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Beyond the short run: monetary policy and innovation investment

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Challenges for Monetary Policy Transmission in a Changing World Network (ChaMP)

This paper contains research conducted within the network “Challenges for Monetary Policy Transmission in a Changing World Network” (ChaMP). It consists of economists from the European Central Bank (ECB) and the national central banks (NCBs) of the European System of Central Banks (ESCB).

ChaMP is coordinated by a team chaired by Philipp Hartmann (ECB), and consisting of Diana Bonfim (Banco de Portugal), Margherita Bottero (Banca d’Italia), Emmanuel Dhyne (Nationale Bank van België/Banque Nationale de Belgique) and Maria T. Valderrama (Oesterreichische Nationalbank), who are supported by Melina Papoutsi and Gonzalo Paz-Pardo (both ECB), 7 central bank advisers and 8 academic consultants.

ChaMP seeks to revisit our knowledge of monetary transmission channels in the euro area in the context of unprecedented shocks, multiple ongoing structural changes and the extension of the monetary policy toolkit over the last decade and a half as well as the recent steep inflation wave and its reversal. More information is provided on its website.

Abstract

This paper provides novel empirical evidence on the impact of monetary policy on innovation investment using unique firm-level data. First, we document the effect of a large, systematic monetary tightening (ECB rate increases from 0% to 4.5% during 2022-23), with average firm-level innovation cuts of 20%. These cuts persist over the medium term, indicating a sustained innovation slowdown. Second, we use the survey to identify elasticities of innovation expenditure to exogenous policy rate changes. Responses to hikes and cuts are significant and largely symmetric at the baseline rate (4.5%), though we detect potential state-dependent asymmetry due to the extensive margin. The financing channel emerges as one of the transmission channels, with more pronounced effects in firms with higher shares of bank loans and variable-rate loans. Crucially, we show that monetary policy transmits via aggregate demand, with stronger responses in firms with pessimistic demand expectations. Forward guidance provides substantial additional stimulus by reducing uncertainty about future rates, suggesting long-term, supply-side effects of announcements. These results challenge monetary long-run neutrality and are suggestive of policy endogeneity of R^* operating through innovation-driven technology growth.

JEL classification: E52, E22, E24, 030, D22.
Keywords: Monetary Policy Transmission, R&D, Endogenous Growth, Forward Guidance, R^*.

Non-technical summary

Central banks have undertaken significant monetary tightening from 2022 to 2023, raising concerns about its impact on innovation and longer-term potential output amid sluggish productivity growth in many advanced economies. However, previous evidence on the transmission of monetary policy to innovation is scarce and confined to time series evidence. This paper contributes to this literature and provides detailed, representative firm-level evidence on how monetary policy shifts influence innovation activities using unique, granular data. In particular, we investigate three key aspects of monetary policy transmission to firm-level innovation investment. First, we document how a systematic monetary tightening (euro area policy rate hikes from 0% to 4.5% during 2022 to 2023) affected firms' innovation investment over the short and medium term. Second, using hypothetical policy rate scenarios, we assess firms' responses to exogenous rate changes (both hikes and cuts). Finally, this paper is the first to provide evidence on how forward guidance influences innovation investment.

Our main findings can be summarized as follows. Regarding the effect of the systematic monetary tightening in the euro area, we document pronounced firm-level innovation cuts (on average 20%) in response to the policy rate hikes. Moreover, 45% of firms that reduced innovation investment eliminated such spending entirely. We show that the innovation reductions are persistent and extend over the medium term. These effects of the systematic monetary tightening were rather homogeneous across sectors and were more pronounced among low-productivity firms, smaller firms, those with greater reliance on bank loans, and those with higher inflation expectations.

The second block of results examines how firms respond to exogenous policy rate hikes using hypothetical policy rate scenarios. Our findings reveal that innovation investment is highly sensitive to monetary policy changes: policy rate hikes discourage innovation investment, while policy rate cuts stimulate it. At the baseline policy rate level of 4.5%, firms' innovation response to hikes and cuts is broadly symmetric, i.e., equally strong. However, we show that this result may depend on the level of the policy rate, as many innovation-active firms may have already eliminated their innovation spending entirely during high-rate periods, which limits their ability to make further reductions in response to additional policy rate hikes. We shed light on the channels through which monetary policy transmits to innovation. Firms with bank loans demonstrate significantly stronger reactions to policy rate changes, underscoring the critical role of financing constraints in innovation decisions. This amplification effect is particularly evident among firms with variable-rate loans. Our analysis

also reveals that monetary policy influences innovation investment via its effect on aggregate demand: policy rate changes generate notable innovation investment responses even among firms without bank loans. Importantly, firms with pessimistic demand expectations show substantially greater sensitivity to policy rate cuts.

We show that forward guidance communication ("low-for-longer") stimulates innovation investment, indicating persistent, supply-side effects of monetary policy communication. Forward guidance announcements are found to be particularly effective in firms relying on bank loans, especially those with variable-rate loans, and in firms with pessimistic demand expectations. Crucially, firms with greater uncertainty about future policy rates respond particularly strongly to forward guidance, emphasizing the role of communication in reducing uncertainty about future policy paths and its importance for firms' innovation decisions.

Our results hold important implications for monetary policy. In particular, our findings suggest that monetary policy transmits through additional channels, namely via innovation and technology growth. Monetary policy may thus have more persistent effects than conventionally assumed, operating through innovation and longer-term aggregate supply. Moreover, our evidence suggests that the natural rate of interest R^* is not only determined by exogenous factors, but also influenced by monetary policy.

1 Introduction

The analysis of monetary policy has traditionally centered on its short-term effects. This perspective stems from the view that while monetary policy can exert significant influence over output in the short run, it does not influence the long-term production potential of the economy. A key underlying assumption is that technology growth and thus long-run supply is exogenous to monetary policy. More recently, an emerging body of literature provides empirical evidence which suggests that monetary policy may have persistent output effects (Jordà et al. (2024)) and that monetary policy shocks affect innovation and technological progress (Ma and Zimmermann (2023); Moran and Queralto (2018)).

This previous evidence is based on aggregated measures of innovation in the time series dimension. To the best of our knowledge, this is the first paper to provide comprehensive firm-level evidence on monetary policy transmission to innovation, drawing upon a unique micro-dataset that spans the full distribution of firms across sizes and sectors. The dataset includes key variables relevant for monetary policy analysis — such as firms' financing structures and frictions, demand expectations, inflation expectations, and expectations about the level of and uncertainty about the policy rate. The survey is typically reported by the CEO or CFO of the company. This information enables us to add to the literature by opening the "black box" of the transmission mechanism of monetary policy to innovation by exploiting firm-level variation in financing and demand. Moreover, this unique data allows us to explore the role of the heterogeneity in the transmission of monetary policy to innovation.

Our contribution centers around three major topics. First, we study the impact of a significant, *systematic monetary tightening* on innovation investment. After more than a decade at the zero lower bound, major central banks recently implemented large monetary tightenings. This has raised key policy questions about the respective impact on technology-enhancing investments and potential output, particularly in the context of weak productivity growth across many advanced economies. This paper provides insights into these questions by assessing the effect of the systematic monetary tightening on firms' innovation investment over the short- and medium-term. Second, we identify the effect of exogenous policy rate shifts, both monetary tightening and easing, using the strategic survey approach. We estimate *firm-level elasticities in response to rate hikes and cuts* of various magnitudes to examine the properties of monetary policy transmission to innovation, with particular focus on asymmetries and non-linearities in transmission. Finally, this is the first paper to study the transmission of *forward guidance* to innovation investment and thus the long-term, supply-side effects of monetary policy communication. This analysis is essential given the long-term orientation of innovation investment and the role of uncertainty around the policy

rate, which we observe in our data.

Our results can be summarized as follows. The first set of results examines the effect of a substantial, systematic monetary policy tightening — specifically the European Central Bank's increase in policy rates from 0% to 4.5% during 2022-2023. We document substantial cuts to innovation investment in response to the monetary tightening. On average firms reduced innovation investment by about 20% over this period compared to the counterfactual (absence of the rate hikes). Notably, 45% of firms reducing innovation investment completely suspended their investment. We further demonstrate that innovation investment cuts are persistent: medium-term cuts (2024-2025) are substantial and strongly correlate with short-term reductions (2022-2023).

As to the determinants of the firm-level innovation investment response to the systematic policy change, we show that smaller firms and firms with higher share of bank loans demonstrate greater responsiveness. We find rather homogeneous firm-level responses across manufacturing and services. High productivity firms cut back innovation investment less strongly than low productivity firms. Furthermore, firms with higher inflation expectations cut innovation investment more.

The second set of results describes the evidence on the impact of policy rate hikes and cuts from a survey-based scenario analysis, where we elicit estimates of planned innovation expenditure from each firm under different interest rate scenarios. Our findings show that innovation investment is highly responsive to monetary policy shocks: policy rate hikes discourage innovation investment, while cuts stimulate it. At the baseline 4.5% policy rate, responses to monetary tightening and easing are largely symmetric. However, we identify potential state-dependent asymmetry, where the relative strength of responses to rate changes depends on the prevailing level of the policy rate. In high-rate environments, firms respond more symmetrically to cuts and hikes because many innovation-active firms have already reduced innovation activities to zero, creating an upper bound for further cuts through the extensive margin, i.e., exit from innovation activity.

