comparison

	Medium-run: 2024-2025			
Short-run: 2022-2023	Decrease	No change	Increase	Total
Decrease	83%	10%	7%	100%
No change	11%	80%	9%	100%
Increase	11%	17%	72%	100%

Source: BOP-F October - December 2023, own calculations.
Notes: Weighted results, Only firms with innovation activities in 2022 or 100 percent reduction.

When focusing on the group of firms which completely stopped investing in innovation, we observe a high degree of persistence in exiting innovation activity. There is an 83% probability of cutting plans by 100% among those firms which had cut innovation by 100%

over 2022-2023. This persistent pattern of "exit" from innovation activity may, as noted in section 3.1 further amplify the persistence of the aggregate innovation in response to the interest rate hike episode. Moreover, of those firms which had decreased (but not fully cut) innovation investment over 2022-2023, an additional 9% cut their plans to zero over 2024-2025.

3.3 Transmission Mechanism: Firm-Level Determinants

Next we investigate the transmission mechanism of the policy rate increase to firms' innovation investment further. First, we show more formally, as previously indicated by descriptive analysis, that firm's decisions to decrease innovation spending in short-term and medium-term are highly correlated. The estimations of biprobit model in Table 4 produces highly significant correlation estimate between decisions in short- and medium terms. This suggest a high persistence of the innovation investment cuts. Moreover, the short-run and medium-run adjustment in innovation by firms are determined by highly similar factors.

Our findings indicate that smaller firms are more responsive to the rate hike than large firms, i.e., a more likely to cut back on innovation investment. Somewhat surprisingly, we find that decrease in innovation spending is not driven by manufacturing sector, though in medium-term it does appears to be somewhat more affected.

Importantly, we show that more indebted firms react stronger to the key interest rate changes. Specifically, innovation investment by firms with a higher share of bank loans relative to their balance sheet are particularly sensitive to the rate hike. This emphasize the importance of the transmission of monetary policy through the cost of financing and the bank lending channel in particular. Alternatively, this may mean that more indebted firms pay more attention to the interest rate changes and integrate it more into their decisions. Survey-based information treatments and hypothetical questions may provide additional insight, as we show further.

Table 4: Probability to Cut Innovation Investment in the Short and Medium Run

	Decrease short-run	Decrease medium-run
Share of bank loans:		
1- 10%	0.385***	0.473***
	[0.089]	[0.087]
10-20%	0.421***	0.600***
	[0.098]	[0.096]
20-40%	0.726***	0.882***
	[0.082]	[0.082]
40% or more	1.074***	1.198***
	[0.095]	[0.096]
Number of empl.:		
11-50	-0.208***	-0.142**
	[0.070]	[0.069]
51-200	-0.539***	-0.475***
	[0.090]	[0.088]
201 - 1000	-0.691***	-0.596***
	[0.119]	[0.115]
$>$ 1000	-0.885***	-0.923***
	[0.198]	[0.195]
Service Sector firm	-0.057	-0.108*
	[0.062]	[0.061]
November Survey	-0.111	-0.09
	[0.072]	[0.071]
December Survey	0.086	0.053
	[0.072]	[0.071]
Constant	-0.546***	-0.504***
	[0.084]	[0.084]
rho	1.551***	
	[0.063]	
Chi2	278.428	
N	2106	

Source: BOP-F October - December 2023.

Notes: Results based on biprobit regression. The outcome variables are coded as 1 if a firm reported in the innovation module having cut innovation investment and 0 otherwise, respectively for innovation investment over 2022-2023 and planned innovation investment over 2024 to 2025. Only firms with innovation activities in 2022 or 100 percent reduction. Correlation parameter *rho* measures dependency between two outcomes: Decisions to decrease innovation expenditure short- and medium run. Standard errors are reported (in parentheses). Significance levels, $*$ $p < 0.1$, $**$ $p < 0.05$, $***$ $p < 0.01$.

4 Policy Rate Scenarios

In the previous section, we investigated how an actual, large-scale rate hike affected firms' innovation investments. It is particular informative for understanding how innovation activity of firms responds to *systematic* component of monetary policy rate shifts. In what follows, we study the effect of incremental *exogeneous* key interest rate hikes and cuts, as well as forward guidance. To do so, we ask each firm to consider several hypothetical scenarios and report how they would adjust their investments in innovation during next two years (2024-2005) in each of the scenarios. The exact survey question is given as follows (see Appendix A.2 for the full questionnaire).