Exploiting the rich firm-level information, we study the role of heterogeneity. Monetary policy effects remain significant across all scenarios even after accounting for firm heterogeneity, confirming that our results are not only driven by firm-specific factors. Firms more exposed to monetary policy changes demonstrate stronger innovation responses, validating our identification strategy. In particular, firms with higher loan shares show greater responsiveness to both rate changes and forward guidance, highlighting the amplification through financial channels. Firms with higher inflation expectations demonstrate reduced sensitivity to further rate hikes —likely because they had already curtailed innovation spending — but exhibit stronger responses to rate cuts. Pronounced rate cuts transmit especially strongly

to firms with high uncertainty about future policy rates.

Using the information on expectations about demand and firm-level financing conditions, we can also shed light on the transmission channels of monetary policy. Firms with bank loans show substantially stronger responses to policy rate changes and forward guidance than firms without, highlighting the importance of the financing channel for innovation. Moreover, this amplification effect is generally more pronounced for firms with variable-rate loans. We also provide evidence that monetary policy influences innovation investment not only via the financing and the cost of innovation but also via its transmission to aggregate demand. First, policy rate changes elicit a pronounced innovation investment response even in firms which do not have outstanding bank loans. Crucially, firms with pessimistic expectations about demand are substantially more responsive to rate cuts and to forward guidance communication.

Finally, we find that forward guidance communication ("low-for-longer") delivers pronounced additional stimulus beyond a standalone rate cut, significantly influencing firms' innovation decisions. Forward guidance proves particularly effective for firms relying on bank loans, especially those with variable-rate loans. Additionally, firms with pessimistic demand expectations show stronger responses to forward guidance announcements. Notably, firms with greater uncertainty about future policy rates demonstrate especially pronounced reactions to forward guidance communication, underscoring how central bank communication reduces uncertainty about future policy paths and influences innovation investment decisions. These findings indicate that firms closely monitor forward guidance when determining innovation investment and that, by influencing innovation investment, forward guidance affects technology growth, suggesting long-term, supply effects of forward guidance.

Our results demonstrate that monetary policy significantly affects innovation investment and thus transmits to technology growth, challenging the exogenous technology assumption underlying conventional New Keynesian models. Linking our innovation elasticities with well-established productivity-innovation elasticities from the literature, we show that the identified innovation investment adjustments translate into pronounced and persistent productivity effects, indicating that monetary policy affects long-term supply dynamics and thus aggregate output well beyond the short run. Our evidence thus suggests that monetary policy may not be long-run neutral, as well as that the natural rate of interest (R^*) may be policy-endogenous rather than solely determined by exogenous factors. Our results align with and support theoretical frameworks that integrate New Keynesian models with endogenous innovation-driven growth. We emphasize that monetary transmission through innovation fundamentally differs from transmission via physical capital as the latter does not evoke changes in technology growth and long-term aggregate supply dynamics. In con-

trast, innovation investment directly enhances technology and drives long-run growth, as established by endogenous growth theory. Consequently, the discussed macroeconomic and monetary implications do not extend to physical capital investment more broadly.

Previous literature. This paper contributes to the literature on the relationship between monetary policy and innovation. Empirical analyses on this link remain scarce in the current literature and can be summarized as follows. Previous studies establish the effect of monetary shocks on aggregated data by means of respectively a VAR approach (Moran and Queralto (2018)) and local projections (Ma and Zimmermann (2023)). As to the role of quantitative easing, Grimm et al. (2021) indicate that the ECB's QE programs positively influenced innovation activities among firms whose bonds qualified for corporate bond purchases. More generally, Jordà et al. (2024) provide evidence on long-term effects of monetary policy on aggregate output through its impact on total factor productivity.

Our paper is, to the best of our knowledge, the first to provide comprehensive firm-level evidence on monetary policy transmission to innovation, utilizing a unique micro-dataset which covers the full distribution of firms. Our main contribution to the prior literature lies specifically in studying the effects of three distinct aspect of monetary policy: 1) systematic monetary policy, 2) exogenous monetary policy shifts in either direction (hikes and cuts; role of asymmetry and non-linearity), and 3) forward guidance. Moreover, exploiting both firm-level variation and crucial information for monetary policy available in our data (e.g., as to firm-level financing and as to expectations about demand, inflation, policy rates and respective underlying uncertainty), we can shed light on the channels of monetary policy transmission to innovation. Our large-scale, comprehensive firm-level data permits also for the analysis of the role of heterogeneity in this setting.

Since we identify two key transmission channels - the financing channel and the aggregate demand channel, our paper is also linked to previous work which demonstrates the effect of financial shocks and frictions (e.g. Lenzu et al. (2024), Duval et al. (2019), Huber (2018)) and of demand shifts (e.g. Ilzetzki (2024), Elfsbacka-Schmöller et al. (2024)) on firm-level innovation and technology growth.

Finally, this paper is closely linked to the theoretical work which studies monetary policy, innovation and technology growth by combining frameworks with nominal frictions and endogenous growth mechanisms (Benigno and Fornaro (2018), Moran and Queralto (2018), Garga and Singh (2021), Queraltó (2022), Fornaro and Wolf (2023), Fatás and Singh (2024)), as well as with prior work which, based on estimated New Keynesian models with endogenous innovation investment and TFP growth, shows that demand shocks and financial shocks can result in persistent slowdowns of technology growth due to the adverse effect on innovation (Moran and Queralto (2018), Anzoategui et al. (2019), Bianchi et al. (2019), Ikeda and

Kurozumi (2019), Elfsbacka Schmöller and Spitzer (2021)).[1]

The use of surveys is very common and well-established in both the measurement of and economic research on innovation.[2] Methodologically, this paper also contributes to the literature by proposing structured hypothetical questions to study how firms change innovation investments in response to monetary policy shocks and forward guidance announcements. Armantier et al. (2022) use a similar approach to assess the 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. More recently, Andre et al. (2022) use hypothetical vignettes to causally identify effects of commonly modeled macroeconomic shocks on households' beliefs about unemployment and inflation. 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 hypothetical questions or vignettes to study behavior of firms is less prevalent, reflecting also limited data availability. As one of the few examples, Gödl-Hanisch and Menkhoff (2023) use vignettes embedded in a survey of German firms to study the pass-through of cost shocks to prices along different time horizons, while Best et al. (2024) use hypothetical questions to isolate the effect of firms' decrease in borrowing costs on investment.

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. Reassuringly, Parker and Souleles (2019) as well as Bunn et al. (2018) establish that answers to hypothetical scenarios and actual outcomes closely match. Additionally, in a survey of Swiss firms, Abberger et al. (2024) demonstrate that the results from hypothetical scenario questions match well the results of randomized control trials - an established experimental method. Notably and distinctively for our survey, over 90% of the respondents are identified as the CEO of the firm, which makes them uniquely qualified to provide answers to questions based on hypothetical scenarios. Not only they are most likely to have the information and knowledge necessary, these respondents are used to conduct "thought

[1] Many of these frameworks build on a two-stage endogenous growth process through R&D and technology adoption (Comin and Gertler (2006)). For a detailed review on hysteresis effects more generally, see Cerra et al. (2023).

[2] Examples for widely used surveys include the Business Enterprise Research and Development Survey (BERD), carried out by the U.S. Census Bureau and the National Science Foundation (see U.S. Census Bureau (2025)), and the Community and Innovation Survey (CIS) in Europe (see Eurostat (2025)). See Mairesse and Mohnen (2010) for a comprehensive review of of the use of innovation surveys in econometric analysis.

experiments" when planning investments and business operations, comparable to what we confront them with.[3] Indeed, the responses we receive are meaningful, match well the evidence on aggregate innovation spending, 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 cannot 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. At the same time, in their Econometric Society Presidential Address 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". Our study contributes to this broader research agenda.

The paper is structured as follows. Section 2 presents our data and empirical approach. We show our results on the effect of the systematic monetary tightening on firms' innovation investment in Section 3. Section 4 demonstrates the results from our survey-based experiment on the impact of exogenous policy rate hikes and cuts as well as of forward guidance on innovation investment. We discuss the macroeconomic and monetary policy implications in Section 5. Section 6 concludes.

2 Data and Empirical Strategy

To investigate empirically how monetary policy changes affect firms' innovation investment, we implemented a *Monetary Policy and Innovation Module* in the Bundesbank Online Panel of Firms (BOP-F), a large, representative survey of German firms, conducted from October to December 2023. Within this module, we employ a survey-based experiment to assess how firms' innovation investment responds to monetary policy shifts. This section describes the data: the Bundesbank Online Panel of Firms (Section 2.1) and the Monetary Policy and Innovation Module, including the underlying survey-based identification strategy (Section 2.2).

[3] Graham and Harvey (2001), Brounen et al. (2004) provide evidence on firm's using contingency planning tools.