QUESTION: *We would like to ask next to what extent would your enterprise change its planned expenditure on all innovation activities $< i >$ for **2024** and **2025** if the European Central Bank were to change its key interest rates $< i >$ as follows in its next meetings?*

Scenarios:

a = *Increase of the key interest rates by 1.00 percentage points (main refinancing rate at 5.50%)*

b = *Increase of the key interest rates by 0.50 percentage points (main refinancing rate at 5.00%)*

c = *Decrease of the key interest rates by 0.50 percentage points (main refinancing rate at 4.00%)*

d = *Decrease of the key interest rates by 1.00 percentage points (main refinancing rate at 3.50%)*

e = *Decrease of the key interest rates by 1.00 percentage points (main refinancing rate at 3.50%) and announcement by the ECB that no further interest rate changes are expected until the end of 2025*

Using within-firm variation, we estimate causally innovation investment responses to the policy rate change. We also study potential asymmetries in the transmission mechanism by comparing the effects of rate hikes versus rate cuts, and explore possible non-linearities in monetary policy transmission by comparing the effect of policy rate changes of different increments (±0.5%, ±1%). The comparison of Scenarios (d) and (e) further permit us to identify the effects of forward guidance announcements (analyzed in Section 5).

4.1 Effect of Incremental Policy Rate Hikes and Cuts

Analysis below concerns firms' innovation investment responses to various policy rate scenarios (hikes and cuts of respectively 1% and 0.5%). Here and further, the changes concern the innovation investment plans over 2024 to 2025 and answers are stated *relative to the counterfactual in the absence of the past rate hike episode*. Thus, results below compare to an average change in planned investment for 2024-2025 relative to pre-rate-hike planned investment, which we estimated to be a decline of of -20% (Section 3.2). We report several findings.

1. High sensitivity of innovation expenditure to monetary policy rate changes:

Table 5: Policy Rate Scenarios: Average Firm-level Innovation Investment Response

	Policy Rate Scenario			
	up 1% (5.5%)	up 0.5% (5.0%)	down 0.5% (4.0%)	down 1% (3.5%)
Mean	-0.28	-0.25	-0.15	-0.08

Source: BOP-F October - December 2023, own calculations

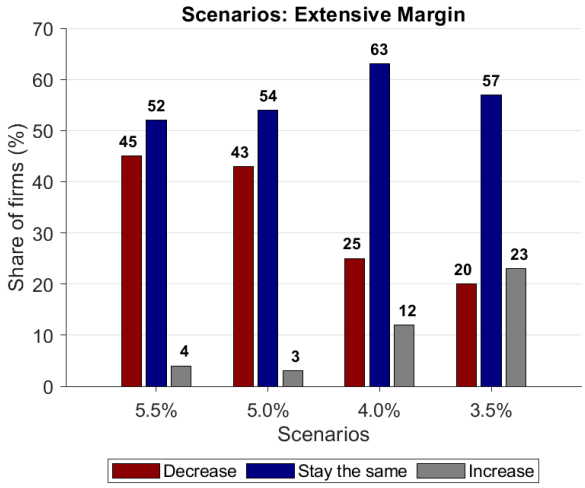
Table 5 shows that firms' innovation investment is highly sensitive to policy rate changes. Interest rate hikes would lead to a more pronounced decrease in innovation investment planned for 2024 to 2025, with mean average cuts of -25% (for a 0.5% hike) and -28% (for a 1% hike) respectively. Conversely, interest rate cuts are found to stimulate innovation investment, resulting in a less severe mean average innovation cut of only -15% (for a 0.5% cut) and -8% (for a 1% cut).

The analysis presented in Figure 2 demonstrates that changes in the policy rate significantly impact firms' innovation behavior at the extensive margins within the groups (decrease-stay the same-increase). In the case of a rate hike, the proportion of firms decreasing innovation investment rises to 43% (for a 0.5% hike) and 45% (for a 1% hike), while the share of firms increasing innovation notably declines (to 3% for a 0.5% hike and 4% for a 1% hike). Conversely, if the interest rate were to be lowered as of the next meeting, the percentage of firms reducing investment would decrease (to 25% for a 0.5% cut and 20% for a 1% cut), while the proportion of firms maintaining their pre-formed plans would increase (to 63% for a 0.5% cut and 57% for a 1% cut). Furthermore, the share of firms that would raise their innovation investment relative to plans would grow to 12% (for a 0.5% cut) and 23% (for a 1% cut).