2.1 Bundesbank Online Panel of Firms

The Bundesbank Online Panel of Firms (BOP-F) is a large survey of German firms.[4] It is representative of the population of firms which have at least one employee, pay social security contributions, and have a turnover exceeding 22,000 euros. The BOP-F covers the full distribution of firms, in terms of size classes, economic sectors, and geography. With more than 3,000 firms participating each month since its launch in July 2021, the survey features a large number of observations, necessary to study potential heterogeneous patterns. Furthermore, a typical survey respondent of the BOP-F is the CEO or CFO of the firm. In fact, over 90% of firms surveyed in our sample, have a respondent identified as the CEO of the company. These respondents are expected to have a detailed understanding and knowledge of firm-level developments and challenges, decision processes, and longer-term planning, making them the ideal respondents for questions about firms innovation investment choice and drivers, as well as longer-term innovation investment plans.

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. Crucially, the BOP-F collects granular information on various angles relevant for the study of monetary policy. First, we observe detailed information on firms' financial situation, financing sources and structure, and potential obstacles to financing. These include, among others, information on firm-level financial frictions, such as the share and type of bank loans (e.g., fixed vs. variable) used by the firm. Furthermore, the survey also captures detailed firm-level expectations regarding demand and anticipated turnover, which constitutes both rarely available information and information crucial for studying monetary policy transmission via the demand channel. Moreover, the BOP-F features firm-level expectations regarding macroeconomic variables key for monetary policy transmission, such as firm-level inflation expectations, as well as both expectations about the level of the ECB policy rate and firm-level uncertainty around the level of the policy rate.

This rich micro-level data is particularly valuable for analyzing monetary policy and, in combination with the Monetary Policy and Innovation Module (discussed in details in the subsequent section), it delivers a unique, granular data set ideally designed to study the impact of monetary policy shifts on firms' innovation investment. Crucially, the data permits us to analyze the specific transmission channels, notably the demand channel and the financial channel, of monetary policy transmission to innovation, while shedding light on the role of various sources of firm-level heterogeneity in this context.

[4]For more information on the BOP-F see Boddin et al. (2022), Boddin and Köhler (2023), https://doi.org/10.12757/bbk.bopf2024q2.01 .

2.2 Monetary Policy and Innovation Module: Identification

To study how firms adjust their innovation spending in response to monetary policy changes, we designed and implemented a dedicated special module within the BOP-F survey, the Monetary Policy and Innovation Module. This module was fielded in a random subsample of the BOP-F and answered by 6,300 firms. Importantly for this paper, firm-level innovation investments reported in the Monetary Policy and Innovation Module closely match estimates of aggregate innovation expenditures in Germany. Based on our data, we estimate that, in 2022, these expenditures amounted to €171 billion, which is aligned with the corresponding estimate of the Mannheim Innovation Panel (MIP), a survey of innovation activities in Germany (€190.7 billion, Rammer et al. (2023)).[5] Additionally, the share of firms engaged in some innovation activities in 2022 as reported in the Monetary Policy and Innovation Module - 59% - matches closely the 57% of active innovators in the Mannheim Innovation Panel.

A distinctive feature of our dataset is that it captures innovation investment and is thus not only confined to R&D, which is typically undertaken by a small subset of firms. Instead, our measure of innovation investment comprises of both frontier innovation (R&D) and non-frontier innovation, i.e. technology adoption, realistically acknowledging different types of firm-level innovation and specifically that R&D is not the only mean for firms to innovate.[6]

Using the collected data, we study the following three aspects: First, the impact of systematic monetary policy on innovation investment, specifically the effect of a large rate hike episode (cumulative policy rate[7] hikes by the European Central Bank (ECB) from 0% to 4.5% during 2022 to 2023). Second, using a set of hypothetical questions, we study the impact of exogenous monetary policy rate changes in either direction and of different magnitudes. This approach permits us, in addition to the study of monetary policy shocks, also the analysis of potential asymmetry and nonlinearities. Third, we study the effect of forward guidance communication in the transmission of exogenous policy rate shifts to innovation investment.

[5] This minor difference between aggregate innovation expenditures in both surveys likely reflects differences in the targeted firm populations, i.e., firms with at least 5 employees (MIP) compared with firms with at least one employee (BOP-F).

[6] This distinction is common in the literature, see, e.g. Comin and Gertler (2006) for reference.

[7] The ECB sets three key interest rates (deposit facility, main refinancing operations, and marginal lending facility). In what follows, we refer to the rate of the main refinancing operations as the policy rate, as it is most commonly referred to as the key policy rate in public discourse. Note that all key interest rates remained constant at their respective peaks (4.00%, 4.50%, and 4.75%) over the period September 2023 to June 2024. During the rate hike episode, the three key interest rates were raised in tandem by identical increments at each rate hike (from starting values of -0.50%, 0.00%, and 0.25% respectively). Pre-rate hikes, the ECB key interest rates had remained at zero lower bound levels for over a decade. See *Key ECB interest rates* for a detailed overview on the monetary tightening episode and prior interest rate developments.

In this paper we explicitly consider the effect of monetary policy rate shifts, i.e. the effect of *aggregate, macroeconomic* changes, on innovation investment. Our aim is thus to study how macroeconomic shifts induced by monetary policy impact firm's innovation investment and thus of changes which are not only faced by an individual firm, but simultaneously by all agents in the macro economy. In such a setting, monetary policy transmission can potentially operate through various channels, notably via the financing channel, as well as the aggregate demand channel. Below, we describe our approach and identification strategy in more detail.

1. Systematic Monetary Tightening. From July 2022 to September 2023, the European Central Bank implemented a series of rate hikes, raising its policy rate from 0% to 4.5% - a cumulative increase of 4.5 percentage points. To assesses the effect of this large, systematic policy rate increase on innovation investment of firms in Germany, we use the first part of the special module in the Bundesbank Online Panel of firms (as described above) to ask firms to retrospectively evaluate how the monetary tightening has influenced their actual spending on innovation, over 2022 to 2023, as well as their planned innovation investment for 2024 to 2025. Specifically, we asked the following:

*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 rate 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:* ____

By using firm's assessments, we gain information about the effect of this large rate hike episode on the innovation investment of firms. Additionally, eliciting the respective response on both realized and planned innovation investment, we can assess how the systematic monetary policy rate hike impacted firm's innovation expenditure over both the short and the medium term. This approach permits us to gauge the degree of persistence of the respective firm-level innovation investment adjustments.

2. Survey-based Experiment. The second part of the module measures the effect of incremental policy rate changes (in either direction and of different magnitudes), as well as of forward guidance communication on innovation investment. More generally, while the first part of the survey studies the effect of a *systematic* policy rate change, the second part aims at the study of *exogenous* monetary policy shifts, i.e., monetary policy shocks. We

do so by means of a survey-based experiment which follows the strategic survey approach (Ameriks et al. (2011), Armantier et al. (2022)).

Each firm is presented with several hypothetical scenarios concerning key interest rate changes by the ECB. Specifically, five scenarios are provided: a larger interest rate hike (of 1%), a smaller interest rate hike (of 0.5%), two interest rate cuts (also of the magnitude of 0.5% and 1% respectively), as well as a forward guidance scenario (cut of 1% combined with an announcement by the ECB that no further interest rate changes are expected until the end of 2025). Firms are asked to report how they would adjust their planned investments in innovations for 2024 and 2025 in response to *each* of these scenarios. More specifically, firms 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?"*[8]

This empirical approach has numerous advantages. First, its usefulness has been established in the literature which study the effect of macroeconomic shocks on economic beliefs and outcomes (see Andre et al. (2022) for overview and an application). Second, it allows us to establish the relevant benchmark. We propose that the relevant benchmark should be the ex-ante (in the absence of an interest rate change) *plans* for innovation spending. Studies so far have used data on *realized* investments in innovations, such as actual spending on R&D, venture capital or patents. However, past data on innovation spending may be less informative on the future plans, especially given a lumpiness of innovation spending (Wang and Zhang (2024)). Second, the monetary policy shifts as suggested in the scenarios can be interpreted as exogenous controlled variation in the monetary policy, which allows to isolate the effect of the monetary policy change on the firm's innovation spending[9]. Third, multiple responses from 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 us to causally identify the sensitivity of innovation spending to unexpected monetary policy changes. The availability of responses to both positive and negative interest rate changes, as well as to forward guidance for *the same firm in the same economic environment*, provides crucial insights into monetary policy transmission. This setup permits us to analyze and compare rate hikes and cuts of similar magnitude and thus to investigate potential

[8] See Section 4 and Appendix A.2 for a detailed description of the survey question setup.

[9] Alternative approaches 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.

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 the transmission mechanism. Finally, we evaluate the impact of forward guidance announcements. Given that such counterfactuals cannot be observed in actual settings, since it is empirically impossible to observe in practice how the same firm with the same conditions is affected by monetary policy changes of different sign and magnitude, our method offers a unique opportunity to empirically study firms' responses to different monetary policy interventions and speaks directly to the needs of monetary policy design and assessment.

3 Systematic Monetary Policy: Evidence from a Major Rate Hike Episode

While a growing body of literature studies the effects of monetary policy shocks on economic activity, the impact of systematic monetary policy changes on innovation remains unexplored. Yet, understanding this relationship is essential, as a significant proportion of monetary policy actions is endogenously determined by broader macroeconomic dynamics rather than exogenous shocks.[10] These systematic responses may offer important insights into the long-term effects of monetary policy on productive capacity. In the following section we investigate the influence of a systematic monetary policy change on innovation by analyzing firms' adjustments in innovation investment. Specifically, we focus on the impact of a major interest rate hike episode, when the Euro area policy rate has increased from zero to 4.5 % rate hike during 2022-2023. To do so, we asked firms, which participated in the Monetary Policy and Innovation Module in the BOP-F survey, to assess the impact of the ECB's interest rate increases on their innovation expenditures in 2022 and 2023, as well as their plans going forward (see Section 2.2 for details).