2. Innovation responds to both rate hikes and cuts: Table 6 presents our estimation results as to the effect of incremental changes in the policy rate. In this analysis, the change in firm-level innovation investment, measured as the midpoint of the reported bins, serves as our outcome variable. The regression utilizes data on innovation investment relative to pre-hike innovation investment plans, as well as the corresponding innovation response under various interest rate scenarios, and a forward guidance scenario (see Section 5. In the baseline estimation (column 1), we assess and compare the impact of hypothetical, incremental interest rate changes against the change in medium-run innovation plans, which permits us to directly measure the affect of the hypothetical rate changes on firms innovation investment. We observe that each scenario induces a significant change in innovation investment vis-à-vis the baseline. Crucially, both rate hikes and cuts induce significant changes, with hikes discouraging and cuts stimulating innovation investment.

For 0.5% changes in the policy rate, hikes (0.049) and cuts (0.054) bring about highly similar changes. For the 1% change, the impact of a rate hike (0.082) is less than that of a rate

Figure 2: Policy Rate Scenarios: Extensive Margin (Distribution)



Source: BOP-F October - December 2023, own calculations.
Notes: Firms' response is categorized in three broad groups (decrease-stay the same-increase) based on the more detailed answer quantitative answer.

cut (0.124). This provides strong evidence of monetary policy transmission to innovation in either direction. Based on our results, we can clearly reject the hypothesis that only monetary policy contractions could harm innovation investment, but that monetary easing would not be as effective in stimulating innovation investment. Instead, our estimates tentatively suggest a stronger effect of cuts compared with hikes. However, it is important to interpret these findings against the background of the high starting value of the incremental policy rate shifts (4.5%). As our earlier results indicated, a substantial share of firms responded that they have undertaken substantial policy rate cuts, potentially implying that a further policy rate increase, likely would not indcued further cuts in innovation expenditures.

3. The Role of the Size of the Policy Rate Change: We next compare the transmission of policy rate changes of different magnitudes, aiming to analyze the transmission of large versus small policy rate changes and thus to gauge the difference between gradualism and rapid policy rate shifts on firms' innovation investment. For rate cuts, we find that a 0.5% reduction yields an impact of 0.054, while a 1% cut results in an impact of 0.124 and thus exceeds twice the effect of a 0.5% policy rate change. Conversely, for rate hikes, a 0.5% increase produces an effect of -0.049, while a 1% hike results in -0.082. In this case, doubling the rate hike generates less than twice the effect on innovation investment, with a ratio of 1.67. It is crucial to note that this decreasing effect on innovation also reflects the underlying level of the policy rate, as many firms cease investing in innovation once a certain threshold is reached. This observation suggests non-linearities in the transmission mechanism of rate hikes at higher levels of the policy rate.

Table 6: Regression Results: Policy Rate Scenarios

	Baseline	Baseline with controls	With inflation expectations	With labor productivity
Scenario: hike 1 pp.	-0.082*** [0.008]	-0.079*** [0.008]	-0.079*** [0.008]	-0.086*** [0.013]
Scenario: hike 0.5 pp.	-0.049*** [0.007]	-0.047*** [0.008]	-0.048*** [0.007]	-0.057*** [0.011]
Scenario 3: cut 0.5 pp.	0.054*** [0.007]	0.057*** [0.007]	0.057*** [0.007]	0.052*** [0.011]
Scenario 4: cut 1 pp.	0.124*** [0.008]	0.127*** [0.008]	0.126*** [0.008]	0.129*** [0.013]
Scenario 5: down 1 pp. for long	0.186*** [0.011]	0.176*** [0.011]	0.176*** [0.011]	0.188*** [0.017]
Share of bank loans				
1-10%		-0.112*** [0.025]	-0.101*** [0.024]	-0.121*** [0.037]
10-20%		-0.105*** [0.025]	-0.104*** [0.025]	-0.150*** [0.042]
20-40%		-0.150*** [0.022]	-0.144*** [0.022]	-0.152*** [0.033]
40% or more		-0.224*** [0.025]	-0.219*** [0.025]	-0.260*** [0.038]
Number of employees				
11-50		0.065*** [0.017]	0.065*** [0.017]	0.048* [0.025]
51-200		0.114*** [0.020]	0.108*** [0.019]	0.088*** [0.032]
201-1000		0.175*** [0.023]	0.164*** [0.023]	0.202*** [0.038]
$>$ 1000		0.191*** [0.029]	0.182*** [0.029]	0.272*** [0.033]
Service Sector firm		0.039** [0.017]	0.040** [0.016]	0.033 [0.025]
November Survey		0.005 [0.017]	0.002 [0.017]	0.023 [0.026]
December Survey		-0.026 [0.018]	-0.028 [0.018]	-0.007 [0.028]
Expected inflation rate in one year			-0.005*** [0.001]	
Labour productivity				-0.063*** [0.011]
Constant	-0.201*** [0.010]	-0.189*** [0.023]	-0.162*** [0.024]	-0.199*** [0.035]
R-squared	0.055	0.110	0.121	0.115
N	14,756	14,285	14,259	6,528

Source: BOP-F October - December 2023.
Notes: Results based on OLS regression. The outcome variables is the midpoint of the interval representing the change in plans, in percent, for 2024 to 2025. Reference category for scenarios: actual change due to the past interest rate hike of 4.5 percent. Only firms with innovation activities in 2022 or 100 percent reduction. Standard errors are clustered at the firm-level (in parentheses). Controls include survey wave, share of bank loans and firm size. Significance levels, $*$ $p < 0.1$, $**$ $p < 0.05$, $***$ $p < 0.01$.

4.2 Firm-level Determinants

Which firms react more or less to the interest rate changes? We find that firms with higher share of loans react stronger. (columns 2-4, Table 6) . This echoes our findings on firm's reaction to actual shocks (see section 4.1). However, in the current experimental setting, the change in interest rate is exogenously given and thus firm's response is not as much dependent on attention. This allows us to conclude that the response to monetary policy shifts is driven at least partially by financial determinants on the firm's level. These results hold also when controlling for firms' characteristics.

We exploit the survey information on firms' inflation expectations and show that firms which expect higher inflation over the next 12 months undertake more pronounced innovation cuts.

As to the role of firm-level labor productivity, we find that higher productivity firms exhibit a stronger reduction in innovation investment. This suggests that rate hikes particularly discourage innovation investment among high-productivity firms, speaking against the notion of a

cleansing effects from monetary tightening in the innovation sector.

4.3 Transmission Mechanisms

We investigate next the transmission channels of policy rate shifts to innovation. We employ a split-sample regression approach: by dividing our sample based on the respective criteria, we can observe how the impact of monetary policy on innovation varies different specifications, thereby providing insights into the interaction and respective role of the channels of interest. Table 7 presents our results.

Transmission through Demand: To study the role of demand, we exploit information on firms' expectations on their turnover and divide our sample into two groups: firms which anticipated a decrease in their turnover and firms which did not. Reductions in the policy rate elicit a substantially stronger innovation response from firms expecting a decline in turnover, which underscores the significance of demand expectations in the transmission of rate cuts to innovation. Firms which expected a turnover drop, in turn, exhibit substantially less responsiveness to rate hikes than those who did not expect a turnover drop. This asymmetry may be explained by the fact that firms expecting reduced turnover have likely already revised their investment plans, effectively pricing in the anticipated downturn in their innovation investment plans. Consequently, these firms may be less sensitive to additional policy rate hikes and corresponding worsening business cycle and demand situation. Furthermore, firms expecting a fall in turnover may be already operating at their financing constraints, limiting the capacity or necessity for further innovation cuts. More generally, our results emphasize the role of the aggregate demand channel in addition to transmission through financing costs, most notably the bank lending channel, which we investigate next.

Bank Lending Channel: To assess the role of the bank lending channel, we compare the responses of firms which have bank loans to those without. Firms with bank loans exhibit substantially higher responsiveness to policy rate changes, which underscores the significance of monetary policy transmission through financing costs of innovation. However, we also observe that firms without bank loans respond significantly to interest rate changes. In line with our results as to the role of turnover and demand, this result highlights the existence of an additional transmission channel operating through firms' expectations about the economic outlook and future demand. This channel may function either through the firms' own assessments of changes in the economy introduced by each rate scenario, most notably shifts in aggregate and firm-level demand. . Interestingly, we observe some degree of an asymmetry in these responses, with the difference between the two groups being more pronounced for rate cuts compared to rate hikes.

Transmission in Firms with Fixed vs. Variable Loans: We next investigate the bank lending channel in further detail by restricting the sample to firms with bank loans and then split