The question is thus intended to gauge both the immediate, i.e. short-run impact (2022-2023), and the medium-run response, i.e., the impact of the monetary policy tightening on firms' innovation expenditure over 2024 to 2025. Throughout the analysis, we restrict our sample to the set of "innovation-active" firms, which either reported positive innovation expenditures in 2022 or indicated they reduced their innovation expenditure to zero as a result of the rate hike, resulting in about 3000 firms.[11] Section 3.1 studies the short-run

[10] See, e.g. Froyen (1974) for reference.

[11] 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

innovation response, Section 3.2 the respective medium-run effect, and Section 3.3 analyzes the firm-level determinants behind the innovation investment response to the systematic monetary policy change.

3.1 Short-run Innovation Investment Response

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

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

Notes: BOP-F October - December 2023, weighted, own calculations.

A substantial share of firms (33%) cut innovation investment in response to the interest rate hike. We also observe a pronounced share of firms (58%) which were not responsive to the interest rate increase, as well as a small portion of firms (9%) which reacted to the rate hike by increasing their innovation investment. Crucially, cuts and increases differ substantially in terms of the intensive margin: cuts are substantial (mean cut: -67%)[12], 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[13] and show that these innovation cuts correspond to at least -€10.7 billion.[14]

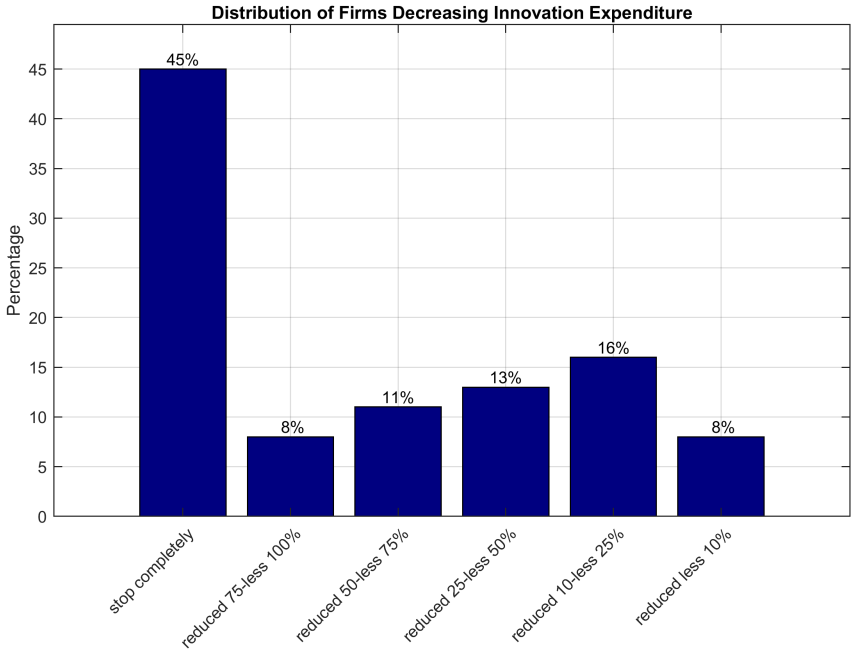
in innovation in response to contractionary shocks.

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

[13]Note that this estimate constitutes a lower bound, i.e. a conservative estimate of the magnitude of the innovation cuts, as it does not include innovation investment cuts of firms which reduced their investment to zero, because we cannot infer their expenditures before the reductions. 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 hike. 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.

[14]This number is also sizable 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)



Notes: BOP-F October - December 2023, weighted, own calculations.

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 as it suggests that firms at least transitorily exit innovation activities[15] in response to the interest rate hike episode. This may result in particularly persistent effects: if firms put their innovation activities fully on hold, this may render ramping up innovation investment, for instance in response to a future policy rate cut, more unlikely.

[15]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 regarding 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

As we document short-term innovation investment cuts in response to systematic monetary policy tightening, the question arises, whether they are transitory or persistent. To answer this question we next present 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 persist at least over medium-term. 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 average -20% per firm. We observe further that the cuts in innovation expenditure plans 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

Notes: BOP-F October - December 2023, weighted, own calculations.

Table 3 presents the details on 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. 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.

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%

Notes: BOP-F October - December 2023, weighted, own calculations.

3.3 Firm-level Determinants and Persistence

We next investigate further the determinants and the persistence of the innovation investment cuts at the firm-level. First, we show more formally, as previously indicated by the descriptive analysis, that firms' decisions to decrease innovation spending over the short term and medium term are highly correlated. The estimation of a bivariate probit model in Table 4 produces a highly significant correlation estimate between the decision to cut innovation investment over the short and medium term respectively. This suggests a high persistence of the innovation investment cuts: firms which cut back on innovation in the short-run typically do so also in the medium term. This pattern, moreover, also implies that innovation investment is not only postponed, but falls in a long-lasting manner.

Moreover, the short- and medium-run adjustments in innovation are determined by highly similar factors. Our findings indicate that smaller firms are more responsive than large firms, i.e., show a higher probability to reduce innovation investment in response to the monetary tightening. More indebted firms react more strongly to the policy rate increase: innovation investment by firms with a higher share of bank loans relative to their balance sheet are particularly sensitive to the monetary tightening. This result emphasizes the importance of the transmission of monetary policy through the cost of financing and the bank lending channel in particular. Additionally, more indebted firms may be more attentive to policy rate changes and be more likely to directly integrate them into their innovation spending decisions.[16]

As to the sectoral dimension, we find homogeneous responses in the short-run to the large rate hike among innovating firms in both manufacturing and services, with service sector being slightly less affected over medium-term. Furthermore, the higher concentration of innovation-active firms in manufacturing is likely to imply, all other things equal, that innovation investment changes in this sector have a disproportionate impact on aggregate

[16]We analyze the role of the financing channel in more detail in the context of the scenario analysis in Section 4.

innovation investment.

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%	0.122***	0.158***
	[0.029]	[0.033]
10-20%	0.134***	0.206***
	[0.033]	[0.035]
20-40%	0.248***	0.315***
	[0.029]	[0.029]
40% or more	0.381***	0.434***
	[0.033]	[0.033]
Number of empl.		
11-50	-0.073***	-0.050**
	[0.024]	[0.024]
51-200	-0.177***	-0.160***
	[0.028]	[0.028]
201 - 1000	-0.218***	-0.195***
	[0.033]	[0.034]
$>$ 1000	-0.263***	-0.279***
	[0.045]	[0.046]
Service Sector	-0.019	-0.037*
	[0.020]	[0.021]
Rho	0.914***	
N	2106	

Notes: BOP-F October - December 2023. Marginal effects after bivariate probit. The outcome variables are coded as 1, if a firm reported having cut innovation investment, and 0 otherwise, for actual innovation investments over 2022-2023 (column 1) and planned innovation investments over 2024-2025 (column 2). Controls include survey wave. Robust standard errors (in parentheses). Significance levels, $*$ $p < 0.1$, $**$ $p < 0.05$, $***$ $p < 0.01$.

Table 5 shows the determinants of the *intensive margin* of the innovation investment cuts. Our results echo the findings for the probability to cut innovation investment. Specifically, firms which rely more intensely on financing through bank loans, as well as relatively smaller firms cut innovation investment more strongly. Consistent with our bivariate probit estimation results, the intensive margin of innovation investment cuts is homogeneous across sectors. Finally, we show that firms with lower labor productivity undertake more pronounced cuts in innovation investment, while firms with higher inflation expectations decrease investments in innovations by more.

Table 5: Change in investment plans 2024-2025, intensive margin

	Baseline with controls		With inflation expectations		With labor productivity	
Share of bank loans						
1-10%	-0.121 ***	[0.023]	-0.118 ***	[0.022]	-0.127 ***	[0.037]
10-20%	-0.099 ***	[0.025]	-0.102 ***	[0.024]	-0.174 ***	[0.044]
20-40%	-0.181 ***	[0.022]	-0.173 ***	[0.022]	-0.196 ***	[0.035]
40% or more	-0.285 ***	[0.030]	-0.270 ***	[0.030]	-0.321 ***	[0.048]
Number of employees						
11-50	0.077 ***	[0.019]	0.066 ***	[0.019]	0.044	[0.030]
51-200	0.146 ***	[0.022]	0.122 ***	[0.022]	0.104 ***	[0.036]
201-1000	0.201 ***	[0.026]	0.168 ***	[0.027]	0.169 ***	[0.042]
> 1000	0.222 ***	[0.033]	0.185 ***	[0.032]	0.308 ***	[0.047]
Service Sector firm	0.020	[0.017]	0.020	[0.017]	0.022	[0.028]
Expected inflation, 12m			-0.028 ***	[0.004]		
Labour productivity, log					0.039 ***	[0.015]
Constant	-0.168 ***	[0.023]	-0.012	[0.031]	-0.338 ***	[0.083]
R^2	0.084		0.103		0.097	
N	2,539		2,493		1,093	

Notes: BOP-F October-December 2023. Results based on OLS regressions. The outcome variable is the midpoint of the interval representing the change in plans (see details in Appendix A.1), re-coded to be between -1 (reduced completely) and 1.1 (increased more than 100%). Labor productivity measure is based on the survey responses about number of employed and turnover in 2022, truncated at the 1% lowest and 5% highest end of the distribution. Inflation expectation is a 12-months point prediction, truncated at 1%. Robust standard errors (in parentheses). Controls include survey wave. Significance levels, $*$ $p < 0.1$, $**$ $p < 0.05$, $***$ $p < 0.01$.