Table 7: Policy Rate Scenarios: Transmission Mechanisms

	Expected turnover drop		**Bank loans**		**Loan type**	
	Yes	No	Yes	No	Fixed rate only	Some variable
Scenario: hike 1 pp.	-0.052^{***}	-0.093^{***}	-0.094^{***}	-0.063^{***}	-0.098^{***}	-0.091^{***}
	[0.015]	[0.009]	[0.012]	[0.011]	[0.015]	[0.020]
Scenario: hike 0.5 pp.	-0.017	-0.064^{***}	-0.056^{***}	-0.039^{***}	-0.063^{***}	-0.046^{**}
	[0.014]	[0.009]	[0.011]	[0.010]	[0.014]	[0.018]
Scenario 3: cut 0.5 pp.	0.111^{***}	0.028^{***}	0.084^{***}	0.028^{***}	0.062^{***}	0.126^{***}
	[0.015]	[0.008]	[0.011]	[0.009]	[0.013]	[0.020]
Scenario 4: cut 1 pp.	0.216^{***}	0.080^{***}	0.183^{***}	0.065^{***}	0.161^{***}	0.224^{***}
	[0.018]	[0.009]	[0.013]	[0.010]	[0.016]	[0.022]
Scenario 5: down 1 pp. for long	0.275^{***}	0.126^{***}	0.264^{***}	0.083^{***}	0.221^{***}	0.337^{***}
	[0.022]	[0.012]	[0.017]	[0.012]	[0.019]	[0.030]
Constant	-0.312^{***}	-0.105^{***}	-0.365^{***}	-0.171^{***}	-0.323^{***}	-0.445^{***}
	[0.047]	[0.022]	[0.030]	[0.032]	[0.037]	[0.054]
Firm controls						
R-squared	0.122	0.108	0.111	0.046	0.109	0.140
N	4,524	9,698	7,828	6,457	4,793	2,949

Source: BOP-F October - December 2023.
Notes: Results based on OLS regression. The outcome variables is the midpoint of the interval representing the change in plans, in percent, for 2024 to 2025. Reference category for scenarios: actual change due to the past interest rate hike of 4.5 percent. Only firms with innovation activities in 2022 or 100 percent reduction. Standard errors are clustered at the firm-level (in parentheses). Controls include survey wave, share of bank loans and firm size. Significance levels, $* \ p < 0.1$, $** \ p < 0.05$, $*** \ p < 0.01$.

the sample by firms which hold exclusively fixed-rate loans and those with at least some variable-rate loans. As to the effect of rate cuts, firms with variable rate loans respond more strongly, in line with an interpretation that rate cuts reduce funding costs under variable rates, but not under fixed rate loans. However, it's noteworthy that firms with fixed-rate loans also respond to policy rate changes, albeit to a lesser degree. This observation reinforces the existence of alternative transmission channels beyond the direct cost of financing, echoing the results presented earlier in this subsection. Interestingly, the response patterns to rate hikes between firms with only fixed-rate loans and those with some variable-rate loans are generally more similar than as to rate cuts.

5 Forward Guidance and Innovation

This section examines the impact of forward guidance on firms' innovation investment. We present our results (Section 5.1) and the underlying transmission mechanism (Section 5.2).

5.1 Forward Guidance and Innovation Investment

As described in Section 4, we confront firms with hypothetical policy rate scenarios, which permits the comparison of a 1% rate cut (*Scenario* ***d***) with a 1% rate cut combined with a

forward guidance announcement (*Scenario* ***e***):

- **Scenario d**: *Decrease of the key interest rates by 1.00 percentage points (main refinancing rate at 3.50%):*
- **Scenario e**: *Decrease of the key interest rates by 1.00 percentage points (main refinancing rate at 3.50%) and announcement by the ECB that no further interest rate changes are expected until the end of 2025:*

Table 8 presents the descriptive results as to the role of forward guidance by comparing mean changes as well as the distribution under Scenario 3 (policy rate cut by 1%) and Scenario 5 (policy rate by 1% and forward guidance announcement that the ECB expects to hold policy rates at this level until the end of 2025 (i.e.,for two year s)). In so doing, we show how the additional monetary policy communication of holding interest rates low for an extended period of time affects firms' innovation investment. Our analysis shows that the scenario with forward guidance is substantially more effective than the one with a 1% rate cut without forward guidance communication. The mean change in innovation investment under forward guidance is -2% - relative to pre-hike plans, compared to -15% for the rate cut alone. As shown in Table 6 (Section 4.2), this disparity generates a significant and substantial average increase in innovation investment of 12 percentage points .

Table 8: Comparison between 1% rate cut and forward guidance scenario

Scenario	**Cut 1% (3.5%)**	**Cut 1% (3.5%) + Forward Guidance**
Distribution		
Decrease	20	16
Stay the same	57	55
Increase	23	29
Mean	**-15%**	**-2%**

Source: BOP-F October - December 2023.

Further analysis of the underlying channels of these differences in average changes reveals two key drivers: firstly, the proportion of firms reducing innovation investment decreases (16%, down from 20%), with those completely halting innovation falling from 6% to 3%. Secondly, the share of firms increasing innovation investment rises from 23% to 29%.

5.2 Insights on the Transmission Mechanism

We analyze the determinants of the impact of forward guidance on innovation investment. In particular, we ask in which states forward guidance is particularly strong and what our findings

tell about the role of the design of monetary policy communication under endogenous innovation investment.