4 Scenario Analysis

In the previous section, we examined how a large-scale monetary tightening influenced firms' innovation investments, providing insights on the effect of the *systematic* component of monetary policy rate changes. The second survey block investigates the effect of incremental, *exogenous* policy rate changes (*monetary policy shocks*), in either direction (hikes and cuts), as well as the impact of forward guidance. Specifically, we ask each firm to consider the following hypothetical scenarios and to report how they would adjust their innovation investments over the next two years (2024-2025) in each case (see Section 2.2 for a detailed description on the underlying identification approach and 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 causally estimate the response of innovation investment to exogenous changes in the policy rate (Section 4.1). Section 4.2 investigates the role of heterogeneity and the firm-level determinants of adjustments to planned innovation expenditure under the different scenarios. We present our results on the transmission mechanism of monetary policy to innovation in Section 4.3. Section 4.4 shows our findings regarding the effect of forward guidance on innovation investment.

4.1 Effect of Policy Rate Hikes and Cuts

In what follows, we present our estimation results on the effect of incremental policy rate changes. The analysis 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 under a forward guidance scenario (see Section 4.4). Formally, we estimate

$$I_{is} = \alpha_i + \sum_{s=0}^{s=5} \beta_s Scenario_s + \sum_{s=0}^{s=5} \gamma_{is} Scenario_s X_i + \delta X_i + \varepsilon_{it}, \tag{1}$$

where I_{is} is the percent change in innovation spending planned for the period 2024-2025 by firm i in policy rate scenario s[17]. Importantly, we define scenario s=0 ("counterfactual") as the *actual change of the planned innovation spending* of firm i under the *current policy rate*. This allow us to compare actual planned changes to innovation spending to the planned changes under hypothetical, incremental policy rate hikes and cuts (scenarios a to e as described above). Put differently, we are able to examine firms' innovation investment responses to various policy rate scenarios under current ex-ante conditions. X_i are the firm-

[17] More specifically, it represents the change in firm-level innovation investment, measured as the midpoint of the reported bins (as described above).

level characteristics, which we also use to study heterogeneity of response to monetary policy changes, as reflected by the interaction term - and the relevant coefficient γ_{is}. We always cluster the error term ε_{it} at the firm's level. Our findings are presented in the first row of Table 6 as a baseline, where X_i is set to zero. These results compare to an average change in planned investment for 2024-2025 relative to pre-rate-hike planned investment of -20% (Section 3.2).

Table 6: Effect of Policy Rate Changes

MP Response:	**Scen.1: hike 1pp.**	**Scen.2: hike 0.5pp.**	**Scen.3: cut 0.5pp.**	**Scen.4: cut 1pp.**	**Scen.5: cut 1pp.(long)**	**N**
Baseline	−0.094*** [0.007]	−0.060*** [0.006]	0.043*** [0.006]	0.109*** [0.007]	0.164*** [0.009]	14,485
Heterogeneity dimensions						
Scenario x Exp. inflation, 12m.	0.009** [0.004]	0.007** [0.004]	0.004 [0.004]	0.010*** [0.004]	0.013*** [0.005]	14,485
Scenario x Loan share, pp.	−0.001*** [0.000]	−0.001*** [0.000]	0.001*** [0.000]	0.003*** [0.000]	0.004*** [0.000]	14,325
Scenario x Labor prod, lg.	−0.013 [0.012]	−0.003 [0.011]	0.001 [0.011]	−0.002 [0.013]	−0.014 [0.017]	6,095
Scenario x Size (empl. high)	0.043*** [0.014]	0.038*** [0.013]	0.014 [0.013]	0.017 [0.014]	0.016 [0.019]	14,456
Scen. x Uncertainty key rate (high)	0.014 [0.013]	0.012 [0.012]	0.008 [0.012]	0.026* [0.014]	0.065*** [0.018]	14,258

Notes: BOP-F October-December 2023. Results based on OLS regression. The outcome variables are the midpoint of the interval representing the change in plans, for 2024 to 2025 (see details in Appendix A.2), re-coded to be between -1 (reduced completely) and 1.1 (increased by more than 100%). Reference category for scenarios: actual change due to the past interest rate hike of 4.5 percent. Labor productivity measure is log-transformed and is based on the survey responses about number of employed and turnover in 2022, truncated at the 1% lowest and 5% highest end of the distribution. Inflation expectation is the 12-months point prediction, truncated at 1%. Standard errors are clustered at the firm-level (in parentheses). Controls include survey wave, share of bank loans and firm size. Significance levels, $*$ $p < 0.1$, $**$ $p < 0.05$, $***$ $p < 0.01$.

Innovation responds significantly to policy rate shifts. Our results show that firms' innovation investment react strongly to monetary policy shocks. Specifically, we find a significant and pronounced response of innovation investment planned for 2024 to 2025 for all five policy scenarios. This demonstrate that monetary policy significantly affects innovation investment through both rate hikes and cuts, a result consistent across all specifications and heterogeneity analyses.

The presented elasticities measure firm-level responses, showing how exogenous policy rate changes translate into firm-level innovation investment adjustments. Note that these firm-level elasticities do not necessarily coincide with the aggregate innovation response as

firms contribute differently to the aggregate due to, among others, innovation budgets of different sizes.

Hikes discourage, cuts stimulate innovation investment. Our results produce evidence of monetary policy transmission operating bi-directionally, with policy rate cuts stimulating innovation investment by firms and rate hikes suppressing it. Our findings demonstrate that monetary policy significantly affects innovation investment through both rate hikes and cuts, a result consistent across all specifications and heterogeneity analyses. At a baseline policy rate of 4.5%, we observe largely symmetric responses to monetary tightening and easing.

State-dependent (a)symmetry between rate hikes and cuts. While it is generally debated what will constitute "normal" levels of the policy rate going forward, and while prior to 2008, 4% was generally the baseline assumption as to steady state interest rates in New Keynesian models, the 4.5% baseline rate in our setting distinctly exceeds post-2008 euro area levels. Section 3 shows many innovation-active firms had already ceased innovation investment at this elevated policy rate, constraining their ability to further reduce spending. We examine to what extent this extensive margin of innovation adjustment — where innovation-active firms completely cease innovation activities at increasingly high policy rate levels — creates state-dependent asymmetry in response to monetary tightening versus easing by analyzing only innovation-active firms with non-zero innovation investment (Table 9). Our results suggest asymmetric responses in this subsample, with stronger effects under rate hikes compared with cuts. These insights suggest that while monetary policy significantly affects innovation investment in both directions, the degree of symmetry between responses to rate hikes and cuts appears to be state-dependent, with higher average policy rates inducing a more symmetric innovation investment response due to the extensive margin of firm-level innovation adjustment.

Larger policy rate changes vs. gradualism. We next compare the transmission of policy rate changes of different magnitudes, aiming to analyze potential non-linearities in monetary policy transmission with respect to larger vs. smaller changes in the policy rate. This analysis provides insights regarding potential differential effect of gradualism and rapid policy rate shifts on firms' innovation investment and thus longer-term supply dynamics. For rate cuts, we find that a 0.5% reduction yields an impact of 0.043, while a 1% cut results in an impact of 0.109 and thus exceeds twice the effect of a 0.5% policy rate change. Conversely, for rate hikes, a 0.5% increase generates an effect of -0.060, while a 1% hike results in -0.094. In this case, doubling the rate hike results in less than twice the effect on innovation investment. This result may speak in favor of potential asymmetries in monetary policy transmission arising in high rate environments resulting from the increased share of

innovation-active firms at zero innovation investment levels.

The presented elasticities measure firm-level responses, showing how exogenous policy rate changes translate into firm-level innovation investment adjustments. Note that these firm-level elasticities do not necessarily coincide with the aggregate innovation response as firms contribute differently to the aggregate due to, among others, innovation budgets of different sizes.

4.2 Heterogeneity: Firm-level Determinants

Our rich firm-level dataset allows for a detailed analysis of heterogeneity in monetary policy transmission and the underlying firm-level determinants, which we examine next. Table 6 (rows (2)-(6)) summarizes our main results, with detailed estimation results provided in Table 8 (Appendix B). Importantly, a significant response to all scenarios persists also when accounting for heterogeneity. This confirms that the identified general response to the scenarios (see Section 4.1) is not merely driven by firm-level differences.

We show that firms with a higher loan share are relatively more responsive to both rate hikes and cuts and to forward guidance. This highlights the additional amplification of monetary policy transmission operating through the financial channel (see Section 4.3 for a detailed analysis). This finding also suggests that firms which are more exposed to shifts in monetary policy via a higher share of financing through bank loans adjust innovation investment more to monetary policy shifts, validating our identification strategy.