Medium-run/ Persistent, Supply-side Effects of Forward Guidance: Our results established two key insights: firms pay close attention to forward guidance announcements in determining their innovation investment choice. Second, the effect can be significant in terms of magnitude. Thus, our research provide direct evidence on the longer-term, supply-side effects of forward guidance. Crucially, by affecting innovation investment, forward guidance affects an influence also on the growth of the technology stock and thus total factor productivity. This evidence suggests potentially highly persistent effects of forward guidance tools, with effects on aggregate output over at least the medium run and potentially beyond.

When is the effect of forward guidance particularly strong? Table 7 demonstrates that in each of the sample split regressions, forward guidance substantially amplifies the stimulus to innovation investment compared to a standalone 1% rate cut, i.e. the effectiveness of forward guidance relative to rate cuts alone, is not conditional on the state of the world in terms of demand or financing situation and structure. However, we observe cases in which the effect of forward guidance is particularly pronounced. First, firms that expect a decline in future turnover show an additional response to forward guidance of approximately 6%, denoted in mean firm-level investment change. For companies relying on bank loans for financing, the additional stimulus rises to about 8% relative to firms without bank loans. Among firms using bank loans, those with a portion of variable interest rate loans exhibit the strongest response, with an extra average 11% boost in innovation investment through forward guidance. Our results suggests thus, that while forward guidance creates pronounced additional stimulus to innovation throughout the different states of the world characterized by the sample splits, forward guidance affects firms' innovation investment particularly strongly under the following conditions: during periods of low demand, in firms which finance themselves through bank loans - in particular if the loan rates are variable.

Implications for the Design of Forward Guidance Communication: Our findings indicate a strong effect of forward guidance on innovation investment. However, this does not necessarily generalize to all types of forward guidance. The strategy we study has specific characteristics, and while the properties underlying it are found to be effective, these results may not apply to forward guidance announcements with different properties. We list and analyze the role of these specific characteristics below.

1. *Calendar-based announcement:* The forward guidance studied in this paper is calendar-based, as the communication entails the expectation to keep interests at the respective lower rate over a specific time period.

2. *Extended time horizon:* Moreover, the forward guidance studied in this paper entails the announcement to hold rates at a lower level over the subsequent 2 years and constitutes thus a commitment to keep rates unchanged over the medium term. This approach ef-

fectively announces the central banks' expectation to hold the policy rate fixed policy for the upcoming two-year period, signaling a rather strong expectation of unchanged policy rates for an extended time period.

3. *Clear, unconditional communication:* The announcement provides firms with a clear and precise communication of the expected path of interest rates. This approach was deliberately chosen to ensure that survey respondents fully comprehend the policy scenario. Notably, the announcement focuses solely on expectations about the policy rate path, without specifying any conditional statements or circumstances under which this scenario would be realized or altered.

6 Discussion: Monetary Policy and Modeling Implications

We next place and discuss our results in the context of monetary economics, in particular with respect to the role of several key underlying assumptions underlying standard New Keynesian models. We discuss in particularly the persistent effects of monetary policy operating through the supply-side of the economy, the assumption of long-run non-neutrality of monetary policy and, ultimately, the endogeneity of the natural rate of interest, R^*, over at least the medium term.

Persistent Effects of Monetary Policy through the Supply Side: Our results show that monetary policy's effects extend beyond the short run via its impact on innovation investment and longer-term aggregate supply. We demonstrate that monetary policy affects innovation investment, and, drawing on endogenous growth theory's central insight that innovation investment is the key driver of technology growth and long-term growth (Aghion and Howitt (1992), Grossman and Helpman (1991), Romer (1990)), influences longer-term aggregate supply. This reveals more persistent effects than traditionally recognized: monetary policy continues to influence aggregate output after shocks dissipate by affecting slowly moving, longer-term variables. This evidence challenges the conventional view of monetary policy as a pure short-run phenomenon, as we observe its influence on variables previously considered exclusively supply-side determinants. Our findings fundamentally alter our understanding of both monetary policy's transmission channels and persistence, suggesting effects that extend well into the medium run and potentially beyond.

Long-run Neutrality of Monetary Policy: Our findings have important implications for the conventional assumption of long-run monetary neutrality. By demonstrating that monetary policy affects innovation—a key driver of long-run growth—our results challenge a fundamental assumption of New Keynesian DSGE models: that monetary policy can only influence the economy in the short run, leaving the long-run output trajectory unaffected. Given our evidence of

monetary policy's impact on innovation and, by extension, on long-run growth, this assumption of long-run neutrality appears to be challenging to maintain. Moreover, our findings challenge the validity of econometric techniques derived from long-run neutrality, such as long-run identifying restrictions.

Policy-endogeneity of R^*: The natural rate of interest ($R*$) is exogenous in conventional New Keynesian models, i.e., it is driven by exogenous shocks only and not to monetary policy shifts themselves. Recent theoretical work on New Keynesian models with endogenous growth through R&D (Elfsbacka-Schmöller and McClung (2024)) demonstrates that the natural rate is an endogenous object, influenced by the endogenous rate of trend growth, suggesting a more complex relationship. Accordingly, monetary contractions reduce innovation investment, leading to lower technology growth and, consequently, lower trend growth.[10] This mechanism implies an inverse relationship between the policy rate and the natural rate. Our empirical results support this view: we find that monetary policy shifts affect innovation investment in a manner consistent with this theoretical framework. Thus, by demonstrating monetary policy's impact on innovation—and by extension, on long-run growth, a key determinant of the natural rate—our findings provide evidence in favor of the policy-endogeneity of $R*$.

7 Conclusion

This paper provides novel evidence on how monetary policy shapes firms' innovation investment using unique survey data from German firms. Our findings reveal several important patterns that challenge conventional wisdom in monetary economics. First, we document that monetary policy substantially affects innovation decisions, with the recent 450 basis point rate increase leading a third of firms to cut innovation expenditures. These cuts were substantial, averaging 67% among affected firms, with many reducing investment to zero, and importantly, these effects persist through 2024-2025. Second, our analysis of incremental policy rate shocks shows that innovation investment is responsive to both rate hikes and cuts, where in particular pronounced cuts exert a strong stimulus on innovation. Our results, moreover, see a role for non-linearities and asymmetries in monetary policy transmission, with larger rate changes having proportionally different effects for hikes versus cuts. Third, we find that forward guidance serves as a powerful amplification mechanism, with clear communication about persistently lower policy rate substantially strengthening the impact of rate changes on innovation investment. This result points towards the potential longer-term effects of forward guidance announcements.
These results have important implications for macroeconomic theory and monetary policy more generally. First, our results suggests that monetary policy is likely to extend beyond the short run through more persistent effects operating via long-term aggregate supply than conventionally

[10]Note that in this framework the steady state growth rate, i.e. the growth rate on the balanced growth, and thus the steady state real rate is constant in this framework.

assumed. Moreover, by demonstrating that monetary policy significantly influences innovation investment — a key driver of technological progress and long-term growth — our findings challenge the conventional assumption of long-run monetary neutrality embedded in standard New Keynesian frameworks. Moreover, the evidence on policy-endogenous innovation investment suggests that the natural rate of interest (R*) may not be purely exogenous but rather influenced by monetary policy decisions themselves.

Our findings call for a reconsideration of how we model and implement monetary policy. The transmission channels we identify, particularly the heightened sensitivity among smaller firms and those with variable-rate loans, suggest that monetary policy's influence extends well beyond short-run stabilization to shape long-term economic outcomes. Future research and policy frameworks should more explicitly account for these persistent effects on innovation and long-term growth potential, in particular with respect to key modeling concepts, such as the natural rate of interest, R^*.

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A Survey Questionnaire

This section details our survey methodology and questionnaire structure. Section A.1 presents the questions that form the basis for our findings regarding the large rate increase. Section A.2 outlines the survey questions pertaining to incremental policy rate changes and forward guidance.[11]

A.1 Questionnaire: Large Policy Rate Increase

Firms were presented with the question below ($< i >$ indicates info boxes, as described under "additional information").

QUESTION:
The European Central Bank (ECB) has raised its key interest rates $< i >$ by a total of 4.50 percentage points since July 2022. How have these interest rate increases affected your enterprise's actual expenditure in **2022** and **2023** as well as your enterprise's planned expenditure for all innovation activities $< i >$ in **2024** and **2025**?

Note: Please refer to expenditure on R&D activities $< i >$ and other innovation activities (excluding R&D) $< i >$ for this question. Please select an answer for each row from the drop-down menu.

a: Actual expenditure on R&D and other innovation activities in 2022 and 2023 $< i >$: _____

b: Planned expenditure on R&D and other innovation activities in 2024 and 2025 $< i >$: _____

Answer categories

1. Decreased by 100% (fully reduced)
2. Decreased by between 75% and less than 100%
3. Decreased by between 50% and less than 75%
4. Decreased by between 25% and less than 50%
5. Decreased by between 10% and less than 25%
6. Decreased by less than 10%
7. No change (0%)

[11] For the orignal, German version of the questionnaire, please refer to this link: `https://www.bundesbank.de/resource/blob/825530/8e3ce5fd00b255e11f9e4b92476d4111/mL/fragebogen-15-data.pdf`.