Smaller firms (with employment below the median) reduce innovation investment more sharply in response to rate hikes, while we do not find a significantly heterogeneous response to policy rate cuts (including forward guidance) between the group of small and large firms.

Using firm-level inflation expectations (1 year ahead), we demonstrate that firms with higher inflation expectations show reduced sensitivity to further policy rate hikes. As observed in Tables 4 and 5, these firms had already curtailed their innovation investment more substantially in response to the ECB monetary tightening. This prior adjustment likely dampens their elasticity to additional policy rate increases. Conversely, regarding policy rate cuts, firms with higher inflation expectations exhibit relatively greater responsiveness in their innovation investment.

On the role of labor productivity, it is important to note that this variable is measured with less precision than other variables[18], available for only a subset of firms, resulting in a lower sample size and higher standard errors. While this likely affects the significance of the

[18]Labor productivity is calculated as the ratio of firm's turnover to the number of employed. Both turnover and employment are provided in the survey either as a point estimate for some cases, or as a middle of interval for other cases, leading to some extent of imprecision.

provided estimates, the effects attributed to productivity are generally homogeneous across monetary policy scenarios, with strongest negative (albeit insignificant) effect emerging in the forward guidance scenario. Importantly, as can be seen in Table 8 (Appendix B), the general effect of labor productivity remains positive and significant. This predicts that more productive firms tend to reduce their innovation investments less in response to changes in monetary policy.

Finally, we exploit firm-level information regarding uncertainty about future key interest rates and demonstrate that firms displaying higher uncertainty react more strongly to large rate cuts. Crucially, their response to the forward guidance announcement is of substantially greater magnitude, underscoring how forward guidance communication transmits to firms' innovation investment by reducing uncertainty about the future path of policy rates.

4.3 Transmission Mechanisms

We next investigate the channels through which monetary policy transmits to innovation. Innovation investment is generally influenced by both the costs of innovation — notably financing costs—and the expected payoff from new innovations, particularly the demand for new innovations. Policy rate cuts (hikes) could potentially increase (decrease) innovation investment by lowering (raising) financing costs, as well as by stimulating (dampening) aggregate demand. Our micro data allow us to study these transmission mechanisms by exploiting firm-level variation and information about firm-level financing and demand expectations. We employ a split-sample regression approach: by dividing our sample based on specific criteria, we can observe how monetary policy's impact on innovation varies across different specifications, thereby providing insights into the interaction and respective roles of these channels. Table 7 presents our results.

Financing channel. Policy rate changes can impact innovation by altering financing costs. To analyze the role of the financial channel in the transmission of monetary policy to innovation, we compare the responses to policy rate changes of firms with bank loans to those without (Table 7, columns 3 and 4). Firms with bank loans exhibit substantially higher responsiveness to policy rate changes, which underscores the significance of monetary policy transmission through the financing costs of innovation and amplification of monetary policy transmission via financial frictions. Interestingly, we observe some degree of asymmetry in the amplification of innovation adjustment through bank loans, with the difference between the two groups being more pronounced for rate cuts compared to hikes. This suggests that rate cuts contribute to releasing financial constraints, particularly at high starting levels of the policy rate, leading to a stronger amplification of the reaction of innovation investment

to policy rate changes.

Importantly, firms without bank loans also respond significantly to policy rate changes. This finding highlights an additional transmission channel operating through expectations about the economic outlook and future demand, aligning with our results on turnover and demand (see below).

Fixed vs. variable loans. To further investigate the financing channel, we restrict the sample to firms with bank loans and compare those holding exclusively fixed-rate loans against those with at least some variable-rate loans. For the effect of rate cuts, firms with variable rate loans respond more strongly, in line with an interpretation that rate cuts reduce funding costs with a short lag 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 in the subsequent paragraph. Interestingly, firms with only fixed-rate loans and those with some variable-rate loans demonstrate more similar response patterns to rate hikes than to rate cuts.

Aggregate demand channel. A key transmission channel of monetary policy operates through its effect on aggregate demand. To study the role of the aggregate demand channel of monetary policy for innovation, we exploit information on firms' expectations of their turnover over the next six months and divide our sample into two groups: firms that 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 that 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 already be operating at their financing constraints, limiting the capacity or necessity for further innovation cuts.

4.4 Forward Guidance and Innovation

Forward guidance influences agents' expectations about future interest rates and economic conditions, potentially reducing uncertainty. Given innovation investments' inherently long-term orientation, particularly for the case of R&D, forward guidance communication may

Table 7: Policy Rate Changes: 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

Notes: BOP-F October - December 2023. Results based on OLS regression. The outcome variables is the midpoint of the interval representing the change in plans, for 2024 to 2025 (see details in Appendix A.2), re-coded to be between -1 (reduced completely) and 1.1 (increased by more than 100%). Reference category for scenarios: actual change due to the past interest rate hike of 4.5 percent. Standard errors are clustered at the firm-level (in parentheses). Controls include survey wave, share of bank loans and firm size. Significance levels, $* \ p < 0.1$, $** \ p < 0.05$, $*** \ p < 0.01$.

critically impact firms' innovation decisions. Despite extensive literature on forward guidance transmission, its effect on innovation investment and hence longer-term aggregate supply dynamics remains unexplored. We address this gap by providing novel empirical evidence on the impact of forward guidance on firms' innovation investment.

Longer-term, supply-side effects of forward guidance communication. Our survey design enables direct identification of the causal effect of forward guidance on innovation investment. Specifically, comparing Scenario 4 (policy rate cut of 1%) with Scenario 5 (policy rate cut of 1% combined with forward guidance on the future policy rate path) allows us to isolate and identify the impact of forward guidance:

- **Scenario 4**: *Decrease of the key interest rates by 1.00 percentage points (main refinancing rate at 3.50%):*
- **Scenario 5**: *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 6 (row 4 and 5) demonstrates that forward guidance provides pronounced additional stimulus relative to a 1 pp. rate cut alone. The difference between a standalone rate cut and a

rate cut combined with communication stating to maintain interest rates at lower levels for an extended period significantly affects firms' innovation investment. This additional stimulus from forward guidance persists also when accounting for heterogeneity. As detailed in Section 4.2, forward guidance elicits particularly pronounced responses in high-productivity firms and in firms with high uncertainty about future policy rate levels.

Table 7 presents key insights into forward guidance transmission to innovation investment. Across all sample split regressions, forward guidance substantially amplifies the stimulus to innovation investment compared to a standalone 1% rate cut. This indicates that 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 contexts in which the effect of forward guidance is particularly pronounced.

Forward guidance communication exerts a stronger effect on firms that finance through bank loans compared to firms that do not rely on such funding (columns 3 and 4). Within bank loan-financed firms, the transmission of forward guidance is especially pronounced for those with variable rate loans versus those with fixed rate loans only. Additionally, forward guidance communication produces a stronger response in firms with pessimistic demand expectations (columns 1 and 2).

Our results establish several key insights: firms pay attention to forward guidance announcements in determining their innovation investment choices, and this effect can be significant in magnitude. They highlight that forward guidance communication significantly influences firms' innovation investment and, consequently, transmits to longer-term aggregate supply dynamics. Crucially, by affecting innovation investment, forward guidance exerts influence on the growth of the technology stock and thus total factor productivity. This evidence suggests highly persistent effects of forward guidance announcements, with impacts on aggregate output over at least the medium run and potentially beyond.

Role of the design of forward guidance communication. Forward guidance communication occurs in different forms, subject to different characteristics. Thus, the specific design of forward guidance employed in our survey is also likely to play a role for how intensely firms' innovation investment responds to the announcement. We discuss the role of these specific characteristics of the announcement in what follows.

Calendar-based announcement. The communication studied in this paper is calendar-based, as it specifies the expectation to keep interest rates at the respective lower level over a certain time period. This explicit statement of the time horizon likely provides clarity for firms as to the underlying time frame which is important for their planning horizon.

Medium-term horizon. The studied announcement involves the expected commitment to keep rates unchanged over the medium term (2 years). In doing so, this signals a rather

strong expectation of unchanged policy rates for an extensive time period, which may amplify the reduction of uncertainty as to the policy rate.

Clear, unconditional communication. The studied announcement provides a clear and precise communication of the expected policy rate path. In particular, it focuses solely on expectations about the policy rate path, without specifying conditional statements or circumstances under which this scenario would be realized or altered. This approach was chosen to ensure that respondents fully comprehend the scenario and, moreover, do not confound the impact of forward guidance with the effect of the information provided as to potential contingencies mentioned in the announcement.

5 Macroeconomic and Monetary Policy Implications

This section discusses the potential productivity effects underlying our results, as well as their broader macroeconomic and monetary policy implications. We emphasize several key aspects: monetary policy transmission through innovation and technology growth, potential productivity effects, the persistence of monetary policy interventions via long-term supply dynamics and their implications for long-run neutrality of monetary policy, and finally, the potential policy-endogeneity of the natural rate of interest, R^*.

Transmission through innovation and technology growth. In the standard New Keynesian model, innovation investment and total factor productivity are treated as exogenous: innovation investment does not enter the model, and TFP is assumed to be driven exclusively by exogenous technology shocks and by structural factors not influenced by monetary policy. Our findings, however, suggest that innovation investment and thus the dynamics of the technology stock are endogenous to monetary policy, challenging the conventional modeling paradigm of exogenous technology and TFP growth. This implies that monetary policy transmits via an additional, previously unaccounted for mechanism — namely, via innovation investment, technology dynamics, and consequently long-term aggregate supply. Our results align with and provide empirical support for modeling approaches that integrate New Keynesian frameworks with endogenous total factor productivity dynamics via innovation-driven technology growth in general equilibrium[19] and emphasize the need for further theoretical research in this area.

Productivity effects. The link between investment in innovation and productivity growth is firmly established by a vast empirical and theoretical literature, dating back to

[19]Examples of frameworks which combine nominal frictions with endogenous long-run growth via innovation include Benigno and Fornaro (2018), Moran and Queralto (2018), Anzoategui et al. (2019), Bianchi et al. (2019), Ikeda and Kurozumi (2019), Garga and Singh (2021), Elfsbacka Schmöller and Spitzer (2021), Elfsbacka-Schmöller and McClung (2024).

at least Griliches (1958). Crucially, the key insight from endogenous growth theory is that innovation investment is the primary driver of technological advancement and long-term economic growth, and thus of long-term aggregate supply dynamics (Aghion and Howitt (1992), Grossman and Helpman (1991), Romer (1990)).[20] The link between innovation investment and productivity changes is also well documented empirically (see Mairesse et al. (2025), Griliches (2000), Hall et al. (2010) and Mairesse and Sassenou (1991) for comprehensive surveys of this vast literature), and we can draw on these estimates in assessing the potential productivity effects of the documented innovation investment changes.[21] This literature on the productivity elasticity to innovation investment is vast and Ugur et al. (2016) condensed them by means of a meta-study approach into an estimate of 0.08.[22] The estimates based on more recent data provided byd'Artis Kancs and Siliverstovs (2016) suggest a mean elasticity of productivity with respect to R&D of 0.15.

We can link our firm-level elasticities of innovation investment to monetary policy shifts and their respective changes in firm-level productivity as follows. For incremental policy rate adjustments, we estimated that a 1 p.p. change in the policy rate would result in a mean firm-level change in innovation investment of roughly 1% (-0.94% for hikes and -1.09% for rate cuts). These changes in innovation investment induced by a 1 p.p. hike/cut could, based on the referred to estimates, be associated with firm-level productivity changes of approximately 0.08% to 0.15%. Regarding the potential productivity effects of the systematic policy rate change, the identified mean firm-level innovation investment cut of 20% could (depending on the elasticity estimate employed) translate to mean firm-level productivity losses of about 1.6% to 3%, compared to the non-rate hike productivity trajectory. This initial productivity decline would be further amplified by the additional medium-term innovation investment cuts we documented, which are of similar magnitude, resulting in additional productivity losses in approximately the same range.

Note that the firm-level productivity loss is additive, representing a compounded negative impact on the productivity trajectory of the described magnitude. Note further that while

[20]Note that the key role of innovation investment in productivity growth has already been established earlier in the literature (see, e.g., Griliches (1973) and Terleckyj (1974)).

[21]Note that our approach of providing productivity effect ranges based on established micro-level evidence represents the most appropriate methodology in our survey context. To see this, recall that we study hypothetical policy rate scenarios, thus the productivity effects of monetary policy shocks cannot be directly inferred from the data. Similar considerations apply to the systematic policy rate hike, where firms report innovation investment changes specifically attributable to monetary policy only. Firms may have undertaken additional innovation adjustments not driven by monetary policy, which is why mapping subsequent productivity trajectories directly would yield biased estimates of the productivity effects of the rate hike.

[22]Note that this estimate is at the lower end and generally lower than the estimates suggested by previous reviews on this literature. The study reviews 773 firm-level elasticities from 33 studies, published during 1980 to 2013.

the respective swings in innovation investment represent *transitory* movements in amounts invested, productivity effects constitute *level* effects, i.e., permanent losses in the productivity trajectory caused by foregone innovation, which over time can accumulate to substantial productivity and thus output losses. This highlights also the impact of the studied monetary policy shifts on the long-term output path via pronounced cumulative productivity losses which persist well beyond the short-term changes in, e.g., the policy rate itself.

Persistent effects of monetary policy through long-term supply and long-run non-neutrality. Taken together, our empirical results suggest that monetary policy significantly influences long-term aggregate supply through its effects on innovation investment. A direct consequence is that monetary policy transmits beyond the short run and thus in a more persistent manner than conventionally assumed, providing evidence in favor of long-run non-neutrality of monetary policy. As discussed earlier, models combining the New Keynesian framework with endogenous innovation, technology, and TFP growth can reconcile the dynamics empirically observed in the data. These frameworks also feature persistent output effects of monetary policy via longer-term aggregate supply and can thus depart from the assumption of long-run neutrality, while maintaining the other crucial insights from New Keynesian frameworks. Moreover, traditional long-run identifying restrictions in time series analysis may merit careful interpretation against the backdrop of our findings.

Policy-endogeneity of R^*. The natural rate of interest (R^*) is typically assumed to be exogenous in conventional New Keynesian models, i.e., it is driven solely by long-term structural factors and exogenous shocks, and does not respond to monetary policy shocks.[23] Our findings, however, suggest a clear link between monetary policy on the one side and innovation investment and productivity, i.e., long-run growth on the other side. Thus, our results indicate a relationship between monetary policy shifts and long-run growth g and, ultimately, R^*. This is due to the positive link between g and R^*: $R^* = f(g, \theta)$ (where $\frac{\partial R}{\partial g} > 0$, θ : exogenous shocks).[24]

Finally, note that monetary transmission through investment in physical capital is fundamentally different from transmission through innovation for at least the following reasons. First, while New Keynesian models frequently incorporate capital investment, this merely

[23] Typically, in the standard New Keynesian framework, the rate of long-run, i.e., steady state growth is set constant and to 0. Any short-run fluctuations in the natural rate of interest are driven by exogenous shocks.

[24] Recent theoretical work on New Keynesian models with endogenous growth through R&D (Elfsbacka-Schmöller and McClung (2024)) demonstrates policy endogeneity of R^* more formally. It shows that under endogenous growth the natural rate is an endogenous object, influenced by the endogenous rate of trend growth. Accordingly, monetary contractions reduce innovation investment, leading to lower technology growth and, consequently, lower trend growth. This mechanism implies an inverse relationship between the policy rate and the natural rate.

adds propagation and generally improves the realism of macroeconomic dynamics: there is no link between changes in physical capital and the technology stock and thus no spillover to long-term growth and long-term aggregate supply dynamics. Innovation investment, in contrast, is *technology-enhancing*, and the main determinant of technology growth, i.e., long-run growth, as fundamentally established by the endogenous growth literature. Due to these inherent differences between physical capital and innovation investment respectively, the key macroeconomic and monetary policy implications discussed in this section (transmission to technology and long-run growth, effect on long-term aggregate supply, long-run non-neutrality, policy-endogeneity of the natural rate) are confined to innovation investment and do not extend to physical capital more broadly.

6 Conclusion

We provide novel firm-level evidence on the effect of monetary policy shifts on innovation investment, challenging conventional assumptions about the long-run neutrality of monetary policy. Using unique micro data spanning the full distribution of firms, we present key results that contribute to our understanding of to what extent and through which channels monetary policy transmits to innovation. First, we analyze the impact of a large, systematic monetary policy tightening (cumulative euro area rate hikes by 4.5% over 2022 to 2023). We document a significant decline in firms' innovation investment, 20% on average, in response to the monetary tightening, which persists over the medium term. This evidence suggests that monetary tightenings can exert long-lasting effects on technology growth. Second, we use the survey to uniquely capture firm-level innovation investment elasticities to both policy rate hikes and cuts, leveraging hypothetical policy rate scenarios. We identify largely symmetric responses at the baseline 4.5% policy rate. However, we find evidence in favor of potential state-dependent asymmetry: the prevailing policy rate level affects the strength of the response by influencing firms' decisions to exit from innovation activities (that is through the extensive margin). On the transmission mechanisms of monetary policy to innovation, we establish the following key facts. First, we identify a clear role for a financing channel, as firms with higher shares of bank loans demonstrate larger responses to monetary policy changes. Financing through variable-rate loans further intensifies the transmission. Second, our results provide novel direct evidence for monetary policy transmission via the aggregate demand channel, identified by the amplified responses from firms with pessimistic demand expectations. Finally, we present evidence on the long-term, supply-side effects of forward guidance: "low-for-longer" communication delivers significant additional stimulus beyond stand-alone rate cuts. Moreover, we show that the corresponding resolution of firm-level

uncertainty about future policy rates is a particularly important transmission channel.

By connecting the estimated innovation elasticities with established productivity-innovation elasticities from the literature, we demonstrate that the innovation investment cuts we estimate translate into significant and persistent productivity effects. This suggests that monetary policy influences long-term supply dynamics and aggregate output well beyond the short run, challenging the exogenous technology assumption that underpins conventional New Keynesian models. Our findings have important implications for monetary policy. First, they suggest that monetary policy may not be long-run neutral, contrary to traditional assumptions. Second, they indicate that the natural rate of interest (R^*) may be policy-endogenous rather than determined solely by exogenous factors. Future research should further study the heterogeneous effects of monetary policy on innovation across different economic environments and firm characteristics, as well as investigate the optimal monetary policy design that considers these long-term supply-side effects. These insights would contribute to developing more comprehensive frameworks that integrate New Keynesian models with rich endogenous innovation-driven growth processes, ultimately enabling more effective monetary policy that balances short-term stabilization with long-term growth considerations.