8. Increased by less than 10%
9. Increased by between 10% and less than 25%
10. Increased by between 25% and less than 50%
11. Increased by between 50% and less than 75%
12. Increased by between 75% and less than 100%
13. Increased by more than 100%
14. Does not apply to my enterprise

To make sure that firms apply a common definition of innovation and R&D activities, the questionnaire includes the definitions shown in the box below. They follow standard definitions employed in the innovation literature and are based on the Frascati and Oslo Manuals of the OECD (OECD (2015), OECD and Eurostat (2018)).

Additional Information:

- After the term "innovation activities", an info box $< i >$ with the following text is shown: "Innovations are new or improved products or business processes (or a combination thereof) that differ substantially from prior products or business processes and that the enterprise in question has introduced to the market or utilised itself. Innovations are often divided into research and development (R&D) and other innovation activities."
- After the term "key interest rates", an info box $< i >$ with the following text is shown: "The ECB Governing Council decides on three different key interest rates: the interest rate on the main refinancing operations, the interest rate on the marginal lending facility and the interest rate on the deposit facility."
- After the term "R&D activities", an info box $< i >$ with the following text is shown: "R&D (research and development) is the systematic creative work undertaken to expand existing knowledge and the use of knowledge gained to develop new applications, such as new or significantly improved products/services or processes (including software development)."
- After the term "other innovation activities (excluding R&D)", an info box $< i >$ with the following text is shown: "Expenditure on other innovation activities (excluding R&D) comprises current expenditure (staff and other operating expenses including outsourced services) and expenditure for investment in fixed assets and intangible assets. They include, amongst others, the purchase of machinery, equipment, software and external knowledge (e.g. patents and licences) and expenditure for construction, design, product design, conception, training, market research, market launch and other preparatory work if it serves the development, production or marketing of innovations."

In general, the BOP-F uses so called "soft-prompts", i.e. "Don't know" and "No answer" are only shown if no response is selected and the participant clicked "Continue".

A.2 Questionnaire: Policy Rate Scenarios

QUESTION:
We would like to ask next to what extent would your enterprise change its planned expenditure on all innovation activities $< i >$ for **2024** and **2025** if the European Central Bank were to change its key interest rates $< i >$ as follows in its next meetings?

Note: Please refer to expenditure on R&D activities $< i >$ and on other innovation activities (excluding R&D) $< i >$ for this question. Please select an answer for each row from the drop-down menu.

Sub questions waves 33 and 34 (October and November 2023)

a = Increase of the key interest rates by 1.00 percentage points (main refinancing rate at 5.50%):

b = Increase of the key interest rates by 0.50 percentage points (main refinancing rate at 5.00%):

c = Decrease of the key interest rates by 0.50 percentage points (main refinancing rate at 4.00%):

d = Decrease of the key interest rates by 1.00 percentage points (main refinancing rate at 3.50%):

e = Decrease of the key interest rates by 1.00 percentage points (main refinancing rate at 3.50%) and announcement by the ECB that no further interest rate changes are expected until the end of 2025:

Sub questions wave 35 (December 2023) ($_V$2)

a = Increase of the key interest rates by 1.00 percentage points (main refinancing rate at 5.50%):

b = Increase of the key interest rates by 0.50 percentage points (main refinancing rate at 5.00%):

c = Decrease of the key interest rates by 0.50 percentage points (main refinancing rate at 4.00%):

d = Decrease of the key interest rates by 1.00 percentage points (main refinancing rate at 3.50%):

e = No change in key interest rates (main refinancing rate at 4.50%) and announcement by the ECB that no further interest rate changes are expected until the end of 2025:

Answer categories

1. Decrease by 100% (fully reduced)

2. Decrease by between 75% and less than 100%
3. Decrease by between 50% and less than 75%
4. Decrease by between 25% and less than 50%
5. Decrease by between 10% and less than 25%
6. Decrease by between 5% and less than 10%
7. Decrease by less than 5%
8. No change (0%)
9. Increase by less than 5%
10. Increase by between 5% and less than 10%
11. Increase by between 10% and less than 25%
12. Increase by between 25% and less than 50%
13. Increase by between 50% and less than 75%
14. Increase by between 75% and less than 100%
15. Increase by more than 100%
16. Does not apply to my enterprise

Additional information and definitions provided to firms, as described in Section A.1.