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A Monetary Policy and Innovation Survey

This section details our survey methodology and questionnaire structure. Section A.1 presents the questions underlying our findings on the systematic monetary tightening and Section A.2 the survey questions pertaining to the scenario analysis (including forward guidance).[25]

A.1 Questionnaire: Systematic Monetary Tightening

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%)
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

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

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.

B Additional Results

This section presents additional results to our analysis.

Table 8: Policy Rate Scenarios (detailed)

	Baseline	**Inflation Expectations**	**Bank Loans**	**Labor Productivity**	**Firm Size**	**Policy Rate Uncertainty**
	(1)	(2)	(3)	(4)	(5)	(6)
Scenario 1: hike 1 pp.	-0.094*** [0.007]	-0.137*** [0.018]	-0.065*** [0.009]	-0.038 [0.063]	-0.110*** [0.008]	-0.101*** [0.009]
Scenario 2: hike 0.5 pp.	-0.060*** [0.006]	-0.093*** [0.017]	-0.041*** [0.008]	-0.051 [0.057]	-0.074*** [0.007]	-0.066*** [0.009]
Scenario 3: cut 0.5 pp.	0.043*** [0.006]	0.023 [0.017]	0.017** [0.008]	0.036 [0.056]	0.037*** [0.007]	0.040*** [0.008]
Scenario 4: cut 1 pp.	0.109*** [0.007]	0.063*** [0.018]	0.055*** [0.009]	0.121* [0.066]	0.102*** [0.008]	0.098*** [0.009]
Scenario 5: cut 1 pp. for long	0.164*** [0.009]	0.106*** [0.024]	0.072*** [0.012]	0.245*** [0.087]	0.157*** [0.010]	0.133*** [0.011]
Inflation exp.		-0.031*** [0.004]				
Scen.1 x infl. exp.		0.009** [0.004]				
Scen.2 x infl. exp.		0.007** [0.004]				
Scen.3 x infl. exp.		0.004 [0.004]				
Scen.4 x infl. exp.		0.010*** [0.004]				
Scen.5 x infl. exp.		0.013*** [0.005]				
Share bank loans			-0.004*** [0.000]			
Scen.1 x share bank loans			-0.001*** [0.000]			
Scen.2 x share bank loans			-0.001*** [0.000]			
Scen.3 x share bank loans			0.001*** [0.000]			
Scen.4 x share bank loans			0.003*** [0.000]			
Scen.5 x share bank loans			0.004*** [0.000]			
Lab. prod, lg				0.040*** [0.015]		
Scen.1 x lab. prod.				-0.013 [0.012]		
Scen.2 x lab. prod.				-0.003 [0.011]		
Scen.3 x lab. prod.				0.001 [0.011]		
Scen.4 x lab. prod.				-0.002 [0.013]		
Scen.5 x lab. prod.				-0.014 [0.017]		
Large firm					-0.079*** [0.017]	
Scen.1 x large firm					0.043*** [0.014]	
Scen.2 x large firm					0.038*** [0.013]	
Scen.3 x large firm					0.014 [0.013]	
Scen.4 x large firm					0.017 [0.014]	
Scen.5 x large firm					0.016 [0.019]	
High policy rate uncertainty						-0.073*** [0.015]
Scen 1. x high pol. rate unc.						0.014 [0.013]
Scen 2. x high pol. rate unc.						0.012 [0.012]
Scen 3. x high pol. rate unc.						0.008 [0.012]
Scen 4. x high pol. rate unc.						0.026* [0.014]
Scen 5. x high pol. rate unc.						0.065*** [0.018]
Constant	-0.165*** [0.008]	-0.023 [0.020]	-0.077*** [0.010]	-0.381*** [0.074]	-0.136*** [0.009]	-0.127*** [0.010]
N	14,485	14,485	14,325	6,095	14,456	14,258
R^2	0.058	0.077	0.105	0.067	0.064	0.065

Notes: BOP-F October - December 2023. Results based on OLS regression. The outcome variable is the midpoint of the interval representing the change in plans, for 2024 to 2025 (see details in Appendix A.2), re-coded to be between -1 (reduced completely) and 1.1 (increased by more than 100%). Reference category for scenarios: actual change due to the past interest rate hike of 4.5 percent. Labor productivity measure is log-transformed and is based on the survey responses about number of employed and turnover in 2022, truncated at the 1% lowest and 5% highest end of the distribution.. Inflation expectation is 12 months point prediction, truncated at 1%. Standard errors are clustered at the firm-level (in parentheses). Controls include survey wave, share of bank loans and firm size. Significance levels, $*$ $p < 0.1$, $**$ $p < 0.05$, $***$ $p < 0.01$.

Table 9: Policy Rate Scenarios (firms with non-zero innovation investment 2024-25)

	Baseline (1)		**Inflation Expectations** (2)		**Bank Loans** (3)		**Labor Productivity** (4)		**Firm Size** (5)		**Policy Rate Uncertainty** (6)	
Scenario 1: hike 1 pp.	-0.132***	[0.006]	-0.139***	[0.019]	-0.085***	[0.009]	-0.120*	[0.065]	-0.134***	[0.008]	-0.125***	[0.009]
Scenario 2: hike 0.5 pp.	-0.096***	[0.006]	-0.102***	[0.017]	-0.060***	[0.008]	-0.129**	[0.059]	-0.097***	[0.007]	-0.089***	[0.008]
Scenario 3: cut 0.5 pp.	0.008	[0.005]	0.020	[0.016]	-0.005	[0.007]	-0.046	[0.049]	0.014**	[0.006]	0.014*	[0.007]
Scenario 4: cut 1 pp.	0.057***	[0.006]	0.057***	[0.016]	0.022***	[0.007]	0.054	[0.056]	0.065***	[0.007]	0.055***	[0.008]
Scenario 5: cut 1 pp. for long	0.091***	[0.007]	0.074***	[0.020]	0.037***	[0.009]	0.101	[0.073]	0.104***	[0.009]	0.081***	[0.010]
Inflation exp.			-0.007**	[0.003]								
Scen.1 x infl. exp.			0.001	[0.004]								
Scen.2 x infl. exp.			0.001	[0.004]								
Scen.3 x infl. exp.			-0.003	[0.004]								
Scen.4 x infl. exp.			0.000	[0.003]								
Scen.5 x infl. exp.			0.004	[0.004]								
Share bank loans					-0.002***	[0.000]						
Scen.1 x share bank loans					-0.002***	[0.000]						
Scen.2 x share bank loans					-0.002***	[0.000]						
Scen.3 x share bank loans					0.001**	[0.000]						
Scen.4 x share bank loans					0.002***	[0.000]						
Scen.5 x share bank loans					0.003***	[0.000]						
Lab. prod, lg							0.014	[0.011]				
Scen.1 x lab. prod.							-0.005	[0.013]				
Scen.2 x lab. prod.							0.005	[0.012]				
Scen.3 x lab. prod.							0.010	[0.010]				
Scen.4 x lab. prod.							0.000	[0.011]				
Scen.5 x lab. prod.							-0.003	[0.015]				
Large firm									0.013	[0.012]		
Scen.1 x large firm									0.006	[0.014]		
Scen.2 x large firm									0.003	[0.013]		
Scen.3 x large firm									-0.016	[0.011]		
Scen.4 x large firm									-0.023*	[0.012]		
Scen.5 x large firm									-0.039***	[0.015]		
High policy rate uncertainty											-0.014	[0.011]
Scen 1. x high pol. rate unc.											-0.013	[0.013]
Scen 2. x high pol. rate unc.											-0.012	[0.012]
Scen 3. x high pol. rate unc.											-0.008	[0.010]
Scen 4. x high pol. rate unc.											0.008	[0.011]
Scen 5. x high pol. rate unc.											0.024*	[0.014]
Constant	-0.058***	[0.006]	-0.026*	[0.016]	-0.016**	[0.007]	-0.128**	[0.054]	-0.062***	[0.007]	-0.052***	[0.008]
N	12,974		12,974		12,871		5,332		12,957		12,813	
R^2	0.081		0.083		0.117		0.083		0.082		0.083	

Notes: BOP-F October - December 2023. Results based on OLS regression. The outcome variables is the midpoint of the interval representing the change in plans, for 2024 to 2025 (see details in Appendix A.2), re-coded to be between -1 (reduced completely) and 1.1 (increased by more than 100%). Reference category for scenarios: actual change due to the past interest rate hike of 4.5 percent. Labor productivity measure is log-transformed and is based on the survey responses about number of employed and turnover in 2022, truncated at the 1% lowest and 5% highest end of the distribution.. Inflation expectation is 12 months point prediction, truncated at 1%. Standard errors are clustered at the firm-level (in parentheses). Controls include survey wave, share of bank loans and firm size. Significance levels, $*$ $p < 0.1$, $**$ $p < 0.05$, $***$ $p < 0.01$.

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